

R2533

SSWMP PUBLICATION #13.6
SEPTEMBER 1973

ON SITE WASTE WATER
DISPOSAL FOR HOMES
IN UNSEWERED AREAS

SMALL SCALE WASTE MANAGEMENT PROJECT
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On-Site Waste Water Disposal for Homes in Unsewered Areas

INTRODUCTION

Homeowners in unsewered areas face a problem of providing safe and effective wastewater disposal systems for their homes. Household wastewaters contain pathogenic bacteria, infectious viruses, putrescible organic matter, and excess nutrients in the form of nitrogen and phosphorus. All of these could potentially create public health hazards and nuisances if the waste is disposed of into the environment without purification.

Conventionally, the septic tank-soil absorption system has solved this problem for most homeowners and has proven very satisfactory when properly designed, installed, and maintained.

THE CONVENTIONAL SEPTIC TANK SYSTEM

A Physical Description

The septic tank system is made up of two components, the septic tank, used to provide partial treatment of the raw waste, and the soil absorption field where final disposal of the liquid discharged from the septic tank takes place.

The septic tanks' primary purpose is to keep the soil absorption field from becoming clogged by solids suspended in the raw wastewater. Wastewater is discharged from the home directly into the tank where it is retained for a day or more. During this time, the larger solids settle to the bottom and a sludge blanket develops. The greases, oils, and other floating particles rise to the top to form a scum layer (Figure 1).

In addition to acting as a settling chamber and providing storage for the sludge and scum, the septic tank also digests or breaks down the waste solids. Anaerobic bacteria (organisms that live without oxygen) feed on the sludge, reducing its volume. In the process soluble organic matter is released from the sludge into the effluent. Methane and carbon dioxide gases are also produced and vented from the tank through the house vent. Only about 40% of the sludge volume is reduced in this manner however, and the accumulated solids must be pumped from the tank once every two to three years. If the solids are not pumped out, the tank will fill, resuspend the accumulated solids, and wash them onto absorption fields where they quickly clog the soil pores.

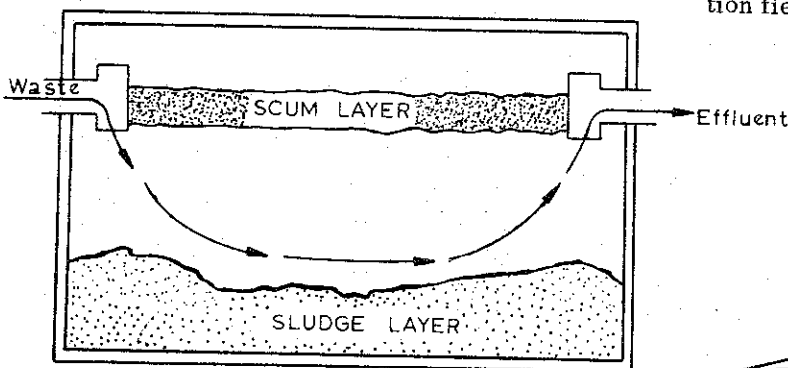


FIGURE 1. Schematic of a typical household septic tank.

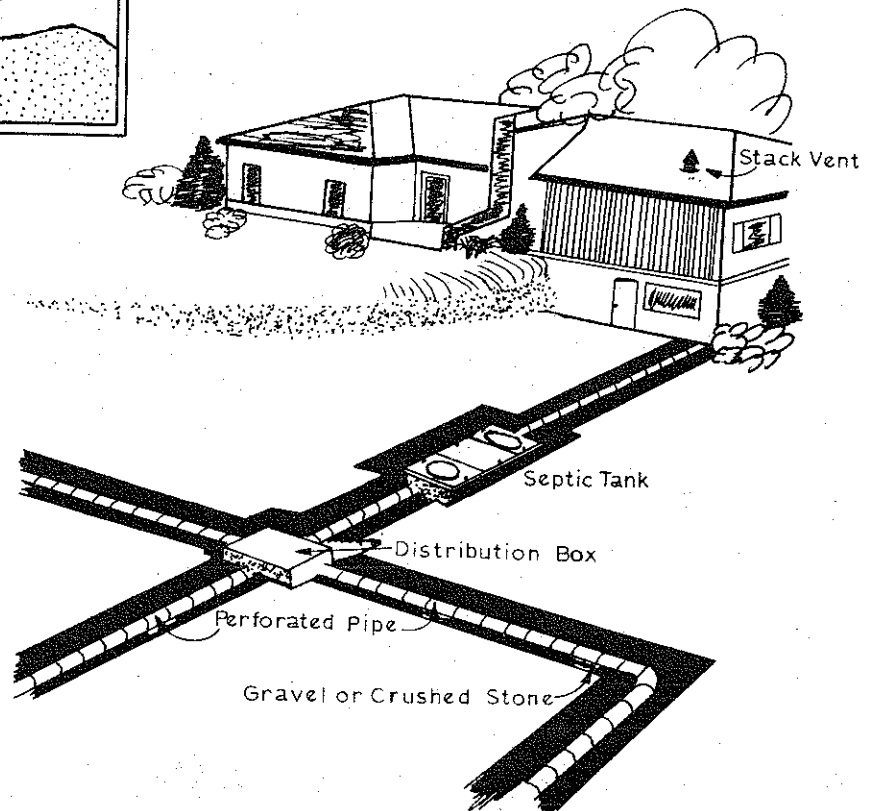


FIGURE 2. The conventional septic tank-soil disposal system.

The clarified liquid flows from the septic tank to the soil absorption field for final disposal. The field is a series of trenches 2 to 3 feet deep. In each trench, perforated pipe overlying 12 inches of gravel distributes the liquid over the field (Figure 3). The septic tank effluent is filtered as it percolates through the soil and is purified before reaching the ground water.

Treatment Efficiency of the Septic Tank System

Wastewater is discharged from a home intermittently. The flow is made up of several distinct water use events between which no flow occurs. These events originate in the kitchen, bathroom,

and laundry in a pattern that is dependent upon the habits of the occupants. Though every event has its own characteristic flow rate and polluttional load, an average waste strength is given in Table 1. The total volume of wastewater generated is usually about 50 gallons per person every day.

Effluent coming from the septic tank is not of a high quality nor is it consistent, but this is not necessary if suitable soil is used for final subsurface disposal. The tank does remove up to 60% of the BOD (Biological Oxygen Demand) and 70% of the suspended solids. Indicator micro-organisms, which are micro-organisms that indicate the possible presence of disease bacteria, are not reduced to low levels (Table 1).

FIGURE 3. A cross-section of the soil absorption trench (right) and of the perforated pipe inside the trench (left).

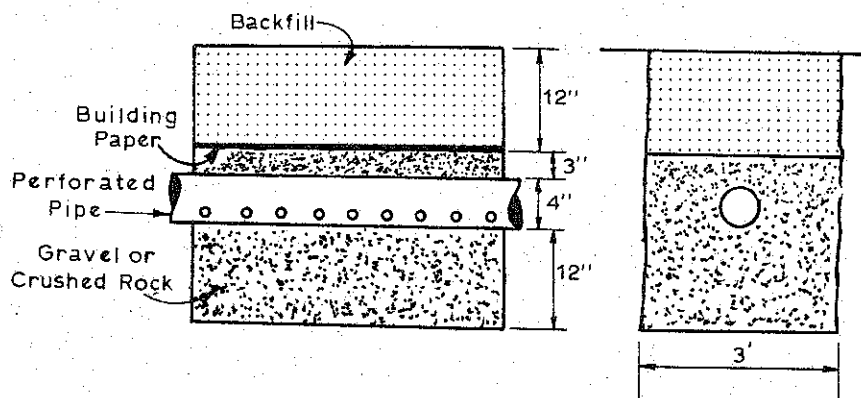


TABLE 1. Average Concentrations of Raw and Septic Tank Wastewaters (Concentrations in milligrams/liter)

Wastewater	Biochemical Oxygen Demand (BOD)	Total Suspended Solids	Total Nitrogen	Phosphorus	Fecal Coliform Bacteria
Raw Waste	350 mg/l	400 mg/l	80 mg/l		
Septic Tank Effluent	150 mg/l	140 mg/l	50 mg/l	20 mg/l	1,200,000/100 ml

A properly operating soil absorption field can treat and nearly completely purify the septic tank effluent. The soil very effectively removes BOD, phosphorus, and bacteria and viruses. Only nitrogen freely moves through the system, but only if it is oxidized to nitrate-nitrogen ($\text{NO}_3\text{-N}$) in well-aerated soil.

Problems Associated with Septic Tank Systems

Building of new residences in unsewered areas is not allowed at locations considered unsuitable for a conventional septic tank-soil disposal system. The State Health Code H62.20, which was adopted in 1969, specifically defines unsuitable sites as: (1) sites having a percolation rate slower than 60 min/inch, as averaged from at least three measurements, (2) sites having less than three feet of soil between the bottom of the soil absorption system and high ground water or bedrock, (3) sites having a surface slope exceeding values between 10% and 20% (the exact percentage depends on the percolation rate) and (4) flood plains.

SOIL TYPE PROBLEMS

Many soils in the State have properties that make them unsuitable for on-site liquid waste disposal according to the Health Code. For example, red clay soils in the northern and eastern part of the State are very slowly permeable as are soils formed in tight glacial till in the central and southern part of the State. Construction of traditional subsurface seepage beds in such soils would result in surface seepage of effluent and surface-water contamination (Figure 4). Shallow loamy soils over creviced bedrock, on the contrary, are too permeable. Here, effluent may contaminate ground water with disease bacteria and viruses due to insufficient purification by soil percolation. Soils of this type occur widely in Door County and Southwestern Wisconsin. Soils with constant or periodic high ground water are common throughout the State. The total land area occupied by these problem soils is estimated to exceed 50% of the land area of the State (Figure 5).

FIGURE 4. Malfunctioning subsurface soil disposal system (Kelly Lake). Effluent surfaced as it was not sufficiently absorbed by the very slowly permeable glacial drift in this Tustin sandy loam. Sand (S) was dumped on top of the absorption field area in a vain attempt to stop leakage.

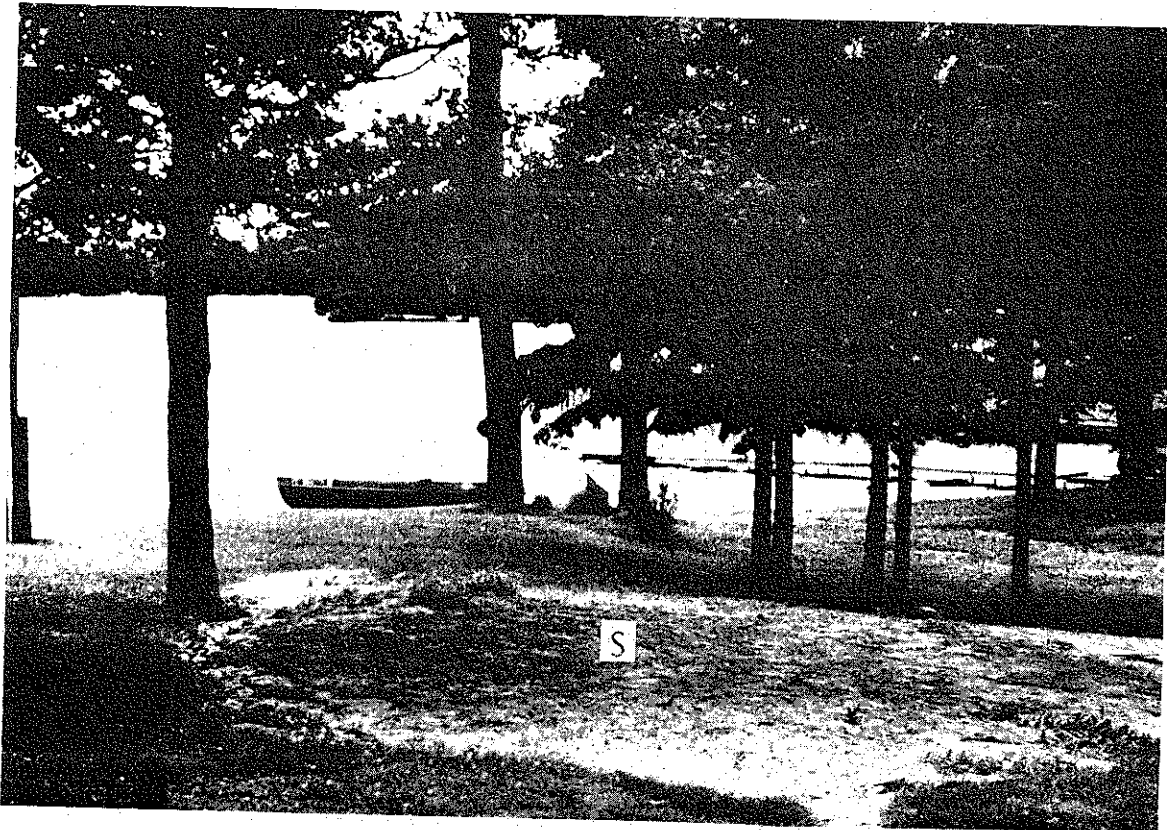
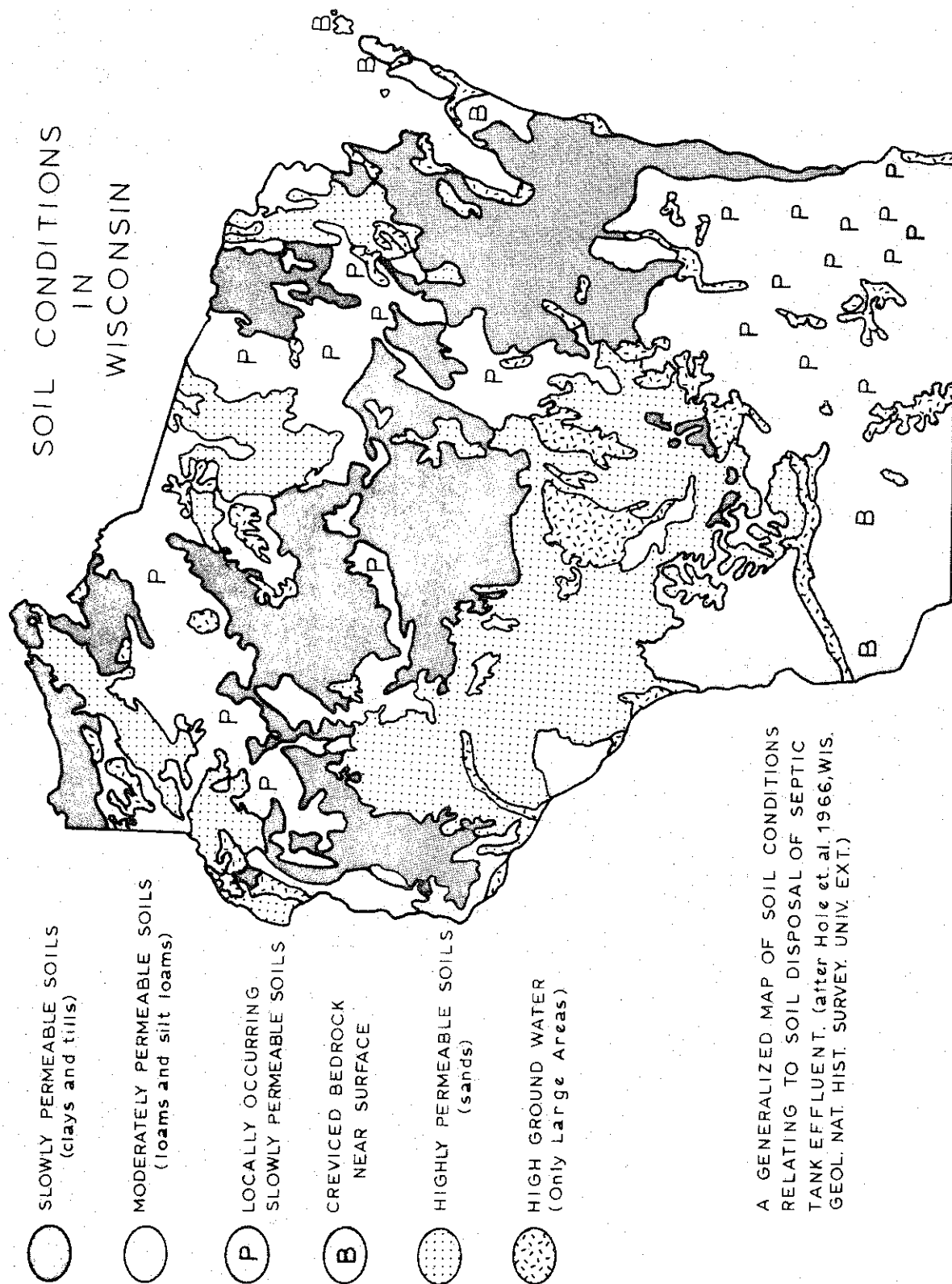


FIG. 5
SOIL CONDITIONS
IN
WISCONSIN



A GENERALIZED MAP OF SOIL CONDITIONS
RELATING TO SOIL DISPOSAL OF SEPTIC
TANK EFFLUENT. (after Ho/e et al. 1966, WIS.
GEOL. NAT. HIST. SURVEY. UNIV. EXT.)

OLD DISPOSAL SYSTEMS

Some problems related to waste disposal in rural or suburban areas are not detailed by the health code. Many old systems constructed at sites to be defined later as unsuitable after the adoption of the health code are malfunctioning now, resulting in pollution of surface and ground waters. But there are also many problems with soil disposal systems in soils that are classified as "suitable" by the current code. For example, permeable soils may lose much of their percolative capacity as a result of the formation of a slowly permeable crust on the infiltrative surfaces in the seepage bed. Crusting may be due to accumulation of solids from the septic tank effluent at the interface of gravel and soil and to microbial growth in the upper few inches of the soil below the bed. This results in an accumulation of organic matter that plugs the soil pores. Hydraulic effects of crusts greatly affect seepage. Research based on *in situ* measurements of hydraulic conditions around operating seepage beds has shown that flow into crusted sand was only 2 inches per day, whereas flow into uncrusted sand was 200 inches per day. A systems failure is evident when effluent surfaces. This surfacing occurs when the total bottom and absorptive sidewall areas of the seepage bed are insufficient in absorbing the effluent.

CHEMICAL POLLUTION

Chemical pollution of ground water by nitrates is another problem. This occurs primarily in sandy soils but can occur in more slowly permeable clayey soils or soils underlain by fractured bedrock. The nitrogen in the septic tank effluent is in the form of ammonia (NH_4^+) due to the decomposition of waste organics in the anaerobic environment of the septic tank. Biological oxidation of the ammonia to nitrate (NO_3^-) takes place when the effluent moves through aerated soil containing nitrifying bacteria. The nitrate is not absorbed by the soil particles but moves freely through the soil. High nitrate contents are found in many ground waters below soil absorption systems. If housewells are not well constructed or when they are located at a close distance down-gradient from the septic system, drinking water may have relatively high nitrate contents, possibly well over 10 mg-N/liter which has been established as a limit by the public health service. Infants in particular are susceptible to methemoglobinemia, an illness which is sometimes fatal and caused by an overdose of nitrate. Aside from the health problem, additions of nitrates to groundwater can also lead to accelerated eutrophication (which is nutrient enrichment sometimes leading to algal blooms) of surface

waters such as lakes and streams. A family of four produces liquid waste with about 72 lbs/N per year, most of which is transformed into nitrates. However, nitrates are also contributed to the soil from atmospheric sources (8 lbs/acre) and by decomposition of organic matter in the soil (up to 45 lbs/acre in some soils). It is estimated that approximately 12 lbs/acre derived from these two sources reaches the groundwater as nitrates. These data illustrate that nitrate contributions derived from septic tank soil disposal fields would approximately be equal to those from natural sources if one dwelling with a septic tank were found on every 6 acres of land. Additions of septic-tank-derived nitrate to the ground water are, thus, insignificant in amount when judged on a scale of a sparsely populated landscape. The only potential health problem could be local contamination of a shallow, down-gradient housewell. Where there is a concentration of many small individual lots, each with a septic tank system, nitrate contamination of the ground water can become a serious problem. When such lots are close to lakes or streams, eutrophication may be accelerated due to transport of nitrates and/or phosphates by flow of contaminated ground water into these surface waters. Many soils can absorb all phosphates but certain types of sandy soils may have a low capacity to retain the percolating phosphates.

Present Legal Alternatives to the Conventional Septic Tank System

A holding tank is the only legal alternative to the septic tank system in unsewered areas of Wisconsin where the soil is unsuitable for seepage bed construction. The liquid wastes are collected and held in a large tank that is periodically pumped by a licensed pumper. The wastewater is hauled away to be disposed of on an approved land disposal field or is discharged at a municipal treatment plant.

The cost of operating a holding tank is high. In Wisconsin, 1 cent per gallon is an average cost of hauling. For a family of four, this amounts to \$600 to \$900 per year. This high cost thus prevents the use of this system.

CURRENT RESEARCH

To improve techniques used in final disposal of wastewaters, research centers around four areas:

1. Waste production
2. Waste treatment
3. Waste disposal
4. Supervision and control.

Wastewater Reduction Methods

The problem of waste treatment and disposal begins in the home where the total volume and strength of the waste can be reduced to minimize the load on the disposal system. Some water conservation habits include partial reuse of water, and disposal of garbage, through means other than the wastewater disposal system.

An average family of four discharges 200 gallons of wastewater from the home each day (50 gallons per person per day). This water is generated at several sources as shown in Figure 6. The greatest

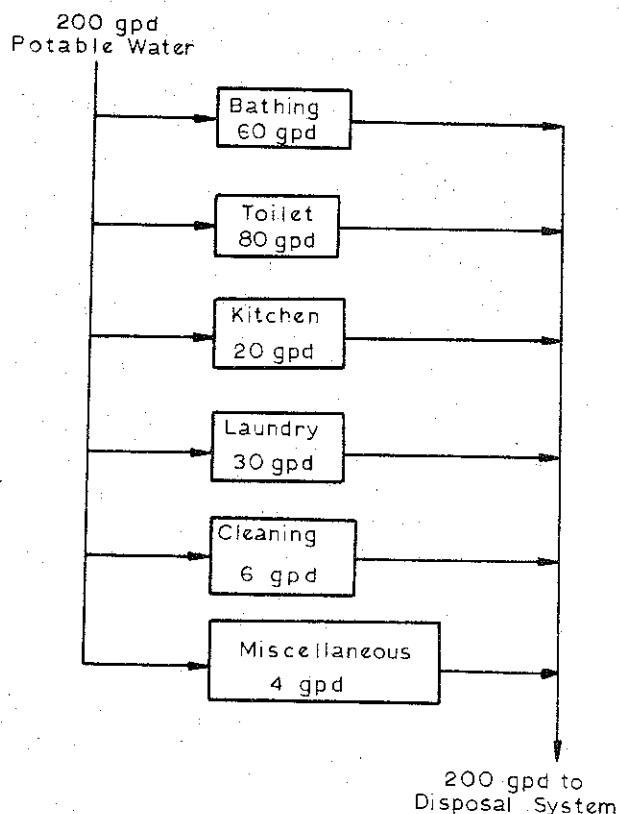
use of water is for bathing, laundering and toilet flushing.

By practicing water-saving habits, the total flow from the home can be significantly reduced. For example, being careful not to turn on the shower full or not filling the bathtub completely can save as much as 10 gallons per use. Washing only full loads of clothes rather than more frequent partial loads can also save significant amounts of water.

To conserve water in toilet flushing, recycle of bath and laundry wastes to the toilets could be practiced if proven safe. The washing and bathing waters may be collected separately from the other household wastes, filtered and pumped into a pressurized tank leading to the toilets. This system could be readily adapted to existing plumbing and save up to 20 gallons per person per day.

Other plumbing fixtures, such as showerheads, faucets, low volume flush toilets, and suds-saving washing machines, mechanically reduce water flow. The use of these devices and conservative habits can reduce the total flow from a home by as much as 40 percent.

FIGURE 6. Wastewater generation by a typical family of four.



Three Wastewater Treatment Units

The primary purpose for treating the wastes is to protect the infiltration capacity of the soil disposal field. If untreated household wastes were discharged directly to the soil, the soil pores would clog and result in ponding of the sewage, a public health hazard.

A wide range of processes exist for the treatment of wastewaters and many have been adapted to the small flows encountered from a single household. Nearly any desired effluent quality can be produced, even potable water, but as the quality increases, so does the complexity of the treatment system and its cost. Improved treatment cannot solve the ultimate problem of disposal, but it may increase the alternatives for safe and effective disposal.

The treatment-process-units marketed for household waste treatment can be grouped into three general categories: (1) anaerobic biological treatment, (2) aerobic biological treatment, and (3) physical-chemical treatment units.

ANAEROBIC BIOLOGICAL TREATMENT UNITS

The most common anaerobic household unit is the septic tank. It is an ideal treatment unit when installed with a properly functioning soil disposal field because it is inexpensive, easy to maintain and requires little attention.

The septic tank (Figure 2) acts as a settling chamber and provides storage for the solids in an environment where anaerobic (without oxygen) bacteria digest the removed solids. As the wastewater flows into the tank, the velocity of flow is reduced by a baffle allowing the larger solids to settle to the bottom to accumulate as sludge. The greases and other floatable solids rise to the surface to form a scum. Anaerobic bacteria present in all wastewater grow and multiply primarily in the sludge layer, feeding on the organic matter there to reduce its volume. During this process, methane and carbon dioxide, hydrogen sulfide and other odorous gases are produced which bubble to the surface and escape through the house vent. The clarified liquid which is discharged from the tank has approximately 50% less putrescible organic matter and 70% fewer suspended particles than does the raw wastewater. Concentrations of indicator organisms, however, remain high.

AEROBIC BIOLOGICAL TREATMENT UNITS

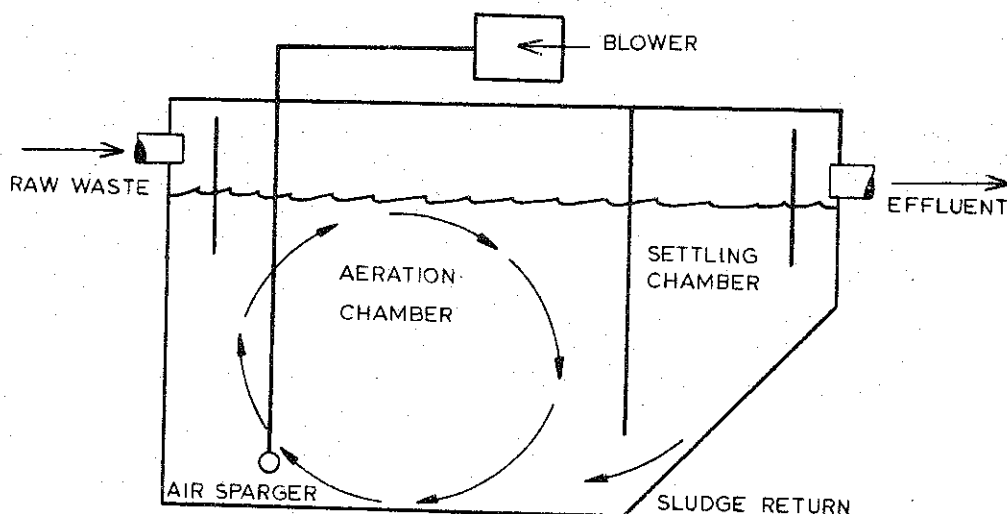
Waste treatment utilizing aerobic micro-organisms (require oxygen) is more efficient because the free

oxygen dissolved in the wastewater allows the organisms to rapidly feed on and degrade both the suspended and dissolved organic matter. In a few hours, up to 90% of the organic matter is destroyed and a similar amount of suspended solids are removed.

A typical household aerobic treatment unit is depicted in Figure 7. It consists of two chambers. Raw or septic tank effluent enters the first chamber and is quickly mixed with the aerobic micro-organisms by the air flow from the blower. The mixing brings the microbes into contact with both the dissolved and undissolved waste matter. The nutrient material is rapidly absorbed by the organisms which utilize it for energy and cell growth converting the majority of the organics in the waste to carbon dioxide, water and settleable sludge solids. Unlike the septic tank, no obnoxious odors are produced. In the second chamber, the sludge which contains the microorganisms settles out and is returned to the aeration chamber to continue the treatment process. The clarified effluent leaves the unit low in organic matter, suspended solids, and considerably reduced in indicator organisms.

While these units can produce a much higher quality of effluent without odors, they require regular maintenance and servicing. The treatment process is easily upset causing discharge of solids to the disposal field. Household aerobic treatment units are considerably more expensive to install and operate than the septic tank.

FIGURE 7. Schematic of a simple household aerobic treatment unit.



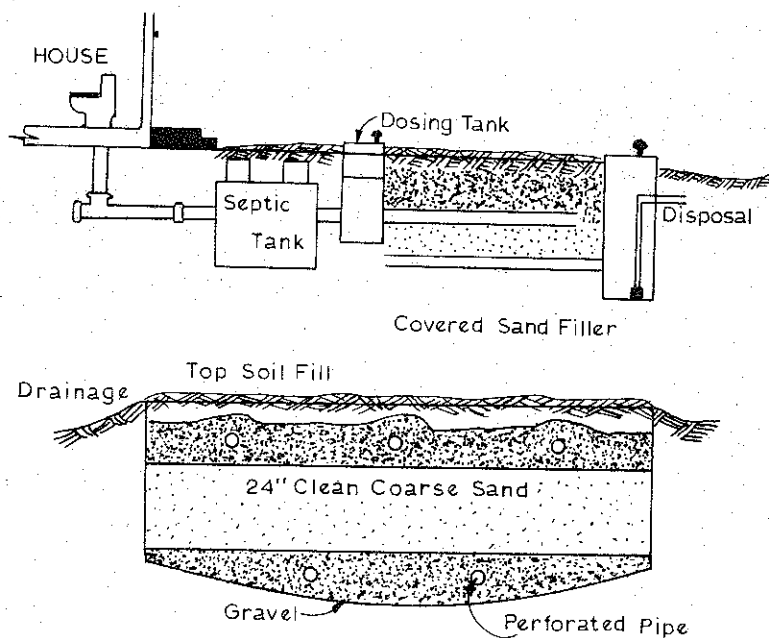
PHYSICAL CHEMICAL TREATMENT UNITS

Physical treatment processes have the advantage of not relying on microorganisms for treatment and are less susceptible to upset. Sewage is treated by the addition of appropriate chemicals for coagulation and precipitation of the suspended and dissolved solids and by physical methods such as filtration. Processes requiring chemical addition are rarely used because of the frequent servicing required and the high cost of chemicals. Filtration, however, is often employed. A typical household sand filter is shown in Figure 8. The filter is able to remove

most of the organic material and suspended solids. Indicator organisms are also reduced to very low levels. A soil absorption field or a mound system provides treatment in a similar manner differing only in that it also serves as a means of final disposal.

The Small Scale Waste Management Project is monitoring these treatment units under both field and laboratory conditions. This monitoring will determine the ability of a particular unit to increase the potential for safe and effective final disposal of household wastes. Systems that perform well will be recommended as alternatives to the conventional system in problem soil areas.

FIGURE 8. Cross-section of a household sand-filler.



Alternative Waste Disposal Methods

ALTERNATIVES FOR SOILS WITH CLOGGING PROBLEMS

Conventional seepage beds receiving septic tank effluent usually have a crusted or clogged layer where infiltration occurs at the bottom and sidewalls. The traditional mechanism of intermittent gravity flow by which effluent is applied to the seepage bed enhances progressive crust formation starting near the point of inlet and proceeding until the total bottom area of the bed and some of the sidewalls are crusted (Figure 9). The 4-inch pipe with many perforations distributes effluent poorly, by depositing

the effluent through the first holes in the pipe. The soil underlying the bed at that point receives a high load of effluent. Crust formation occurs because of bacterial action in the soil and an accumulation of solids on top of the infiltrative surface. As the clogging develops, the whole bed is crusted as the septic tank effluent must move farther and farther into the seepage bed to reach uncrusted soil. Studies in this project have shown that periodic aeration of the infiltrative surface reduces crust development by oxidizing the clogging components. Crusting can be controlled by applying the effluent intermittently and evenly over the seepage bed area. This procedure uses the soil more effectively than the tradition-

FIGURE 9. Progressive crusting of infiltrative surfaces in subsurface seepage beds.

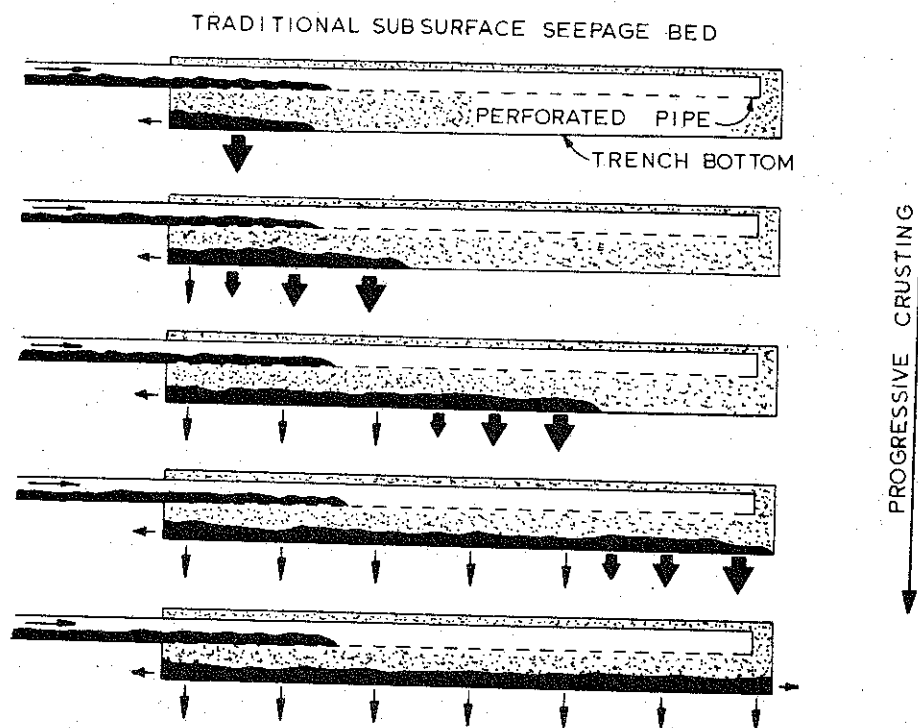
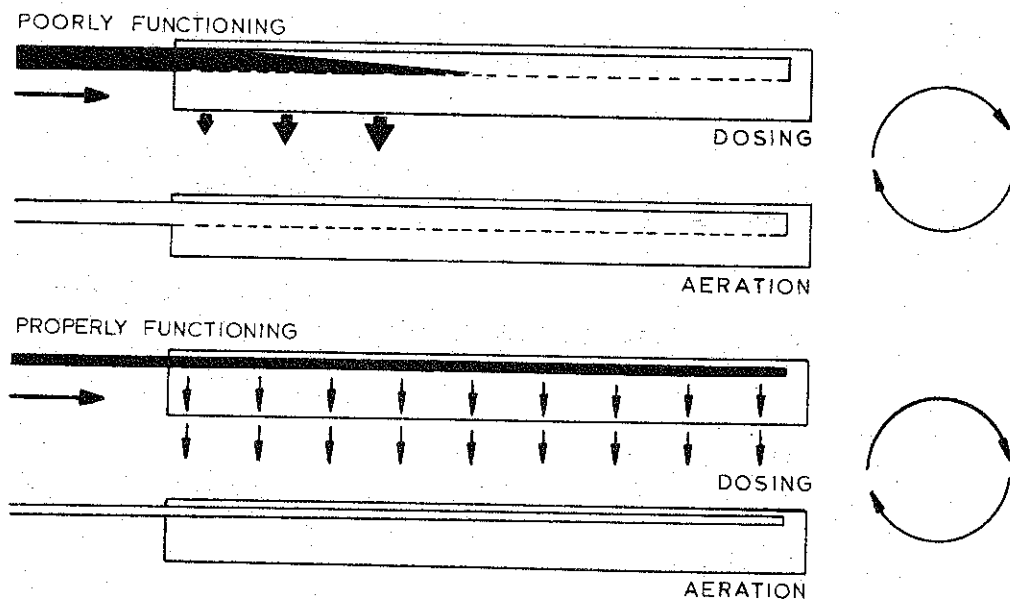
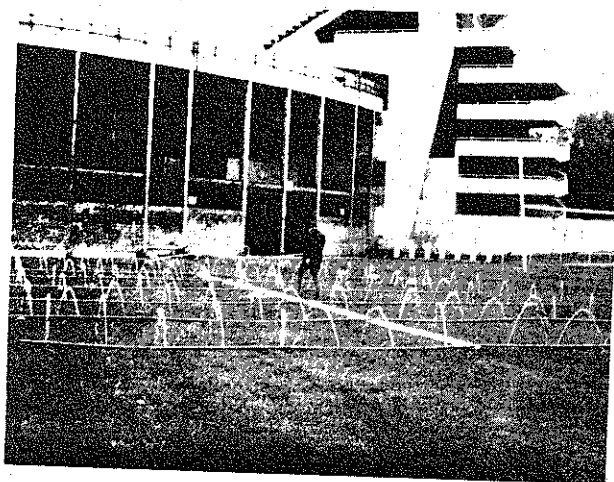


FIGURE 10. Poor distribution of effluent during dosing due to use of large, highly perforated pipe (upper picture) and good distribution due to use of small diameter pipe with few holes (lower picture).



al system. The effluent can be evenly distributed by pumping through small diameter pipes with relatively small holes (Figures 10 & 11). This procedure is being tested now under field conditions in soils that have a sufficiently high permeability when uncrusted. Not only septic tank effluent is used to "dose" seepage beds, but also effluents from aerobic treatment units which may induce less crusting because they contain less waste organics. An alternative to dosing is to build two conventional seepage beds rather than one, and shift use between them periodically, "resting" one. The aeration period during "resting" will induce decomposition of the crust that builds up during use. One experimental so-called "dual-bed" system is being tested under field conditions to determine the required necessary period of "resting."

FIGURE 11. Hydraulic test of pressure distribution system showing the even distribution achieved. (Holes in laterals upward for test only.)



ALTERNATIVES THAT AVOID CHEMICAL POLLUTION OF GROUND WATER

Experimental systems using treatment units or soil materials are being developed that can remove significant amounts of nitrate by processes of microbiological denitrification, which occurs when anaerobic bacteria (growing without oxygen) use the oxygen molecules in the nitrate (NO_3) thereby releasing the nitrogen (N_2) as a gas to the atmosphere. In addition, adsorption of phosphate (P) by soils is being studied to improve the capacity of different soils or fills to remove phosphates from percolating effluent. Improved P removal may also be achieved by using certain types of physical-chemical treatment units.

ALTERNATIVES FOR UNSUITABLE SOILS

Soils currently classified as being unsuitable for an on-site liquid waste disposal system have one property in common; the soil available for percolation is unable to achieve satisfactory purification or disposal for reasons of shallow bedrock, high ground water or low permeability. Satisfactory purification

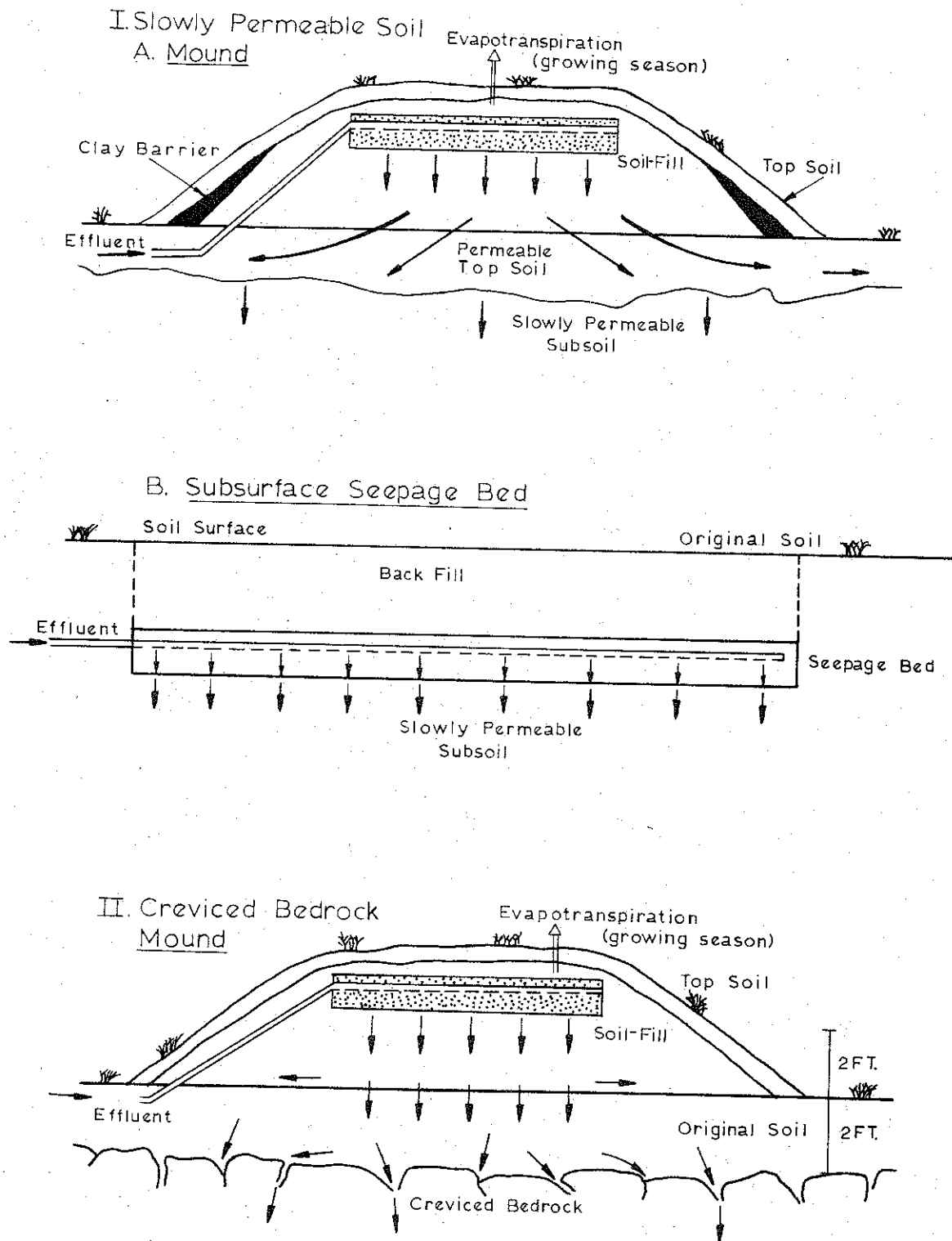
FIGURE 12. Experimental mound system constructed on slowly permeable red clay at the University of Wisconsin-Ashland Experiment Station.



and disposal can be achieved in many ways and soil or soil materials do not necessarily have to be part of a system. If attention is confined in this context to use of soil, however, it is evident that additional soil has to be provided to achieve the degree of purification that the soil *in situ* is unable to provide.

One experimental system of this type is the mound system (Figure 12), which is currently being tested in different soils of the state. Liquid waste is pumped into a gravel-filled seepage bed constructed inside a mound of sandy fill. Loading rates, bed-dimensions, and dosing schedules can be calculated using basic physical permeability characteristics determined for the fill. In areas where shallow creviced bedrock or high ground water exist the fill in the mound serves to purify the liquid waste before it reaches the bedrock or water table (Figure 13). Column experiments in the laboratory have shown that percolation through two feet of sandy fill, followed by one foot of silty topsoil, is sufficient to purify the septic tank effluent, in terms of removal of pathogenic bacteria and viruses. This requires good distribution of effluent over the whole seepage bed area during each dosage, preferably once a day.

FIGURE 13.

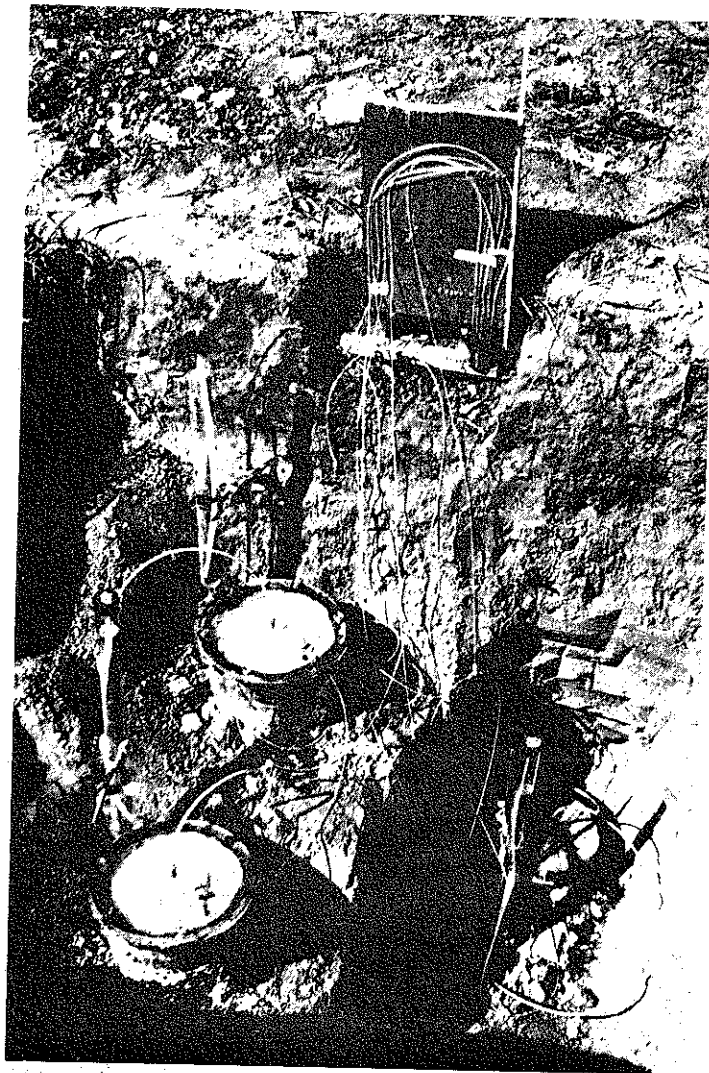


The function of the fill in mounds in tight or slowly permeable soils is somewhat different in that it is used to prolong the infiltration capacity of the original soil. The permeability of the upper foot of soil in situ is usually relatively high even in very tight soils, because of root and worm channels. Liquid enters tight soils more easily at the soil surface, where soil crusting is unlikely to occur because of the open, heterogeneous pore structure. The probability of

around the mound and inside the mound on top of the original soil surface. This ensures distribution of liquid over the entire basal area.

An alternative to the mound system is to build a conventional subsurface seepage bed large enough for the slowly permeable soil to accept the liquid waste (Figure 13, IB). Uniform distribution through a pressurized system during each dosage of effluent is essential, however, to avoid crusting. This seep-

FIGURE 14. Exact field determination of soil permeability using the crust-test procedure, as applied to the studied soils in the project.



clogging is also reduced because of the purification of effluent that occurred during the downward percolation through the fill in the mound system. The total basal area of mounds is determined by considering the loading rate and by measuring the permeability of the subsoil with a newly developed highly sensitive soil physical test, called the crust test (Figure 14). In tight soils, a clay barrier is built

age bed can only work if the bottom and sidewall area are not compacted or puddled during construction, a common occurrence in wet clayey soils. The permeability of the soil may then be very much reduced, making adequate absorption of effluent impossible. If compaction can be avoided, improving effluent quality by mechanical pretreatment of the liquid waste may be helpful to retard soil clogging.

Two experimental field systems with large seepage beds in slowly permeable soils, are currently monitored in the project. The seepage beds receive a daily dose of mechanically pretreated effluent.

Improved Supervision and Control of On-Site Disposal Systems

Many of the problems and failures associated with existing septic tank systems can be attributed to poor design, installation, and maintenance. If more complex systems are developed for single households as suggested, this problem of supervision of their installation and insuring maintenance would only become more acute. Present control is merely over system design and approval. Once the system is installed, it is the complete responsibility of the homeowner, who may or may not have the inclination or the ability to properly maintain it. If a malfunction occurs, experience shows that the homeowner

often will not repair it unless sewage is backing up in his home or it is brought to the attention of the regulatory agency by a third party. Thus, many public health hazards and nuisances often go undetected by public health officials.

To insure systems are maintained properly, two approaches have been considered. The first is to require the homeowner to purchase a service contract from a reputable company that would regularly inspect and service the system as needed. The second is to establish a sanitary or utility district which would shift ownership of the systems from the private to the public domain. It is the second alternative which seems to offer the greatest number of advantages and is favored by most investigators. The advantages of such an organization are: (1) the regular servicing and (2) the proper design and supervision of installation of the system. The district would be capable of providing the most economical "mix" of sewers and individual systems to serve the residents. Grants-in-aid of construction could also be obtained by the organization to offset the cost of installation.

PREFACE

Major work is now in progress at the University of Wisconsin-Madison in response to the need for safe, economic and reliable alternative treatment and disposal systems for domestic liquid wastes in unsewered areas.

The Wisconsin Geological and Natural History Survey, University of Wisconsin-Extension has been working on the problem since 1969, with initial support from the Wisconsin Department of Natural Resources. The Upper Great Lakes Regional Commission made funding available to the University of Wisconsin-Extension since July, 1971 for test-demonstrations. Special research funds were appropriated by the State of Wisconsin in November,

1971 to the College of Agricultural and Life Sciences, University of Wisconsin-Madison, to develop solutions to the problem. The Small Scale Waste Management Project grew out of an integration of these activities.

The purpose of this comprehensive report is to illustrate the scope of the problem and to describe the general nature of the research and demonstration efforts currently underway in the Small Scale Waste Management Project. More detailed results for specific problem areas will be presented in special reports and in publications to be published in scientific journals.

Participating Groups

UNIVERSITY OF WISCONSIN-MADISON

College of Agricultural and Life Sciences

- School of Natural Resources
- Center for Resource Policy Studies
- Departments of: Soil Science, Bacteriology, Food Research Institute, Agricultural Engineering, and Agricultural Economics

College of Engineering

- Sanitary Engineering Laboratories

Graduate School

- Water Resources Center

UNIVERSITY OF WISCONSIN-EXTENSION

Division of Economic and Environmental Development

- Environmental Resources Unit
- Geological and Natural History Survey