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SMALL SCALE WASTE MANAGEMENT PROJECT

Design of Conventional Soil Absorption Trenches and Beds

by

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DESIGN OF CONVENTIONAL SOIL ABSORPTION TRENCHES AND BEDS

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When rural electrification brought a clean power source to the farm, families were able to install pressurized water systems in their homes and the use of modern indoor plumbing became commonplace. With no sewerage available, however, the generated wastewater created a disposal problem. Cesspools were generally used but subsurface irrigation systems, the forerunner of today's soil absorption field, were occasionally installed. These were usually constructed by the homeowners themselves or by local entrepreneurs in accordance with plans furnished by federal and state departments of health. Trenches were dug wide enough to accomodate 8.5 to 15 cm (3 to 6 in) diameter drain tile which was laid directly on the exposed trench bottom in open joint fashion. The joints were covered with tar paper before backfilling. No aggregate was used. A drain tile length of 12 m (40 ft) per person was considered sufficient despite the different soil conditions encountered though some health departments suggested that in "dense" soils the trench be excavated somewhat deeper and wider and the bottom filled with coarse aggregate before laying the tile (Fish, et al. 1924; Frank and Rhymus 1920; Frazier 1916; Horton 1919; Perry 1923). The purpose of the aggregate was to provide a porous media through which the septic tank effluent could flow to increase the infiltration area and to provide storage of the liquid until it could seep away.

Not surprisingly, failures, characterized by surfacing effluent were quite common. These concerned Henry Ryon of the New York Health Department because of the potential public health hazards they created. He felt better design criteria could be developed relating soil type to the amount of absorption area required. To develop these criteria Ryon devised the percolation test and correlated the soils percolation rate measured by the test with its ability to accept septic tank effluent. From these correlations he made recommendations for absorption area required per person versus the measured percolation rate (Ryon 1928; Federick 1948). His recommendations assumed a trench width of at least 30 cm (12 in) with a 15 to 18 cm (6 to 8 in) layer of clean gravel below the drain tile.

Ryon's method improved the performance of septic tank systems and was quickly adopted throughout much of the United States. Failures still occurred, but because the systems served isolated residences, they went largely unnoticed. However, after World War II, there was an unprecedented expansion of small lot housing developments in the metropolitan fringes beyond the reach of sewers. Incidences of widespread failures were reported which became a concern because of the health hazards and nuisances they created. The number of failures indicated that on-site disposal systems were poorly understood. Responding to the need for improved practices, the federal government funded extensive

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studies of septic tank systems by the Public Health Service (Weibel, et al. 1949; Bendixen, et al. 1950; Weibel, et al. 1954) and the University of California (Winneberger, et al. 1960; McGauhey and Winneberger 1965). The results of the studies culminated in the writing of the Manual of Septic Tank Practice first published by the U.S. Public Health Service (USPHS) in 1957 and revised in 1967. The Manual made recommendations for improved practices including a standardized percolation test procedure, consideration of other site characteristics in addition to the percolation test for design, decreased maximum loading rates, absorption field sizing based on the size and type of the building to be served rather than its present use, and limiting the use of septic tank systems to soils with percolation rates faster than 24 min/cm (60 min/in). These recommendations were adopted by most state health departments.

If used in conjunction with good construction procedures and good maintenance programs, the recommendations made in the Manual of Septic Tank Practice (USPHS 1967) proved adequate in most cases. However, cases of contaminated wells from inadequately treated septic tank effluent (New York Department of Health 1969; U.S. Federal Water Pollution Control Agency 1961) and nutrient enrichment of lakes from near shore developments (Dudley and Stephenson 1973) prompted a shift in emphasis from merely absorption of the effluent to providing treatment as well. It became apparent that the design should meet three objectives: (1) absorb all effluent generated, (2) provide a high level of treatment before the effluent reaches the groundwater, and (3) have a long useful life.

NECESSARY SOIL AND SITE CHARACTERISTICS

If a soil absorption system is to meet these three objectives it is obvious that proper site selection is critical. Some sites simply are not suited for disposal of wastewater by the conventional septic tank system. Factors which must be considered include: (1) the hydraulic conductivity characteristics of the soil, (2) the unsaturated depth of the soil, (3) the depth to bedrock, (4) the bedrock characteristics, (5) the landscape position, (6) the slope of the land, and (7) the proximity to surface waters, wells, road cuts, buildings, etc.

Each of these factors must be carefully considered in design. Optimal sites are those with soils having percolation rates of greater than zero but less than or equal to 24 min/cm (60 min/in) with a vertical separation between the ground surface and high groundwater or bedrock of 1.5 to 1.8 m (5 to 6 ft) located on level or gently sloping sites away from bases of slopes or depressions, and far from surface waters, wells, buildings, etc. Each of these factors are discussed in detail by Parker, et al. (1977).

TRENCH AND BED DESIGN

When wastewater is continuously applied to the soil, a clogging mat usually forms at the infiltrative surface. The mat creates a barrier to liquid flow, restricting the movement of water into the soil by closing the entrance to the pores. This is beneficial to a point, for it enhances treatment of the wastewater by creating unsaturated soil conditions below the mat (Bouma 1975; Tyler et al. 1977) but it does slow absorption. Fortunately, the clogging mat does not seal off the soil completely, but continues to transmit liquid albeit at a much reduced rate. The flow rate through the mat seems to reach an equilibrium value which varies from soil to soil when the system is operated under uniform conditions.

Sizing the Infiltrative Surface

Loading Rates: Direct measurement of how the soil will respond to continuous wastewater loading cannot be done practically. It requires that flow through unsaturated soil be predicted. While a field method has been developed to measure the unsaturated hydraulic conductivity of soils directly (Bouma and Denning 1972), it is a complex technique which takes some time to run by a highly trained technician. It is not intended to be run at every site. Instead, a simple, short term test is preferred.

The test most commonly used is the percolation test. This test attempts to measure the saturated conductivity of the soil from which the required infiltration area is determined empirically (USPHS 1967). This test has served well but it has a high degree of variability (Bouma 1971; Healy and Laak 1973; Winneberger 1974). In one series of tests run at the same site by the same technician, variability was shown to be as much as 90% (Bouma 1971). If the percolation rate is the sole criteria used for sizing, failures must be expected when the variability can be this great.

Modifications of the percolation test have been tried to reduce variability but they have met with little success (Bendixen, et al. 1950; Bouma, et al. 1972; Weibel, et al. 1949, 1954; Winneberger, et al. 1960). Other attempts have been made to correlate loading rates to specific soil properties, such as the saturated permeability (Healy and Laak 1974; Bouma, et al. 1972) or soil texture sieve analyses (Norwegian Department of the Environment 1975), but while these may reduce the variability of the test, each still rely on an empirical relationship to arrive at an acceptable loading rate. Saturated hydraulic conductivity tests do not reveal how the soil will conduct wastewater under prolonged loading because once the clogging mat forms, liquid movement below the system is through unsaturated soil. Direct correlation of saturated to unsaturated conductivities is not possible because soils with the same saturated conductivities may have different unsaturated conductivities due to differences in texture, structure and minerology. Soil texture sieve analyses also give limited insight to the percolative capacity of the soil because structure and minerology are ignored.

With no reasonably simple alternative to determine the equilibrium infiltration rate of soils under wastewater application, the percolation test continues to be favored. However, other information such as soil texture and genesis should be used to supplement and confirm the test.

Equilibrium infiltration rates through clogged soil surfaces have been measured by different methods. When they are compared, they are found to differ little. Table I presents recommended rates for sizing the infiltrative surface from the Manual of Septic Tank Practice (USPHS 1967), Healy and Laak (1973) and Bouma (1977). The Manual of Septic Tank Practice correlated percolation rates measured in adjacent soils with the known loadings of existing soil absorption systems. Healy and Laak used a flow net analysis with the saturated hydraulic conductivity of the soil and depth to groundwater as known inputs. However, to make this analysis they had to assume the water table would rise to the bottom of the absorption system upon loading. This condition should not occur in a properly functioning system. Bouma (1975) measured soil moisture potentials under the clogging mats of existing systems and determined the flow rates from the measured unsaturated hydraulic conductivity characteristics of adjacent soils. All investigators studied soil absorption systems receiving household septic tank effluent. Most were continuously ponded. Also it should be noted that these loading rates are based upon household wastewater discharged from an adequately sized and maintained septic tank. Different wastes and different loading regimes may require that different loading rates be used from those recommended in Table II. For example, restaurants and laundromats have significantly different waste characteristics which may require more absorption area than domestic wastewaters while dosing and resting loading regimes may permit the field size to be reduced. These are areas of needed research.

There are some discrepancies between investigators. Bouma (1975) recommends a higher loading rate in silt loams and porous silty clay loam soils than the

Table I. Comparison of Loading Rates Suggested by Different Investigators

Percolation Rate min/cm (min/in)	Soil Texture	USPHS (1967)	Healy & Laak (1973) [from Machmeier (1975)]	Bouma (1977)
		Suggested Loading Rates for Bottom Area cm/day (gpd/ft²)		
<0.2 (<0.5)	Coarse sand, gravel			
0.2-2 (0.5-5)	Medium sand	9.5 (2.15)		
2.4-6 (6-15)	Fine sand, sandy loams	5.0 (1.2)	5.4 (1.3)	5.0 (1.2)
6.4-12 (16-30)	Loams, porous silt loams	3.5 (0.8)	3.5 (0.8)	3.0 (0.7)
12.4-18 (31-45)	Silt loams, porous silty clay loams	2.5 (0.6)	2.0 (0.45)	
18.4-24 (46-60)	Clays, compact silt loams and silty clay loams	2.0 (0.5)	1.6 (0.38)	3.0 (1.2)
		2.0 (0.45)	1.4 (0.33)	0.6 (0.15)

Table II. Suggested Loading Rates for Soil Absorption Systems from Literature Review (After Machmeier, 1975)

Percolation Rate min/inch	Beds	Trenches: Depth of rock below distribution pipe cm (inches) 15 (6)	30 (12)	45 (18)	60 (24)
	Suggested Loading Rates for Bottom Area from Literature[a] cm/day (gpd/ft²)				
1/2 or less	Not suitable for adequate wastewater treatment				
1/2 - 5	5 (1.20)	5 (1.20)	6.5 (150)	8 (1.80)	8.5 (2.00)
6 - 15	3.5 (0.80)	3.5 (0.80)	4.5 (1.00)	5 (1.20)	5.5 (1.30)
16 - 30	2.5 (0.60)	2.5 (0.60)	3.5 (0.75)	4 (0.90)	4.5 (1.00)
31 - 45	2 (0.50)	2 (0.50)	3 (0.65)	3.5 (0.75)	3.5 (0.85)
46 - 60	2 (0.45)	2 (0.45)	2.5 (0.55)	3 (0.70)	3.5 (0.75)

[a] Based on 150 gpd/bedroom

other investigators because he found the strong pedal structure in these soils is capable of maintaining higher infiltration rates despite the fine texture. Bouma also recommends a much lower loading rate in the clays and clay loam soils because of the very fine texture and shrink-swell potential of these soils. It is apparent more definitive work is needed to establish accurate design loadings in the finer textured soils. Until such work is done, Machmeier (1975) suggests the design loadings presented in Table II be used based on his review of the literature.

One feature of Machmeier's recommendations is that conventional soil absorption systems not be constructed in soils with percolation rates less than 0.02 min/cm (0.5 min/in). This is made to insure adequate treatment of the waste effluent is maintained. The Great Lakes Upper Mississippi River Board (Ten-States) Committee for On-Site Sewage Systems (1977) makes a similar recommendation. However, they suggest a minimum of 2 min/cm (5 min/in) where unacceptable contamination of ground or surface waters may result. Certainly, a minimum percolation rate should be set to protect ground and surface water quality, but presently there is too little data to be conclusive as to what this minimum should be.

Factors of Safety: It is common practice to size the infiltrative surface directly from the measured percolation rate. For example, to size a system for a household in a soil with a percolation rate of 12 min/cm (30 min/in), the Manual of Septic Tank Practice (USPHS 1967) recommends an absorption area of 22.8 m^2 (250 ft^2) per bedroom. This is based on a waste flow of 568 L/d (150 gpd) per bedroom assuming two occupants per bedroom each generating 284 L/d (75 gpd). While it is often good practice to size the disposal system according to the potential use of the building rather than the present use, this particular method of sizing automatically provides two factors of safety which may or may not be adequate for a given situation. Current data indicate that individuals generate 150-190 L/d (40 to 50 gpd) rather than 284 L/d (75 gpd) when using conventional plumbing fixtures (Bennett, et al. 1975; Cohen and Wallman 1974; Siegrist, et al. 1976). Therefore, the assumption that 284 L/d (75 gpd) is generated per capita provides a 1.5 factor of safety for wastewater volume. Also the number of people occupying a home is not solely dependent on the number of bedrooms which provides another factor of safety. These factors of safety multiply in the design. In the above example, the total factor of safety is 4.5 (1.5 x 3) for a couple occupying a three bedroom home while it is only 1.5 (1.5 x 1) for a family of 6 in the same house.

A better method of sizing would be to apply an appropriate factor of safety after the field has been sized. Using the soil's equilibrium infiltration rate for septic tank effluent and an accurate estimate of the maximum daily wastewater volume that can be generated by the fixtures installed in the building, the absorption area can be sized and then enlarged or reduced by applying an appropriate factor of safety. If designed in this manner, allowances for differences in plumbing fixtures used, the potential use of the building, etc., could easily be made. This would permit a seasonal resort restaurant, for example, to have a smaller absorption system than a similar size restaurant located at an interstate highway exchange. While the seating capacity may be the same, the potential use is much different. The difference in use could be reflected in the factor of safety applied. Such factors of safety need to be developed.

Administratively, this method could pose problems unless a table of safety factors was prepared for different categories of establishments by the regulatory agency. Such a table would be similar to the table of wastewater quantities to be expected from different types of establishments presented in the Manual of Septic Tank Practice (USPHS 1967). To be useful, however, subdivisions would need to be made within most establishment types. In the case of restaurants, for example, the group could be divided into cafeterias, supper clubs, resorts, highway interchange oases, fast food, 24-hour, etc. The table could be reviewed regularly by the agency and additions or changes made to correct any problems experienced without changing the design criteria for all establishments within the larger group.

Geometry

Bottom vs. Sidewall Area: Both the horizontal bottom area and vertical sidewalls of a subsurface soil absorption system can act as infiltrative surfaces for wastewater absorption. When a system is first put into operation the bottom area is the only infiltrative surface. However, after a period of wastewater application, this surface can become clogged sufficiently to pond liquid above it, at which time the sidewalls become infiltrative surfaces. Because the gradients and resistances of the clogging mats at the two surfaces are rarely the same, the infiltration rates will be different. Which surface would have the greatest infiltration rate will depend on a number of factors. Vertical and horizontal hydraulic conductivities and gradients in the soil, clogging mat resistances, and soil moisture contents of the surrounding soil are factors that will effect the direction and rate of liquid movement through the soil. Thus, the more significant infiltrative surface may vary with time and between sites. The objective in design, therefore, is to maximize the area of the surface expected to have the highest flow rate.

Based on investigations done at the University of California in Berkeley, McGauhey and Winneberger (1965) concluded that the sidewall is ". . . by far the most effective infiltrative surface." They reasoned that (1) suspended solids in the effluent do not contribute to sidewall clogging, (2) rising and falling liquid levels within the system allow alternate loading and resting of the surface while the bottom is continuously inundated, and (3) sloughing of the clogging mat can occur during resting periods. Therefore, they recommend that subsurface soil absorption systems should provide a maximum of sidewall surface per unit volume of effluent and a minimum of bottom surface.

Sidewall area is included as part of the total infiltrative surface in many regulatory codes. The Manual of Septic Tank Practice (USPHS 1967) recognizes the contribution by the sidewall but recommends the bottom area as the principal infiltrative surface. A statistical allowance for the sidewall is included in the recommended bottom area per bedroom assuming a 15 cm (6 in) vertical sidewall (See Table I). If deep trenches are used the USPHS statistical allowance permits a reduction of the total bottom area by a factor determined by the relationship:

Percent of length of standard trench (15 cm [6 in] sidewall) =

$$\frac{w + 2}{w + 1 + 2d} \times 100 \quad . \; . \; . \; . \quad (1)$$

where w = the width of the trench and d = the depth of the gravel below the distribution pipe. While this gives credit for sidewall absorption, it assumes that the infiltration rate is less than that of the bottom. No allowance is made for deep beds. The Ohio state code, on the other hand, considers the bottom area to be ineffectual in more slowly permeable soils. In such soils, only the trench length is specified. The trench width may be as narrow as 20 cm (8 in) (Martin 1975).

The extent to which the sidewall becomes an infiltrative surface would depend upon the prevailing hydraulic gradients which is largely determined by the soil type and soil wetness surrounding the system. At the bottom surface, gravity, the pressure of the ponded water above, and the matric potential of the soil below all contribute to the total hydraulic potential of the liquid while at the sidewall, gravity is eliminated since it operates vertically only and the pressure potential diminishes to zero at the liquid surface. In temperate climates, frequent rainfall particularly in the spring and fall may reduce the matric potential at the sidewall to low levels due to percolating precipitation. During such times, the horizontal gradient could be significantly less than the vertical gradient with the effect that the bottom surface would become the dominant infiltrative surface. For this reason, Bouma (1975) recommends that in temperate climates, systems should be sized on bottom area only. Healy and Laak (1974) do not suggest that a system be designed on bottom area only, but they do recommend that in temperate zones systems be designed to function under gravity potential only because of the problem during wet portions of the year. They state that evapotranspiration during such times is too low to remove significant volumes of wastewater because of the wet soil. The ability of the soil to transport the liquid to the surface for evapotranspiration, of course, is directly related to the matric potential or "wicking" action of the soil.

Deep narrow trenches could be constructed to increase the hydraulic gradient across the sidewall, as recommended by McGauhey and Winneberger (1965) assuming the trenches remain ponded. However, this would diminish the advantages of shallow trenches which enhanced the potential for evapotranspiration and avoid construction in the deeper soil horizons where puddling and compaction are more likely due to clay accumulation. It might be concluded that in humid regions systems should be designed on bottom area while maximizing the sidewall by utilizing shallow trenches rather than beds. In more dry regions, with rather permeable soils, the sidewall area could be maximized at the expense of the bottom area.

<u>Trench versus Bed Design</u>: Most codes define trenches to be 45 to 90 cm (1.5 to 3 ft) wide with a minimum spacing of 1.8 m (6 ft) while absorption areas wider than 90 cm (3 ft) are defined as beds. Though seepage beds often are more attractive than seepage trenches because total land area requirements, cost and time of construction are less, trenches are more desirable in terms of maintaining the infiltrative and percolative capacity of the soil. This is particularly true in soils with significant clay contents (>25 percent by weight). The principal advantages of trenches over beds are that (1) more infiltrative surface is provided for the same bottom area and (2) less damage to the bottom infiltrative surface occurs due to compaction, puddling and smearing during construction.

For the identical bottom areas trench designs of absorption fields can provide more than 8 times the sidewall area. This can be of benefit in preventing failure through clogging. In humid climates there may be portions of the year that the sidewall loses much of its effectiveness for absorption which necessitates designing the system to function on bottom area only. However, it is recognized that the sidewall is beneficial and it is certainly recommended to maximize it in any system (Bouma 1975; McGauhey and Winneberger 1965).

In addition, the seepage bed design can cause severe damage to the natural soil structure during installation. This is a particular concern in clayey soils. Rapid absorption of liquid by the soil depends on a suitable soil structure being maintained (Bouma 1975; Bouma, et al. 1975). When mechanical forces are applied to moist or wet soil the structure is partially or completely destroyed because clay particles in the soil are able to slip relative to one another. This movement, which results in compaction, puddling or smearing closes the larger pores between soil aggregates and those made by roots, or burrowing soil fauna.

To construct a seepage bed, it is common practice to first scrape off the topsoil using a front end loader and then return with a backhoe for digging to final grade in an attempt to leave a fresh soil surface. However, these two operations may require several passes over the bed area by the construction machinery often with heavy loads. When digging is complete, trucks may be backed into the bed to unload aggregate which is spread over the bottom of the bed with machinery. After the distribution piping is laid, additional gravel is placed over the pipe and covered with soil. By the time the bed is completed, the soil structure may be destroyed.

This problem is further compounded when soil conditions are wet. A busy contractor is unable always to schedule his work when the soil is dry so construction often proceeds when conditions are marginal at best. The trench design reduces the severity of these problems because the construction machinery are able to straddle the trench so that the future infiltrative surface is never driven upon.

Fortunately, many state and local codes require the construction of trenches over beds (Plews 1977). However, the <u>Manual of Septic Tank Practice</u> (USPHS 1967) which some state and local codes still adhere to, limits trenches to 1.5 m (5 ft) widths with 1.8 m (6 ft) separations between sidewalls. This favors the construction of beds over trenches. A 100 m^2 (1076 ft^2) absorption bed can be laid out in an 8 m x 12.5 m (26 ft x 38 ft) rectangular bed while a trench system would require an 8.1 m x 22.2 m (27 ft x 74 ft) area assuming three 1.5 m (5 ft) wide trenches are used. These larger areas required by trenches are often undesirable. In addition, trench systems can cost more because additional time and care is required for construction.

To make trench systems more favorable, codes should encourage the use of trenches. A reasonable approach would be to require more bottom area for beds than trenches for the same size household. Two methods might be used: (1) give credit for sidewall area thereby reducing the bottom area required for trenches or (2) increase the bottom area now required for beds in proportion to the amount of sidewall area lost by not using the trench design. Machmeier (1975) recommends the former approach based on a review of literature (see Table II). The Ten-States Committee (1977) uses the latter method by recommending the bottom area of beds be twice that required for trenches. However, more needs to be learned about the relative contributions of the sidewall and bottom areas as infiltrative surfaces.

<u>Shallow versus Deep Absorption Systems</u>: Shallow soil absorption systems offer several advantages over deep systems: (1) the upper soil horizons are usually more permeable than the deeper subsoil because of greater plant and soil fauna activity and eluviated clay, (2) evapotranspiration is greater, (3) the upper soil dries quicker than the subsoil so construction can proceed over longer periods of the year with less smearing, puddling and compaction, and (4) less excavation is necessary, reducing the cost. Some state codes prohibit the construction of absorption systems deeper than 90 cm (36 in) and which is also proposed by the Ten-State Committee (1977). This restriction seems reasonable but only if more permeable soil horizons do not exist at greater depths. In such instances, deep systems may be practical where the groundwater table does not preclude their use.

Freezing of shallow absorption systems is not a problem if kept in continuous operation even when frost penetration is quite deep. Weibel, et al. (1949) reviewed the literature and made contacts with health authorities and plumbers in the northern states to determine if failures of shallow systems were frequent due to freezing. They concluded that carefully constructed shallow systems 45 cm to 60 cm (18 in to 24 in) in depth would not freeze even in areas where frost penetration reaches 1.5 m (5 ft), if the tile lines were gravel packed and header pipes insulated where it is necessary for them to pass under driveways or other areas usually cleared of snow.

<u>Porous Media</u>

The function of the porous media placed below and around the distribution pipe is four-fold. Its primary purpose is to provide a media through which the septic tank effluent can flow from the distribution pipe to reach more bottom and sidewall infiltration area. A second function is to provide storage of peak flows of effluent. Third, the media dissipates any energy incoming effluent may have which could erode the infiltrative surface. Finally, when placed over the pipe it helps to insulate the pipe not only from freezing but also from root penetration (USPHS, 1967).

The depth of media may vary. Fifteen centimeters (6 in) seems to be an accepted minimum below the distribution pipe invert. At least 5 cm (2 in) is usually recommended to cover the crown of the pipe. These depths are sufficient to perform the necessary functions. Greater depths may be used, however, to increase the sidewall area and to increase the hydraulic head on the infiltrative surface. The maximum depth would depend on the particular soil profile and economics.

Gravel or crushed rock is usually used but any material which performs the necessary functions can be used. If gravel or rock is used it should neither be so small as to become biologically clogged nor should it be so large as to cause problems in handling and leveling of the distribution pipe or to significantly "mask" the infiltration surface. Sizes recommended range from 1.25 to 6.25 cm (1/2 to 2-1/2 in) (USPHS 1967). The Ten-States Committee (1977) recommends a larger minimum size of 1.85 cm (3/4 in). The material should be durable, resistant to slaking and dissolution. It should have a hardness of

3 or greater on the Moh's Scale of Hardness. Rock that can scratch a copper penny without leaving any residual rock meets this criterium. Crushed limestone is unsuitable unless dolomitic. The media should be washed and free from fines which could seal off the infiltrative surface. In place of gravel or rock, open bottom concrete vaults or lengths of perforated pipe have been employed.

To maintain the porous nature of the media, the media must be covered with some material to prevent backfilled soil from migrating downward and filling the voids. Tar paper, which was once employed to cover the media, has been abandoned in favor of untreated building paper, marsh hay or straw. The latter materials do not create a vapor barrier and therefore permit some liquid to pass through to the soil above, where it could be removed by evapotranspiration (USPHS 1967). However, the untreated paper may not be sufficient to prevent the soil from entering the porous media. This also is true of marsh hay and straw when not used in sufficient quantity. Harkin (1977) has observed significant penetration of soil in systems where these materials have been used. This may contribute to system failure. The problem seems to be most acute in granular soils where soil stabilization is more difficult. In older systems where tar paper was used, Harkin found no penetration. Marsh hay was found to be sufficient if a 5 cm (2 in) compacted thickness was used.

The advantages of using a material which will not create a vapor barrier would be in the finer textured soils where absorption is more difficult. In such instances, it would seem a 5 cm (2 in) compacted layer of marsh hay or straw be required. In sandy soils with high absorptive capacities, evapotranspiration is not necessary and tar paper could be used if establishing a grass cover over the system is not a problem. Untreated building paper which is easily torn and punctured during backfilling and quickly decays should be abandoned. If used, only the heavier grades should be specified.

Distribution Networks

Distribution networks are provided to introduce the wastewater to the infiltrative surface. Several methods are used which are discussed by Otis, et al. (1977). Conventionally, 10-cm (4-in) diameter perforated drain pipe is used laid on a 0.167 to 0.333 percent slope in an effort to distribute the effluent uniformly down the length of the pipe. Lengths greater than 30 m (100 ft) are usually prohibited. The reason for this length restriction is that there is fear of root penetration, uneven settling, or breakage that could disrupt flow down the pipe rendering the remaining downstream length of the trench useless (USPHS 1967). In light of current knowledge, this restriction seems unnecessary, since the large diameter perforated pipe or drain tile does not provide uniform distribution (Converse, 1974). Long trench lengths may be necessary particularly on some sloping sites. In such cases, maintaining an open porous media to permit effluent spreading down the trench or using small diameter pipe pressure networks (Otis, et al. 1977) have been used successfully.

There are a variety of materials which are presently in use within the United States for distribution pipe. They include:

1. Plastic pipe: ASTM standard 2729 or equal
2. Polyetheylene pipe: ASTM standard 405 or equal
3. Rubber styrene pipe: ASTM standard 2852-72 or equal
4. Bituminous fiber pipe: ASTM standard D2312-69 or equal
5. Concrete pipe: ASTM standard C14-67 or equal
6. Clay pipe: ASTM standard C13-69 or equal

Recently there has been a strong tendency to utilize plastic pipe because of its light weight and ease of handling.

Vents

Some health departments recommend or require that fresh air inlets to the absorption field be provided (Winneberger and Klock 1973; Wisconsin Department of Health and Social Services, 1976). They are usually vertical pipes connected to the distribution piping at the furthest downstream end of the field and extending above grade with a vent cap. If not connected to the piping they are merely placed on the infiltrative surface and extended through the porous media with perforations in the section located within the porous media.

The vents are meant to perform two functions. First, they are intended to maintain aerobic conditions within the system. There is real question whether this is achieved, however. If the system is ponded, little oxygen would ever reach the infiltrative surface because of the high oxygen demand of the septic tank effluent. The vents would only be beneficial in unponded systems. Second, the vents serve as points to observe the functioning of the system. However, depths of ponding can be determined only if the vent extends to the infiltrative surface. Those terminating in the distribution piping are of limited value. The vents greatest value seems to be for observation purposes and then only if they extend down to the soil's infiltrative surface.

SYSTEM CONSTRUCTION

Preparation of the Infiltrative Surface

Probably the most frequent cause of early failure of a properly designed soil absorption system is poor construction. Absorption of waste effluent by soil requires that the soil pores remain open at the infiltrative surface. If these are sealed during construction by compaction, smearing and puddling of the soil, the system may be rendered useless.

Compaction, smearing and puddling occur primarily in soils containing greater than 25 percent clay by weight. The flat clay particles adhere to each other in dry soil making it hard and very stable to high compressive forces. However, when wet, the clay plates separate when forces are applied. The water acts as a lubricant as the clay plates move relative to one another to close channels and voids reducing the permeability of the soil to very low levels.

Not all soils are equally susceptible to this structural destruction. Tendency toward compaction and puddling depends upon the soil type, the moisture content and the applied force. Soils with high clay contents are easily puddled while sands are affected little (see Table III). However, soils with clay will not puddle if they are only slightly moist. Instead, under pressure, dry clay breaks into small fragments along pedal boundaries rather than smearing, thereby keeping the large pores open.

Table III. Approximate Infiltration Rates into Different Natural Soil Materials

Surface Type	Infiltration Rate — cm/day (gpd/ft^2)			
	Sand (C-Plainfield)	Sandy Loam (IIC-Batavia)	Silt Loam (B-Batavia)	Clay (B-Hibbing)
Open	500 (120)	75 (18)	38 (9)	2.5 (0.6)
Biologically clogged	5 (1.2)	0.5 (0.12) and less	-	0.5 (0.12)
Mechanically puddled	-	5 (1.2)	0.5 (0.12)	0.3 (0.05)

Careful construction techniques will minimize this cause of soil clogging. The following techniques are recommended:

1. Work should be done in clayey soils only when the moisture content is

below its plastic limit. If the soil forms a "wire" instead of breaking apart when attempting to roll it between the hands, then it is too wet.

2. Excavating equipment should not be driven on the bottom of the system. Trenches rather than bed construction are preferable in clayey soils because equipment can straddle the trench, thus reducing compaction and smearing.
3. Trench or bed widths should be made larger than the bucket used for excavation to minimize sidewall compaction. Buckets are usually made to compact the sidewall to prevent caving in deep excavations. If the excavation is wider than the bucket, this effect is minimized.
4. The bottom of each trench or bed must be level throughout to insure no local overloading by effluent occurs.
5. Shallow systems should be constructed to place the infiltrative surface in more permeable horizons and to enhance the potential for evapotranspiration. This is particularly beneficial in clayey soils because they are generally wetter for longer periods of time, especially at greater depths.
6. The bottom and sidewall areas should be left with a rough open surface. Any smeared or compacted surfaces should be removed. Compaction may extend as deep as 20 cm (8 in) in clays. This requires hand spading to expose a fresh infiltrative surface.
7. Work should be scheduled only when the infiltrative surface can be covered in one day because wind blown silt or raindrop impact can clog the soil.

Backfilling

Once the infiltrative surface is properly prepared the backfilling operations must be carefully done. The following recommendations are made:

1. If gravel or rock is used as the porous media it should be laid in by a backhoe or front end loader rather than dumped in by truck. This should be done from the sides of the system rather than driving out on to the exposed bottom. Leveling should be done by hand.
2. The distribution pipes should be covered with a minimum of 5 cm (2 in) of gravel or rock to retard root growth and insulate the pipe.
3. The media should be covered with 5 cm (2 in) of compacted marsh hay or other material resistant to rapid decay to prevent the unconsolidated soil cover from entering the media. Light weight untreated building paper is not satisfactory particularly in coarse-grained soils. Tar paper would be suitable in sandy soils.
4. The backfill material should be similar to the natural soil or no more permeable to restrict surface percolation into the system. It should be mounded over the system to allow for settling and promote runoff away from the system.

SUMMARY

The septic tank - soil absorption field has been used for the on-site treatment and disposal of small wastewater flows in unsewered areas since the late 1800's. However, it has been only in the last twenty years that concerted efforts to understand the system have been made by regulatory agencies and research institutions. Despite these efforts, the design of conventional septic tank systems has remained more of an art than a science.

While the practices recommended in the Manual of Septic Tank Practice (USPHS 1967) were based on rational decisions, the reasoning behind these decisions was often lost when they were adopted into state and local codes. In some cases this loss has resulted in a digression in the state-of-the-art. Because failures have continued to occur, many regulatory agencies have simply made design guidelines more conservative rather than analyzing the cause of the failures. This is unwise because if many failures are due to poor construction techniques, for example, increasing the size of the system does little good except to delay the date of failure. The owner's money could be better spent for construction supervision. A return to rational designs methods is desirable.

In reviewing the present state-of-the-art there are several areas of needed research. They include:

1. Measurement of more accurate loading rates for fine textured soils.
2. Determination of an acceptable minimum percolation rate above which adequate soil treatment can be maintained.
3. Establishment of suitable factors of safety in absorption field sizing for different types of buildings and uses.
4. Determination of relative contributions to absorption by the sidewall and bottom areas of absorption fields.
5. Determination of suitable loading regimes for different soil and site characteristics.

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