Proceedings: Sixth Workshop on On-Site Wastewater Treatment in Colorado

Edited by

Robert C. Ward

Colorado Water Resources Research Institute

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SIXTH WORKSHOP ON ON-SITE WASTEWATER TREATMENT IN COLORADO

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Robert C. Ward

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COLORADO WATER RESOURCES RESEARCH INSTITUTE
Colorado State University
Fort Collins, Colorado 80523

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INTRODUCTION

The Sixth Workshop on On-Site Wastewater Treatment in Colorado, held April 9, 1986, is only a part of the total effort by the Cooperative Extension Service and the Water Resources Research Institute at Colorado State University to address the information needs of professionals and the public in water-related areas. The workshop focused on the information needs of sanitarians, engineers, contractors, pumpers, developers, suppliers and the public regarding proper planning, design, installation, operation and maintenance of the wastewater treatment technology which today is serving between 25 and 30 percent of the homes in the United States.

On-site wastewater treatment technology has been viewed quite differently over the years. After World War II it was viewed as a necessary nuisance until a central sewer could be installed. This view prevailed at the national level until the mid-'70s when the cost of serving "all" the country came into better focus. This has resulted in a rethinking of the role of on-site wastewater treatment technology in the total wastewater treatment picture in the United States. The past ten years have seen the renewed interest in on-site technology generate many new developments in the field. Also, many of the old practices are being seriously questioned.

At the local government levels around the U.S. there has been a steadily increasing recognition of the need to improve design and regulation of on-site systems. While it was possible for the higher levels of government to view on-site systems with changing opinions, local governments have had to deal with the systems day in and day out from, literally, the trenches! Local governments, as a result, have developed a steady, if sometimes viewed as slow, approach to improving on-site technology design and regulation. Today local governments, as well as those at the national level, are also asking similar questions about the technology.

As a result, many efforts are being made around the U.S. and Colorado to improve on-site wastewater treatment technology. The theme of this Sixth Workshop was "Update, '86," and its focus was on updating attendees on: (1) design innovations and applications; (2) current research efforts; and (3) regulatory concerns. A session was organized around each of the above topics. Also, an "Information Exchange" table was part of this Sixth Workshop as a means of additional update for attendees.

Hopefully, the update on current efforts and thinking in the field of on-site technology increased the ability of the technology to fulfill its role in the total wastewater management picture in Colorado. Those of us involved in increasing the successful utilization of on-site technology need to exchange information regularly to further enhance our professional approach to such utilization. The series of on-site workshops at CSU over the years has had and will continue to have this as a major goal.

These workshops are sponsored by the Colorado Water Resources Research Institute and the Cooperative Extension Service at CSU. The support of these organizations over the years is gratefully acknowledged. I want to thank all the speakers who devoted their time and resources in preparation of a talk and paper for the proceedings. We work on a very low budget for these workshops and it takes contributions by such qualified individuals to make the workshops successful. I also want to acknowledge the assistance we received from the CSU Conference Services staff in handling the meeting details.

WELCOME

by

Don Kaufmann
Acting Associate Director
Cooperative Extension
Colorado State University

I am here on behalf of Ken Bolen, our new Director of Cooperative Extension. He came on deck January 1 and has been quite involved since then, heavily involved, in the budgeting process. As you know, we have a three-way partnership--federal, state and county--and it seems this year that we're hitting some budget problems. You know about the Gramm-Rudman reduction at the federal level, and at the state house they're looking at cuts in various programs and even the counties--I think probably some of you who work with the counties--know what the budget situation is. So Ken was not able to be here this morning. You probably know that Cooperative Extension was designed back in 1914 as a part of the land grant system to disseminate research-based information and teach leadership skills for adults and youth to be used in our communities. And, we are involved in a number of subject matter areas. Right now the Legislature is questioning whether we ought to be involved in urban extension programs but we feel that as a broad-based, tax-supported institution we ought to be available to provide information to all the people of Colorado whether rural or urban. But, I guess in tight times, they perhaps feel they need to set priorities for us, so we're evaluating priorities as we move ahead. We have 57 county offices out in the state and we certainly hope you have had the opportunity to get acquainted with your local Extension staff. If you haven't, we encourage you to do so.

Our four major program areas are agriculture, home economics, 4-H and youth and we do have some involvement in what we call community development. These are the four major programs, but we certainly get involved with a number of subject areas within each of those. For instance, in agriculture we have subject matter specialists in a number of departments here on campus including Agricultural and Chemical Engineering, Animal Sciences, Agronomy, and a number of other departments here on the University campus.

There are three legs making up the land grant institution. We have the research component, the teaching component, and Cooperative Extension as the outreach educational function of the land grant institution. We have been particularly involved in the last few months (Bob asked me to mention...a few things we have been heavily involved in) with agricultural issues. You are aware, if you live in an agricultural community, that the agricultural/financial situation has been one of the areas where we have been working quite prominently. We have provided farm financial management workshops, stress management workshops, and also family financial management workshops. So, we have been pretty heavily involved in programs to help the rural communities. We are also heavily involved in the Governor's so-called ARC Program (Agricultural Resources in Colorado), in which the Governor designated over a television press conference that county Extension offices would be a one-stop shopping center for information for the farm and ranch community. We like to think we have played this role for 75 years, but the ARC Program has given new evidence of Extension's mission in providing educational assistance.

I would like to welcome you now on behalf of Cooperative Extension. We have, as I said, a number of programs going. I also told Bob I brought a copy of an Extension Fact Sheet to assist in explaining our role and mission. It tells about Extension Programs, where the offices are located around the state, and some of the major activities we have been involved in over the past few months. Again, welcome, and I hope you have a good program.

PRIVATE WASTEWATER MANAGEMENT FOR A LARGE SUBDIVISION: CRYSTAL LAKES, COLORADO CASE STUDY

by

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History and Background

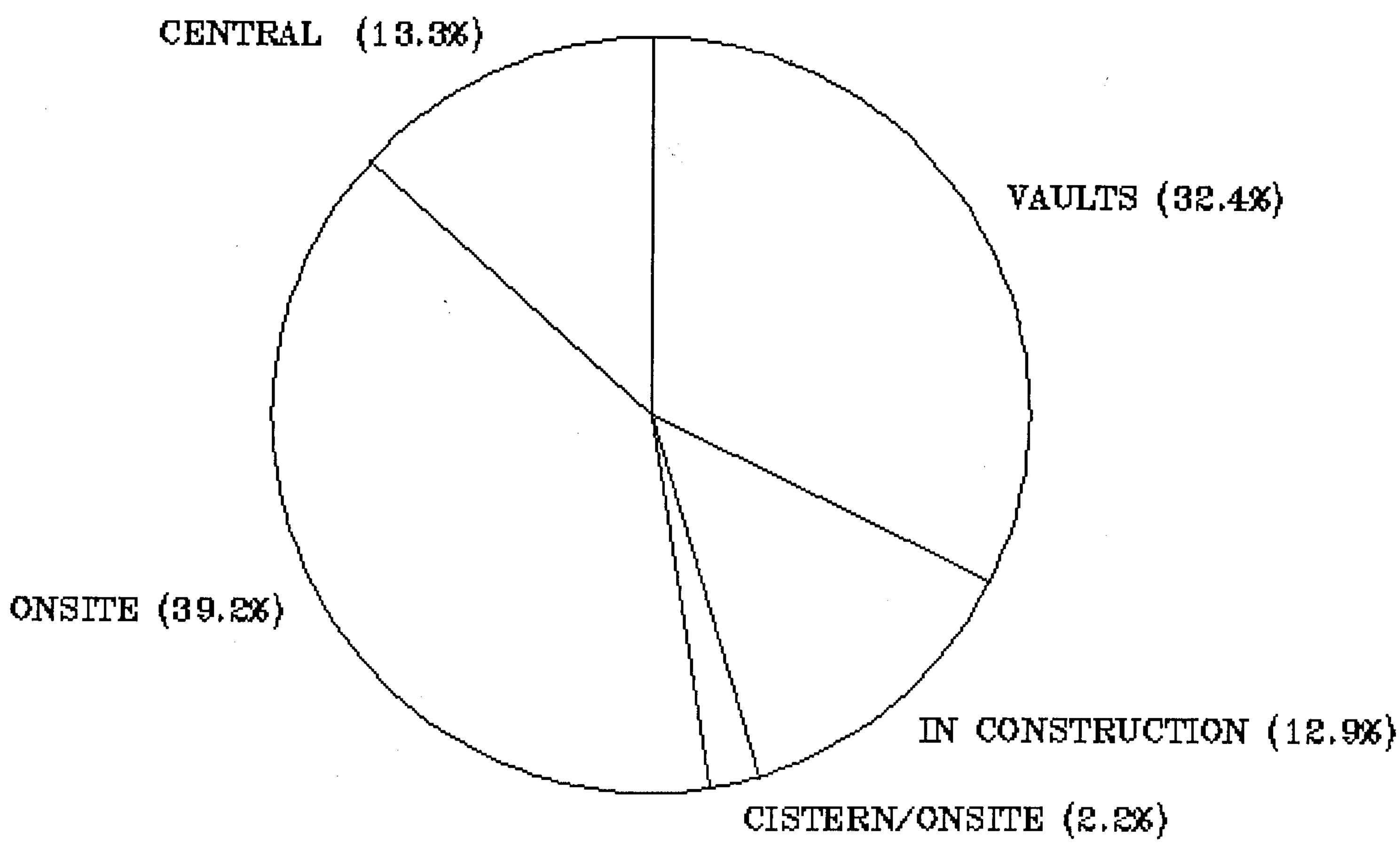
Management of decentralized wastewater facilities opened the door for development of a rural subdivision in Colorado. In the early 1970s a private developer planned a large subdivision with over 1,100 lots in the mountains in northern Colorado. Planning at this scale required an innovative water and wastewater management system. The proposal was to develop cluster soil absorption systems, cisterns, vaults and septic tank systems. The Larimer County Health Department established new management requirements for this subdivision. Health department constraints required that the developer establish a wastewater management system similar to that found in a municipality. However, in this case the management entity was responsible for decentralized wastewater facilities.

Not all facilities are decentralized; for the most valuable land a large soil absorption system treats wastewater. Wastewater for this system is collected in six-inch sewers and pretreated in specially designed septic tanks. A community soil absorption system was also required for the resort lodge which housed the sales office, restaurant, community laundry, and community shower facilities (used by campers). The management system also supported development of a number of community wells and a trucking system to fill cisterns. Wastewater service for houses on vaults required the purchase of a sewage pumping truck. Standard engineering details were developed for the cisterns, vaults and on-site soil absorption systems used throughout the development.

In 1984 the homeowners association managed 278 homes; 37 homes on the central water and sewer cluster system, 125 on on-site soil absorption, and 96 with vaults. Twenty-six of the vacation cabins are being built by the owners and have partially complete systems. Figure 1 shows the overall distribution of facilities. The homes under construction may have just a

Figure 1. CRYSTAL LAKES ONSITE SYSTEMS

TECHNOLOGY DISTRIBTION



vault and they may haul their water in by their RV. Private wells supply 85 homes while 64 have cisterns which the association fills by truck from the community well. In the one filing of the subdivision where central water and sewage is provided (only in the summer months) the homeowners also have cisterns and vaults for winter weekend occupation. The decentralized utility is operated by two men who are responsible for the water system, including the 2,000-gallon delivery trucks (also used for fire fighting) and the wastewater systems, including a 2,000-gallon sewage pumping truck and monitoring the community soil absorption systems.

Technologies

Given the large area the soils and home sites vary dramatically. The log cabin batholith granite results in shallow soils developed primarily from decomposed granite. The homeowner is not only faced with building a wastewater system but the expense of drilling for water and paying for the water rights. Wells commonly cost $5,000 and may only deliver 0.5 gpm. In these situations the homeowners have cisterns and may have to repressurize the water for in-home use. Where soils are suitable, water and wastewater facilities for weekend or vacation homes can run over $10,000. Given these costs and the vacation home type development the subdivision builds out slowly. Decentralized facilities are the only financially viable solution to water and wastewater treatment needs. Planning of wastewater facilities called for identification of suitable sites for cluster soils absorption systems. For lots located where required site conditions for wells and on-site wastewater facilities are lacking, cisterns and/or vaults are a viable option.

On-Site Systems

In the late 1970s Utility Engineering managed the development of this project providing special engineering details for the construction of the alternating bed soil absorption systems. Each bed has 50 percent of the required absorption capacity. In order to ensure the necessary treatment of the septic tanks' effluent the decomposed granite must be over-excavated by four feet and relayed before the gravel and pipe are installed. Pumping the septic tank is the responsibility of the homeowner; however, district personnel are available to inspect the tanks for $20. In cases where the homeowner has a cistern and on-site soil absorption system, district personnel switch the alternating value on the leachfields when the first summer water delivery is made. All leachfields are sized for normal wastewater generation assuming water is supplied from a well. Homeowners with cisterns will probably drill wells when water demand justifies the expense and risk.

Each leaching bed is equipped with an observation port which allows the homeowner to check the buildup of effluent in each bed. If effluent builds up he may switch the valve before the capacity of the leaching system is exceeded. In practice the homeowners switch the beds on an annual basis. A general information newsletter distributed by the recreation association reminds the homeowners to inspect their systems and switch the valve.

Cluster Soil Absorption Systems

Two community leachfield systems are located within the subdivision. Sewage generated at the scattered homes outside these systems primarily is hauled to a third site. The sewage is bled from an equalization tank into a specially designed Imhoff-type septic tank which pretreats the sewage before it discharges to the large soil absorption system. Careful records are maintained of the sewage treated at each cluster soil absorption system. Water use in homes or facilities connected to the cluster facility plus the amount of sewage dumped at each site is carefully recorded. The annual report for the association shows that homes connected directly to the cluster system only generate 900 gallons a season, leaving room for a daily load of sewage from a nearby vault.

Like the individual system the cluster systems are segmented with splitter boxes and monitoring ports. The beds are loaded heavily and then rotated out of service. The current rotation is three weeks on and three weeks off. Annual precipitation of 14 inches a year mostly from a few snow storms causes the systems to dry out during the off season. The seasonal use of the development also reduces the stress on the systems. The current build-out on the subdivision is such that the cluster systems are between 16 percent and 46 percent of their design capacity. Additional cluster systems have been designed and will be constructed by the homeowners' association as demand increases. Treatment of sewage collected from the vaults places the major demand on the soil absorption systems. The major sewage generator (on a vault) is a promotional condominium complex used by the developer for overnight and weekend accommodation for prospective buyers.

Water Use

The community may be broken down into three groups of individuals; summer weekend, year-round weekend and year-round. The summer or year-round weekenders who are building their cabins favor use of vaults for their recreational home. The summer recreational group manages on 2,000 gallons a year, while those taking advantage of the cross-country skiing or otherwise enjoying the winter recreational resort use no more than 4,000 gallons a year (two truckloads in and out). Assuming a 12-weekend summer season, homes generate about 83 gallons per day. One family which comes up almost every weekend throughout the year averaged about 56 gallons per day. Homes are outfitted with low-flush toilets and low-flow shower heads (not ultra water conservation devices). The lodge for the community with its own cluster system has complete laundry facilities used by the citizens throughout the community.

System Economics

Management of both the water and wastewater system is paid through annual dues of $60 per lot. For the area with central water and sewer there is an additional $40 availability fee charged to each lot owner. If one is connected to the seasonal central water and sewer system an additional $120 charge is assessed. This charge also covers removal of a 2,000-gallon load of sewage from a vault during the winter.

Property owners at Crystal Lakes are free to develop a variety of water and wastewater technologies (Figure 1). Depending on their use of the property and funds they want to invest in the water and wastewater utilities, owners may choose a well and on-site/soil absorption system, cistern/soil absorption system or vault/cistern system. Indidivuals in on the sixth filing have access to a central water and sewer system. Almost 13 percent of the lot owners are building their cabins and camping on their property. These individuals may have a cistern, vault or on-site system. Some are using incineration toilets while others may use the holding tanks in their recreation vehicles.

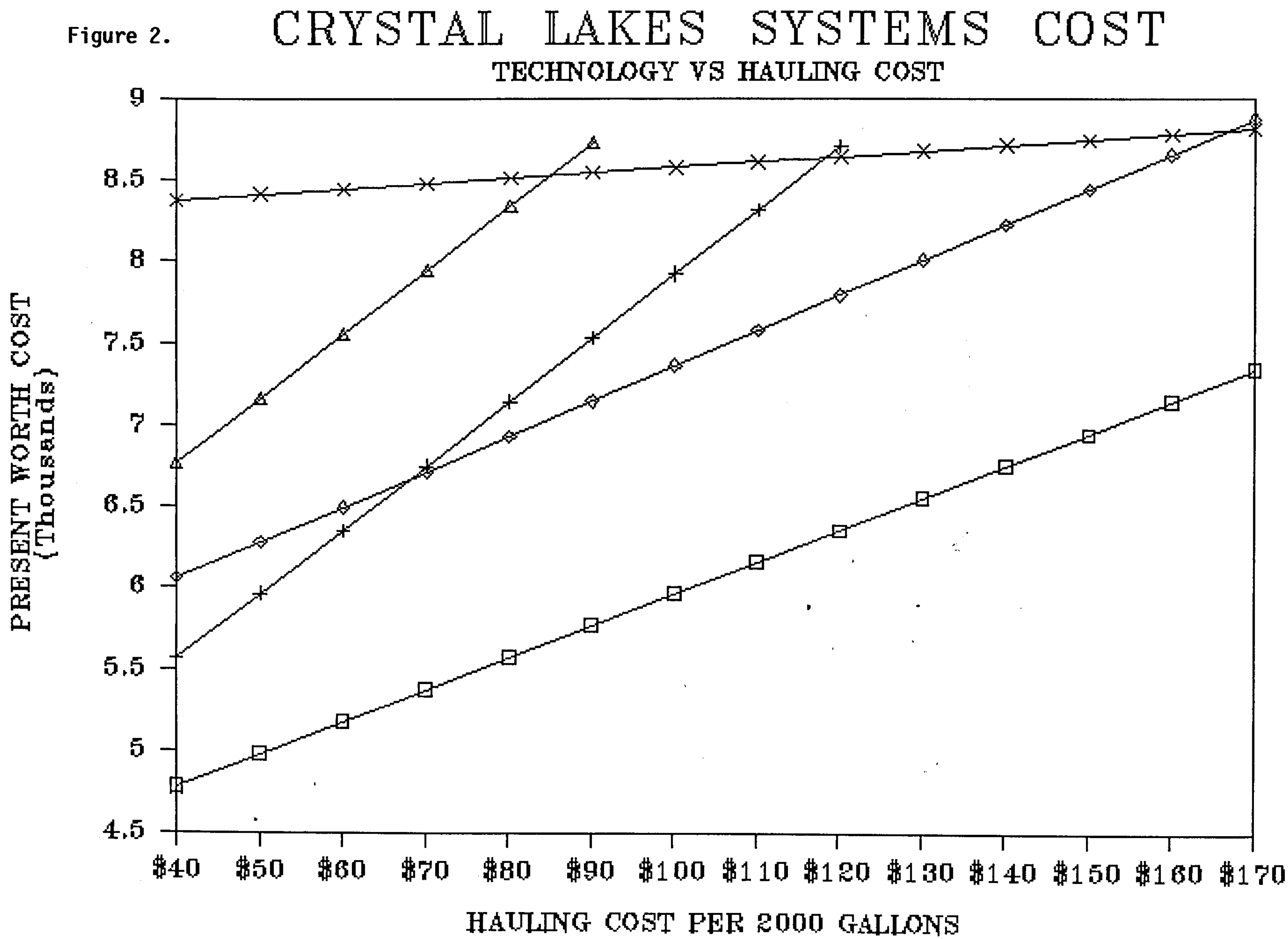
The presence of the management agency with the services it provides enables the homeowner to acquire permits from the health department which would not otherwise be allowed. From Figure 1 we can see that the most common technology is a well and on-site system. What may surprise the reader is that almost one-third of the property owners have selected a vault system. Traditionally this technology is forbidden by the health departments around the country because the high cost of maintaining this technology discourages individuals from pumping the vaults as required.

Analysis of the economics of hauling water and transporting sewage by truck shows that the cistern/vaults system is the most economical system in this resort community. Figure 2 gives the present worth for various technologies. Table 1 presents the data used to develop Figure 2. If you are using the cabin only a few weeks or on weekends over the summer 2,000 gallons of water is sufficient. Cabins in Crystal Lakes fit this category at the present time, which explains why this system is so popular. At the present rate of $100 per 2,000 gallons (in and out) an individual could put $5,000 in the bank at 8 percent interest and pay for his sewage system for the next 20 years. Individuals using the cabin on weekends throughout the year report a need for 4,000 gallons a year. As Figure 2 shows, the cistern/vault system is the least-cost system until the pumping and hauling cost exceeds about $70 per 2,000 gallons (one way). If hauling costs exceed this amount and where a homeowner uses 4,000 gallons a year he would save money by installing a soil absorption system. However, if a homeowner spends more than just weekends and needs over 8,000 gallons a year and the hauling charge exceeds about $82 per load, the well and on-site system is the least-cost technology.

Problems and Solutions

The implementation of a private decentralized wastewater utility is not without problems. Collection of delinquent payments of annual dues requires court action. Liens must be placed on homeowners' property to force the payment in some cases. Collection of defaulted payments through this court process is expensive and consequently only initiated after substantial arrears have accrued. In the case of Crystal Lakes the utility waited nine years to initiate the court action. Delinquent payments average about ten percent and must be assumed in preparing the annual operating budget.

Figure 2.



CRYSTAL LAKES SYSTEMS COST
TECHNOLOGY VS HAULING COST
PRESENT WORTH COST (Thousands)
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
$40
$50
$60
$70
$80
$90
$100
$110
$120
$130
$140
$150
$160
$170
HAULING COST PER 2000 GALLONS

Table 1.

CRYSTAL LAKES PRESENT WORTH ANALYSIS		CRYSTAL2
HAULING CHARGE	$50	
SEPTAGE PUMPING COST	$100	
WELL COST	$5,000	
ONSITE SYSTEM COST	$3,000	
CISTERN COST (INSTALLED)	$2,200	
VAULT COSTS (INSTALLED)	$1,800	
INTEREST RATE	0.08	

TRUCK LOADS	2		2	4	4
GALLONS/YR	2000	UNLIMITED	4000	4000	8000
	CISTERN	WELL &	CISTERN	CISTERN	CISTERN
YEAR	VAULT	ONSITE	ONSITE	VAULT	ONSITE
0	$4,000.00	$8,000.00	$5,200.00	$4,000.00	$5,200.00
1	$100.00	$25.00	$100.00	$200.00	$200.00
2	$100.00	$25.00	$100.00	$200.00	$200.00
3	$100.00	$25.00	$100.00	$200.00	$200.00
4	$100.00	$25.00	$100.00	$200.00	$200.00
5	$100.00	$125.00	$100.00	$200.00	$200.00
6	$100.00	$25.00	$100.00	$200.00	$200.00
7	$100.00	$25.00	$100.00	$200.00	$200.00
8	$100.00	$25.00	$100.00	$200.00	$200.00
9	$100.00	$25.00	$100.00	$200.00	$200.00
10	$100.00	$125.00	$200.00	$200.00	$200.00
11	$100.00	$25.00	$100.00	$200.00	$200.00
12	$100.00	$25.00	$100.00	$200.00	$200.00
13	$100.00	$25.00	$100.00	$200.00	$200.00
14	$100.00	$25.00	$100.00	$200.00	$200.00
15	$100.00	$125.00	$200.00	$200.00	$200.00
16	$100.00	$25.00	$100.00	$200.00	$200.00
17	$100.00	$25.00	$100.00	$200.00	$200.00
18	$100.00	$25.00	$100.00	$200.00	$200.00
19	$100.00	$25.00	$100.00	$200.00	$200.00
20	$100.00	$125.00	$200.00	$200.00	$200.00
NET PRESENT	$4,981.81	$8,412.81	$6,281.11	$5,963.63	$7,163.63

NET PRESENT WORTH VS PUMPING COST ANALYSIS

PUMPING COST	2000 GPY CIST/VAULT	4000 GPY CIST/VAULT	4000 GPY CIST/ONSITE	8000 GPY CIST/ONSITE	WELL & ONSITE
	$4,982	$5,964	$6,281	$7,164	$8,413
$40	$4,785	$5,571	$6,065	$6,771	$8,379
$50	$4,982	$5,964	$6,281	$7,164	$8,413
$60	$5,178	$6,356	$6,497	$7,556	$8,446
$70	$5,375	$6,749	$6,714	$7,949	$8,480
$80	$5,571	$7,142	$6,930	$8,342	$8,513
$90	$5,767	$7,535	$7,146	$8,735	$8,547
$100	$5,964	$7,927	$7,362	$9,127	$8,580
$110	$6,160	$8,320	$7,578	$9,520	$8,614
$120	$6,356	$8,713	$7,795	$9,913	$8,647
$130	$6,553	$9,105	$8,011	$10,305	$8,681
$140	$6,749	$9,498	$8,227	$10,698	$8,714
$150	$6,945	$9,891	$8,443	$11,091	$8,748
$160	$7,142	$10,284	$8,660	$11,484	$8,781
$170	$7,338	$10,676	$8,876	$11,876	$8,814
Key to Figure	□	+	✢	△	×

A private-sector utility can also have problems. Failure to pay for services can result in health hazard. In one case a multi-family dwelling and resort complex on a vault was allowed as a temporary system by the health department prior to construction of a cluster system. In this case the developer went bankrupt, refused to pay for hauling sewage and the utility eventually refused to pump the vaults. Needless to say there are inappropriate applications for vaults. Even temporary use of the vaults can lead to problems if the management system cannot control the wastewater generator.

Construction of future systems can also be a problem when the sale of lots generates the funds for wastewater system construction. To alleviate this problem Larimer County took control of a number of lots with assessed value equal to the cost of the planned wastewater facilities. These lots could not be sold until all facilities were completed to the satisfaction of the County Health Department. In the event that the developer goes bankrupt the lots are turned over to the utility, sold, and the funds used to complete the planned wastewater facilities.

The current appraisal value of the lots shows that today's market value will generate about a 15 percent shortfall if they are sold and all wastewater systems are constructed. The utility does not see this as a problem. Given the slow buildout and phased construction of cluster systems, they are a long way from completing the facilities for the entire community. Changes in the market value of the land or investment of these funds could easily change this financial situation.

Summation

For newly developing subdivisions in rural areas, wastewater management can play an important role in the development. At Crystal Lakes all lot owners support this agency, paying $60 a year. In return they are allowed to phase in development, gaining the beneficial use of the property while they build the facilities. The vault/cistern system costs 40 percent less on a 20-year present worth basis and can be improved with a well and on-site system at a future date. This flexibility expands the marketability of lots as it significantly reduces front end investment, allowing property owners to pay according to their use. Development of a wastewater management system makes it possible to develop at the large subdivision scale where individual wastewater systems would not be allowed.

This approach need not be limited to private-sector developments. Municipalities and county-wide wastewater service districts are possible throughout the United States. Public utilities have the potential of providing their constituents with flexible economical wastewater facilities. One such public facility (which manages vaults) is Lake Heritage Municipal Authority in Adams County, Pennsylvania.

REVIEW OF ALTERNATIVE WASTEWATER TREATMENT SYSTEMS FOR SMALL COMMUNITIES IN EPA REGION VIII

by

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Introduction

The Clean Water Act of 1977 encouraged the use of small alternative wastewater systems (SAWS) that serve small communities. Small communities are defined as communities with a population of 3,500 or less or sparsely populated areas of larger communities. The Act and subsequent regulations provided that each State with a rural population of 25 percent or more must reserve four percent of the State's annual allotment beginning with the fiscal year 1979 allotment for the purpose of funding alternative wastewater treatment systems of small communities. States with less than 25 percent rural population may set aside a reserve for grant assistance for small communities. The following applies to grants made to SAWS for small communities. (1)

- SAWS for residences and small commercial establishments in use on or before December 27, 1977 are eligible for grant assistance.

- A public entity must apply for the grant assistance for both publicly and privately owned SAWS.

- SAWS serving individual homes or small clusters (privately owned systems) must serve "principal residences" (i.e., not second homes or vacation, recreation homes).

- Seventy-five or fifty-five percent basic grants are taken from small communities reserve. The ten or 20 percent incentive for using alternative/innovative (I/A) technology is taken from the I/A reserve.

  Note: The small communities reserve can only be used if I/A technology is proposed.

- The 15 percent cost effective preference for I/A (i.e., grants may be awarded to I/A projects if the total present worth cost of treatment does not exceed the most cost-effective alternative by more than 15 percent) applies to SAWS for small communities but not to SAWS for individual systems.

Funding SAWS prior to October 1, 1984.

- Eighty-five percent funding of eligible project elements for 20-year design, 75 basic funds plus 10 percent bonus for I/A.

Funding SAWS after September 30, 1984.

- Seventy-five percent of cost to treat existing wastewater flows, 55 percent basic funds plus 20 percent bonus for I/A.

Small Alternative Wastewater Systems, SAWS

The main reason Congress in the 1977 Amendments to The Clean Water Act placed added emphasis on evaluating and where cost effective funding SAWS was the increasing cost of construction and operation and maintenance of conventional wastewater treatment systems. Much of EPA's effort has been to develop a planning and management approach to promote the implementation and improve the performance of SAWS. The key to a successful program includes: (3)

1. Public education acceptance, and local political support.
2. Availability financing and reasonable cost.
3. Institutional structure for system management.
4. Clear legal authority with appropriate regulations and enforcement powers.
5. Appropriate technology and technical skills.

It should also be noted that in some cases a combination of conventional systems and SAWS may provide the most cost effective alternative; for example, a combination of septic systems with soil absorption fields and/or small pressure sewers to gravity sewers and a centralized treatment system.

Listed below are typical SAWS which qualify for grant assistance if all statutory and regulatory requirements are met. (2)

- Septic tank and soil absorption trench
- Septic tank and soil absorption bed
- Septic tank with alternating absorption fields
- Septic tank with contoured absorption fields
- Septic tank with seepage pit

- Septic tank with leaching chambers
- Septic tank with sand filter, disinfection, and discharge
- Septic systems refinements (closing or closed loop)
- Aerobic system and soil absorption field
- Mound system
- Evapotranspiration bed
- Low-pressure subsurface pipe distribution system
- Holding tank (vault)
- Cluster system (two or more users on same SAWS)
- Dual system (separation of black and gray-water)
- Small diameter gravity sewers (collection from septic tanks for further treatment)
- Vacuum sewers (collection for further treatment)
- Pressure sewers and grinder pumps (collection for further treatment)
- Pressure sewers (septic tank effluent pump)
- Treatment of waterless or low-water toilet systems (Note: toilets of any other wastewater generating fixtures are ineligible for grant assistance; only the treatment of residues is allowable cost).
- Land treatment

Other systems not listed as SAWS but which qualify as alternative treatment and may be cost effective for small communities are total containment (evaporation) lagoons and wetland treatment.

It should be emphasized that considerable care and caution must be exercised in the use of some small alternative wastewater systems to protect public health and to avoid groundwater pollution. In the planning and design of SAWS, very careful consideration must be given to drinking water supply practices in the areas in which the alternative systems are to be used. For example, if each residence in an area has its own private water supply well, the use of septic tank-soil absorption systems on individual lots may certainly be a questionable practice unless the lots are large and the residences widely spaced. Also, any alternative using treatment and surface discharge of wastewater has great potential for public health problems in residential areas. Such practices probably require State Health Department permits, but they also certainly require consideration of the possibility that children and pets may be exposed to the discharged wastewater or that insects and rodents may come in contact with it, becoming possible disease carriers.

EPA, Region VIII SAWS Projects: Successes and Failures

EPA Region VIII States include Colorado, Montana, North Dakota, South Dakota, Utah and Wyoming. The States of Colorado and Utah are the only non-rural states in the Region. From Fiscal Year 1979 through 1985 each of the Region's rural states have reserved and spent $4,041,264 of small community funds for a regional total of approximately $16.2 million. These funds have provided grant assistance for a variety of small alternative wastewater treatment systems for small communities.

North Dakota has been one of the most active states in promoting the use of on-site SAWS. Of our six States within Region VIII North Dakota, by far, has more small communities which record population of 3500 and less. In recent years the smallest community to receive grant funds for construction of a small lagoon system was Sibley, North Dakota with a population of 21.

SAWS funded in North Dakota have included:

- Small diameter pressure and gravity sewers collecting septic tank effluent for further treatment.
- Mound systems.
- Land treatment - spray irrigation and overland flow.
- Septic tanks and absorption fields.
- Total evaporation lagoons.
- Wetland treatment presently being evaluated.

Along with the many successes in North Dakota there have been failures. Presently a mound system for the Town of Clifford (pop. 51) has failed. Two other mound systems recently constructed are experiencing operational problems. Although not yet verified, the failure of the Clifford mound system is suspected to be the result of hydraulic overloading and groundwater mounding. These two problems raise the question of design and construction deficiencies. A revised EPA design manual for Small Sewered Communities which will provide improved guidance for the design and construction of community mounds is scheduled for release in the fall of 1986.

Examples of SAWS constructed with EPA Federal grant assistance in Region VIII States:

- Lake Metigoske, N.D. (pop. 2200) and North Dakota State Parks - septic systems with leach fields, small diameter gravity and pressure sewers, grinder pumps, and central treatment with a controlled discharge lagoon system.

- Lake Madison, S.D. - Initially proposed several on-site systems which included mounds, total evaporation lagoons, small diameter sewers, grinder pumps, and rapid infiltration basins. Project being constructed: small gravity and pressure sewers, grinder pumps, and central treatment utilizing a 2-cell lagoon and a 4-cell infiltration/percolation basin for a population of 2000.

- Wolsey, S.D. - Project involves the construction of a 2-cell pretreatment/storage lagoon followed by wetland treatment for a population of 490.

- East Glacier, Mt. - Two cell treatment/storage lagoon system followed by rapid infiltration basins to serve 240 people.

- Geyser, Mt. - Treatment storage system spray irrigation designed for 175 people.

- Upper Blue River, Summit County, Co. - Proposed project consists of on-site systems utilizing community septic tank/soil absorption system, addition of soil absorption system to existing extended aeration facility, and dual sequencing batch reactors followed by soil absorption systems. Existing basin population is 15,400. On-site systems will be designed to serve small cluster of homes and condominiums.

- Bear Lake, Ut. - Project consists of small diameter sewers, grinder pumps, lagoons, and land application designed for a population of equivalent of 4,931 with an existing population of 862 permanent residents and 800 part-time residents.

- Elk Mountain, Wy. - Population 300, proposed total evaporation lagoons.

- Lusk, Wy - Population 1800, wastewater treatment using treatment/ storage lagoons followed by land application.

Although the States of Colorado and Utah haven't reserved funds for small communities, they have continued to encourage the use, where appropriate, of SAWS and/or any innovative/alternative system which proves cost effective. If nothing else the mandatory set-aside of funds for small communities in the designated rural state has provided grant assistance to areas that would have had a hard time competing for priority with the large populated areas. Also, in addition to apparent savings of both Federal and local dollars, water quality and health benefits have been realized through no discharge or pollutants and the beneficial use of wastewater effluent and sludge.

REFERENCES

1. EPA, Construction Grants 1985 (CG-85), July 1984.

2. EPA, Small Wastewater Systems, Alternative Systems for Small Communities and Rural Areas, FRD-10, January 1980.

3. EPA, Management of On-Site and Small Community Wastewater Systems, July 1982.

CONTROL OF GROUNDWATER MOUNDING UNDER LARGE-SCALE SOIL ABSORPTION BEDS

by

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In recent years there has been considerable interest in alternatives to the conventional chemical-biological wastewater treatment plant traditionally used in areas of high population density. Most of this interest has been expressed by small communities where the costs of the conventional system, both for construction and for operation and maintenance, would be prohibitively expensive (Goldstein, 1972).

One proposed solution to the problem of wastewater treatment in small communities is the use of a large-scale septic tank-leachfield system (Otis, 1978; Diodata, 1980; Rubin and Carlile, 1981). In this system each home or business has an individual septic tank connected to a small diameter gravity or low-pressure sewer system that conveys the tank effluent to a large-scale soil absorption bed (commonly called a large-scale leachfield and typically handling 13.22 m^3 (3,500 gallons or more per day). The treatment of the wastewater begun in the septic tank is then completed in the unsaturated soil beneath the leachfield.

The type of system described above has several advantages for an existing small community. The cost of construction is generally lower than the conventional system because small-diameter plastic PVC pipe can be used for collection purposes since most of the solids have been settled out in the septic tank (Otis, 1978). The cost of operation and maintenance is lower since trained operators are not required to operate and maintain the plant 24 hours a day (Otis, 1978). Operation and maintenance of the septic tanks (pumping out solids) is also more uniform because pumping is no longer the responsibility of the individual homeowner (Englehardt, 1983).

Another advantage of the above system is that in areas where only a limited area of soil is suitable for a leachfield, the suitable area can be used for a leachfield while homes can be built on areas without suitable soils (Rubin and Carlile, 1981). Also, this system replenishes groundwater, but with added nitrates, whereas the conventional system usually discharges the treated effluent into a surface stream (Laak, 1980).

A major drawback of the large-scale leachfield is the buildup of a groundwater mound beneath the leachfield. Although this buildup is not a problem in itself, it becomes one if an unsaturated zone of sufficient thickness is not maintained below the leachfield (EPA, 1980). This zone of unsaturated soil must be maintained to allow for adequate treatment of the effluent before it reaches the groundwater.

Objectives

There were two objectives of the research. The first was to develop a model of groundwater mound buildup which describes the impact of the effluent upon the maintenance of the unsaturated zone. The purpose of the model was to estimate the size of the recharge area which will limit the mound height to a value necessary for maintenance of an unsaturated zone.

The second objective was to place the model on a microcomputer in a computer-aided design mode to facilitate its use by county health departments, consulting engineers, and other interested parties.

Scope

The unsaturated zone, the primary design criteria, must be of sufficient thickness to ensure that bacterial die-off and the conversion of organic nitrogen to nitrate is complete before the effluent reaches the water table. Criteria established by the U.S. Environmental Protection Agency (1980) were used to define the thickness of the unsaturated zone. No effort was made to verify that this thickness will in fact provide the treatment required.

The design only considered soil absorption beds located in aquifers that could be approximated as infinite in a real extent. This condition was incorporated into the design because soil absorption beds should not be used in aquifers with obvious impermeable side-boundaries.

Model Development

The Rao and Sarma (1981) model of the groundwater mound buildup under a rectangular recharge area in a finite aquifer was chosen for use in this design. The Rao and Sarma (1981) model is as follows:

$$s(x,y,t) = \frac{8p}{K} \frac{A^2B^2}{\pi\ 4} \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{1}{mn} \left\{ \frac{1}{m^2A^2+n^2B^2} \right.$$

$$\left[1-\exp\{-a\ ^2\{(m^2A^2+n^2B^2)t/(A^2B^2)\}\}\right] \left(\sin \frac{m\pi L}{B}\right)$$

$$\left.\left(\sin \frac{n\pi D}{A}\right) \left(\cos\frac{m\pi x}{B}\right) \left(\cos \frac{n\ y}{A}\right)\right\} + \frac{2paLD}{KAB}\ t \qquad (1)$$

where:

H = height of water table above the base of the aquifer
K = hydraulic conductivity
e = specific yield
p = constant rate of recharge
h = initial height of the water table
x,y,A,B,L and D as defined in Figure 1
$s = H^2 - h^2$
$a = K\bar{h}/e$
$\bar{h} = 1/2\ (H+h)$

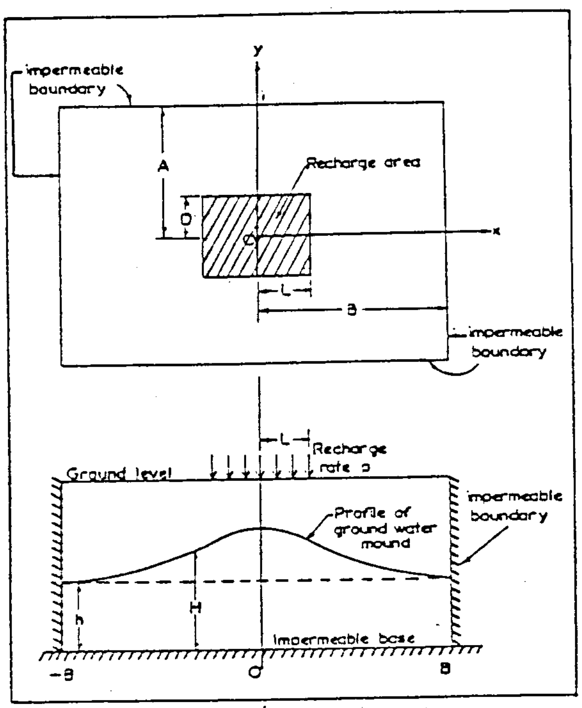


Fig. 1. Physical System of Rao and Sarma Model. (Source: Rao and Sarma, 1981)

Equation 1 can be modified for use in the design of large-scale soil absorption beds by taking advantage of the results of Rao and Sarma's (1981) research and the physical configuration of such beds. Using these facts, Equation 1 was changed into the form shown in Equation 2 for use in this design.

$$s(0,0,t) = \frac{8p}{K} \frac{A^2B^2}{\pi 4} \sum_{m=1}^{130} \sum_{n=1}^{130} \{\frac{1}{mn} \frac{1}{m^2A^2+n^2B^2} \left[1-\exp\{-a\pi^2\left[(m^2A^2+n^2B^2)t/(A^2B^2)\right]\}\right] (\sin \frac{m\pi L}{B}) (\sin \frac{n\pi D}{a})\} + \frac{2paD^2}{KAB} \quad 5 \qquad (2)$$

For further information on model development see Nettles (1984) or Nettles and Ward (1985).

Model Evaluation

To ensure that there were no errors in the program the model was tested with a time constant recharge rate using the data from Bianchi and Haskell (1975). The input data was as follows: hydraulic conductivity = 3.7×10^2 cm/s (52.0 in/hr), specific yield = 0.089, recharge rate = 9.7 cm/d (0.32 ft/d), time of recharge = 5.15 days, and an original water table height of 4.88 meters (16 ft). It was found that both the height and the area portions of the model calculated values within 3.0 percent of the measured values, as shown in Table 1.

Table 1. Comparison of Measured and Predicted Values

	Measured value m (ft.)	Calculated value m (ft.)	Percent error
Height	5.79 (19.0)	5.96 (19.5)	2.8
Side Length	90.0 (295.0)	91.4 (300.0)	1.7

Sensitivity of the model to changes in hydraulic conductivity, effluent volume, and shape (i.e., square vs. rectangular) was evaluated. With respect to hydraulic conductivity, results of the sensitivity analysis suggest that for large soil absorption systems, the lower limit of 5×10^{-3} cm/s, suggested by Laak (1980), is in fact the extreme lower limit that should be considered acceptable. The results of the hydraulic conductivity testing are shown in Table 2.

Table 2. Change in Recharge Area With a Change in Hydraulic Conductivity

Hydraulic Conductivity cm/sec (in/hr)	Side Length m (ft)	Area m^2 (ft^2)	Mound Height m (ft)
4.2×10^{-2} (59.5)	51 (167)	2,583 (27,889)	5.83 (19.13)
2.97×10^{-2} (42.1)	54 (177)	2,930 (31,329)	5.80 (19.03)
1.73×10^{-2} (24.5)	72 (236)	5,208 (55,696)	5.66 (18.57)
5.0×10^{-3} (7.1)	458 (1,503)	209,556 (2,259,009)	5.93 (19.46)

The evaluation of changes in effluent volume found an almost linear (r=0.989) relationship between effluent volume and recharge area. This implies that one of the easiest ways to reduce the recharge area required is to reduce the flow volume, as shown in Table 3.

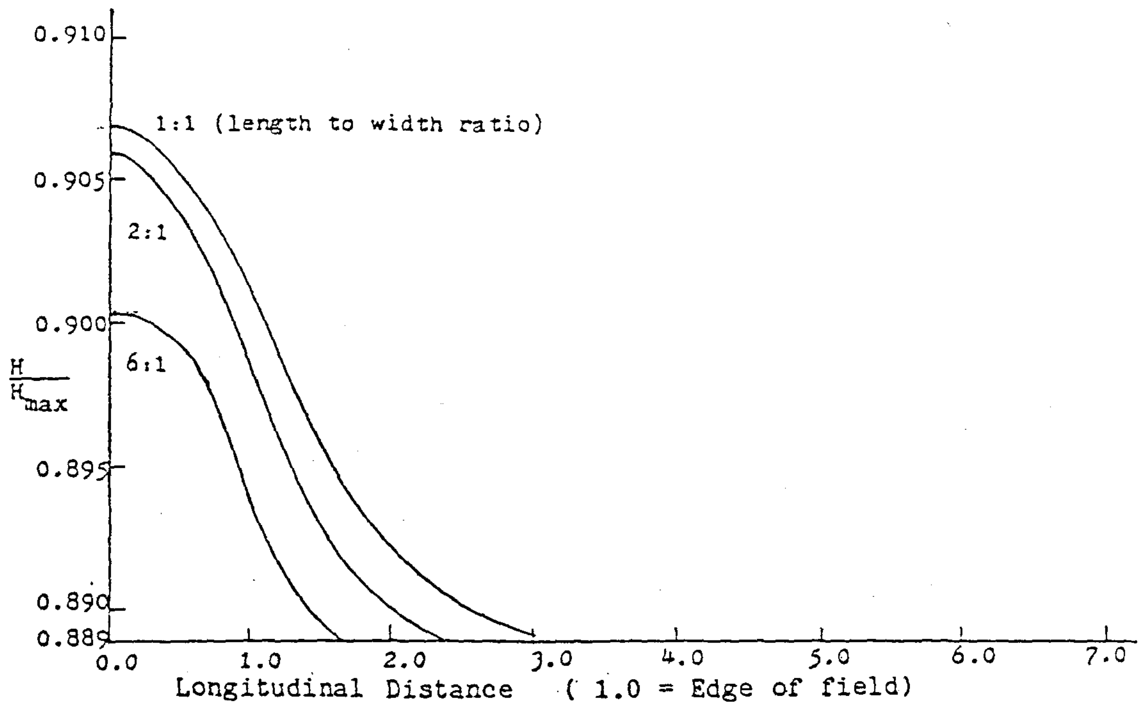
Table 3. **Change in Recharge Area with a Change in Effluent Volume Applied**

Effluent Volume Applied m^3/d (gpd)	Side Length m (ft)	Area m^2 (ft^2)	Mound Height m (ft)
35.5 (9,375)	36 (118)	1,302 (13,924)	5.79 (19.00)
71 (18,750)	54 (177)	2,930 (31,329)	5.80 (19.03)
142 (37,500)	98 (322)	9,683 (103,684)	5.75 (18.86)
284 (75,000)	246 (807)	60,516 (651,249)	5.88 (19.29)

The square leachfield shape had the greatest mound buildup (see Figure 2). Thus, using the area calculated for square leachfield (as was done here) to size a rectangular leachfield introduces a safety factor. This safety factor helps in addressing the need to account for the capillary fringe height and precipitation events not included in the estimated recharge volume. Both of these latter topics need additional research.

Computer-Aided Design Package

The model was placed in a computer-aided design mode on the IBM-PC. It was set up to be run in one of three options: (1) estimate the leachfield area given an estimate of the leachfield area, a time, a flow volume, the aquifer specific yield, the aquifer hydraulic conductivity, the aquifer thickness, and the maximum acceptable groundwater mound height buildup; (2) estimate the groundwater mound height given the same parameters as in option (1) but without the maximum acceptable groundwater mound height buildup; and (3) estimate the distance from the center of the leachfield to the point of negligible mound buildup given the same parameters as in option (1).



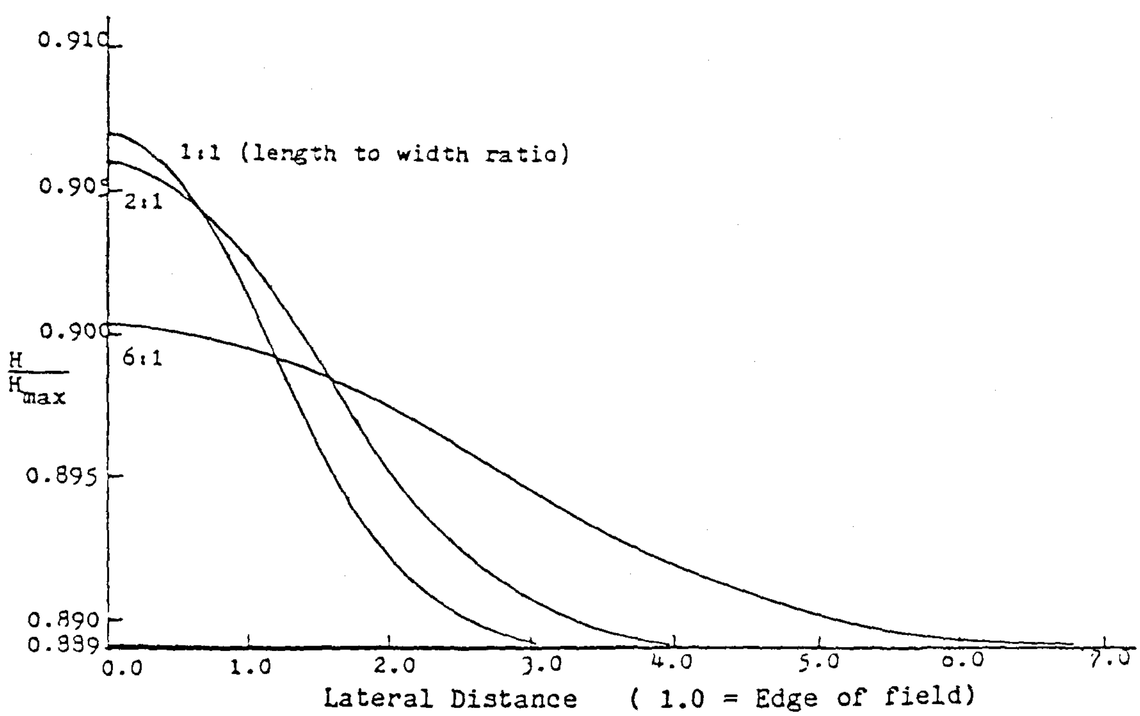


Figure 2 . Dimensionless Mound Profiles for Square and Rectangular Recharge Areas.

Required Parameters

Time: The time used is the time at which it is desired to know the groundwater mound height. It is recommended that the time used be the design life of the leachfield.

Flow Volume: The flow volume should be the estimated daily effluent volume applied to the absorption bed.

Specific Yield: The specific yield is a measure of the pore space available for a water table rise. It may be estimated as the storage coefficient (apparent specific yield) calculated in most aquifer tests.

Hydraulic Conductivity: Hydraulic conductivity is a measure of the ease with which water flows through a soil. It may be estimated from most aquifer tests.

Aquifer Thickness: This is the saturated thickness of the aquifer.

Maximum Acceptable Groundwater Mound Buildup: The maximum acceptable groundwater mound height buildup should be calculated as the distance from the base of the aquifer to a point that is the capillary fringe height plus 1.22 meters (4 ft.) below the bottom of the leachfield.

Hardware Required to Run the Design Package

The design package was developed on a Cyber 205 mainframe computer in FORTRAN 77. The package was then converted to Microsoft FORTRAN 77 and run on an IBM Personal Computer XT.

The design package's executable statements require approximately 115 kilobytes (k) of memory with each design option requiring approximately 38.333 k. Thus, the entire design package will fit on a single, single sided diskette (175 k available) with enough space left to include a users

Example Application

An example of how the design package is used is presented in this section. This is accomplished by running the Area option of the design package with hypothetical data.

A 30-unit housing development is proposed for installation on a site with no obvious groundwater flow boundaries. An aquifer test on the proposed site revealed that the aquifer saturated thickness was approximately 6.71 meters (22 ft.) and that the depth to the base of the aquifer was approximately 9.75 meters (32 ft.). Analysis of the drawdown data, by the Theis method, yielded the following results: the storage coefficient (apparent specific yield) is estimated to be 0.09 and the transmissivity (hydraulic conductivity multiplied by the aquifer thickness) is estimated as

$8.72\ cm^2/sec.\ (0.56\ in^2/min)$

to give a hydraulic conductivity of

$8.72\ cm^2/s/671\ cm = 1.3 \times 10^{-2} cm/s\ (18.4\ in/hr).$

If it is assumed that the bottom of the leachfield is 1.52 meters (5 ft.) below the ground surface and the capillary fringe thickness is 0.21 meters (0.69 ft.), the maximum acceptable groundwater height increase is calculated as

$9.75\ m - 1.52\ m - 0.21\ m = 8.02\ m.$

Once the aquifer-related properties have been established, a determination of the flow volume and design life of the leachfield must be made. Since there are no records of water use for this proposed community, the daily volume of effluent applied to the leachfield must be estimated. Information from the developer indicates that all 30 units in the development are to have three bedrooms. Assume that the State Health Department estimates wastewater generation to be 0.57 cubic meters (150 gal.) per bedroom per day, from which the daily effluent volume is calculated as

$0.57\ m^3/d\ (30\ units * 3\ bedrooms/unit) = 51.3\ m^3/day.$

The design life of this system is established as 20 years (7300 days). The data required to run the Area option is listed, in the order it is needed, in Table 4.

Table 4. Data for Example Application

first estimate of one-half field side length = 30 m
design life = 7300 days
daily effluent volume = 51.3 m
specific yield = 0.09
hydraulic conductivity = 0.013 cm/s
original water table height = 6.71 m
maximum acceptable water table height = 8.02 m

From the above discussion it can be seen that any IBM compatible microcomputer with a Microsoft FORTRAN 77 capability and 64 k of memory should be able to run the design package. The specification of 64 k of memory results from the package requirements for the storage of program-generated values and the storage requirements of internal machine operations.

At this point it should be pointed out that, although a printer is not required to run the design package, it is convenient to have a printed copy of the users' manual to refer to. It is also much more convenient to have a printout of the results of the Distance option because of the table of values generated. Figure 3 is a copy of the welcome, input, and output screens for this example.

Figure 3 shows that for the example data used, a square leachfield of 43.0 meters (141 ft.) per side with an area of 1,815 square meters (19,902 $ft.^2$) will have a maximum groundwater mound buildup of 7.90 meters (25.9 ft.) after 20 years. A rectangular leachfield with the same surface area would have an even lower groundwater mound buildup.

The design values shown above should not be accepted by the designer as the final design area and groundwater mound buildup for the leachfield. Any design should be critically examined to determine if the design seems reasonable. This is especially true of this design because of the large spatial variability of hydraulic conductivity over small distances, which can induce a false sense of security in the accuracy of this design.

Conclusions

The model, as expressed by the computer-aided package, is a useful tool in approximating the design of large-scale soil absorption systems.

```
          THIS PROGRAM IS DESIGNED TO ESTIMATE THE AREA
          REQUIRED FOR A LARGE-SCALE LEACHFIELD.  THE PRIMARY
          DESIGN CONSIDERATION IS THE MAINTENANCE OF AN
          UNSATURATED ZONE OF ADEQUATE THICKNESS BENEATH
          THE LEACHFIELD.

ENTER THE FOLLOWING DATA

FIRST ESTIMATE OF ONE-HALF FIELD SIDE LENGTH (M)
30
NUMBER OF DAYS EFFLUENT IS APPLIED TO FIELD
7300
VOLUME OF EFFLUENT APPLIED TO FIELD PER DAY (CU.M)
51.3
SPECIFIC YIELD
0.09
HYDRAULIC CONDUCTIVITY (CM/SEC)
0.013
ORIGINAL WATER TABLE HEIGHT (M)
6.71
MAXIMUM ACCEPTABLE WATER TABLE HEIGHT (M)
8.02

          HEIGHT  =                                        7.90

          SIDE LENGTH (M.)                =               43.

          FIELD AREA (SQ. M.)             =             1815.
```

Fig. 3. Screen Appearance of Example

The model needs additional testing before any widespread use is made of its capabilities. Tentatively, the model indicates that:

(1) Approximating the dosing procedure used on most large-scale soil absorption beds with a constant recharge rate applying the same effluent volume per day is acceptable in this design.

(2) The acceptable hydraulic conductivity range appears to be 5×10^{-3} to 4.2×10^{-2} cm/s.

(3) With the above hydraulic conductivities flow through the soil is often very rapid, which raises questions as to the ability of the 1.22 meter (4 ft.) unsaturated zone to adequately "treat" the wastewater.

ACKNOWLEDGEMENTS

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REFERENCES

1. Bianchi, W.C. and E.E. Haskell. 1975. Field Observations of Transient Groundwater Mounds Produced by Artificial Recharge into an Unconfined Aquifer. Rep. W-27, Agricultural Research Service, U.S. Department of Agriculture, Washington, D.C.

2. Diodata, F.D. 1980. Community On-site Disposal Systems--the Iselin Demonstration Project. Proceedings of the Seventh National Conference on Individual On-Site Wastewater Systems, National Sanitation Foundation, Ann Arbor, Michigan.

3. Englehardt, J.D. 1983. Quantification of On-Site Wastewater Treatment Operation and Maintenance. Unpublished Masters Thesis, Colorado State University, Fort Collins, Colorado.

4. U.S. Environmental Protection Agency. 1980. Design Manual for On-Site Wastewater Treatment-Disposal Systems. Technology Transfer Program, U.S. EPA, Washington, D.C., EPA 625/1-80-012.

5. Goldstein, S.N. 1972. Community Sewage Systems vs. On-Site Sewage Treatment Systems. On-Site Waste Management Series. Hancor, Inc., Findlay, Ohio, 1:2-27.

6. Laak, R. 1980. Wastewater Engineering Design for Unsewered Areas. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan.

7. Nettles, D.L. 1984. Design Methodology for a Large-Scale Soil Absorption Bed for Septic Tank Effluent. Unpublished Masters Thesis, Agricultural and Chemical Engineering Department, Colorado State University, Fort Collins, Colorado.

8. Nettles, D.L. and R.C. Ward. 1985. Design Methodology for a Large-Scale Soil Absorption Bed for Septic Tank Effluent. Proceedings of the Fourth National Symposium on Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, Michigan.

9. Otis, R.J. 1978. An Alternative Public Wastewater Facility for a Small Community. Small-Scale Waste Management Project, University of Wisconsin, Madison, Wisconsin.

10. Rao, N.J. and P.B.S. Sarma. 1981. Groundwater Recharge From Rectangular Areas. Ground Water 19(3):271-274.

11. Rubin, A.R. and B.L. Carlile. 1981. Large-Scale On-Site Systems. Proceedings of the Eighth National Conference on Individual On-Site Wastewater Systems, National Sanitation Foundation, Ann Arbor, Michigan.

MICROORGANISM MOVEMENT IN COARSE COLORADO SOILS

by

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Introduction

The mountainous regions of Colorado contain many areas which are severely limited in regard to the placement of on-site systems. These areas include both steep mountain slopes with coarse, shallow soils as well as valleys commonly filled with coarse river alluvium. These coarse soils have limited clay fractions and organic matter, resulting in poor filtration, adsorption, and degradation of pathogenic and non-pathogenic microorganisms commonly released from these on-site systems. Rapid microbial transport through coarse alluvium or fractured bedrock may result in extensive contamination of the groundwater. Little is known about the removal efficiency of on-site systems in coarse soils during either normal environmental conditions or during "adverse" conditions. Bacterial flux in these soils under adverse conditions has not been determined.

Problem Statement.--Glaciation in many areas removed much of the existing soil cover leaving steep mountain slopes with bedrock surfaces and valley floors filled with morainal and outwash sediments. Fluvial processes on the valley floors caused these sediments to be reworked. These dynamic processes removed much of the finer sediment leaving numerous paleochannels within terrace and valley floor deposits. These coarse-grained paleochannels, usually masked on the surface, have often served as groundwater sources. The characteristics that make them good groundwater sources, such as proximity to the surface, recharge potential, and apparent specific yield, are those which also make them easily contaminated and difficult to control.

Soil development on mountain slopes is slow. There is a natural downslope movement of surface sediments, so the development, depth, and fertility of soils on mountain slopes is often severely limited. Often the soil has a preponderance of coarse fragments resulting in a soil with an excess of large pores that tends to be droughty (Williams et al., 1978).

Beneath this veneer of surface litter and soil is fractured bedrock or a thick layer of macro-crystalline gravel ("grus") overlying the fractured bedrock below. This band of unconsolidated parent material holds little water, and the hydraulic conductivity may be greater than that of the rock below or the soil horizons directly above, thereby providing a layer for lateral flow of water (Mueller, 1979).

The presence of restrictive layers or of highly porous unconsolidated bands of grus over bedrock makes these mountain and alluvial soils particularly susceptible to lateral flow during the snowmelt and rainfall events which occur primarily in the spring.

Any restriction to soil drainage can lead to saturated flow conditions in the zone just above the impermeable layer. That saturated or near-saturated conditions aid in bacterial transport and survival is a well documented concept (Olivieri, 1983). Reneau et al. (1975), Hagedorn et al. (1978) and others have commented on the major distances traveled by indicator organisms after rainfall events--usually the result of a rainfall-elevated water table. Stenstrom and Hoffner (1982) suggested that dosing with large volumes of low ionic strength water aided in microorganism transport. Bacteria movement at rates of 1 to more than 10 m/hr has been recorded (Rahe et al., 1978; McCoy and Hagedorn, 1980, Allen and Morrison, 1973).

The presence of an unsaturated, aerobic zone is essential to bacterial degradation and to minimal movement of microorganisms (Carlile, 1983). Because intestinal microorganisms survive best under anaerobic conditions and die off rapidly when competing with aerobic organisms, any conditions that cause saturated soil near leachfield trenches increase the potential for anaerobicity. The result is a greater probability of anaerobe transport to the groundwater (Carlile et al., 1981).

On-site wastewater systems placed in these environments are designed and installed with the assumption that most pathogenic organisms will not pass unaltered through an unsaturated zone located below each system. Estimated seasonal fluctuations of the water table are incorporated in all designs. Transport of most contaminants can be effectively limited by a good soil profile of sufficient depth with adequate amounts of clay, silts, fine sands and organic matter (Gerba et al., 1975). Studies have shown that 0.6 to 1.2m (2 to 4 ft.) of unsaturated soil below a septic tank drainfield are sufficient to remove bacteria and viruses; greater depths are necessary for coarse, permeable soils (Otis et al., 1980; Hagedorn et al., 1981; Nichols et al., 1983). Many states, Colorado included, have adopted standards establishing a minimum soil depth to bedrock or the highest level reached by the water table for installation of a septic tank-leachfield system (Baker, 1978). These standards are chosen with little information regarding the maximum depth of unsaturated soil necessary for proper treatment under the range of environmental conditions that may occur at a particular site (McCoy and Hagedorn, 1979).

Although regulations vary from state to state and county to county, they generally require a soil percolation rate greater than 60 min/in (3 cm/hr) and less than 5 min/in (30 cm/hr), a four foot (1.2 m) depth between the bottom of the leachfield trench and bedrock or high water table, and 100 foot(30 m) distance to a potable water supply.

The depths and distances were chosen with little scientific foundation. The numbers became embedded in literature, and subsequent research efforts were directed toward validating the existing regulations.

The limit in horizontal distance to potable water evolved from Caldwell's (1937, 1938) studies on the nature of groundwater pollution caused by privies extending below the water table. He suggested 50 feet as adequate for dilution of wastewater. As a result, California, the Federal Housing Authority (FHA), and the U.S. Public Health Service (USPHS) suggested 50 feet. Implicit in their choice was the assumption of failure. Their primary concern was choosing a distance thought to be sufficient to dilute the wastewater after it passed through the unsaturated zone and entered the groundwater.

During Colorado's efforts to update the regulations in 1973, Elwood Bell, a former Larimer County sanitarian, recalls:

> "I can remember looking through all the material to determine well distances from a septic field. We found one reference which said that the farthest in good soils (what we ended up calling suitable soils) was 75 feet from a privy. And so, with our wisdom of public health, we added a little safety factor and came up with 100 feet." (Bell, 1981)

The choice of four-foot depth below the leachfield was not the result of scientific study. After World War II the FHA suffered major financial losses through mortgage defaults when people vacated homes with malfunctioning septic tank-leachfield systems. Through the USPHS the FHA launched investigations into septic tank practices. The investigations began in the mid-1940s and ended in the early '60s with the publication of the Manual of Septic Tank Practices. During the early USPHS field studies, investigators found homes with troubled systems were often located in subsurface drainage swales or topographic basins. Evidently local practices failed to identify trouble spots. The investigators chose a depth of four feet above the seasonal high water table elevation, hoping that fewer incorrect placements would occur. No reason was given for the four-foot guideline because the USPHS people did not wish to insult local authorities. The USPHS assumed the local authorities could not recognize the problem in placing leachfields in areas of poor drainage (Winneberger, 1984).

It is important to reiterate two points: (1) it was generally assumed that the systems would fail, and the wastewater would reach the groundwater; and (2) there was little scientific basis to the choice of the four vertical feet and the 100 horizontal feet distances. The four-foot distance was chosen to keep the leachfield placement out of the saturated soil (Phreatic zone). The 100-foot distance was chosen as adequate for dilution of wastewater in groundwater.

The literature indicates that soils with high clay and organic matter content (without cracks, wormholes, etc.) will remove bacteria within four feet--usually much less. The literature says little regarding bacterial movement in coarse soils subjected to adverse rainfall events.

Objective.--The objective of an ongoing study at CSU (the topic of this Ph.D research) is to model microbial activity and transport in coarse soils and to determine if the 4 foot (1.2 m) guideline is adequate for removing bacteria before they reach saturated soils. The assumptions and processes relevant to such modeling will be discussed and analyzed.

Scope.--This paper reports on the mechanisms pertinent to the modeling effort and, as such, is a progress report on the larger study currently underway at CSU. Results from the bacterial transport modeling are not available at this time. The important processes influencing bacterial transport, both at a microscopic and macroscopic level, are described in this review.

Assumptions

In analyzing or modeling microbial transport in soil, one must make several critical assumptions. These assumptions are required because of the system complexity and the state-of-the-art in both biological analysis and mathematical analysis. These critical assumptions relate to macropore flow, microhabitats, sampling methodology, utilization of laboratory results, and the clogging mat.

Macropores (large continuous openings) are the result of animal activities, plant roots, freeze/thaw cycles, shrinkage caused by dessication, and chemical weathering. There is not yet a consensus of what defines a macropore, but generally it is any pore with a diameter greater than 1 mm to 3 mm (Beven and Germann, 1982). Macropores are a factor as shown by the work of Smith et al., 1985. They found that intact silt loam soil cores would transmit 79 percent of influent bacteria. The same soil, after being mixed, sifted and repacked, transmitted only 5 percent of the influent bacteria. Studies in macropore flow theory have not resulted in suitable methods for modeling water flow or microbial transport in both the soil matrix and the associated macropores. Modeling efforts largely ignore the effects of macropores.

The "concept of discrete microhabitats" presented by Stotzky (1974) suggests that if a soil system is not homogeneous then microbial population dynamics must be viewed stochastically (randomly). This concept is derived from the fact that soil is heterogeneous, discontinuous, and dominated by a solid phase of varying-sized particles. The variability and discontinuity in particle size results in soil being a composite of numerous small microbial communities each with its own ambient environment. These particles form aggregates with water surrounding each aggregate and forming bridges with adjacent aggregates. Each microhabitat is an independent entity. If one accepts the concept of discrete microhabitats, even temporarily, it is possible to accept the concept of the diversity of microhabitats, and by extension, the variability in the microbial composition between even closely adjacent microhabitats. The physical and chemical characteristics will differ between microhabitats and the types of microbes entering and persisting will vary. The parameters commonly used to describe microbial activity, such as the Monod coefficients, will also vary. There is spatial dependence, but single-valued parameters cannot be applied throughout a heterogeneous soil system. The parameters are, in effect, random variables, and the equations describing microbial behavior are stochastic, not deterministic.

Modeling microbial transport is complicated by "inherent" sampling error. The true population of septic tank influent or effluent microorganisms is not known. Sublethal injury (McFeters et al., 1982) resulting from several environmental factors which impact sampling and sample transport (McFeters et al., 1974 and Bissonnette et al., 1975), and competition from heterotrophic plate count bacteria (LeChevallier and McFeters, 1985) during culturing limits the validity of many sample results. The problem with sampling viruses amplifies the problem. Sampling error cannot be avoided with certainty, but its presence lends credence to the stochastic approach to systems analysis. Because analyzing bacterial samples is less complex than analyzing viral samples, modeling bacterial transport is the logical starting point.

Problems develop when trying to apply laboratory column results to field situations. Organisms with the same genotype may show different phenotypes in the field. Bacteria typically do not develop extracellular polysaccharides in laboratory cultures, although their presence is common and important in a natural situation. Much experimental work has been carried out with chemostat cultures under steady state conditions. Field conditions are not steady state; they are transient. On a pore scale, batch culture conditions may be more realistic. In spite of these difficulties, most microbial population studies utilize the Monod equation. The Monod equation is not valid in non-steady state conditions because the parameters are not independent of time (Curds and Bazin, 1977). It is impossible to specify any microbe in precise terms of its structure and function without specifying the environmental conditions common at that time and point in space. Therefore, the problem of "plastic physiology" vs. growth in natural conditions becomes unavoidable (Tempest et al., 1983). Unfortunately, the laboratory vs. field problem cannot be solved at this time. In-situ experimental work is very difficult, if not impossible in some cases, and many of the results are suspect. One is forced to utilize experimental results determined in the laboratory.

Research has not clearly defined or quantified the impact of the clogging mat on microbial population dynamics. Numerous studies have reported the bacterial population changes between the influent and effluent port of a septic tank for a few commonly studied bacteria (Ziebell et al., 1975; Otis et al., 1975; Tyler et al., 1978; and Stenstrom, 1984). The literature is limited with respect to what happens to a microbial population as it is carried from the septic tank through the drainpipe to the pipe/soil interface. It is known that a biological mat develops in the pipe and the pipe/soil interface. The role of the biological mat in microbial population reduction is not well defined or quantified. The usual approach is to utilize the population determined at the septic tank effluent port and "deliver" that population to the soil surface in the drainfield.

Processes

Accepting the previously described critical assumptions allows one to analyze, and to ultimately model, the processes that affect the microbial population (now limited to bacteria) as it enters and moves through the soil. The potential for a given bacterial population is unlimited. Temperatures favorable to bacterial life extend to a depth of 2000 m (assuming a normal temperature increase of $3^{\circ}C/100$ m). Water pressures are not high enough to deter bacterial activity, and many bacteria can live under high osmotic pressures of saline water (Bouwer, 1984). Other environmental factors may be limiting, and they are described in the paragraphs that follow.

As the fluid (effluent mixed with rainfall or snowmelt) moves through the soil it is confined to the smaller pores if the soil is unsaturated, because the driving force is capillary pressure (suction), not gravity. The larger pores transmit gases which allow the more efficient aerobic and facultative organisms to dominate metabolically (Hansel and Machmeier, 1980). As the soil becomes saturated the larger pores transmit water, gases become entrapped or expelled, and anaerobic organisms dominate.

As the larger pores drain during a drying period, soil aggregates themselves remain saturated internally. A spherical aggregate will frequently remain anaerobic in all but the outer 3 mm thickness (Griffin, 1981). On the exterior of the aggregates, fungi and spore-forming aerobic bacteria tend to dominate, while on the interior gram negative, non-spore formers are more common (Darbyshire, 1975).

Bacterial activities in soil tend to drop sharply as water content drops--as capillary pressure head (suction) drops between -0.5 and -3.0 bars (Griffin, 1981). For reference, recall that field capacity is approximately -0.1 bar for sandy soils and -0.3 bar for loams and silt loams, while the wilting point is often defined as -15.0 bars. Harris (1981) has suggested that -0.1 bar is normally associated with saturation of soil pores 30 μm in diameter, -0.3 bar is associated with saturation of soil pores 4 μm in diameter, and at -5.0 bars water is in a thin film only a few molecules thick.

There are numerous processes and factors that influence bacterial activity at the microscopic/pore scale. Among the most important are adsorption, straining/clogging, growth, death, stress, old age, motility, dispersion, diffusion, convection (advection), sedimentation, and competition and predation from other organisms. Bacterial transport is a macroscopic process. Many of the previously mentioned processes and factors may be important in a microscopic frame of reference, but they may be of limited importance in a macroscopic frame of reference. Elimination of those factors with limited importance allows one to simplify the governing equations describing transport. These simplifications introduce error into the results. It is impossible to quantify this error given the state-of-the-art of biological and mathematical analysis. These restraints suggest that a stochastic approach is more meaningful than a deterministic approach, and that results should be expressed as probabilities, not exact values.

Many of the previously mentioned processes and factors will be described. The importance of each to macroscopic bacterial transport will be indicated.

Motility.--Motility is the movement of the specific organisms. For convenience, diffusion resulting from bacteria being "bumped around" by other molecules (Brownian motion) is included here. Brownian motion, random motility, and chemotaxis are expected to be of minor importance to macroscopic bacterial transport.

Escherichia coli have flagella randomly distributed over the cell body. *Pseudomonas aeruginosa* has one or two flagella located at the polar region. The flagella, individually or as a bundle, rotate like a corkscrew causing forward motion. Polar flagella in uniflagellate bacteria move much faster than peritrichously flagellate bacteria--70 m sec^{-1} (25 cm hr^{-1}) for *Pseudomonas* vs. 30 m sec^{-1} for *Salmonella* (Rowberry et al., 1983). Most of the swimming is random in occurrence and direction. Swimming is mixed with tumbling (erratic behavior caused by a reverse in rotation or unbundling of flagella) (Berg, 1983).

Even when pores are filled with water, bacteria will not be able to move freely if the pore necks are too small. For a rod-shaped bacterium, a pore neck radius of 1 to 1.5 μm is likely to restrict the rate of passage, whether by Brownian or flagellar movement (Griffin and Quail, 1968).

Chemotaxis is a directional movement toward higher chemical concentrations. Seymour and Doetsch (1973) suggest that while positive chemotactic responses may be of occasional value to bacteria under natural environmental conditions, negative chemotactic responses nearly always develop toward lethal or hostile chemical gradients. Bacteria are chemotactically attracted to many chemicals, most of which could serve as nutrients; however, there is no correlation between the energy production of a particular substance and its ability to attract bacteria. Some carbohydrates such as glycerol, gluconate, succinate, and fumerate, which are metabolized by Escherichia coli, fail to attract bacteria, whereas in other cases the bacteria are attracted to non-metabolizable compounds (Chet and Mitchell, 1976).

Purcell (1977) estimated the Reynolds Number (the ratio of inertial to viscous forces) in fluids near particles in unsaturated porous media to be on the order of 10^{-4}. The kinematic viscosity would be on the order of 0.01 $cm^2\ sec^{-1}$. Purcell suggested that if a coliform bacteria were to propel itself with its flagella, it would coast approximately 0.1 Angstrom and would slow to a stop in 0.6 μsec. He compared the fluid to molasses in a swimming pool. To move any appreciable distance would require a large amount of energy. It is more likely that the bacterium benefits by utilizing nutrients that enter the immediate vicinity.

The relative impacts of Brownian motion (causing diffusion), random motility, and chemotaxis are minor at the macroscopic scale. Brownian motion and random motility do not result in a specific directional flux. Elimination of these processes may be a valid step in transport model simplification.

Sedimentation/Settling.--Gravitational settling or sedimentation is important for the accumulation of inorganic mineral suspension (density about 2.5 g/cm^3), but not for microorganisms less than 5 μm, with a density of around 1 g/cm^3 (Pekdeger and Matthess, 1983 and Yao et al., 1971). The gravitational velocity of a 5 μm bacteria is on the order of groundwater flow velocity (Corapcioglu and Haridas, 1984). Hagedorn (1981) indicated that sedimentation of bacterial clusters occurred throughout the saturated zone. In unsaturated soils, both the individual bacteria and the clusters are subject to surface forces influencing adsorption as well as clogging in small pores or pore necks.

Straining/Adsorption.--Retention (clogging, straining, adsorption, etc.) of bacteria by soil is occurring simultaneously with their release (sloughing of clusters, declogging, etc.), although the magnitude of release may be small relative to retention.

Hagedorn et al. (1981) suggested that straining and filtration of bacteria by soil particles were the main limitations to travel in soil. Butler et al. (1954) concluded that removal of bacteria from a percolating liquid is inversely proportional to the particle size of the soil. Column studies using uniform spherical materials indicate bridging occurred when the diameter of suspended particles moving through a medium was more than 0.2 times the diameter of particles of the medium itself (Bouwer, 1984). This would suggest that bridging at pore necks is common even in sand. Previously filtered (strained) bacteria can act to reduce the effective pore diameters thus increasing the filtering action of the soil (Crane and Moore, 1984).

Adsorption varies with microbial species and adsorbent types. The sorption environment is affected most by pH and the presence of various inorganic and organic compounds that alter surface charges. The strongest adsorption of bacterial cells generally occurs at pH of 3-6. Addition of multivalent cations to a solution can increase adsorption, while the addition of inorganic salts to a suspension can promote desorption (Daniels, 1980). Roper and Marshall (1978) found that sorption of microorganisms to large particles increased with increasing electrolyte concentration and electrolyte valency. At low electrolyte concentration microorganisms were repulsed from the surface. Rainfall would dilute the electrolyte concentration which would be primarily nitrates and chlorides--both low valency ions. It is thought that humic or fulvic acids--the highly colored organic compounds naturally present in water and soil--also cause desorption (Sobsey, 1981).

Part or all of the outer surface of some bacteria is hydrophobic--such bacteria are rejected from the aqueous phase and attracted toward any non-aqueous phase (including solid surfaces) (Marshall, 1976). Usually both the bacterial and soil particle surfaces are negatively charged in aqueous environments. As a result, bacterial cells will experience a repulsive force when their diffuse double layers overlap with the double layer of the collector surface (Fletcher et al., 1980). The potential energy barrier between the bacterial cells and the collector surface can be circumvented if the bacteria forms extracellular material, which as a polymer molecule is able to approach close to the collector surface. It is thought that extracellular polysaccharides or at least polymer formation by bacteria is involved in their ability to adhere to surfaces. Lipopolysaccharides (LPS) extend a considerable distance from the end of the outer membrane of organisms such as E. coli and Salmonellae. They could, therefore, reach the collector surface and "bridge" the high energy barrier (Rogers, 1979). These polymer bonds are thought to be irreversible (Wimpenny et al., 1983). Intermittent flow over collector surfaces may provide adequate time for these polymer anchorages to develop, and they are not readily subject to liquid shear (Powell and Slater, 1982).

Accumulation of bacteria on a collecting surface can be divided into three stages--adsorption, attachment, and colonization (growth) (Fletcher et al., 1980). Adsorption of bacteria to a soil surface can be a factor in restricting bacterial transport, and the effectiveness of the soil in this respect is thought to increase as soil becomes less structured and clay content decreases (Crane and Moore, 1984). Gerba et al. (1975) suggest that adsorption is important in soils that contain clay. In coarse soils a low clay content and reduced surface area may reduce the impact of adsorption of bacteria.

Empirical equations for determining virus adsorption constants have been developed based on the surface area of soils (Reddy et al., 1981; Enfield et al., 1976; Zantua et al., 1977). These equations assume zero retention for soils with a clay content less than 18 percent. Gerba et al. (1975) suggested that adsorption was a greater factor with viruses than bacteria. Results from an investigation of bacterial adsorption to sand, silt loam, and clay show no adsorption to sand (Hendricks et al., 1979). Matthess and Pekdeger (1985) report that autochthonous (indigenous) bacteria are more likely to adsorb to particles while enteric bacteria show hardly any growth and should show minimal adsorption. Accepting these results allows one to assume that adsorption of viruses and bacteria is limited in sand, loamy sand, and sandy loam soils (Cosby et al., 1984).

Adsorption can be assumed less important than straining because of the low clay content of coarse soils. Low water flow velocities (low Reynold's number) may reduce the importance of desorption and declogging.

Growth/Death/Stress.--The major reason for enteric bacterial die-off in a foreign environment is the inability of these organisms to lower their metabolic requirements in a situation of lower nutrient availability (Crane and Moore, 1984). If the bacteria lack nutrient reserves or lack the ability to enter resting (dormant) states, they starve to death.

Enteric bacteria are copiotrophs entering an oligotrophic soil environment. Copiotrophs are those organisms that do not grow (probably starving) in dilute nutrient environments, but which have the ability to rapidly oxidize substrates if the concentration of nutrients increases. Oligotrophs are those bacteria that appear to grow (slowly, but well) in dilute environments, but which do not respond as rapidly to changes in nutrient flux as do copiotrophs. Oligotrophs have high affinity systems for nutrient uptake (Breznak, 1984). In a carbon-limited environment those bacteria that will establish a steadily growing population will be those that can remove the limiting substrate with the highest efficiency (Pfennig, 1984). Oligotrophic environments are those with less than 10 mg of dissolved organic carbon liter^{-1} (Balkwill and Ghiorse, 1985). Enteric bacteria prefer glucose over organic acids as the primary carbon and energy source for growth (Harder et al., 1984).

It is thought that extracellular polymers such as polysaccharides can aid bacteria in oligotrophic environments by improving their ability to bind to the surfaces of minerals where nutrients may accumulate. It is also thought that the extended network of polymer material may be used for scavenging trace nutrients in low concentrations (Ghiorse and Balkwill, 1983). The extracellular polysaccharide material accumulates with nutrient deprivation in oligotrophs, and the accumulation increases with increasing stress (White et al., 1983). Extracellular polysaccharide material may also protect bacteria from water stress and attack by protozoa and bacteriophages (Hepper, 1975).

Activated sludge, trickling filter, oxidation ditch, and irrigation pond effluents derived from domestic wastewater are carbon-limited for microbial growth (Jenkins and Richard, 1982 and Moore et al., 1981). Viraraghavan (1976) found a 78 percent reduction in soluble organic carbon between the influent and effluent of septic tanks. It is reasonable to assume that wastewater entering the soil beneath leachfield trenches is also carbon-limited. The nutritional situation in soil is more analogous to a nutrient-limited continuous culture than to a batch culture where cells are growing at maximum specific growth rate (Gray and Williams, 1971). In this carbon-limited, low nutrient environment, bacteria that grow slowly at low substrate concentration will have a selective, competitive advantage over those bacteria adapted to growth at higher nutrient levels (Poindexter, 1981 and Pfennig, 1984). Allochthonous (introduced) bacteria will have a reduced competitive ability and lower metabolic rate (Klein and Casida, 1979). Indigenous, oligotrophic soil bacteria and saprophytic bacteria in wastewater will have a competitive advantage over enteric bacteria coming from the leachfield drainpipes.

Predation.--Soil bacteria are subject to predation from other bacteria, bacteriophages, and larger soil fauna such as protozoa and nematodes (roundworms). Protozoa and nematodes are ubiquitous in soils and are as much as 96 percent by weight of the soil microfauna (Anderson et al., 1978). The protozoa of interest are typically shelled and naked amoeba and ciliates.

Only a small proportion of nematodes are found with any frequency in soils where no "violent" decomposition occurs (Kuhnelt, 1976). The size of nematodes (0.3 to 2.5 mm) also limits their distribution (Freckman, 1982). As a result their presence and growth is less in fine textured than in coarse soils, and their distribution in the soil reflects the distribution of organic matter (Yeates and Coleman, 1982). Myxobacteria, which resemble cellular slime molds and share the same ecological niche in the soil, also feed on bacteria (Kaiser, 1984).

Protozoa and Bdellovibrio are the dominant predators of soil bacteria. Protozoa are concentrated in surface litter and in the rhizosphere where food is in ample supply (Clarholm, 1981). They are generally limited to pores with a diameter greater than 3 µm (Darbyshire et al., 1985). Bdellovibrio are obligate aerobes (Dawes, 1976) whose prey is specifically gram-negative species (Starr and Huang, 1976). The concentration of potential prey might be a limiting factor for Bdellovibrio. Cell densities as high as 10^6 cells/ml do not ensure existence of Bdellovibrio (Varon et al., 1984). Predation at 2 or 3 m depth in a nutrient-poor environment is probably limited. The exact nature of predation or protozoan and nematode activity in leachfield soils is not known. No literature on the subject is readily available.

Dispersion/Advection.--The process by which bacteria are carried along with the bulk motion of the flowing water is advection (a term more appropriate than convection) (Freeze and Cherry, 1979). This is the major mode of transport of bacteria in a porous medium. Most of the other processes tend to reduce the number of bacteria reaching a particular point.

Dispersion is mechanical mixing and is caused by three mechanisms. In the varying pore network, the fluid will travel at different velocities owing to drag resulting from the roughness of the pore surfaces and to variable pore diameters. Also, different pathways are available for travel through the pore network (Freeze and Cherry, 1979). Dispersion causes bacteria to spread out laterally during vertical flow. This process will slow bacterial transport through the soil matrix.

Conclusion

Assuming indigenous (autochthonous) bacteria will be dominant and protozoan activity will be reduced because of limited food with low nutrient value (Stout, 1973), predation by protozoa, nematodes, myxobacteria, and *Bdellovibrio* will be of minor importance. Growth by the introduced (allochthonous), enteric bacteria will be limited.

The processes having the greatest impact on enteric bacteria percolating below leachfield trenches are postulated to be retention by physical entrapment, adsorption and starvation leading to cell death. These processes are to be incorporated into the bacterial transport model.

The governing hypothesis of this research is that under the influence of adverse rainfall events commonly occurring in the spring, indicator bacteria (fecal coliforms and fecal streptocci) leaving on-site wastewater leachfield beds or trenches will travel beyond the four-foot depth in coarse soils. It is entirely possible that, given the state of knowledge regarding microbial processes in the soil, modeling efforts may indicate that the four-foot guideline is adequate, even in coarse soils--defined as equal to or more permeable than sand or loamy sand permeability.

REFERENCES

Allen, M.J. and S.M. Morrison, 1973. Bacterial movement through fractured bedrock. Ground Water, 11(2):6-10.

Anderson, R.V., E.T. Elliott, J.F. McClellan, D.C. Coleman, C.V. Cole, and H.W. Hunt, 1978. Trophic interactions in soils as they affect energy and nutrient dynamics. III. Biotic interactions of bacteria, amoebae, and nematodes. Microb. Ecol. 4:361-371.

Baker, F.G., 1978. Model for planning and location of on-site waste disposal systems. Water Resour. Bull., 14(1):144-156.

Balkwill, D.L. and W.C. Ghiorse, 1985. Characterization of subsurface bacteria associated with two shallow aquifers in Oklahoma. Appl. Environ. Microbiol. 50(3):580-588.

Bell, E., 1981. Activities of the advisory committee for individual sewage disposal systems. IN: Proc. 4th Workshop on Home Sewage Disposal in Colorado State/County Cooperation in Managing Small Wastewater Flows. R.C. Ward (ed.), Colo. Wat. Resour. Res. Inst. Ft. Collins, pp. 9-12.

Berg, H.C., 1983. Random walks in biology. Princeton Univ. Press. Princeton, N.J. 142p.

Beven, K. and P. Germann, 1982. Macropores and water flow in soils. Water Resour. Res. 18(5):1311-1325.

Bissonnette, G.K., J.J. Jezeski, G.A. McFeters, and D.G. Stuart, 1975. Influence of environmental stress on enumeration of indicator bacteria from natural waters. Appl. Microbiol. 29(2):186-194.

Bouwer, H., 1984. Elements of soil science and groundwater hydrology. IN: Groundwater Pollution Microbiology, G. Bitton and C.P. Gerba (eds.), J. Wiley and Sons, N.Y., pp. 9-38.

Breznak, J.A., 1984. Activity on surfaces - group report. Microbial Adhesion and Aggregation. K.C. Marshall (ed.) Dahlem Konferenzen Berlin. OO. 203-221.

Butler, R.G., Orlob, G.T. and P.H. McGauhey, 1954. Underground movement of bacterial and chemical pollutants. J. Am. Wat. Works Assoc. 46:97-111.

Caldwell, E.L., 1937. Pollution flow from pit latrines when an impervious stratum closely underlies the flow. Jour. Infectious Disease 61:270-288.

Caldwell, E.L., 1938. Pollution flow from a pit latrine when permeable soils of considerable depth exist below the pit. J. Infectious Disease 62:219-258.

Carlile, B.L., 1983. Research needs: soil science and soil absorption of wastewater. In: Proc. NSF Workshop on Research Needs Relating to Soil Absorption of Wastewater, Ft. Collins, CO, June, 1983, pp. 21-36.

Carlile, B.L., C.G. Cogger, M.D. Sobsey, J. Scandura, and S.J. Steinbeck, 1981. Movement and fate of septic tank effluent in soils of the North Carolina coastal plain. Sanitation Branch, North Carolina Division of Health Sciences, Raleigh, N.C. 164 pp.

Chet, I. and R. Mitchell, 1976. Ecological aspects of microbial chemotactic behavior. Ann. Rev. Microbiol. 30:221-239.

Clarholm, M., 1981. Protozoan grazing of bacteria in soil--impact and importance. Microbial Ecol. 7:343-350.

Corapcioglu, M.Y. and A. Haridas, 1984. Transport and fate of microorganisms in porous media: a theoretical investigation. J. Hydrol. 72:149-169.

Cosby, B.J., G.M. Hornberger, R.B. Clapp, and T.R. Ginn, 1984. A statistical exploration of the relationships of soil moisture characteristics to the physical properties of soils. Water Resour. Res. 20(6):682-690.

Crane, S.R. and J.A. Moore, 1984. Bacterial pollution of groundwater: a review. Water Air Soil Pollution. 22:67-83.

Curds, C.R. and M.J. Bazin, 1977. Protozoan predation in batch and continuous culture. IN: Adv. Aquatic Microbiol. Vol. 1, M.R. Droop and H.W. Jannasch (ed.), Acad. Press, London. pp. 115-177.

Daniels, S.L., 1980. Mechanisms involved in sorption of microorganisms to solid surfaces. IN: Adsorption of Microorganisms to Surfaces. G. Bitton and K.C. Marshall (eds.) J. Wiley and Sons, N.Y. pp. 8-58.

Darbyshire, J.F., 1975. Soil protozoa-animacules of the subterranean microenvironment. IN: Soil Microbiology. N. Walker (ed.), J. Wiley and Sons, N.Y., pp. 147-163.

Darbyshire, J.F., L. Robertson, and L.A. Mackie, 1985. A comparison of two methods of estimating the soil pore network available to protozoa. Soil Biol. Biochem. 17(5):619-624.

Dawes, E.A., 1976. Endogenous metabolism and survival. IN: The survival of vegetative microbes. T.R.G. Gray and J.R. Postgate (eds.), Cambridge U. Press, Cambridge. pp. 19-54.

Enfield, C.G., C.C. Harlin, and B.E. Bledsoe, 1976. Comparison of five kinetic models for orthophosphate reaction in mineral soils. Soil Sci. Soc. Am. J. 40:243-249.

Fletcher, M., M.J. Latham, J.M. Lynch, and P.R. Rutter, 1980. The characteristics of interfaces and their role in microbial attachment. IN: Microbial Adhesion to Surfaces. R.C.W. Berkeley (ed.) Halsted Press, N.Y., pp. 67-78.

Freckman, D.W., 1982. Parameters of the nematode contribution to ecosystems. IN: Nematodes in Soil Ecosystems, D.W. Freckman (ed.), Univ. Texas-Austin Press, Austin, Tex. pp. 81-97.

Freeze, R.A. and J.A. Cherry, 1979. Groundwater. Prentice-Hall, Englewood Cliffs, N.J.

Gerba, C.P., C. Wallis, and J.L. Melmik, 1975. Fate of wastewater bacteria and viruses in soil. ASCE J. Irrigation and Drain. Div., 101 (IR3):157-174.

Ghiorse, W.C. and Balkwill, D.L., 1983. Enumeration and morphological characterization of bacteria indigenous to subsurface environments. Dev. Ind. Microbiol. 24:213-224.

Gray, T.R.G. and S.T. Williams, 1971. Microbial productivity in soil. IN: Microbes and Biological Productivity, 21st. Symp. Soc. Gen. Microbiol. Univ. College, London. D.E. Hughes and A.H. Rose (ed.) Cambridge Univ. Press. pp. 255-286.

Griffin, D.M., 1981. Water potential as a selective factor in the microbial ecology of soils. IN: Water potential relations in soil microbiology. SSSA Spec. Pub. #9. Soil Sci. Soc. Am., Madison, WI. 141-151.

Griffin, D.M. and G. Quail, 1968. Movement of bacteria in moist, particulate systems. Aust. J. Biol. Sci. 21:579-582.

Hagedorn, C., 1981. Transport and fate of bacterial pathogens in groundwater. IN: Proc. USEPA Conf. on Microbial Health Considerations of Soil Disposal of Domestic Wastewaters, J. Kreissl (ed.), May, 1981. Nat. Center for Ground Water Res., Norman, OK. pp. 84-102.

Hagedorn, C., D.T. Hansen, and G.H. Simonson, 1978. Survival and movement of fecal indicator bacteria in soil under conditions of saturated flow. J. Environ. Qual. 7(1):55-59.

Hagedorn, C., E.L. McCoy, and T.M. Rahe, 1981. Potential for ground water contamination from septic tank effluents. J. Environ. Qual. 10(1):1-8.

Hansel, M.J. and R.E. Machmeier, 1980. On-site wastewater treatment on problem soils. J. Wat. Poll. Cont. Fed. 52:548-558.

Harder, W., L. Dijkhuizen, and H. Veldkamp, 1984. Environmental regulation of microbial metabolism. IN: The Microbe 1984, Pt.2, Prokaryotes and Eukaryotes. D.P. Kelley and N.G. Carr (ed.), Cambridge Univ. Press, Cambridge, England, pp. 51-96.

Harris, R.F., 1981. Effect of water potential on microbial growth and activity. IN: Water potential relations in soil microbiology, SSSA Spec. Pub. #9. Soil Sci. Soc. Am., Madison, WI. pp. 23-96.

Hendricks, D.W., F.J. Post, and D.R. Khairnar, 1979. Adsorption of bacteria on soils. Water Air Soil Pollut. 12(2):219-232.

Hepper, C.M., 1975. Extracellular polysaccharides of soil bacteria. IN: Soil Microbiology, N. Walter (ed.), J. Wiley and Sons, N.Y. pp. 93-110.

Jenkins, D. and M.G. Richard, 1982. Factors affecting the selection of filamentous organisms in activated sludge. Symp. Impact of Applied Genetics in Pollution Control. Notre Dame. C.F. Kulpa, R.L. Irvine and S.A. Sojka (eds.), pp. 63-86.

Kaiser, D., 1984. Regulation of multicellular development in myxobacteria. IN: Microbial Development, R. Losick and L. Shapiro (eds.), Cold Spring Harbor Lab, Cold Spring Harbor, N.Y. pp. 197-218.

Klein, D.A. and L.E. Casida, 1967. Escherichia coli die out from normal soil as related to nutrient availability and the indigenous microflora. Can. J. Microbiol. 13:1461-1470.

Kuhnelt, W., 1976. Soil Biology. Michigan State Univ. Press. East Lansing, MI.

LeChevallier, M.W. and G.A. McFeters, 1985. Interactions between heterotrophic plate count bacteria and coliform organisms. Appl. Environ. Microbiol. 49(5):1338-1341.

McCoy, E.L. and C. Hagedorn, 1979. Quantitatively tracing bacterial transport in saturated soil systems. Wat., Air and Soil Pollut., 11:467-479.

McCoy, E.L. and C. Hagedorn, 1980. Transport of resistance-labeled Escherichia coli strains through a transition between two soils in a topographic sequence. J. Environ. Qual., 9(4):686-691.

McCuen, R.H., W.J. Rawls, and D.L. Brakensiak, 1981. Statistical analysis of the Brooks-Corey and Green-Ampt parameters across soil textures. Wat. Resour. Res. 17(4):1005-1013.

McFeters, G.A., G.K. Bissonnette, J.J. Jezeski, C.A. Thomson, and D.G. Stuart, 1974. Comparative survival of indicator bacteria and enteric pathogens in well water. Appl. Microbiol. 27(5):823-829.

McFeters, G.A., S.C. Cameron, and M.W. LeChevallier, 1982. Influence of diluents, media, and membrane filters on detection of injured waterborne coliform bacteria. Appl. Environ. Microbiol. 43(1): 97-103.

Marshall, K.C., 1976. Solid-liquid and solid-gas interfaces. IN:

Interfaces in Microbial Ecology. Harvard Univ. Press. 156p.

Matthess, G. and A. Pekdeger, 1985. Survival and transport of pathogenic bacteria and viruses in groundwater. IN: Ground Water Quality, C.H. Ward, W. Giger, and P.L. McCarty (eds.) J. Wiley and Sons, N.Y. pp. 472-482.

Moore, B.E., B.P. Sagik, and C.A. Sorber, 1981. Viral transport to groundwater at a wastewater land application site. J. Wat. Pollut. Cont. Fed. 53(10):1492-1502.

Mueller, D.K., 1979. The effect of subdivision development on soil moisture and groundwater recharge in the Colorado Front Range. Master's thesis, Colorado State University, Ft. Collins, CO. 85pp.

Nichols, D.S., D. Prettyman, and M. Gross, 1983. Movement of bacteria nutrients from pit latrines in the BWCA wilderness. Wat. Air Soil Pollut. 20:171-180.

Olivieri, V.P., 1983. Research needs: Health implications of bacteria and parasites in soil absorption of wastewater. In: Proc. NSF Workshop on Research Needs Relating to Soil Absorption of Wastewater, Ft. Collins, CO, June 1983, pp. 76-102.

Otis, R.J., G.D. Plews, and D.H. Patterson, 1978. Design of conventional soil absorption trenches and beds. IN: Proc. 2nd Nat. Home Sewage Treatment Symp., Chicago, Dec. 1977. ASAE, St. Joseph, Mich., pp. 86-99.

Otis, R.J., W.C. Boyle, E.V. Clements, and C.J. Schmidt, 1980. Design Manual: On-site wastewater treatment and disposal systems. EPA 625/1-80-012, U.S. Environ. Pro. Agency, Wash. D.C. 391p.

Pekdeger, A. and G. Matthess, 1983. Factors of bacteria and virus transport in groundwater. Environ. Geol. 5(2):49-52.

Pfennig, N., 1984. Microbial behavior in natural environments. IN: The Microbe 1984, Pt. II Prokaryotes and Eukaryotes, D.P. Kelly and N.G. Carr (ed.) Cambridge Univ. Press, Cambridge, pp. 23-50.

Poindexter, J.S., 1981. Oligotrophy, fast and famine existence. Adv. Microbial Ecol. 5:63-89.

Powell, M.S. and N.K.H. Slater, 1982. Removal rates of bacterial cells from glass surfaces by fluid shear. Biotech. Bioeng. 24:2527-2537.

Purcell, E.M., 1977. Life at low Reynolds number. Amer. J. Physics 45(1):3-11.

Rahe, T.M., C. Hagedorn, E.L. McCoy and G.F. King, 1978. Transport of antibiotic resistant *Escherichia coli* through western Oregon hillslope soils under conditions of saturated flow. J. Environ. Qual. 7(4):487-494.

Reddy, K.R., R. Khaleel, and M.R. Overcash, 1981. Behavior and transport of microbial pathogens and indicator organisms in soils treated with organic wastes. J. Environ. Qual., 10(3):255-266.

Reneau, R.B., J.H. Elder, D.E. Pettry, and C.W. Weston, 1975. Influence of soils on bacterial contamination of a watershed from septic sources. J. Environ. Qual. 4(2):249-252.

Rogers, H.J., 1979. Adhesion of microorganisms to surfaces: some general considerations of the role of the envelope. IN: Adhesion of Microorganisms to Surfaces. E.C. Ellwood, J. Melling, and R. Rutter (ed.), Academic Press, London. pp. 29-55.

Roper, M.M. and K.C. Marshall, 1978. Effects of a clay mineral on microbial predation and parasitism of _Escherichia coli_. Microbial Ecol. 4:279-289.

Rowberry, R.J., J.P. Armitage, and C. King, 1983. Movement, taxes, and cellular interactions in the response of microorganisms to the natural environment. IN: Microbes in their natural environments. J.H. Slater, R. Whittenbury, and J.W.T. Wimpenny (eds.), 34th Symp. of the Soc. Gen. Microbiol. Cambridge Univ. Press, Cambridge, U.K. pp. 299-350.

Seymour, F.W.K. and R.N. Doetsch, 1973. Chemotactic responses by motile bacteria. J. Gen. Microbiol. 78:287-296.

Smith, M.S., G.W. Thomas, R.E. White, and D. Ritonga, 1985. Transport of _Escherichia coli_ through intact and disturbed soil columns. J. Environ. Qual. 14(1):87-91.

Sobsey, M., 1981. Transport and fate of viruses in soil. IN: Proc. USEPA Conf. on Microbial Health Considerations of Soil Disposal of Domestic Wastewaters, J. Kreissl (ed.), May, 1981. Nat. Center for Ground Water Res., Norman, OK. pp. 103-125.

Starr, M.P. and J.C. Huang, 1972. Physiology of the _Bdellovibrios_. Adv. Microbiol. Physiol. 8:215-261.

Stenstrom, T.A., 1984. Reduction of pathogenic miocroorganisms in soil filtration systems. IN: Proc. Int. Conf. on New Technol. for Wastewater Treatment and Sewerage in Rural Areas. P. Rantala, E. Santala, and H. Vikman (eds.), Tampere Univ. of Technol., Tampere, Finland, pp. 331-344.

Stenstrom, T.A. and S. Hoffner, 1982. Reduction of enteric microorganisms in soil filtration systems-field and laboratory experiments, In: Proc. of the Conf. on Alternative Wastewater Treatment, Oslo, Norway, Sept. 1981. A.S. Eikum and R.W. Seabloom (ed.), pp. 169-181.

Stotzky, G., 1974. Activity, ecology, and population dynamics of microorganisms in soil. IN: Microbial Ecology. A.I. Laskin and

H. Lechevalier (eds.). CRC Press, Boca Raton, FL. pp. 57-135.

Stout, J.D., 1973. The relationship between protozoan populations and biological activity in soils. Amer. Zool. 13:193-201.

Tempest, D.W., O.M. Neijssel, and W. Zevenboom, 1983. Properties and performance of microorganisms in laboratory culture: their relevance to growth in natural ecosystems. IN: Microbes in their Natural Environment. J.H. Slater, R. Whittenbury, and J.W.T. Wimpenny (eds.), 34th Symp. of the Soc. Gen. Microbiol. Cambridge Univ. Press, Cambridge, U.K. pp. 119-152.

Tyler, E.J., R. Laak, E. McCoy, and S.S. Sandhu, 1978. The soil as a treatment system. IN: Proc. 2nd Nat. Home Sewage Treatment Symp. Chicago, Dec., 1977. ASAE, St. Joseph, Mich. pp. 22-37.

Varon, M., M. Fine, and A. Stein, 1984. The maintenance of Bdellovibrio at low prey density. Microbial Ecol. 10:95-98.

Viraraghavan, T., 1976. Septic tank efficiency. ASCE J. Environ. Eng. Div. 102(EE2):505-508.

White, D.C., H.F. Fredrickson, M.J. Gehron, G.A. Smith, and R.F. Martz, 1983. The groundwater aquifer microbiota: biomass, community structure and nutritional status. Dev. Ind. Microbiol. 24:189-199.

Williams, O.R., S.L. Ponce, J.R. Meiman and M. Spearnak, 1978. Hydraulic conductivity of mountain soils. Colo. Wat. Resour. Res. Inst. Completion Rep. No. 92, Ft. Collins, CO. 52p.

Wimpenny, J.W.T., R.W. Lovitt, and J.P. Coombs, 1983. Laboratory model systems for the investigation of spatially and temporally organized microbial ecosystems. IN: Microbes in Their Natural Environment. J.H. Slater, R. Whittenbury, and J.W.T. Wimpenny (eds) 34th Symp. Soc. Gen. Microbiol. Cambridge Univ. Press, Cambridge, U.K., pp. 67-117.

Winneberger, J.H.T., 1984. Septic-tank systems, Vol. I Subsurface disposal of septic-tank effluents. Butterworth Pub. Boston.

Yao, K.M., M.T. Habibian, and C.R. O'Melia, 1971. Water and wastewater filtration: concepts and applications. Environ. Sci. Technol. 5:1105-1112.

Yeates, G.W. and D.C. Coleman, 1982. Role of nematodes in decomposition. IN: Nematodes in Soil Ecosystems, D.W. Freckman (ed.) Univ. Texas-Austin Press, Austin, TX. pp. 55-80.

Zantua, M.I., L.C. Dumenil, and J.M. Bremmer, 1977. Relationship between soil urease activity and other soil properties. Soil Sci. Soc. Am. J. 41:350-352.

Ziebell, W.A., D.H. Nero, J.F. Deininger, and E. McCoy, 1975. Use of bacteria in assessing waste treatment and soil disposal systems. IN: Proc. Nat. Home Sewage Disp. Symp., Chicago, Dec., 1974. ASAE, St. Joseph, Mich. pp. 58-63.

Evolving Programs in Environmental Health at CSU

by

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The reason I was invited to speak to you today is to update you on changes taking place in the environmental health (EH) program at CSU and to outline several new research interests of the faculty related to groundwater quality and effects of on-site waste treatment which might be of interest to you as local environmental health practitioners. Many of you may not be familiar with the EH program at CSU, although some of you will be as graduates of the program. I would like to start by presenting an overview of the EH program as it currently exists, detail proposed, upcoming changes in the program, and end with current research areas perhaps of interest to you.

The Colorado Commission on Higher Education, recognizing the need for broadly trained environmental health specialists in Colorado and the Rocky Mountain Region, requested the formation of an environmental health academic program at CSU in 1969. Significant environmental activities already existed at that time at CSU in the areas of atmospheric sciences, water quality and biomedical research within the College of Veterinary Medicine and Biomedical Sciences. The program was established in 1970 with a grant from the W. K. Kellogg Foundation in the form of the Institute of Rural Environmental Health (a "sister" program called the Institute of Urban Environmental Health was also sponsored at this time at the University of Colorado, Denver, which has subsequently ceased activity). The stated goals of this Institute were: "improvement of the health, safety and wellbeing of residents in Colorado and the Rocky Mountain region, especially those in agriculture, by application of preventive medicine through research, education and service." The original faculty numbered six who were housed within the Department of Microbiology at CSU.

The EH program steadily increased in size through the '70s, becoming the Department of Microbiology and Environmental Health in the late '70s. Currently the EH program entails 13 faculty, all holding doctoral degrees, 15 academic-professionals, 37 graduate students and 50 undergraduate

15 academic-professionals, 37 graduate students and 50 undergraduate students. The EH division currently offers the B.S., M.S. and Ph.D degrees (the latter under the EH option in the Department of Microbiology and Environmental Health). Graduate students come to the EH program with diverse backgrounds, and most have had significant professional experience prior to returning to CSU to undertake graduate studies. Currently the EH program is headed by Dr. Eldon P. Savage and is structured into three sections:

(1) Chemical Epidemiology Section - Dr. Eldon P. Savage, program director;

(2) Industrial Hygiene/Occupational Health and Safety Section - Dr. Roy M. Buchan, program director; and

(3) Comparative Medicine and Zoonoses Section - Dr. John S. Reif, program director.

In addition, the Institute incorporates the Colorado Epidemiologic Pesticide Research Center and the CSU Pesticide Analytical Laboratory (Mr. John Tessari, director).

Some of the more outstanding achievements of the EH faculty include establishment of the Colorado Epidemiologic Pesticide Research Center, which is involved in state, regional, national and international research on pesticide residues in human tissues, and the Colorado Occupational Safety and Health Association (OSHA) program, which provides small, high-hazard industries and businesses in Colorado with free consultation on health and safety-related problems. In addition, EH faculty are actively involved in the areas of environmental epidemiology, environmental toxicology, and environmental sanitation. The Institute also contains the CSU Pesticide Analytical Laboratory, a state-of-the-art laboratory with broad analytical capabilities including computerized gas chromatography, gas chromotography - mass spectroscopy, and atomic absorption spectroscopy equipment. This laboratory provides services to the EH faculty and to other institutions, governments, private firms and individuals.

Some significant highlights of past faculty research endeavors include: epidemiology of lung cancer and air pollution in metropolitan Denver; veterinary epidemiologic studies related to infectious diseases in the intensive food animal industry in Colorado; zoonoses in commercial and wild animal populations; epidemiologic investigations of acute pesticide poisonings, both in Colorado and nationally; regional, national and international monitoring programs for human body burdens of xenobiotics; human health assessment for exposure to groundwater contaminants such as gasoline and mixed industrial contaminants such as occur at the Rocky Mountain Arsenal in Denver; institution and evaluation of occupational health and safety programs in small, high-hazard industries in Colorado; and training in hazardous waste management for local health officials.

CSU is currently undergoing a redirection of programs, called Planning for Progress, in which many existing programs are being reduced while a select few, recognized as areas of strength, are being nurtured. The EH program at CSU has been fortunate in being considered as an area of strength. It is anticipated that the EH program will achieve department status shortly, becoming the Department of Environmental Health - a clear mandate to improve and enlarge this area of research, education and service for Colorado. It has been proposed that two noted faculty in the Microbiology division join this new department: Drs. Donald Klein and William Boyd. Dr. Klein is well known for his work on the ecotoxicology of metals in soils and groundwater and the miocrobiology of strip-mined land reclamation. Dr. Boyd is currently Director of the CSU Water Quality Laboratory and is well known for his work in microbiological water quality. The CSU Water Quality Laboratory would then be housed in the new Department of Environmental Health. This facility, in combination with the existing Pesticide Analytical Laboratory, would give the Department of Environmental Health outstanding capabilities for both chemical and microbiological analyses (both laboratories are, or will shortly be, EPA certified).

As I indicated in my introductory remarks, I would like to highlight several water quality concerns now being pursued through research by EH faculty. The following is an outline of some of the proposed or ongoing studies:

(1) The potential for translocation of bacteria from on-site septic systems through coarse, mountainous soils during high rainfall/snowmelt events as discussed by our previous speaker, Mr. Thomas Peterson.

(2) Potential groundwater contamination by toxic chemicals used in the home and discharged to on-site septic systems, e.g., trichloroethylene (TCE) in solvents and septic tank cleaners.

(3) Possible contamination of potable water by groundwater contaminants

via permeation through PVC pipe used in the water distribution system, e.g., toxic gasoline components.

(4) Development of a low-cost, effective groundwater quality monitoring program for potentially impacted rural populations using groundwater near an industrial hazardous waste land disposal site (Last Chance, Colorado).

(5) Assessment of human health effects, if any, of high well water nitrate content in eastern Colorado.

(6) The improvement in design and operation of community wastewater treatment systems (activated sludge) so as to control poor settling and foaming, caused by the growth of filamentous bacteria. These problems are widespread in Colorado (circa 75 percent of plants) and often result in degradation of water quality in receiving waters.

The EH program at CSU stands ready as a valuable resource available to you: in undergraduate and graduate training; in professional continuing education; in service and consultation; and in research. Our mission, should we decide to accept it, is to initiate and pursue research into water quality problems in Colorado impacting the environment and public health now and in the future, in both surface and subsurface waters.

PERCOLATION TESTS
Do the Current Test Procedures Produce Consistent Results? Problems and Possible Solutions

by

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It is a pleasure to again participate in this workshop here in Fort Collins. This is the fifth time I have had the opportunity to attend, and in each case the information presented proved valuable and timely. I would like to thank Colorado State University and Robert Ward for organizing the conference, particularly at this time of the year. It gives those of us in the mountains a chance to briefly escape from what is known locally as "mud" season.

Today I would like to address some aspects of the percolation test in relation to the sizing of conventional waste disposal systems in Colorado. The initial studies on various soil percolation test procedures were performed in the early 1920s by a character named Henry Ryon in New York State. His methods established a direct, but empirical relationship between the percolation rate and the ultimate performance of an on-site wastewater disposal system. An assumption was made that the ability of a soil to absorb sewage effluent over a prolonged period of time could be predicted from the initial ability to absorb clear water. As a result of Ryon's studies, a rigid protocol for the performance of these tests was established, and the prescribed methods have changed surprisingly little in the last sixty years. Despite efforts to develop a more reliable technique for soil evaluation, the test has persisted because it is simple, expedient, and requires only minimal proficiency.

Most recent studies, however, have demonstrated that there is less of a relation between percolation rate and the long-term performance of a septic system than originally concluded. Further, the methods of conducting the test and the interpretation of percolation test results have been demonstrated to vary widely, depending on changes or modifications prescribed in each state or local code, the individual conducting the test and his training and experience, the various ways the test holes are prepared, and the accuracy of measuring the amount of water drop in the established time frame.

Fifteen years ago when I entered the field of public health I was told that one of the simplest things I had to do was to perform a percolation test for a homeowner or contractor wanting a permit to build a septic system. A wise and respected professional whom I worked with at the time told me at that time that all that was necessary was to pour some water in a hole, observe it for a while, and say "Yep, it goes away!"

Procedures

However, the basic procedure proved to be much more complicated and cumbersome. I suspect that most of the regulatory officials and engineers in the audience have conducted a percolation test, or at least what passed for one. Unfortunately, with the Colorado regulations and guidelines prescribing the system size based solely on this test, a probability exists that continuing errors are being made with each ensuing year's permits to install absorption fields, and occasionally these mistakes can cost the homeowner money.

Have any of you occasionally noticed wide variations in the percolation results from test hole to test hole? Or perhaps you have encountered a case where the engineering data presented cannot be correlated to the soil types common to a specific area or to what expected percolation rates should be. Further, although the person performing a percolation test may be aware of all the standard methods for conducting a test how often can you say that, given the other time constraints of a job and the amount of the fee normally charged for this service, one or more of the significant details of the percolation test procedure have been omitted or ignored?

U.S. Public Health Service Manual 526 (1), the EPA On-site Wastewater Treatment and Disposal Systems Design Manual (2), and most civil and soils engineering manuals and textbooks, including the Standard Handbook for Civil Engineers (3) generally specify the same procedure. Further, most of the state guidelines and laws that I have been able to research include a rather specific and almost identical method of conducting percolation tests and interpreting the results for sizing.

A. Test hole size and preparation

The procedure, as developed at the Robert A. Taft Sanitary

Engineering Center and modeled after Ryon (1), dictates that six or more percolation test holes be dug or bored in an area where the proposed absorption field site has been selected. Colorado regulation only requires three test holes. These test holes should be spaced uniformly, have a horizontal dimension of between 4 and 12 inches, vertical sides, and be dug to the depth of the proposed absorption trench, usually about three feet. It is important to note that the procedure recommends in order to "save time, labor and the volume of water required" (1) it is best to bore the holes with a 4-inch auger. After a test hole is dug, it is suggested that the bottom and sides of the hole be scratched in order to remove any smeared soil surfaces, all loose soil be removed, and two inches of course sand or fine gravel be added to protect the bottom from scouring and sediment.

Presoaking periods are uniformly required and are generally specified to be between 4 and 24 hours with longer periods required to achieve swelling in those soils with a high clay content. The depth of clear water needs to be carefully maintained at about 12 inches above the gravel for the presoaking period. An automatic siphon (Figure 1) is suggested for refilling periodically.

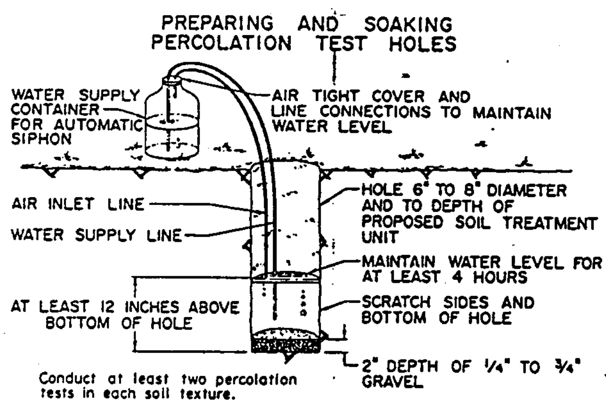


Figure 1.

B. Percolation test measurement

Twenty-four hours after the presoak is started (with the exception of some sandy soils), the test hole is refilled to a depth of six inches above the gravel. Then procedures call for measuring the water drop, using a batter board and stick to measure the change in water level from a fixed reference point over intervals of between 10 and 30 minutes (Figure 2) until a stable, uniform drop is observed (1). To arrive at the percolation rate, the final measurement is generally used as the rate for each hole and an average calculated. This rate is then applied to charts or used in a formula to calculate the required square footage of a "properly" designed absorption bed. The inverse, a loading rate, can also be calculated. Various ingenious devices to accomplish measurements of water drop during the test have been developed, and are recommended to improve the accuracy of the field percolation test measurements. These include the percometer and "hook gauge" (Figure 3 and Figure 4). Each of these is a good alternative to the batter board/measuring stick approach and should provide for more consistent and precise results (6).

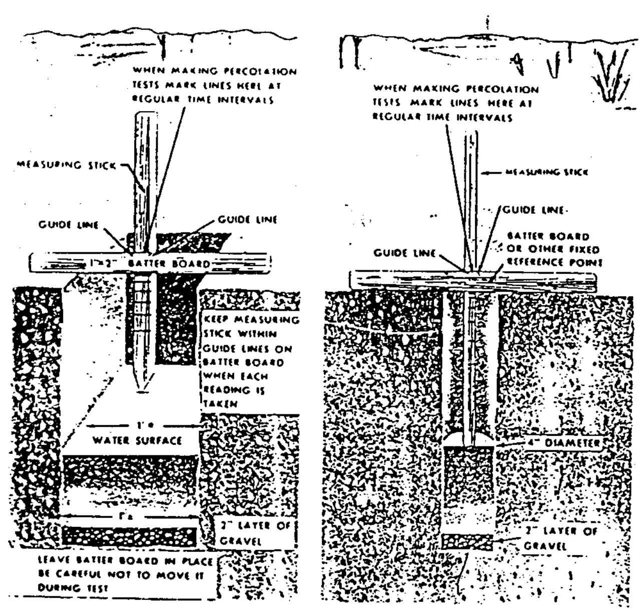


Figure 2.

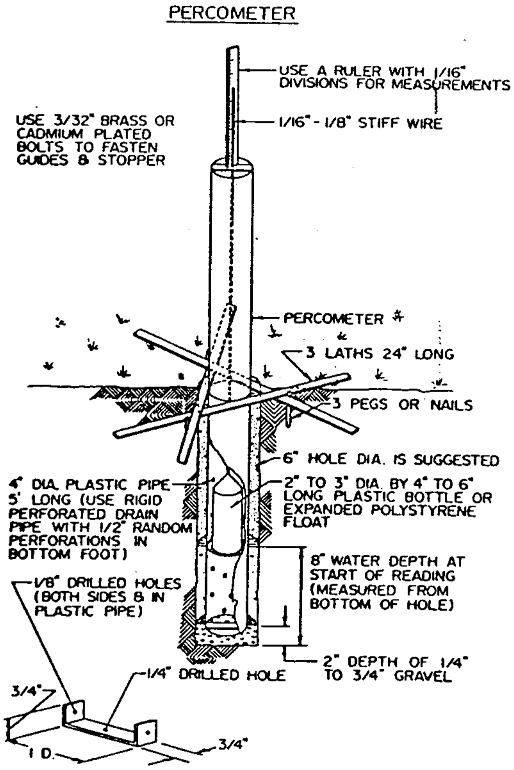


Figure 3.

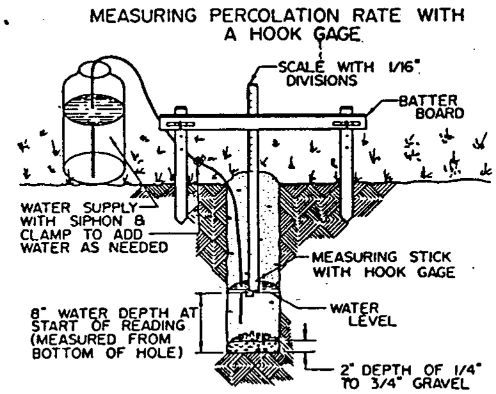


Figure 4.

Problems

As I mentioned, the percolation test is only a single tool in the evaluation of a lot for suitability for a sewage disposal system. It is based primarily on experience and observation. The established rate of clear water being absorbed into a saturated test hole actually has little scientific basis when related to the movement of wastewater effluent through various soils. For instance, in saturated conditions a soil with a rate of 60 minutes per inch, a limiting value in septic system design, can still absorb about 150 gallons of liquid in 10 square feet each day, and a loose, sandy soil with a measured percolation rate of five minutes per inch could absorb clear water at a rate of as much as 300 gallons per square foot per day (4). Ryon's charts for sizing an absorption area are reduced by a factor ranging from 20 to 2,500 from measured volumes absorbed (5).

The test is therefore often justifiably criticized because of its variability and its failure to predict hydraulic conductivity and crust formation accurately. Variability in percolation tests conducted by experienced professionals are reported to be from 90 percent to over 200 percent (2,4), with as much as a 50 percent variation within a set of test holes all prepared in exactly the same manner and tested at the same time (5). We, as professionals, must recognize the shortcomings of the test and the causes for a wide divergence in the range of results which can be obtained.

It is extremely difficult without the time and proper equipment to add water and maintain a level of six inches of water depth at the start of each measurement in a test hole. I suspect that, as a result, a falling head percolation test is actually performed in the field. This method generally yields a slower rate of absorption if the test hole is filled no more than six inches above the bottom and measured without refilling over several time intervals. However, if the test hole is filled higher, say 12 or 14 inches above the bottom, the rate will be faster. As the water level moves down, the area available for horizontal flow through the sidewall of the test holes decreases. If the last of several consecutive readings is used as the basis to calculate the percolation rate, it will be directly dependent on the water depth. Standard tables used in sizing septic systems do not specify an absorption field size based on the water depth in a test hole, and the less water over the gravel at the time of the final measurement, the larger the seepage system dictated.

When the local health department is requested to perform the percolation tests, most often the test holes are dug by the homeowner. This responsibility is often unjustifiably given to the owner of the property or a contractor because of limited staffing and the number of systems that need to be inspected by local health departments each year. As a result of the time constraints which local regulatory offices are under, concessions are invariably made which limit the accuracy of each percolation test. Test holes prepared by a homeowner or contractor may be the largest of these compromises. The test hole sidewalls often are not scraped and remain smeared and to a large extent, in typical silt and clay soils, compacted. It is difficult to evaluate these conditions in a presoaked test hole, but the result would be a slower than expected average rate and, most likely, an inconsistent rate between test holes.

I have noted that even when it is recommended in printed literature and instructions given out with an application that gravel be placed in the bottom of test holes, the homeowner will, unless a source of gravel is readily available, omit this step in the preparation procedure. Again, the resulting percolation rate measured is often slower than would be expected if the gravel had been placed in the test holes. Variability of results between test holes is much greater without gravel in the bottom of each.

Presoaking is another test hole preparation responsibility which is left to the contractor or homeowner. This is usually done haphazardly by pouring from a five-gallon bucket. Usually when the initial water supply is gone no more is brought to the site. It is also unlikely that the test holes have been soaked for the required time period and certainly not at a consistent depth. In fact, there is no reliable way of knowing that presoaking has been accomplished at all.

Invariably, when water is carelessly added to percolation test holes during presoaking, soil particles from the sidewalls and bottom are scoured and settle to the bottom of the hole. The soil which is sloughed off impedes the measured absorption of water. To a slight extent if the gravel has been placed in the hole the impact of the silt layer is lessened; but often with careless preparation a layer of mud several inches thick is built up to slow down the measured rate.

A calculated percolation rate determined by the measurement techniques explained is the only means of determining absorption size under Colorado regulations. It is common practice that the average of between three and six test holes is applied in a formula or to charts which dictate the minimum required area. Even though the rate arrived at may not make much sense and might vary from what is expected to be encountered in a general soil type, it is used as the ultimate criteria to size septic systems and to determine if any system, under Colorado law, needs to be engineered. The important point is to be sure that the method of applying percolation rate to sizing and design equates to those factors and methods utilized in developing the table and charts.

The calculation of the hydraulic loading into the soil is likewise based on the average percolation rate using a formula which is the inverse of the percolation rate square root. This calculation seems arbitrary and not necessarily in line with the performance with the sewage disposal system when a clogging mat forms. The calculation (gallons per square foot per day) is based on the following simple formula which equates the percolation rate to the loading:

$$\text{Loading Rate} = 5 / \sqrt{\text{Percolation Rate}}$$

There is a great deal of weight placed on the average percolation test result in the calculations and charts, and it is important to note the situations which can cause large variation in septic system design based upon percolation rate.

Test holes often vary and are allowed to vary according to most manuals specifying procedures from a four-inch round hole to a 12-inch square hole. A contention is often made that the influence of test hole dimension does not significantly affect the rate of drop in water level. This may be true if the water would have to pass through the bottom of the test hole, but this is rarely the case. It is calculated that the variation in these rates may be as much as 2.4 times given the surface area/volume relations (6). The accompanying figure illustrates this point (Figure 5). Obviously, it is incorrect to assume that small variations in test hole size do not significantly affect measured rates.

EFFECT OF HOLE DIAMETER ON PERCOLATION RATE

Percolation Rate as measured in a 6-inch diameter hole, minutes per inch	Percolation rate will be if measured in a hole of diameter		
	4"	8"	12"
5	4	6	7
15	11	18	22
30	23	35	45
45	35	53	70
60	45	70	90
90	67	105	135

Figure 5.

It certainly can be concluded that there should be no significant variation from the originally specified percolation test methods used to develop sizing criteria unless sufficient comparative tests have been run to demonstrate that application of a different methodology produces system design data which are equal to data obtained when the original methods are used. Further, because of the variability a percolation test should be considered a blunt means of determining septic system sizing, and must be applied after all the other site factors have been weighed and considered.

Alternative Site Evaluation

These other site factors include the soil texture, structure, and color. Soils information from the conservation service or contained in foundation reports can also be valuable in arriving at the size of an absorption system.

The most important of the other soil evaluation techniques is the soil texture. The soil textural triangle can dictate the classification if approximate percentages of sand, silt and clay are known. Each classification has properties which are quite common to it when it is wet or dry. The feel, general physical appearance and the ability to case or ribbon when wet is often more of a determinate in sizing than widely variable percolation rates.

Structure can also significantly influence the ability of a soil to accept and transmit water. It is based upon the aggregation of soil particles into clusters often referred to as peds, which are separated by surfaces of weakness. These surfaces result in planar pores or cracks observed in a test pit or boring. These pores obviously influence the movement of water and modify the influence of texture. Well-structured soils with large voids or cracks transmit water more rapidly than structureless soils of similar texture, which are commonly massive and exhibit very slow percolation rates.

Color usually is a good indication of the general drainage characteristics of a soil, and aids in identifying some seasonally saturated conditions. Mottling and grey colors indicate the possibility of a saturated condition and more likelihood of slow absorption rates, whereas reds and some yellows often indicate a well drained soil which probably percolates at an acceptable rate.

Occasionally there will be a conflict between the permeability indicated in soil map and the measured or reported percolation rate. It is important to view this discrepancy in light of the variability of the percolation test and consider the other factors which make up a suitable soil. It is always a good idea to use soil surveys and maps and reported measurements of hydraulic conductivity as a means of checking percolation test results. When differences are noted, the results should be rejected and the tests should be redone.

I would like to briefly touch on the other factors in the sizing and design of the on-site wastewater disposal systems which, while not related to soil type or absorption rate, can influence the operation of a system, and must be factored into a sizing formula or accounted for as another variable.

Water runoff will saturate any soil during snow melt or storms and can often lead to periodic failure if a soil is not well drained and the percolation rates are slow. All runoff must be controlled and diverted from the absorption field area.

The amount of slope will often dictate design changes which could include changes in sizing criteria. Percolation tests are particularly difficult to prepare on slopes and often more are required for an accurate idea of permeability. Further, the sun exposure and amount of moisture in a given soil seasonally is determined by aspect. Generally those soils on a south-facing slope will perform more satisfactorily than those on a north-facing slope. The change in radiation and reduced moisture common in the soils will alter absorption patterns in otherwise similar soils.

Physical separations (minimum distances between septic system components and wells, water lines, property boundaries, and road cuts) add another variable to the sizing criteria. Generally on parcels over one acre in size there is little problem; however, on smaller lots these setbacks dictate size and often can prohibit construction. In these cases it is even more important to conduct a careful percolation test and evaluate all other soil factors in order to be fair to the owner.

Water usage patterns have been demonstrated to be quite variable from household to household. Complicating the matter further, these water usage events demonstrate wild fluctuations from day to day and hour to hour. Ideally the absorption system is loaded at a specific rate each day, but the chances of this occurring are small. System sizing should account for these hydraulic peaks.

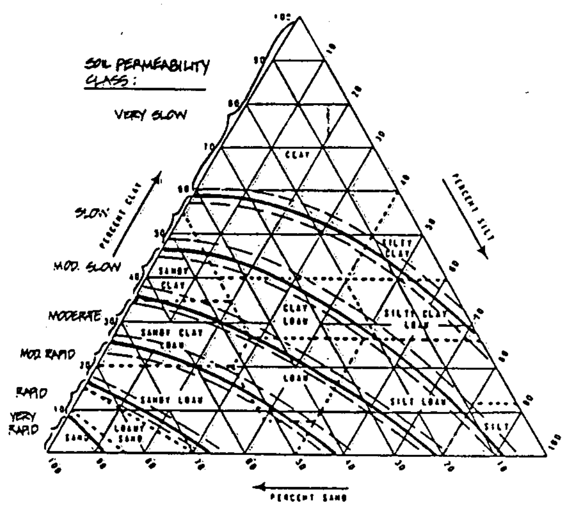
Many systems fail because the contractor smeared or compacted the soil during construction. Even the most carefully conducted soils evaluation could be ineffective in dictating absorption size if this occurs. Extensive soil damage does not usually occur in sandy soils, but when the clay content increases the mechanical forces applied, particularly when the soil moisture is high, close the soil pores. The result is compaction, puddling, and smearing, and the resultant ability to absorb water is dramatically altered.

Suggested Changes for Colorado

Because there are so many recognized problems with the standard percolation test, other methods of measuring a soil's hydraulic conductivity have been developed. However, for the most part while the results can be correlated to system performance in experimental installations, the test methods are cumbersome, time consuming and expensive. Additionally there is not much performance data which correlates the sizing criteria to successful usage of absorption fields. Further, the regulatory officials responsible for imposing requirements on absorption system design do not understand the complicated formulas and methods involved. These do not offer alternatives to the percolation test at this time.

There has been a slow trend among other states to move away from the percolation test as the primary element in septic system design. In a survey done by the National Small Flows Clearinghouse, soils and soil survey information are becoming more important to regulatory requirements (8,9). North Carolina, Tennessee, Virginia, Maine, Ohio, and Oregon apparently rely primarily on detailed survey results in design. Other states such as Florida, Minnesota, Wisconsin, Washington, New Mexico, and Arkansas use the soils information and require optional percolation tests or use percolation results for additional information. Given the variability of the percolation test it is suggested, like other states, in further revisions of the Colorado State Guidelines that soil textural analysis be used more for sewage disposal system sizing and design. While the appendix of the current guidelines does contain the USDA Textural Triangle, there is little mention of it in the text and no way to relate it to the sizing of absorption fields.

Permeability is often most governed by soil texture and bulk-density. Comparisons of field and laboratory data have shown a significant correlation between percolation test results and the position of soils within the illustrated permeability areas (10). Soil permeability can be directly and easily related to textural class in a manner which easily could predict approximate percolation rates and eventually septic system sizing (Figure 6). The analysis provides a convenient, reproducible method of evaluating soil conditions. Because the textural class has been further demonstrated to have an optimum specified loading rate of septic tank effluent to establish a stabilized clog mat (2,4,7), the sizing factors developed can be applied as system requirements. This procedure would reduce the dependence on percolation test results and allow the regulatory authority to issue permits without performing redundant percolation tests when sufficient soil data is presented with an application or readily available. The option of using soil textural classes is currently available to the local jurisdictions if the Colorado Guidelines are properly interpreted. However, a percolation test is still required.



NOTES:

1. Correction for Gravel and Cobble - Add 1% sand for each 10% gravel and cobble. (Vol.)

2. The solid center line separating the permeability classes is for soils that have moderate medium structure, or fine granular, or medium or coarse granular or single grained. The dotted line below the solid line is the extension of the permeability class for soils that have weak or fine structure or very fine granular. The dotted line above the solid line is the extension of the permeability class for soils that have strong structure or prismatic blocky, thick platy or massive.

3. Reduce rating one or more classes for soils that are compact or that have pH >9.0. Rate one class more rapid soils that have many medium or coarse pores. Rate as compact loam or finer textured soils that have bulk density of >1.5 and soils more sandy than loam that have bulk density of 1.7 or higher.

Soil Permeability Class Related to Texture - USDA (Erickson 1973)

Figure 6.

In Pitkin County our local requirements have been changed to include a sizing factor based on a percolation rate range increasing for each 10 minutes per inch so that the required square footage is the same for instance at 10 minutes per inch as 20 minutes per inch and we have tried to relate this absorption rate to soil textures. Where there is a good correlation, the sizing criteria are felt to be adequate and are calculated rapidly and in a straightforward manner that the homeowners and contractors seem to understand and accept. In a silty loam with an expected percolation rate of about 35 or 40 minutes per inch, for example, the typical single family residence would require 550 square feet of absorption trench per bedroom under the current regulations.

Despite the problems related in conducting percolation tests they should continue to be run, but only in a more standardized, careful manner. They are practical and useful in ranking relative soil conductivity, and requiring them forces the professionals, engineers and health officials alike to spend useful time between measurements in the water drop to conduct site inspections on lots where occasionally conditions leading to failures and malfunctions might not otherwise be noticed. I feel that the sizing criteria should be based on a number of factors other than percolation, and hopefully these criteria will be developed into a more regimented testing regime and eventually incorporated into the Colorado State Guidelines. We would be doing the public we serve a more professional and better job of evaluation of sites for septic system installation and providing better and more realistic design criteria. Thank you.

REFERENCES

(1) U.S. Public Health Service (1967), "Manual of Septic Tank Practice," Circular 526, Washington, D.C. U.S. Government Printing Office.

(2) U.S. Environmental Protection Agency, Office of Water Program Operations (October, 1980), "Design Manual - Onsite Wastewater Treatment and Disposal Systems," EPA 625/1-80-012, Cincinnati, Ohio.

(3) Merrit, Fredrick S., Ed. (1976), Standard Handbook for Civil Engineers, 2nd Edition, McGraw-Hill Book Company, Art. 22-27.

(4) Bouma, J., et al. (1972), "Soil Absorption of Septic Tank Effluent - A Field Study of Some Major Soils of Wisconsin," Bulletin 20, University Extension and Geological and Natural History Survey, University of Wisconsin, Madison, Wisconsin.

(5) Bouma, J. (November-December 1971), "Evaluation of the Field Percolation Test and an Alternative Procedure to Test Soil Potential for Disposal of Septic Tank Effluent," Soil Sci. Soc. Am. Proc., 35, 6, pp. 871-875.

(6) Machmeier, R.E. (1979), Town and Country Sewage Treatment. Bulletin 304, University of Minnesota, St. Paul, Agricultural Extension Service.

(7) Small Scale Waste Management Project, University of Wisconsin, Madison (September, 1978), Management of Small Waste Flows, EPA-600/2-78-173, Municipal Environmental Research Laboratory, Cincinnati, Ohio.

(8) Dix, Stephen P. (March, 1984). Personal communication with S. Dix, Director, EPA Small Flows Clearinghouse, West Virginia University, Morgantown, West Virginia.

(9) Plews, G.D. (1977), "The Adequacy and Uniformity of Regulations for On-Site Wastewater Disposal, A State Viewpoint," Proceedings of the U.S. Environmental Protection Agency Conference on Less Costly Wastewater Disposal Systems for Small Communities.

(10) Hantzsche, N.N., W.T. Neikirk, and T.V. Wistrom (1982), "Soil Textural Analysis for On-Site Disposal Evaluation," Proceedings of the Third National Symposium on Individual and Small Community Sewage Treatment, American Society of Agricultural Engineers, St. Joseph, Michigan.

SAFETY FACTORS IN SEPTIC SYSTEM DESIGN
"ENOUGH IS TOO MUCH (?)"

by

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We live in a litigious age, one in which we've all had to learn to pile redundancy upon redundancy simply to protect ourselves against future legal action. In the rush to provide ourselves with safety factors, however, we have tended to forego a cardinal engineering principle from a bygone age. That principle is that, "Until you've found a solution that is cost-effective as well as safe, you haven't solved the problem."

We also live in a time and area where the desire for life "out away from the City" is a large part of the marketplace. For that reason and others, the septic system business is alive and well, which is why we are here today. Some of us are charged with protection of the "public health, safety and welfare." Some of us deal with the area of design of systems; some of us build them or maintain them; some of us also use them. Ultimately, however, we all are interested in and responsive to the needs of the consumer or user of the product.

Recently, lower interest rates have brought temporary relief of a sort to the soaring housing prices we have been experiencing. Still, many willing and hopeful home purchasers are unable to qualify for long-term financing even with two incomes. Obviously a septic system unnecessarily redundant in size and cost doesn't do much to speak to that problem.

Caught between these often conflicting "horns of the dilemma" it seems rather urgent, then, to understand the difference between safety factors and mere redundancy.

There are many reasons why no one wants to experience a septic system failure. They are so numerous and so obvious they needn't be repeated here. There are also many reasons why a system can fail, and some of them are not so obvious or understood. Basically, however, they fall into three general categories: problems with design (which include soils characteristics); problems with installation and/or inspection; and problems relating to use and maintenance. In my opinion, we have tended to provide the same basic solution in each of these areas - overdesign. Yes, we have raised our standards to require licensed sanitarians or engineers to run percolation tests and to design systems which are "non-standard." Yes, we have, at least in Larimer County, a licensing program for installers and we hire trained sanitarians as inspectors. Still, what we mostly do in these areas is just change our formulas to make beds bigger. In the third category we basically only wring our hands and say that, "the homeowner doesn't want to understand the system; he just wants the sewage to disappear." This third area is outside the stated scope of this paper, but clearly what we are currently doing, as an industry, to increase the user's awareness of his own responsibility is inadequate.

I'd like to take a clear look at our current basic solution in the first two areas, which I have characterized as "overdesign." To do so, I would like to use the present Larimer County Septic System Regulations as an example. They are not necessarily better or worse than those of other areas, but they are familiar and close at hand. The major areas we will examine will be similar in most regulations. In all fairness I must say that the Health Department maintains a Citizens Advisory Committee which meets regularly to discuss and recommend revisions to those regulations.

The first area of suspected overdesign is that of absorption into the soil. It is generally understood that except in the case of very pervious gravels, virtually all of the treatment which occurs as a result of soil absorption happens within the first two to three inches below the bed. However, the current State Regulation, and hence the County's, requires 48 inches of soils between the bottom of the bed and water table or bedrock. Dividing 48 by two or three, we have a vertical safety factor of at least 16, and maybe 24. Horizontally, where the clearance to bodies of water or wells, regardless of geologic or terrain separation, is in most cases 100 feet, the safety factor is almost beyond calculation. Of course, we justify these "safety factors" with horror stories of the past, and by reassuring ourselves that, since the user has not been a reliable maintainer in the past, he cannot be trained to be so. It does seem that perhaps where enough reliable soils or geologic data is available, regulation could be tempered with wisdom and common sense.

The second area of overdesign is in calculating the quantity of sewage to be treated. Initially, we say a person uses 75 gallons per day which will end up in the septic tank. Actual use based on records of water districts, and studies of cities which have factored out commercial uses, tends to place that figure somewhat nearer to 60 gpd, but that's only an increase of 25 percent, easily justifiable. Then we say that there are two people per bedroom. Census records seem to place the occupancy level nearer one than two, but that's only double. Next, we design for the maximum day, which we say is 150 percent of the average day. We know that the maximum day flow occurs only about 5 percent of the time, and one of the values of a septic tank is that it levels out the flow, but that's only a little bit more. Then we add 60 percent for the use of automatic washing machines and garbage disposals. Once upon a time, when these items were a rarity, that was probably a good idea. However, the studies and records mentioned above are recent enough to include the use of those appliances in the usage rates shown. By the time we've used this 1.6 as a multiplier on all the other factors, we've added another major Safety Factor. On the above basis, then, a typical single family three-bedroom home would generate a design flow of:

3x2x75x1.5x1.6 = 1080 gpd, or 1.2 ac.-ft./yr.

while actual <u>average day flow</u> may be more in the range of:

3x1.2x60 = 216 gpd, or 20 percent of the design flow.

These safety factors are summarized in the following table:

Item	Design	Actual	S. F.
Usage	75 gpd	60 gpd	1.25
Occupancy	2 pers/br.	1.2 pers/br.	1.67
Peak Flow	150%	100%	1.45
Automatic Appliances	160% of peak	Included	1.6
Water-Saving Devices (If Mandatory)	100%	77%	1.30
		Total	7.27

In many instances today, several water-saving devices are available, often installed as a matter of course, and effective. A recent program sponsored by the Northwest Colorado Council of Governments has documented annual water saving in both rural communities and County areas in excess of 23 percent, merely with the use of faucet aerators, shower-head flow restrictors and toilet dams. Obviously, some well-placed regulation in this area alone could widen the gap between design and actual even more.

The question which must be asked now is whether a design safety factor of five to seven, added to an absorption safety factor of 16, really is in the interest of "public health safety and welfare," as well as being within the economically justifiable range for the consumer. Traditionally, we have merely said that all these positive safety factors merely balance (hopefully) the negative safety factors resulting from lack of care by the owner. If the negative factors are really that large, then why are we not addressing that end of the problem? Aren't we just trying to cure a plugged artery by applying a larger band-aid?

As an alternative, there are three areas of effort which appear justifiable. First, attack the problem at its source. Find ways to educate and inform the septic system user without assuming that he wants to remain ignorant of his responsibilities. For instance, computerized tax records could trigger a letter from the Health Department to the new owner of a septic system-equipped home. Lenders could be alerted to question rural area home buyers about the system in their proposed home. The same kinds of triggers could serve to notify the owner of impending need for pumping the septic tank. A copy of the design could be left with the new buyer by the installer, or furnished by the Health Department. Even general mailings to rural dwellers, using water district customer lists, could be utilized to help educate the user.

As this first effort becomes effective, both design and function safety factors could be reduced to reasonable levels, perhaps more in the range of two to 2.5 rather than five to seven for design, and four to eight for absorption rather than 16 to 24. Horizontal clearances could be made more subject to modification on specific data basis.

Last, but equally important, the use of innovative design techniques should be encouraged, such as more careful attention to proper understanding of the nature of percolation in different types of soils, effect of altitude or other factors on evapotranspiration and the use of water conservation techniques. Only as we try to update the user's understanding as well as our technology will our industry be able to become totally responsive to the needs of its users.

Since the relationship between absorption area and quantity being dispersed is a straight line, so is the cost of the system. The user then obviously directly benefits from heightened understanding of proper use of his system. First cost of the system is only the tip of the iceberg. Long-term financing costs and ultimate replacement reserves must be considered also. However, those replacement costs are also highly responsive to proper care by the owner.

In summation, continuing the concept that"bigger is better" in our design techniques seems counter-productive in several ways. First, the costs increase arithmetically. Second, more materials are used up in bigger systems, which ultimately is a cost to the whole society. Although our streams continue to produce gravel, the time will come when shipping distance will make it prohibitive to obtain. Last, ignoring the need to encourage users to become responsible continues to leave us developing societal mediocrity. Safety factors merely for the sake of redundancy are clearly not the answer to our dilemma. Awareness and education are. Let's look for a change at spending some time and money on solving the real problem rather than just applying a bigger bandage in the form of leach fields so big the outer end never even gets wet.

ISDS PERMIT FEES - ARE THEY TOO LOW?

by

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My purpose as a speaker today is not to show you the one best way to set fees or to suggest what the maximum fee level should be. The information provided to me by 19 agencies presents an opportunity to examine what methods are currently used to determine costs and what range of fees presently exists.

The authorization for the services provided by all these agencies in the individual sewage disposal program is contained in State Statute, State Health Department Guidelines, and local Regulations. These are identified in Table 1. The Statute and local Regulations contain specific procedures associated with issuing a permit for constructing a new septic system. The variance in procedures used to issue repair permits and other activities is too great to enable discussion. My comments, therefore, are related to new construction only.

Table 2 lists programmatic activities associated with issuing a permit. Some of these may be overlooked when determining what the total required effort is. We have a tendency to fix our thoughts on the "active" portion of the effort; filling out forms, reviewing plans, consultations, and inspections. However, there are such less well-recognized functions as records maintenance, program evaluation, and staff training. It is more difficult to arrive at a per-permit-cost for these, but there is a cost.

For purposes of our discussion I have used four cost centers which can be considered when building a permit fee structure. These are described in Table 3. Personal Services includes salaries, wages and benefits for all staff working in the program, not just field personnel. Administrative Support refers to such items as space costs, utilities, and payroll and financial services. Mileage may either be a reflection of a reimbursement for miles driven in personal cars or actual costs of operating fleet vehicles. Supplies/Equipment refers to durable items such as tools and expendables such as forms.

Once these parameters are identified a fee may be constructed. The data supplied to me indicated two general approaches used to arrive at a fee level. The first involves identifying the total ISDS program cost and dividing this by the total number of permits issued. The result is an average cost per permit. The second method goes one step further and focuses on costs associated with new permits directly. The percentage of permits which are for new construction is first identified and this same percentage of the total program budget is then determined. Finally this figure is divided by the number of new construction permits and an average cost per new construction permit is established. Tables 4 and 5 depict these procedures.

There may be other ways to build a permit fee. I do not intend that my examples represent the only or even the best ways. The methods I have used do identify significant cost centers and use them in a logical manner.

From the two specific examples in Table 5, we see that the cost is not met. The upper limit, as mentioned, is set by Statute. We must recognize the political as well as economic factors in selecting an appropriate fee. If a conscious decision is made to support the program through general fund monies, then that is what will be done. I believe it is still desirable to know what the cost of providing the service is. In fact, accountability requires that the costs be known.

The last two Tables 6 and 7 identify those agencies which supplied data to me, what their fee for a new permit is, and how they arrived at the fee. It is readily apparent that the majority are charging the maximum allowable. The two examples I have shown in Table 5 indicate that the costs exceed the imposed limit.

My data, by itself, is not sufficient to make a blanket statement that the fee level is too low. However, this seems to be the case.

I recommend that accurate cost information be developed on a regular basis using the activity and budget data as described. I also recommend that, periodically, a cost for individual permits be determined. This requires more accurate and detailed monitoring. If this is done, an indication of the variability in actual costs will be revealed. An examination of this variability may prove helpful when evaluating program functions.

The data I have shared with you was intended to be informative. I hope you gained something from it. Thank you for your attention.

TABLE 1.

LEGAL BASIS FOR ISDS PROGRAMS

STATUTE:	INDIVIDUAL SEWAGE DISPOSAL ACT ARTICLE 10, SECTION 25, C.R.S. 1973
STATE GUIDELINES:	INDIVIDUAL SEWAGE DISPOSAL ACT ARTICLE 10, SECTION 25, C.R.S. 1973
LOCAL REGULATIONS:	PART 5, ARTICLE 1, TITLE 25, C.R.S. 1973 COUNTY AND DISTRICT HEALTH DEPARTMENTS
	PART 7, ARTICLE 1, TITLE 25, C.R.S. 1973 REGIONAL HEALTH DEPARTMENTS
	RESOLUTION OF COUNTY COMMISSIONERS ESTABLISHES HEALTH DEPARTMENTS
	BOARDS OF HEALTH ADOPT ACTUAL REGULATIONS
FEE LEVELS:	PART 1. (104(6)), ARTICLE 10, TITLE 25, C.R.S. 1973. ". . . FEES AUTHORIZED IN THIS ARTICLE SHALL BE SET AT SUCH AMOUNTS AS ARE DEEMED NECESSARY TO COVER THE OPERATION EXPENSES OF THE SEVERAL AGENCIES . . ."
	PART 1 (106(1)(A)), ARTICLE 10, TITLE 25, C.R.S. 1973. ". . . A FEE NOT TO EXCEED $150 OR COST OF PROVIDING THE SERVICE . . ."

TABLE 2.

WORK ACTIVITIES ASSOCIATED WITH ISDS PROGRAM

PROCESSING APPLICATION

SITE VISITS

PLAN REVIEWS

CONSULTATIONS

CONSTRUCTION INSPECTIONS

RECORDS MAINTENANCE

PROGRAM REVIEW/EVALUATION

STAFF TRAINING

TABLE 3.
ISDS PERMIT FEE COMPONENTS

PERSONAL SERVICES	- INCLUDES SALARIES AND FRINGE BENEFITS FOR ALL STAFF INVOLVED IN THE PROCESS.
ADMINISTRATIVE SUPPORT	- SUCH COSTS AS SPACE, HEAT, LIGHTS, FINANCE, PAYROLL, ETC. SHOULD BE IDENTIFIED.
MILEAGE	- EITHER IN THE FORM OF MILEAGE REIMBURSEMENT WHEN PRIVATE VEHICLES ARE USED OR ACTUAL OPERATING EXPENSES FOR GOVERNMENT FLEET CARS.
SUPPLIES/EQUIPMENT	- THESE CATEGORIES WOULD INCLUDE EXPENDABLE AND MORE DURABLE ITEMS USED IN PERFORMING TASKS IN THE ISDS PROGRAM.

TABLE 4.

ISDS PERMIT FEE METHODOLOGY

1. IDENTIFY TOTAL PERSONAL SERVICES COSTS FOR ISDS PROGRAM: DIRECT AND INDIRECT

2. ESTABLISH TRANSPORTATION COSTS FOR PROGRAM.

3. SPECIFY COSTS OF EQUIPMENT AND SUPPLIES.

4. ARRIVE AT TOTAL COST FOR PROGRAM.

5A. ESTABLISH NUMBER OF ISDS PERMITS (ALL TYPES) ISSUED FOR SPECIFIED PERIOD.

6A. DIVIDE COST BY TOTAL NUMBER OF PERMITS.

7A. YIELD IS AVERAGE COST PER PERMIT FOR ALL TYPES.

5B. ESTABLISH NUMBER OF NEW CONSTRUCTION PERMITS ISSUED AND TOTAL NUMBER OF PERMITS ISSUED.

6B. IDENTIFY WHAT PERCENT OF PERMITS ARE FOR NEW CONSTRUCTION.

7B. MULTIPLY TOTAL PROGRAM COST BY THE PERCENTAGE WHICH INDICATES NEW CONSTRUCTION.

8B. YIELD IS COST FOR NEW CONSTRUCTION PERMITS.

9B. DIVIDE NEW CONSTRUCTION PERMIT COST BY NUMBER OF NEW CONSTRUCTION PERMITS.

10B. YIELD IS AVERAGE COST FOR NEW CONSTRUCTION PERMIT.

TABLE 5.
EXAMPLES OF COST BUILDING METHODS

EXAMPLE COUNTY A

COST CENTER	DOLLAR AMOUNT	%
PERSONAL SERVICES	$53,783	86
ADMINISTRATIVE OVERHEAD	5,535	9
TRANSPORTATION	2,998	4
SUPPLIES/EQUIPMENT	496	1
TOTAL	$62,812	100%

$62,812 317 PERMITS = $198 AVERAGE COST

EXAMPLE COUNTY B

COST CENTER	DOLLAR AMOUNT	%
PERSONAL SERVICES (INCLUDES OVERHEAD)	$65,273	93
TRANSPORTATION	1,300	2
SUPPLIES/EQUIPMENT	3,455	5
TOTAL	$70,028	100%

173 NEW CONSTRUCTION PERMITS OUT OF TOTAL OF 435 = 40%

40% OF TOTAL PROGRAM COST = $28,011

$28,011 ÷ 173 NEW CONSTRUCTION PERMITS = $162 AVERAGE COST

DOLLAR FIGURES ARE NOT FROM SAME CALENDAR YEAR

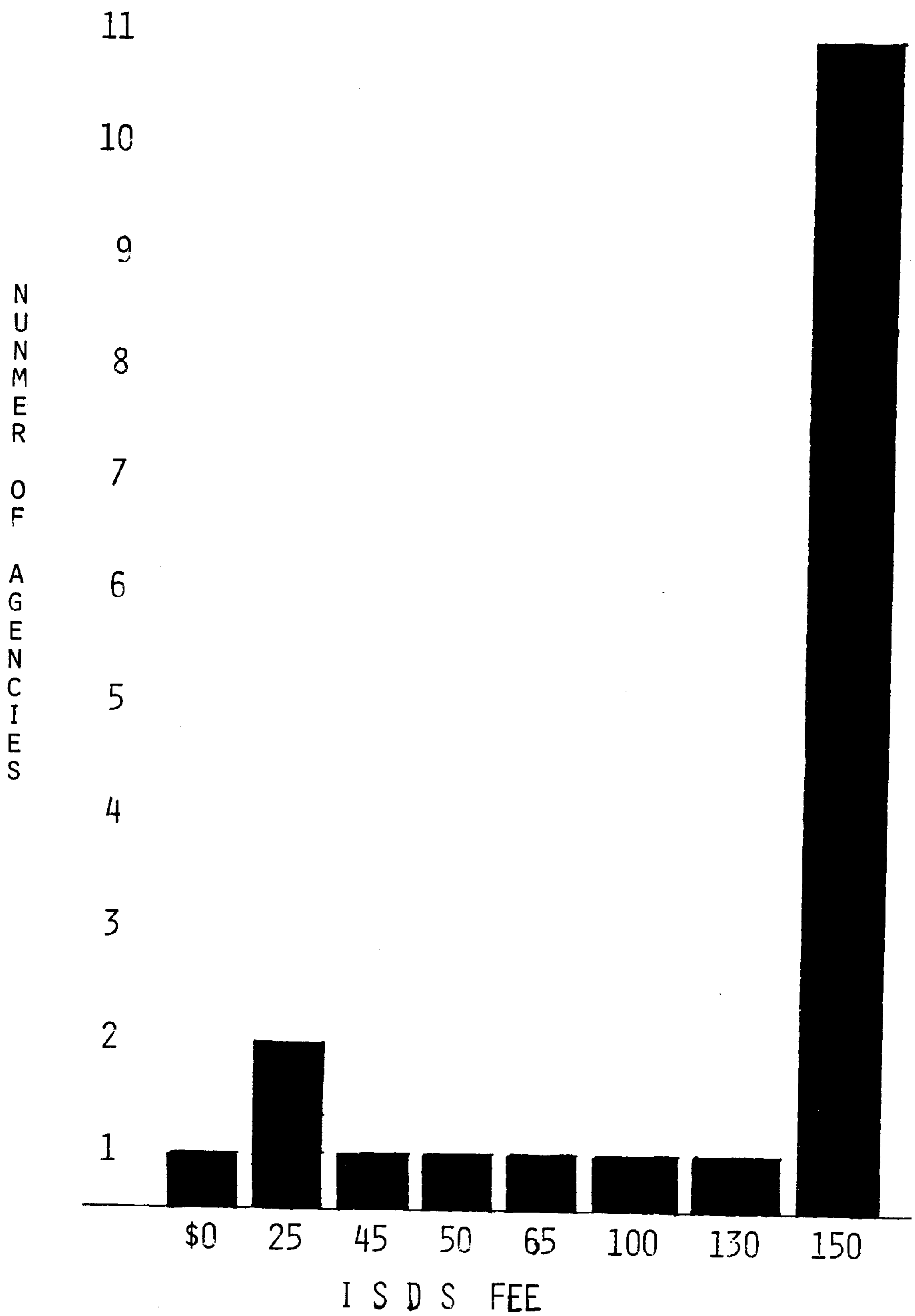
TABLE 6.
PARTICIPANTS IN SURVEY

COUNTY	FEE LEVEL*	BASIS FOR FEE
BOULDER	$150	COST OF SERVICE STUDY
CHAFFEE	0	---
DELTA	65	UNSPECIFIED
EAGLE	150	UNSPECIFIED
EL PASO	150	COST OF SERVICE STUDY
GUNNISON	50	UNSPECIFIED
JEFFERSON	150	COST OF SERVICE STUDY
LARIMER	150	COST OF SERVICE STUDY
LAS ANIMAS	150	UNSPECIFIED
MESA	150	COST OF SERVICE
MONTEZUMA	45	COST OF SERVICE STUDY & MARKET CONDITIONS
PUEBLO	150	COST OF SERVICE STUDY
PITKIN	100	COST OF SERVICE STUDY
RIO BLANCO	25	UNSPECIFIED
ROUTT	25	---
SAN JUAN BASIN	150	COST OF SERVICE STUDY
TRI-COUNTY DISTRICT	130	COST OF SERVICE STUDY
WELD	150	COST OF SERVICE STUDY

*DOES NOT INCLUDE PERC TEST

TABLE 7.

DISTRIBUTION OF FEES AMONG SURVEYED AGENCIES



6TH WORKSHOP ON ON-SITE WASTEWATER TREATMENT

APRIL 9, 1986

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HOLYOKE, CO 80734

40. DONELL JEFFRIES
JEFFRIES ENGRG.
3315 SPRINGRIDGE CIR.
COLORADO SPRINGS, CO 80906

41. MIKE JENSEN
NATL. PARK SERVICE
P.O. BOX 25287
DENVER, CO 80225

42. CANDACE L. JOCHIM
COLORADO GEOLOGICAL SURVEY
1313 SHERMAN ST., RM. 715
DENVER, CO 80203

43. PETER JOHNSON
WRIGHT WATER ENGRS., INC.
3490 W. 26TH AVE., STE 55A
DENVER, CO 80211

44. SUSAN JONES
E.O. CHURCH, INC.
925 E. 17TH AVE.
DENVER, CO 80218

45. TERRY KARR
PARK CTY. HEALTH DEPT.
P.O. BOX 216
FAIRPLAY, CO 80440

46. DON KAUFMANN
CSU-COOP. EXT. SERVICE
201 ADMINISTRATION BLDG.
FORT COLLINS, CO 80523

47. RICHARD W. KETCHAM
NATL. PARK SERVICE
301 S. HOWES, RM. 343
FORT COLLINS, CO 80521

48. RICK KINSHELLA
TRI-CTY. HEALTH DEPT.
4857 S. BROADWAY
ENGLEWOOD, CO 80110

49. KAYE MAEZ
SAGUACHE CTY.
501 4TH P.O. BOX 326
SAGUACHE, CO 81149

50. JEAN P. MARCHAND
GRONNING ENGR. CO.
1333 W. 120TH AVE., STE 314
DENVER, CO 80234

51. JOHN E. MARTINEZ
LAS ANIMAS CTY. HEALTH DEPT.
412 BENEDICTA
TRINIDAD, CO 81082

52. DON MATVEIA
CHAFFEE CTY. HEALTH DEPT.
P.O. BOX 699
SALIDA, CO 81201

53. DAVE MCCLOSKEY
LARIMER CTY. HEALTH DEPT.
363 JEFFERSON ST.
FORT COLLINS, CO 80524

54. MARTIN MECHTLY
BOULDER CTY. HEALTH DEPT.
3450 BROADWAY
BOULDER, CO 80501

55. PHIL METZ
S. FORT COLLINS SANIT. DIST.
4700 S. COLLEGE
FORT COLLINS, CO 80525

56. ROBERT NELSON
ASPEN/PITKIN ENV. HEALTH DEP
130 S. GALENA ST.
ASPEN, CO 81611

57. DAVID NETTLES
COLO DIV OF WATER RESOURCES
1313 SHERMAN ST. RM. 818
DENVER, CO 80203

58. THOMAS PETERSON
COLORADO STATE UNIVERSITY
DEPT. AG. & CHEM. ENGR.
FORT COLLINS, CO 80523

59. ALLEN PIERRE
EL PASO CTY. HEALTH DEPT.
501 N. FOOTE
COLORADO SPRINGS, CO 80909

60. GREG PINK
MONTROSE CTY. SANITARIAN
P.O. BOX 1289
MONTROSE, CO 81401

61. ALEX RACHAK
CLIVUS MULTRUM/ALEX RACHAK
P.O. BOX 33656
NORTHGLENN, CO 80233

62. MICHAEL RICHARD
CSU-DEPT. MICROBIOL.& HEALTH
212 SPRUCE HALL
FORT COLLINS, CO 80523

63. MICHAEL RIGDON
GRAND CTY. BLDG. DEPT.
GRAND CTY. COURT HOUSE
HOT SULPHUR SPRINGS, CO 80451

64. VERNON ROMINGER
RIO GRAND CTY. COMMISSIONER
P.O. BOX 396
DEL NORTE, CO 81132

65. VICTOR SAINZ
COLORADO DEPT OF HEALTH
4210 E 11th AVE
DENVER, CO 80220

66. MANUEL SAIS
NATIONAL PARK SERVICE
P.O. BOX 25287
DENVER, CO 80227

67. PHILLIP F. SEELING
SEELING & ASSOC.
P.O. BOX 2302
BRECKENRIDGE, CO 80424

68. DAVID SHUPE
LANDMARK ENGRG., LTD.
2300 W. EISENHOWER BLVD.
LOVELAND, CO 80537

69. STAN SMITH
US EPA
999 18TH ST.
DENVER, CO 80202

70. DAVID STEWART
STEWART ENV. CONSULTANTS INC
214 N. HOWES P.O. BOX 429
FORT COLLINS, CO 80522

71. MARILYN SWETT
TRI-CTY. HEALTH DEPT.
4857 SO. BROADWAY
ENGLEWOOD, CO 80110

72. LARRY O. THOMPSON
HIGH COUNTRY ENGR., INC.
STE. 205, VILLAGE PLAZA
GLENWOOD SPRINGS, CO 81601

73. GEORGE VARGULICH
WELD CO. HEALTH DEPT.
1516 HOSPITAL RD.
GREELEY, CO 80631

74. TOM WALTERS
CLEAR CREEK CTY. ENV. HEALTH
P.O. BOX 2000
GEORGETOWN, CO 80444

75. ROBERT C. WARD
CSU AG & CHEM ENGRG DEPT
FORT COLLINS, CO 80523

76. DOUGLASS WEITZEL
SELF EMPLOYED-DOUG WEITZEL
2630 W. MULBERRY
FORT COLLINS, CO 80521

77. LLOYD WILLIAMS
TRI-CTY. HEALTH DEPT.
15400 E. 14TH PL.
AURORA, CO 80011

78. KELLY YEAGER
RIO GRANDE CTY. LAND USE
P.O. BOX 396
DEL NORTE, CO 81132

79. DWIGHT ZEMP
SANILOGICAL CORP.
7925 E. HARVARD, STE. B
DENVER, CO 80231