Recommendation & SWOT Form 33

RECOMMENDATION SUMMARY

- Due to existing/potential overcrowding and old residential structures, Hawaii's design flow calculation method can be made slightly more lenient at 150-200 GPD per bedroom.
- The septic tank capacity calculation method can be kept largely the same as it is largely consistent with other states and guidance documents.
- Hawaii's absorption bed area calculation method is incorrect, resulting in the lowest bed sizing in the country and is likely not protecting groundwater well, especially in low percolation rate soils (e.g., coast land). Calculation method must be revised accordingly.

INTERNAL FACTORS

STRENGTHS +	WEAKNESSES –
- Improve groundwater protection. - Improved rationale for our records. - Align our rules with the regulations of other state's and guidance documentation.	- Organize training for review engineers. - Adapt internal database, forms, and public facing website to accommodate the significant change. - Develop internal procedure to reconcile potential conflicts between old records and new ones.

EXTERNAL FACTORS

OPPORTUNITIES +	THREATS –
- Allows up to six bedrooms. - Improved groundwater protection. - Improved rationale from which engineers can use to inform their work. - Closer alignment with other states makes it easier for more wastewater engineers to enter the market.	- Increased absorption bed sizing may lead to more variances and the requirement for additional treatment. - Cost of installation will go up. Could potentially be offset by reviewing deep absorption trenches, alternatives to absorption beds, and adding more flexibility to seepage pit designs.

ADDITIONAL INFORMATION

See attached sheet for citations and detailed breakdown of problems/issues and recommendations.

Once completed, please email this form to doh.wwb.cesspool@doh.hawaii.gov.

Note: This rationale focuses mostly on domestic wastewater and residential wastewater treatment using on-site wastewater systems, specifically septic tanks.

Section 1: Separation between design flow and tank capacity

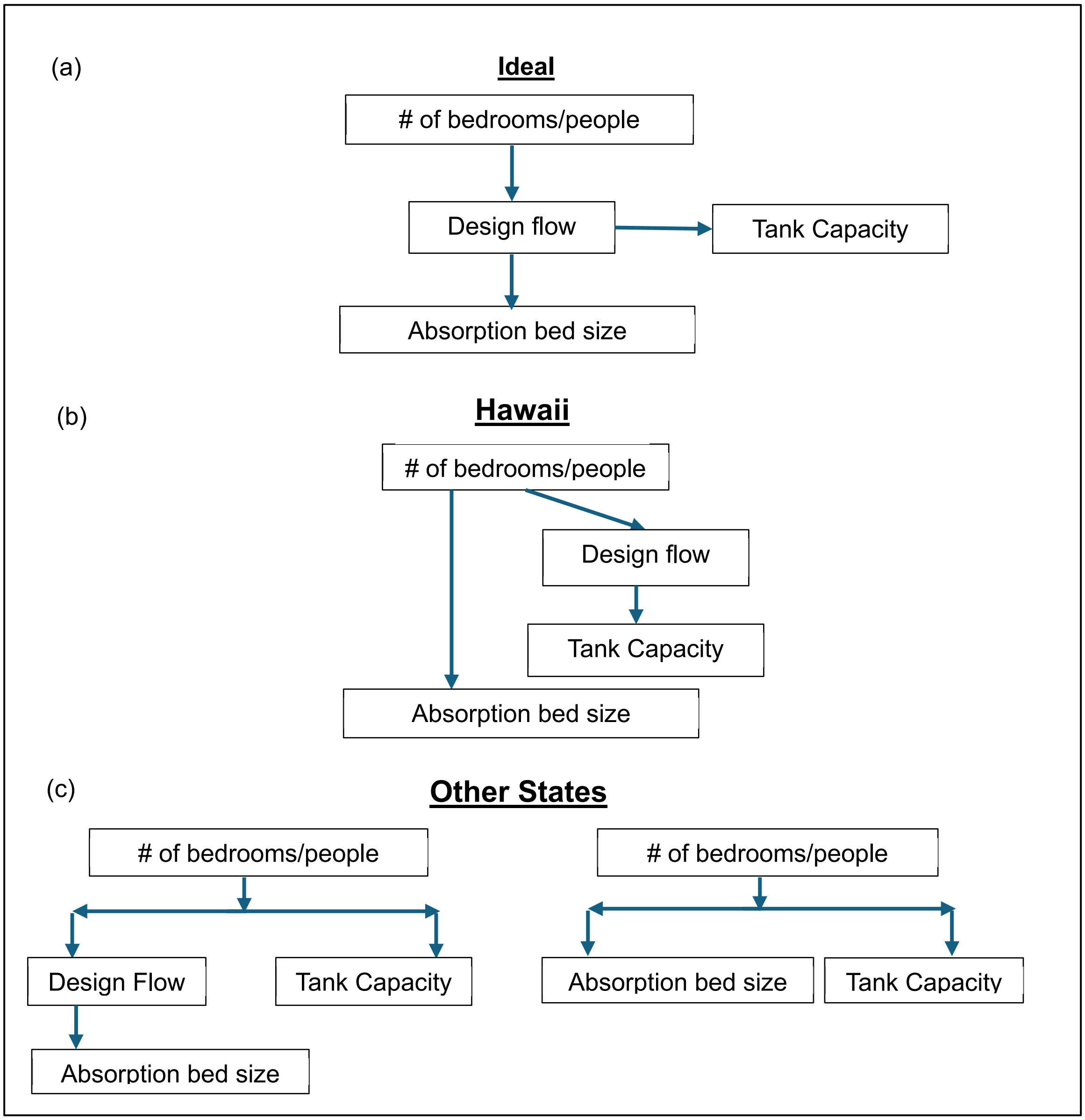

Figure 1. Flow chart summarizing various methods used to determine individual wastewater system design.

Before discussing the specifics of how to adjust the design flow, minimum septic tank capacity, and the minimum absorption bed size, it is beneficial to discuss how the regulations determine these specifications.

Ideally, from an engineering perspective, the septic tank capacity and absorption bed size should be based on the design flow which is calculated based on some combination of the number of bedrooms and the number of people occupying those bedrooms (see Figure 1(a)).

Hawaii's HAR Chapter 11-62 appears to follow this engineering approach, but further research into the origins of Appendix D, Table III reveals that it follows a logic similar to that shown in Figure 1(b). That is, although the tank capacity is based on design flow with a minimum tank capacity set, the absorption bed size is independent of design flow and is instead based only on the number of bedrooms with no clear reference to the assumed wastewater generation from those bedrooms.

This issue with Appendix D, Table III can be seen by interrogating the header which says, "Required Absorption Area (ft2/bedroom or 200 gallons)". First, it should be "200 gallons per day" and not "200 gallons" because it is referring to the design flow not the tank capacity. Second and most important, the original version of this table, which can be found in the 1969 Manual of Septic Tank Practice [1], does not reference a "200 gallons per day" flow rate or any flow rate for that matter. This is because it is based on a 1965 Public Health Service manual for state legislation and regulation [2] that chooses to eschew including a flow rate or design flow in state regulations altogether.

In a short review of six other states, regulators approach the process with a varying combination of these two types of approaches that can be seen in Figure 1(c). Taking into consideration the literature and regulations used by other states, this report will attempt to develop a revised approach to calculating design flow rate, absorption bed sizing, and septic tank capacity.

Section 2: People per bedroom

Hawaii's HAR Chapter 11-62 assumes two people per bedroom as part of the design flow calculation. This has been challenged throughout the years as being too conservative an estimate. However, review of the literature, like [3] and [4], clearly state that it is a *maximum* of two people per bedroom and that it is considered, in effect, an indirect factor of safety for homes taking into consideration the *potential* capacity of the home.

The question though is does Hawaii *need* this indirect factor of safety. A 2019 study of Hawai'i Housing by SMS Research and Marketing Services, which is cited by the State's Department of Business, Economic Development and Tourism's 2024 data book, shows that crowding in household units has risen slowly over the past few years (See Figure 2). Noting further that, "Hawai'i's crowding rate has long been among the highest in the nation. In 2017 Hawai'i was ranked first in crowding for owner-occupied units (6.3%) second for renter-occupied conditions (12.8%)" [5,6]. Furthermore, when compared to national numbers, Hawai'i's crowding has been slowly increasing (See Figure 3)[6]. Given the rate of crowding that occurs in Hawaii, especially when compared to the entire nation, and that the trend suggests that crowding will continue to increase in the near future, the indirect factor of safety of assuming a maximum of two people per bedroom is likely still needed (in some form) for Hawaii.

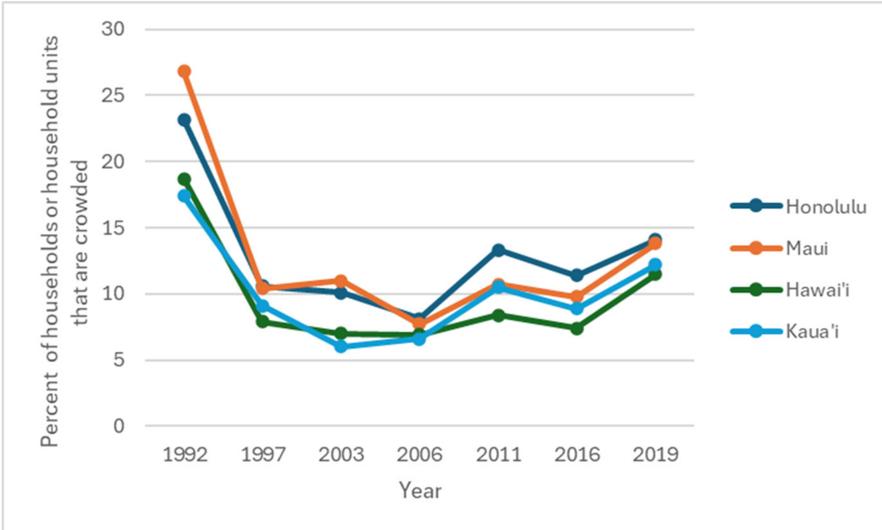

Figure 2. Percent of household units that are classified as “crowded”. Crowded in this case refers to more than one person per room for data from 1992-2011 and more than 2 person per bedroom from 2016-2019. Data from [5].

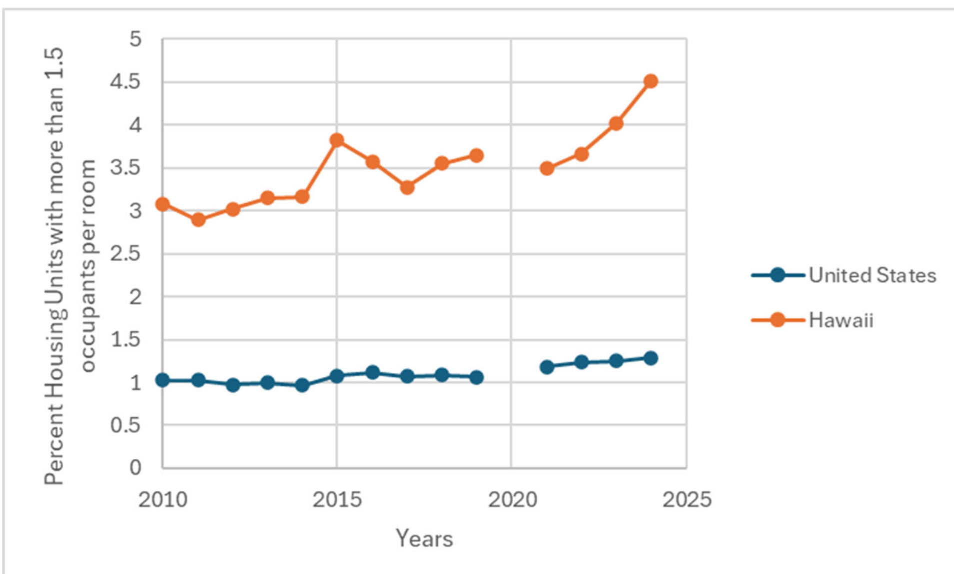

Figure 3. Percentage of housing units with more than 1.5 occupants per room for Hawaii versus the entire United States. Data from [6].

Section 3: Low-flow fixtures

A maximum water usage standard for water fixtures being sold after January 1, 1994 was put into effect by the Energy Policy Act of 1992 [7]. This maximum water usage standard for water fixtures, like toilets, showerheads, faucets, etc. is still in effect and can be found in 10 CFR 430.32(q). It is stated in EPA’s Onsite wastewater manual that, as a result of this legislation, homes built after 1994 or retrofitted with compliant water fixtures would have a typical average daily of 40 to 60 gpd/capita [4]. However, it should be noted that 66.3% of structures in Hawaii were built prior to 1989 [8]. As a result, the typical average daily flow may be slightly higher than 40 to 60 gpd/capita depending on whether these structures have been retrofitted.

Section 4: Design flow calculations and flow rate per capita

Hawaii's HAR Chapter 11-62 assumes a 100 gallons per day per capita flow rate. The design flow is then calculated by multiplying the number of bedrooms by 200 gallons per day per bedroom (assumes a maximum of 2 people per bedroom). The initial flow rate has been challenged as being too conservative and the largest flow rate in the country.

There are different types of flow rates and the flow rate mentioned in Hawaii's HAR Chapter 11-62 is not clearly defined. For example, it could be referring to average flow or peak flow rate, and it's not clear what sort of safety factors were incorporated. This 100-gallons-per-day-per-capita flow rate is a number commonly found for wastewater treatment works sizing, for example the Ten States Standards specify 100 gallons per day per capita and a peaking factor between about 2 and 4 depending on the population size being served [9]. The 1980 EPA Design Manual for Onsite Wastewater Treatment and Disposal Systems [4] attributes this, in part, to several safety factors stating:

> *"the average wastewater contribution is about 45 gpcd (170lpcd) (2). As a safety factor, a value of 75 gpcd (284 lpcd) can be coupled with a potential maximum dwelling density of two person per bedroom, yielding a theoretical design flow of 150 gal/bedroom/day (570 l/bedroom/day). A theoretical tank volume of 2 to 3 times the design daily flow is common, resulting in a total tank design capacity of 300 to 450 gal per bedroom (1,140 to 1,700 1 per bedroom)."*

It's easy to imagine that the original writers of the HAR Chapter 11-62 likely combined these two considerations and determined that 200 gallons per day per bedroom is sufficient for designing individual wastewater systems. This concept of safety factors being applied to average flow rates occurs in the literature as well, Otis et al. [10] breaks it down even further:

> *"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 (40-50 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."*

Additional research reveals, however, that this is not a simple issue because the relationship between wastewater generation and household size is not linear. For a given household as the number of occupants ranges from one to eight, the flow rate per capita starts at 97 gpd/capita and levels out to around 50 gpd/capita [11]. I suspect that the resulting decrease is due to the sharing of facilities in a single dwelling unit which causes the average flow rate per capita to decrease. This is likely the basis for why many states use a minimum design flow for the first two or three bedrooms in a dwelling unit, then add on a smaller flow rate per capita for each successive bedroom, like New Mexico [12], Oregon [13], or Vermont [14]. This is why when compared to other states, as shown in Figure 4, Hawaii has lower design flow for the first bedroom than begins to outpace other states significantly as the number of bedrooms increases.

However, Hawaii only requires 200 gpd per bedroom regardless of the number of dwelling units. That is, properties with many one-to-two-bedroom dwelling units would have lower design flow using Hawaii regulations when compared to calculations using other state's regulations.

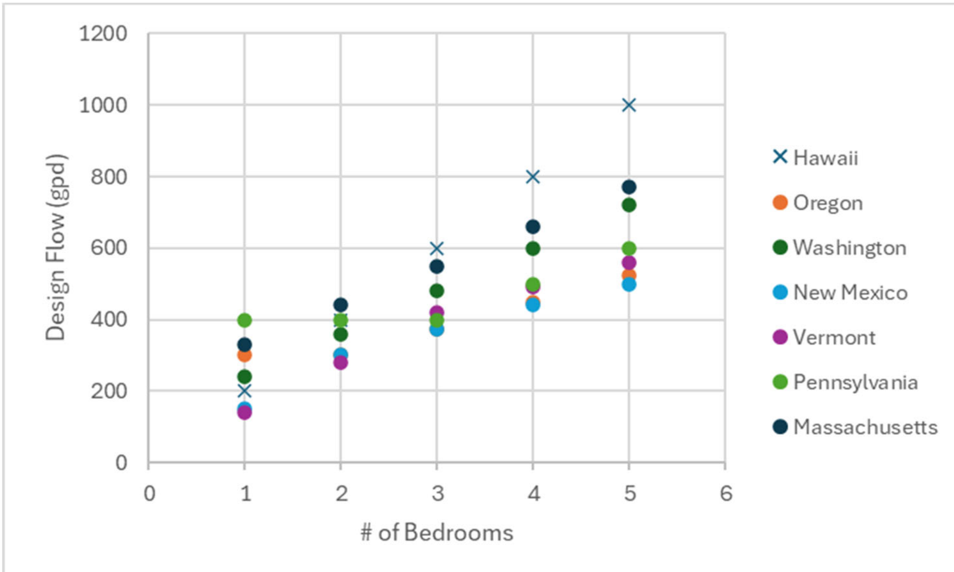

Figure 4. Comparison of design flows calculated using wastewater regulations from different states [12, 13, 14, 15, 16, 17].

Specifying a minimum design flow is preferred because it simplifies the design process while still accounting for the variable flow rate of dwelling units based on occupancy. Unfortunately, it is difficult or not possible to incorporate a minimum design flow in HAR Chapter 11-62 because of HRS 342D-73, which states in part that, "An individual wastewater system may serve up to five bedrooms, regardless of the number of: (1) Dwellings or dwelling units; or (2) Accessory units as defined by the counties". That is, setting a minimum design flow for a dwelling unit would make it not possible to reach five bedrooms when there are multiple dwelling units being served by an individual wastewater system.

Section 5: What about septic tank capacity?

Hawaii's HAR Chapter 11-62 specifies a minimum tank capacity of 1000 gallons and a capacity calculation of design flow x 1.25. Most states follow a similar approach with a similar minimum capacity of 1000 gallons or just have a table for determining the septic tank capacity. This results in Hawaii's septic tank capacity being consistent with other states' regulations (See Figure 5).

Strangely, this is where all the states deviate noticeably from guidance documentation. Many guidance documents recommend a minimum of 750 gallons for the septic tank capacity and then 150 to 300 gallons for each bedroom after the second bedroom [1, 2, 3, 4, 18].

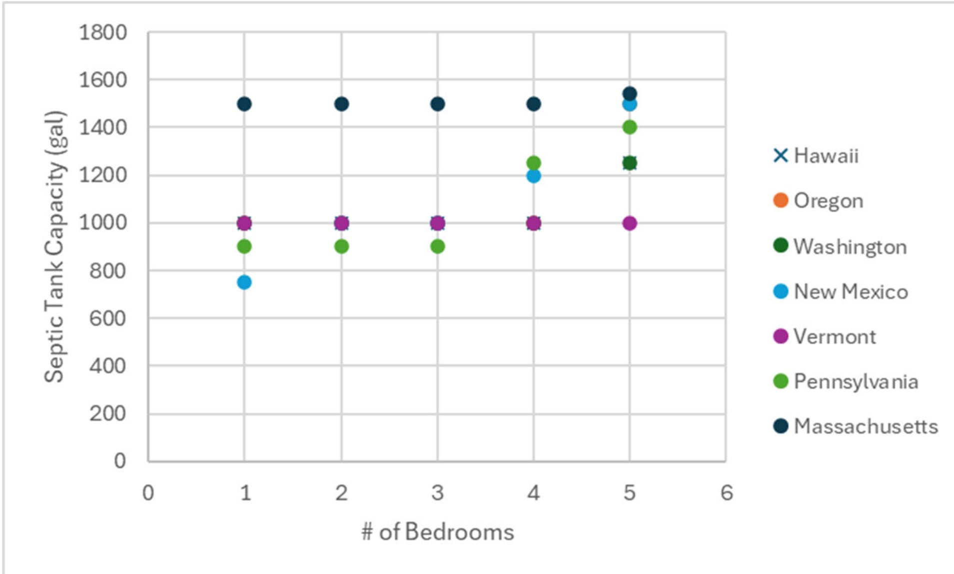

Figure 5. Comparison of septic tank capacity calculated using wastewater regulations from different states [12, 13, 14, 15, 16, 17].

Section 6: The absorption bed calculation is incorrect

Hawaii's HAR Chapter 11-62's approach to calculating the absorption bed area is incorrect. As mentioned previously, the absorption bed calculation uses a table and plot found in the 1969 Manual of Septic Tank Practice [1], which references the 1965 Public Health Service manual for state legislation and regulation [2]. Although this absorption bed area sizing was only intended to be used with a bedroom count, the writers of HAR Chapter 11-62 decided to relate it to a rate of 200 gpd per bedroom. Of the state regulations that I reviewed, none of them used the table or plot used by HAR Chapter 11-62. Additionally, HAR Chapter 11-62 incorrectly incorporated the table and plot found in the 1969 Manual of Septic Tank Practice by not including that the minimum number of bedrooms, which should be used to calculate the absorption bed size, is two bedrooms.

As a result, when compared to other states, Hawaii's HAR Chapter 11-62 specifications for absorption bed area are undersized and among the lowest in the nation (See Figure 6). Many other states use what is known as an application rate or loading rate with units of gpd/ft^2. Dividing the design flow by the maximum loading rate yields the minimum square footage of the bottom area of the absorption bed. Often this loading rate is correlated with soil characteristics [14, 15, 19], but can also be correlated with percolation rate [16, 17, 20]. However, the 1980 EPA Onsite Wastewater Design Manual does warn that, "Soil texture and measured percolation rates will not always be correlated as indicated, due to differences in structure, clay mineral content, bulk densities, and other factors in various areas of the country (see Chapter 3)" [3].

Most states, like Pennsylvania [16], Vermont [14] and Washington [15], use loading rates that are relatively consistent with those seen in Table 7-2 of the 1980 EPA Onsite Wastewater Manual [3]. While other states require smaller loading rates (i.e., larger absorption bed area) like Arkansas [20] and Massachusetts [17]. Further research into Table 7-2 of the 1980 EPA Onsite Wastewater Manual leads to a paper by Otis et al. that was published in 1978 titled "Design of Conventional Soil Absorption Trenches and Beds". Paper by Otis et al. discusses various specifications to consider when designing an absorption trench or bed, and most importantly includes a table of suggested loading rates based on percolation rate (see Figure 7 for screenshot of table). These loading rates are based on an assumed 150 gpd per bedroom and vary by depth to bedrock [10].

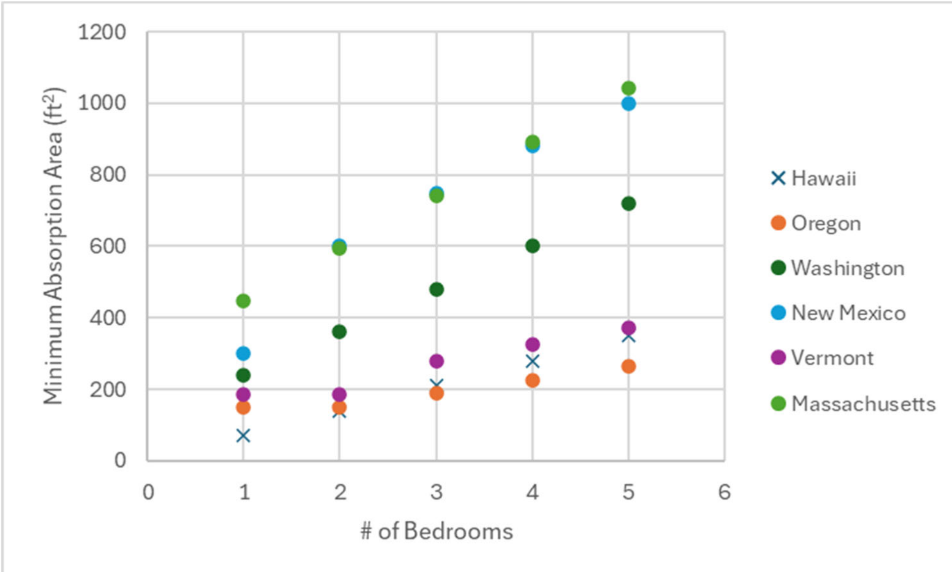

Figure 6. Comparison of minimum possible absorption bed area sizing calculated using wastewater regulations from different states [12, 13, 14, 15, 16, 17].

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

Percolation Rate	Suggested Loading Rates for Bottom Area from Literature[a]				
	Beds	Trenches: Depth of rock below distribution pipe cm (inches)			
		15 (6)	30 (12)	45 (18)	60 (24)
min/inch	cm/day (gpd/ft^2)				
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

Figure 7. Screenshot of Table II from Otis et al. [10].

Section 7: Proposed changes

Based on evidence provided in the previous sections, I would suggest the following revisions to our design flow, septic tank capacity, and absorption bed area calculations and regulations:

<u>Adopt a variable design flow calculation based on:</u>

- An assumption of 200 gpd per bedroom for the first two bedrooms. Note: This assumption is necessary to comply with HRS 342D-73. Due to this, one bedroom dwelling units are likely to have an underestimated design flow.
- a slightly conservative 50 gpd/person based on a possible range of 40 to 50 gpd, and considering consistency with low-flow fixture rates, expected flow rates based on household size, and the regulations of other states,
- a factor of safety of 1.5 for the per capita flow rate based on literature and the regulation of other states,
- a conservative two people per bedroom based on census data, potential usage of homes including an additional minor factor of safety,
- a minimum design flow rate for a dwelling unit based on a minimum of two bedrooms based on guidance documents and being consistent with other state regulations.

Table 1. Proposed changes to how the design flow is calculated.

# of Bedrooms	Design Flow (gpd)
1	200
2	400
3	550
4	700
5	850
6	1000

Adopt a septic tank capacity calculation based on:

- Note: Sizing a septic tank for five one-bedroom dwelling units will likely be undersized due to the restrictions placed by HRS 342D-73.
- a very lenient conversion factor of 1.25 gallons per gpd between design flow and septic tank capacity is maintained,
- maintaining a minimum septic tank capacity of 1000 gallons.

Table 2. Proposed changes to how the septic tank capacity is calculated.

# of Bedrooms	Capacity (gal)
1	1000
2	1000
3	1000
4	1050
5	1063
6	1250

Adopt a new absorption bed area sizing calculation based on:

- a slightly adjusted loading rate based on the literature, guidance documents, and other state regulations.

Table 3. Proposed changes to how the absorption bed area is calculated.

Percolation Rate (min/inch)	Loading Rate (gpd/ft^2)
<1	Unsuitable
1-5	1.2
6-15	0.8
16-30	0.6
31-45	0.5

45-60	0.45
>60	Unsuitable

Section 8: Expected impacts

- The number of bedrooms allowed would increase to six bedrooms.
- The septic tank capacity sizing would see a slight increase at higher bedroom counts.
- The absorption bed sizing will increase (See Table 4 for example calculation).

Table 4. Example of changes to minimum absorption bed sizing.

# of Bedrooms	Old Design Flow (gpd)	Old Absorption Bed Area (ft^2)	New Design Flow (gpd)	New Absorption Bed Area (ft^2)
1	200	70	200	166
2	400	140	400	333
3	600	210	550	458
4	800	280	700	583
5	1000	350	850	708
6	-	-	1000	833

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DESIGN OF CONVENTIONAL SOIL ABSORPTION TRENCHES AND BEDS

R. J. Otis G. D. Plews D. H. Patterson

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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Otis, R.J., G. D. Plews, and D. H. Patterson. Design of Conventional Soil Absorption Trenches and Beds. In: Proceedings of the Second National Home Sewage Treatment Symposium, Chicago, Illinois, December 1977. American Society of Agricultural Engineers, St. Joseph, Michigan, 1978. Pp. 86-99.

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

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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

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Table I. Comparison of Loading Rates Suggested by Different Investigators

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

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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

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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) =

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

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

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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.

Trench versus Bed Design: 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 Manual of Septic Tank Practice (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.

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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.

Shallow versus Deep Absorption Systems: 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.

Porous Media

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

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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

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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			
	Sand (C-Plainfield)	Sandy Loam (IIC-Batavia)	Silt Loam (B-Batavia)	Clay (B-Hibbing)
	cm/day (gpd/ft^2)			
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

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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

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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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