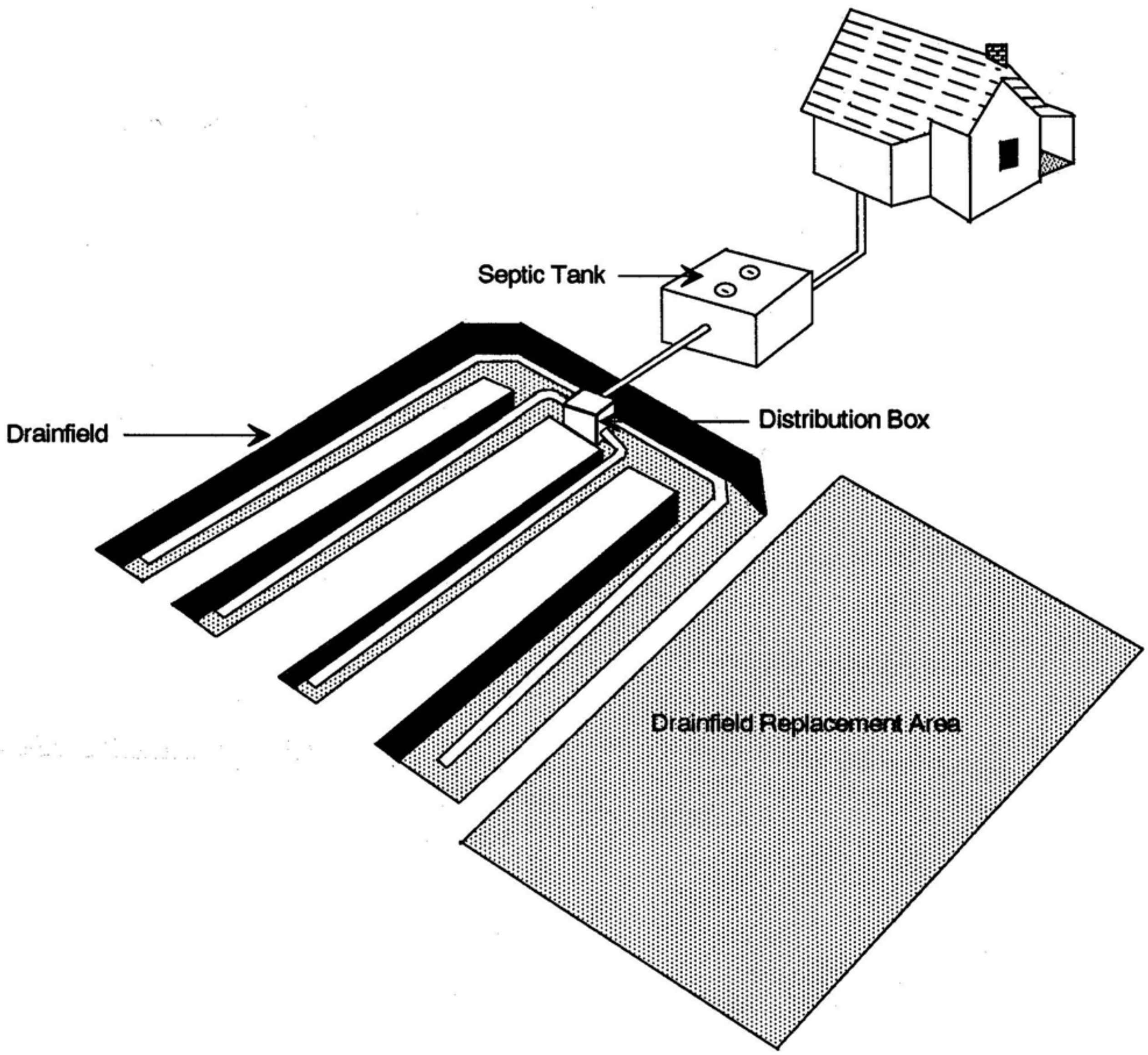
BASIC PRINCIPLES

of

ONSITE SEWAGE



Washington State Department of
Health

11/92

TRAINING SYLLABUS

BASIC ON-SITE SYSTEMS

I. Expectations and Objectives

A. Disease Prevention

Diseases spread through contact with untreated or inadequately treated sewage are many and are well documented. They include but are not limited to hepatitis, shigellosis, poliomyelitis, infestations with various round and flat worms, cholera, typhoid, bacillary dysentery and amoebic dysentery. On-site sewage systems, when properly designed, installed, operated and maintained treat domestic sewage to a high level of quality and thus eliminate the potential for disease transmission through preventing contamination of ground water, surface water, shellfish and ground surfaces.

Onsite systems, in addition to providing good treatment, are also expected to provide good disposal, minimal exposure of the public to the harmful components and long-term performance, all at a reasonable cost.

B. Treatment Potentials and Levels Normally Attained

The quality of sewage treatment in on-site systems varies only slightly according to the type of system installed. In almost all cases, the final and highest degree of treatment occurs in the soil or soil substitute under unsaturated flow conditions over a vertical distance of 2 to 3 feet. Under these conditions, treatment levels are often better than those achieved in all but the most advanced municipal systems. Typically, the following levels of treatment can be expected from a properly functioning onsite system: biochemical oxygen demand (BOD_5) - 10 mg/l; total suspended solids (TSS) - 10 mg/l; and fecal coliforms - less than 200 per 100 ml. These treatment levels are jeopardized when the when the flows in the drainfield are saturated, the unsaturated flow is for less than 2-3 feet, the strength of the sewage is too high, toxic chemicals are being put into the system, or the system is too deep in the ground for air to reach the soil beneath the infiltrative surface. Proper siting, design, installation, operation and maintenance will promote optimal treatment levels.

C. Onsite Sewage Flow Regimes

On-site systems must have the capacity to handle sewage loads that are not steady but rather are in distinct peaks. The volume of the septic tank is designed to accept the peak flows through the system while providing a minimum retention time of 36 hours for separation of solids from the liquid. The drainfield must also have the capacity to accept the peak daily and weekly flows, not just the average daily flow.

II. Factors Affecting System Performance

A. Soil

The soil in an on-site sewage system performs two major functions: (1) treating the wastewater to eliminate pollutants before releasing it to the groundwater, and (2) disposing the treated wastewater so that it moves away from the site, making room for more treated wastewater. In order to assure that the particular soil is capable of performing these valuable and necessary functions, it must be examined for its capacity to treat and dispose of wastewater.

Several properties of the soil are important to proper design and functioning of an on-site system. These include soil texture, structure, depth, compaction, and landscape position.

Texture is a function of the relative amounts of sand, silt and clay particles, and determines the pore size, surface area and capacity for unsaturated flow. Soils with coarse texture have large void spaces and a high capacity to move water away from the site as long as a water table or other barrier is not present. However, the limited surface area and potential for rapid flow through soils reduce their ability to treat effluent. Finer textured soils have about the same volume of void space as other soils, but have smaller pore sizes and larger surface areas. Therefore, water moves through finer textured soils at a much slower pace, and thus these soils have a much slower disposal capacity. These same soils can move wastewater by unsaturated flow and therefore can provide a high level of treatment. Soils with a mixture of particle sizes such as loams, sandy loams, loamy sands, and silt loams usually provide the best balance between treatment and disposal.

The **presence and degree of structure** (tendency to form distinct aggregates, with lines of separation between) has an important impact on the soil's ability to treat and dispose of wastewater. The structure will create channels to move water away from the site (disposal), but in some cases can act to short circuit the treatment process.

Depth of soil of unsaturated soil is important to ensure adequate contact time and distance for treatment to occur. There needs to be 2-3 vertical feet of unsaturated flow for adequate treatment to occur.

Compaction of the soil, even loams and sandy loams, can create a barrier to water flow, and therefore adversely affect treatment and disposal.

Landscape position often determines the moisture regime of the soil, such as a high water table, a well drained soil, or somewhere in between. For example, soils at the bottom of slopes tend to accumulate water, whereas soils at the upper end of the same slope will tend to release their water and therefore be drier. Sites near riverbeds and in flood planes will also likely have higher water tables.

B. Wastewater characteristics

Most on-site sewage systems are designed to treat and dispose of sewage with the strength and characteristics of normal domestic wastewater (see Table 1). As the BOD_5 of the wastewater approaches 230 mg/L or exceeds this level, the treatment efficiency and longevity of a standard on-site system is reduced, and other technology should be incorporated (e.g. aerobic treatment device) prior to discharge to a soil component. Alternatively, a lower wastewater strength can be accomplished by altering habits and practices in the home, such as not using garbage grinders and not dumping grease down the drain (see section II.D.). Introduction of biologically active chemicals (e.g. large quantities of chlorine bleach or antibiotics) will also affect the performance of an on-site system. Therefore if the facility being served by an on-site system normally would introduce such materials into their wastewater, a pre-treatment will likely be necessary for the system to perform correctly. Chemicals such as petroleum products, degreasers, pesticides, and cleaning solvents, will not only harm the system but will also degrade groundwater and therefore should never be put down the drain.

Table 1. Characteristics of raw sewage and septic tank effluent
(Note that the numbers for the Raw Sewage and Septic Tank Effluent are from different sets of data.)

Characteristics	Raw Sewage[1]	Septic Tank Effluent[2]	
	Range	Range for 95% of Samples	Average
pH			7.2
Total suspended solids (mg/l)	200-290	47-62	54
BOD_5 (mg/l)	200-290	142-174	158
Total Nitrogen	35-100	48.9-61.6	55.3
Total Phosphorus	18-29	11.4-17.7	14.6
Fecal coliforms (MF) per 100ml	10^7-10^9	2.88×10^5-6.16×10^5	4.21×10^5

[1] From EPA Design Manual, Onsite Wastewater Treatment and Disposal Systems
[2] From Otis, R.J., W.C. Boyle and D.K. Sauer, 1974. "The Performance of Household Wastewater Treatment Units Under Field Conditions", *Home Sewage Treatment*, American Society of Agricultural Engineers Publication, St. Joseph, MI.

C. Loading rates

The design flow from a house is estimated based on the number of people in the house (usually 2 per bedroom). Sixty gallons per person per day is a common quantity used for calculating design flows. These estimates of flows can be grossly in error if the number of occupants increases, if they take in outsiders' laundry, throw large parties every week, have a large jacuzzi bathtub which empties after each fill, etc. Loading rates are the amount of septic tank effluent that is applied to each square foot of infiltrative surface per day. If the system design were based on a loading rate of .6 gpd per square foot, but the actual flows resulted in a design flow of .8 or 1.2 gpd per square foot, the drainfield would likely become hydraulically overloaded and be headed for early failure. Loading rates are established in Washington according to the type of soil, which is based largely on the texture of the soil receiving the septic tank effluent.

D. Users' lifestyle

Flows into the onsite sewage system that are in excess of the design flows can lead to hydraulic overloading of a system. Examples of situations which could lead to excess water flows were mentioned in the preceding paragraph. Other causes are leaking fixtures, excessive flushing of the toilet, and roof downspouts plumbed into the house drain. Use of a garbage grinder can shorten the interval between pumpings of the septic tank, and could produce high strength effluent which the system is not designed to handle, and thereby lead to excessive thickness of the biomat (see section V.A.b.3.) or anaerobic (absence of air) conditions in the drainfield. Excessive use of cooking fats and oils which find their way into the sewage system can clog pipes, overload the septic tank and finally the drainfield.

E. Operation and maintenance

On-site sewage systems are designed for long-term operation, i.e. for the lifetime of the house. In order for this to happen, proper operation and maintenance must be carried out. Only materials appropriate for the system should be put down the drain. The following types of materials should never be introduced into the system: disposable diapers, condoms, sanitary napkins and tampons, grease, gasoline, paint, paint thinner, pesticides, and organic solvents, etc. Performing necessary, routine maintenance is essential for systems to perform trouble-free for many years. For example, check septic tank baffles for intactness and proper positioning, and have the tank pumped when the solids have accumulated to the maximum level that is safe for the system (See figure below).

F. Temperature

Treatment of sewage relies heavily on biological activity. Lower temperatures will reduce the biological activity approximately one half for each 10°C drop in temperature until almost all activity stops at about 2°C (35°F), providing little more treatment than physical filtering and adsorption in the soil component and physical separation in the septic tank. Fortunately, most drainfields, even in the winter, stay above the 2°C level because of heat from the incoming sewage, heat from the biological activity, and heat from the surrounding soil. Temperature also affects the flow and mixing characteristics in the septic tank as well as the efficiency of grease and oil separation in the septic tank (the cooler the better).

G. Rainfall

Rainfall can adversely affect on-site system performance by placing an additional hydraulic load on the soil. The greatest effect is when the groundwater table rises enough to decrease the vertical separation (distance between the infiltrative surface and the impervious layer or water table) to less than 2 or 3 feet, and thus decreasing the treatment of the wastewater. Rainfall has a positive affect by diluting the nitrates that are released from an onsite sewage system, and thereby reduces the pollution and potential health risks of nitrates in the treated effluent. At the same time however, the additional water increases the rate at which these nitrates travel from the site.

F. Surrounding Development

A parcel of land, when being considered for development using an onsite sewage system, must be evaluated in relation to surrounding parcels and their accompanying onsite systems' contribution to groundwater. Accumulative affects of onsite systems from developments can raise the water table significantly in some cases and thereby degrade the performance of the system if this factor was not adequately considered during the design and installation phases.

III. Water Movement in Soils

A. Saturated and Unsaturated Flow

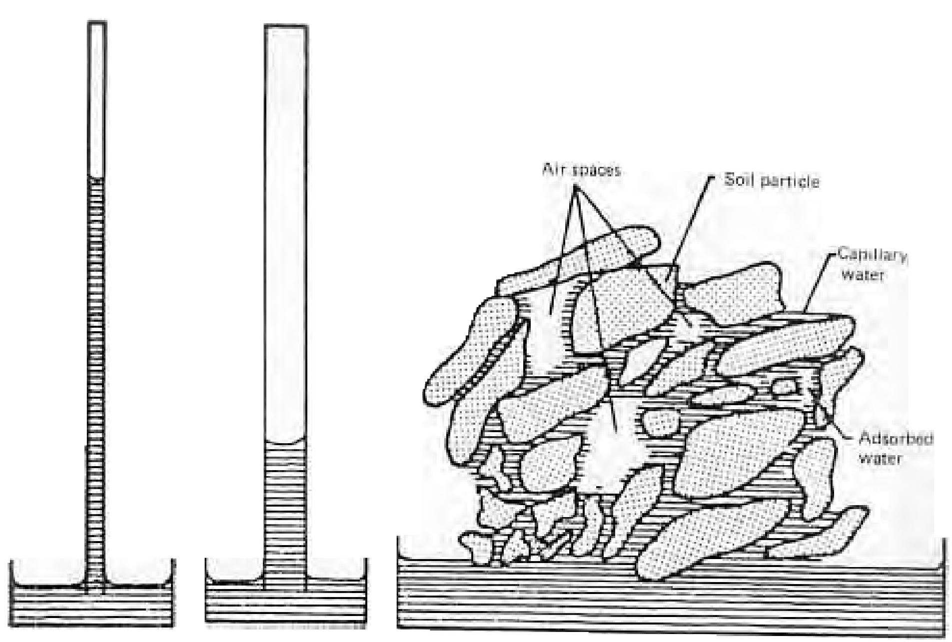
When sufficient water is applied to soil to fill all the pores, it flows rapidly downward with the force of gravity. This movement is called saturated flow. When water is applied to the soil without filling the larger pores, it is drawn along the soil particle surfaces by capillary (or matric) forces, the same forces that draw water up the sides of a glass. This movement can be in the horizontal (for short distances - up to a few feet) as well as the vertical directions. Capillary flow occurs under unsaturated conditions, proceeds much slower than saturated flow, holds the water close to the soil particles and allows air to enter through the open pores. It should be noted that there is a gradual transition between the extremes of saturated and unsaturated flows. The more saturated the flow, the larger are the pores that are filled with water, and the faster the water will flow downward. In addition, the larger the pores that are filled with water, the more difficult it is for air to move into the soil from the atmosphere.

B. Hydraulic conductivity

This term relates to how fast water can flow through the soil. Coarser soils have a higher hydraulic conductivity than finer soils, and hydraulic conductivity decreases as the soil becomes drier.

C. Capillary or matric forces

As explained in "A" above, capillary or matric forces are what move water through soil during unsaturated conditions. Finer textured soils have smaller pore sizes than coarser textured soils and therefore, like smaller capillary tubes compared with larger ones, exert greater matric forces to move water through them. See illustration.



Upward movement by capillarity in glass tubes as compared with soils (after Brady[10]).

D. Through layered soils

Unsaturated water movement through soil is interrupted when it encounters a layer with an abrupt textural change. This delayed flow occurs both when moving from a finer texture to a coarser texture, and vice versa. When water flows from a finer to a coarser-textured layer, movement slows because the larger pore sizes of the coarser material do not exert as strong a matric force on the water. Therefore the finer soil must reach near saturation at the interface in order for water to pass into the coarser material. Likewise, when water encounters a layer that consists of clay or compact material, unsaturated flow is interrupted because it cannot pass as rapidly through the finer pores as water collects above it.

F. Horizontal movement

Water movement in the horizontal direction requires a horizontal water gradient and saturated flow conditions if it is to proceed for much distance. Horizontal movement, as will be discussed in more detail later, does not provide a known degree of treatment of wastewater. Its major contribution to the functioning of on-site sewage systems is in disposal, i.e. carrying the treated wastewater away from the site.

G. Entry to groundwater

The final fate of wastewater treated by an on-site system is discharge to, and dilution with, groundwater. Properly sited, designed and functioning on-site systems provide a high degree of treatment of the wastewater, and therefore do not degrade the groundwater to any significant degree. However, the potential for contamination always exists due to poor siting, design, installation or poor operation and maintenance.

H. Where does all that water (>100,000 gal/yr) go?

100,000 gallons???!!! Yes, the typical three-bedroom household discharges 100,000 gallons per year through their on-site system. As mentioned above, this water is discharged to the groundwater. The accumulative contribution from the thousands of homes in the state each year is a significant quantity of groundwater recharge each year, and can be a positive asset when adequate treatment precedes the discharge.

IV. Sewage Treatment

A. What is sewage?

1. Definition in on-site regulations

"Sewage" means any urine, feces, and the water carrying human wastes, including kitchen, bath and laundry wastes from residences, buildings, industrial establishments or other places.

2. Domestic vs industrial?

Domestic sewage is all the human body and water-carried waste generated in a normal household. Industrial waste may contain most of the same items as domestic waste, but also contains waste from industrial processes, high strength waste and a whole variety of chemical pollutants in quantities beyond the ability of onsite systems to handle. On-site systems are designed specifically to treat and dispose of domestic sewage.

B. When is sewage no longer sewage?

Normal household sewage is represented in the following table at different points in the onsite system.

CONTAMINANTS IN DOMESTIC WASTEWATER [1,2]

Source of Samples	Total Suspended Solids (mg/l)	BOD_5 (mg/ml)	Nitrogen (mg/l)	Phosphate (mg/l)	Fecal Coliforms (per 100ml)
Raw Domestic Sewage	200-290	200-290	35-100	18-29	10^7-10^9
Septic Tank Effluent	50.8	158	54.3	14.6	$4.2x10^5$
Following Treatment Component	<10	<10	>18.3	0	<200

Obviously this treated effluent does not meet drinking water standards, and could conceivably still contain some factors that pose a risk to human health. At this point, the key contaminants of public health concern are the nitrogen and the coliforms, the former being an indicator of possible chemical contamination by soluble constituents, and the latter an indicator of microbial contamination.

For nitrogen, very little removal treatment occurs in conventional systems, which must rely on dilution with groundwater to render the concentration inconsequential to health. There are

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[1]Ziebell, W.A., D.H. Nero, J.F. Deininger and E. McCoy, 1974, Use of Bacteria in Assessing Waste Treatment and Soil Disposal Systems." *Home Sewage Treatment*, American Society of Agricultural Engineers Publication Proc-175, St. Joseph, MI, p.58.

[2]Brown, K.W., J.F. Slowey & H.W. Wolf, 1977. "The Movement of Salts, Nutrients, Fecal Coliform and Virus Below Septic Leach Fields in Three Soils", *Home Sewage Treatment*, American Society of Agricultural Engineers Publication 5-77, St. Joseph, MI.

certain alternative systems that can reduce significantly the nitrogen concentration. For the coliforms, the little research that has been done in this area indicates that coliforms will not migrate more than 3 to 4 feet in unsaturated soil, and this is the key. There are plenty of examples in the literature where coliforms and pathogens have migrated long distances from drainfields having saturated conditions under them. It is reasonable to assume that sewage is no longer sewage when it has received a degree of treatment that yields the above quality wastewater, even though it does not meet drinking water quality. Pathogen removal in soil is dependent on vertical separation, loading rates appropriate for the soil conditions, distribution methods, clogging mat, and soil temperature.

C. How is sewage treated?

Reactions and processes that treat sewage occur on the surfaces of soil particles. Treatment depends on the accessibility and types of surfaces available. Very coarse-textured soils have limited surface area and water travels through so fast as to limit the level of treatment. Very fine-textured soils on the other hand have vast amounts of surface area and retain water for long periods of time. Their problems are: releasing the water so that new water can have contact with the surfaces and therefore be treated and, diffusing adequate oxygen through the soil pores. As a consequence these fine-textured soils cannot process water as fast as a household will deliver it. Most other textured soils have enough surface area while maintaining enough permeability for good disposal. **Note:** A discussion on texture vs void space and surface area appears in section II.A.

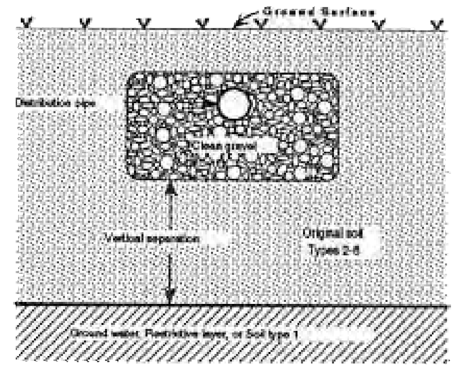
In the soil with aerobic conditions, bacteria use for food the organic material that produces the BOD (literally, they break down the BOD and solids, and incorporate them). Pathogens are trapped in the soil, either by being adsorbed onto soil particles (electrical and chemical interactions between the soil particles and the surfaces of the sewage microbes), or by becoming stuck to the microbial slimes laid down by soil bacteria. Once trapped, some pathogens die because of unfavorable temperature, lack of moisture and food, and other causes. Others are inhibited or killed by antibiotics given off naturally by soil fungi and other organisms. Still others are actually preyed upon by soil bacteria and are literally eaten. This process proceeds faster with warmer soil temperatures and slower with cooler temperatures. A total vertical distance of unsaturated (and therefore aerobic and slow) wastewater flow of 2 to 4 feet is sufficient to produce high quality effluent with very low disease potential.

Nitrogen enters the drainfield soil from a septic tank largely as ammonia but is quickly oxidized to nitrate when it encounters unsaturated, aerobic conditions. From aerobic devices, most of the nitrogen will enter the drainfield already converted to nitrate. Nitrates are very soluble and therefore move with the water as it passes out of the drainfield and mixes with the groundwater.

Phosphates are normally tightly bound to the soil clays and hydrous oxides, and therefore do not migrate far from the drainfield area, even under saturated flow conditions, until all the binding sites are utilized (a very long-term process). Few soils are completely devoid of clay and hydrous oxides, but the less they contain, the sooner the time when phosphates will begin to migrate a distance from the drainfield area. Phosphates are only a problem where septic systems are located in coarse-textured soils surrounding a lake. In these cases the phosphate will eventually exceed the soil's binding capacity and leach into the lake, where it will cause excess growth of algae and aquatic plants.

D. Vertical vs Horizontal Separation

Assurance of public health protection traditionally has relied on a combination of vertical separation from the water table and horizontal separation from a drinking water source, surface water or some other sensitive area. Vertical separation means the depth of unsaturated soil between the infiltrative surface of a drainfield and an impervious layer or water table. It is in this unsaturated zone that treatment of the sewage in the soil occurs.



Horizontal separation is the horizontal distance between the infiltrative surface and the feature needing protection from sewage. As noted before, vertical separation furnishes the treatment of sewage, and if adequately provided for, will render sewage nearly harmless. On the other hand, horizontal movement across the horizontal separation occurs almost exclusively under saturated conditions and therefore may not yield much treatment except perhaps dilution, and for certain, does not yield consistent, known levels of treatment. Since we want to maximize the known treatment before releasing the effluent into the environment, it is far superior to rely on the known treatment capability of vertical separation for public health protection than to hope for adequate dilution during horizontal flow. For the most part, if adequate treatment is provided by vertical separation, horizontal distances are not of great concern.

E. Basis for loading rates.

Loading rates are based on long-term experimental observations of installed systems, comparing loading rates in the drainfields with the soil texture in which they were placed. The outcome of this research is that these rates vary with the soil texture. The rates and corresponding soil types and textures used for systems installed in Washington State are shown in the table below.

The rate at which water will infiltrate into undisturbed, native soil is many times greater than the loading rates in the state regulations. As a soil treatment system matures, a clogging mat forms across the face of the soil where the wastewater is applied. In gravity distribution systems, this mat, together with the loading rates, regulates the rate at which the effluent is applied to the receiving soil. It is the soil that provides the matric potential ("sucking force") to draw the fluid through the mat. This matric potential will depend on the texture and on the degree of saturation in these soils. The intent is to add effluent into the infiltration network no faster than it can move through the clogging mat and into the soil under unsaturated flow conditions.

In pressure distribution systems, the pressure dosing, which provides relatively equal distribution, regulates the rate at which the effluent is applied to the soil, even before a mat forms. In this case, the loading rates are set to allow for unsaturated flow in the receiving soil. A clogging mat will likely form eventually and slow the passage of effluent into the soil. The loading rates account for these conditions.

RECOMMENDED RATES OF WASTEWATER APPLICATION
FOR TRENCH AND BED BOTTOM AREAS

Soil Type	Soil Texture	Percolation Rate (min/in.)	Application Rate (gpd/ft)^2
1	Coarse sand or coarser	<1	Not suitable
2	Medium sand	1 - 5	1.2
3	Fine sand, loamy sand	6 - 15	0.8
4	Sandy loam, loam	16 - 30	0.6
5	Porous, well-developed structure in silt and silt loams	31 - 60	0.45
6	Other silt loams, silty loams, clay loams[a]	61 - 120	0.2

([a] Soils without expandable clays.)

F. Life expectancy

Well designed, constructed, operated and maintained on-site sewage treatment and disposal systems are capable of very long term service. They should be able to perform their intended functions for the lifetime of the dwelling they serve. Unfortunately, there are many places where errors can be made during the development of a system. Lack of maintenance and misuse can also lead to failure. Therefore it is prudent to include a replacement area into the design of a property.

G. What is a Failure?

"Failure" means a condition of an on-site sewage system that threatens the public health by failing to adequately treat the sewage or by creating a potential for the public to come in direct contact with sewage. Examples of failure include:

1. Sewage on the surface of the ground;

2. Sewage backing up into a structure caused by slow soil absorption of sewage;

3. Sewage leaking from a septic tank, holding tank, pump chamber, or collection system;

4. Cesspools or seepage pits where concerns exist for the quality of the ground water or surface water; or

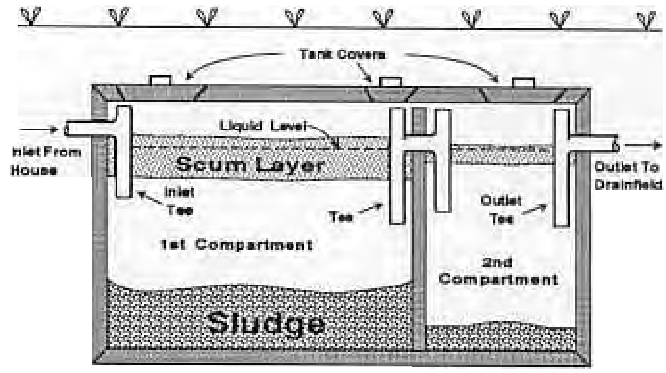
5. Sewage contaminating ground water or surface water.

V. Components of On-site systems

A. Conventional system

1. Septic tank

a. Anatomy of a Septic Tank



(1) Inlet baffle or tee

This device directs the incoming waste stream downward and allows venting of the tank through the house plumbing stack with a minimum of disturbance of the tank contents.

(2) Compartment divider

The divider is a barrier to inhibit the movement of solid material from the 1st compartment to the 2nd compartment. In Washington State, 2 compartments are required to provide improved solids separation and to provide a safety margin if there is a failure to pump the tank.

(3) Outlet baffle or tee

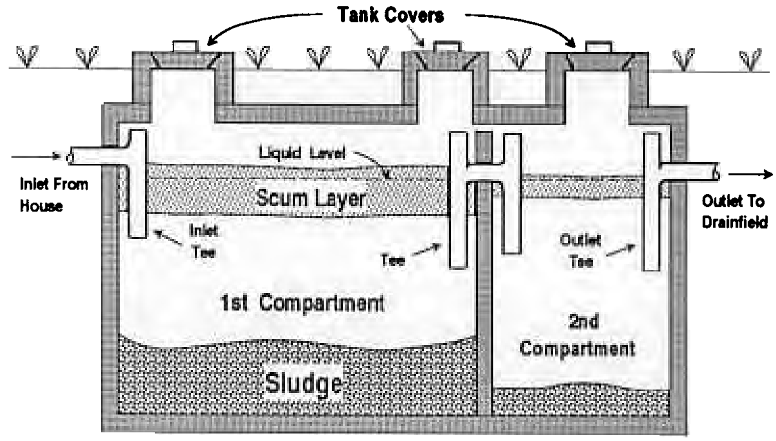
The outlet tee inhibits movement of suspended and floating solids from the septic tank to the drainfield by drawing liquid from the most clarified zone..

(4) Outlet filter

Sometimes a filter is placed on or used in place of the outlet tee. It serves to prevent all but the very fine suspended solids from entering the drainfield or pump chamber.

(5) Access ports and covers

These ports, or openings, are essential for monitoring the condition of the baffles, tees, sludge depth and the scum layer. They also are required when it is necessary to pump the septic tank. The standard access ports currently used in tanks installed in Washington (see previous illustration) have several important drawbacks. Because they do not rise to the surface they are difficult to locate after several years of being buried. In addition, they require considerable work to dig up when the tank is to be inspected or pumped, and then allow dirt and debris to fall in while the cover is off. Finally, these standard ports are not water tight and therefore may allow water to leak in. There are septic tank designs that can accommodate watertight risers to the surface or just below the surface to overcome the drawbacks listed here (see illustration below).



b. Water tightness

(1) Why it is important

There are at least three important reasons for watertightness in septic tanks and pump chambers. Liquid in the tanks is only partly treated and therefore should be released into the environment only after passing through the drainfield. Hence, it is undesirable for liquid to leak out of the tank. Another consequence of a leaky tank is that water may enter into it, resulting in reduced retention time, upset of temperature and oxygen levels. Thirdly, leaking tanks can result in infiltration of water into the system, thereby leading to hydraulic overloading of the drainfield, sand filter or mound.

(2) How to achieve it

Leaks in concrete septic tanks can occur most readily around the inlet and outlet holes, in the seams of a 2-piece tank, in the corners between sides and floor, and through cracks that develop in other places. Pouring a water-tight septic tank requires a more expensive set of molds and considerably greater care in the manufacturing process than now commonly used. These tanks therefore, are somewhat more costly, but can be built with current technology.

Plastic and fiberglass septic tanks, although constructed of water-tight material, are not necessarily water-tight. Unless properly reinforced and installed, they can deform, over time, when filled with water or when backfilled. When a plastic or fiberglass tank deforms it can leak at the inlet and outlet ports, at welded joints and at the joints between the upper and lower halves (2-piece tanks). Major advantages of these tanks are impervious to water, corrosion resistent materials, and lighter weight for installation and transportation.

To assure watertight tanks, a system for certifying tanks needs to be developed, as has been done already with many other construction materials. In addition, a properly designed and constructed tank may leak if installed improperly. Thus, tanks will continue to need a final inspection for damage during transportation and for correct installation.

(3) Current status in Washington

No accurate figures are available for the percentage of water-tight septic tanks in the state. Many regulators in the local health departments report that many tanks they see are clearly not water-tight (water level coincides with groundwater, or is below the outlet invert). It is likely that the manufacturers supplying concrete septic tanks in Washington are not using the molds, correct concrete mix, or quality control necessary for water tight construction. Other problems are likely behind the leaking fiberglass and plastic tanks.

c. Size

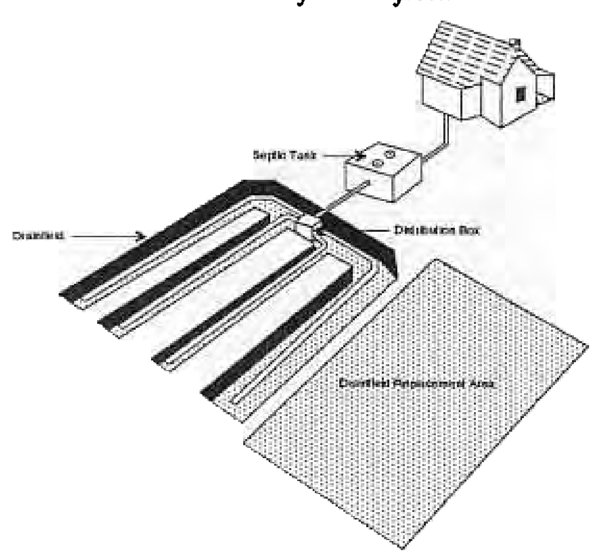
The sizing of septic tanks is based on a 36 hour retention time and storage volume for sludge. A longer retention time may have some merit, as evidenced by the higher quality effluent produced by tanks receiving waste from homes equipped with water conservation fixtures resulting in significant flow reductions. Currently in Washington, the minimum size tank is 750 gallons for less than 3 bedrooms, 900 gallons for 3 bedrooms, 1000 for 4 bedrooms, and 250 gallons more for each additional bedroom.

d. Function

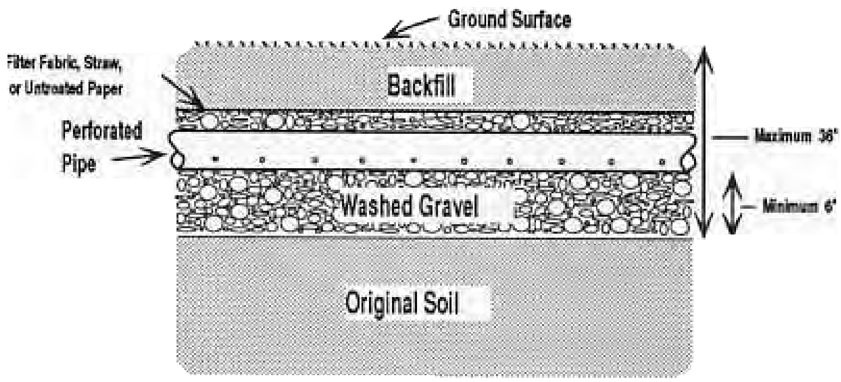
The primary purposes of a septic tank are to separate the solids from the liquid fraction, provide a retention time adequate to achieve this separation, and an anaerobic treatment process to reduce the volume of solids. Retention of solids is crucial to long-term functioning of the drainfield.

2. Drainfield

Overview of Drainfield



Cutaway of Drainfield Section



a. Piping

A network of piping carries the septic tank effluent to the treatment and disposal area. In gravity distribution systems, the network consists of 4 inch diameter pipe which is solid from the tank to the drainfield and then perforated with 1/2 inch holes in the drainfield. It should be noted that research has shown that the liquid exits the pipe through just a few holes, usually those closest to the septic tank, and then flows along the bottom of the trench until absorbed. Eventually the requirement for pipe in gravity drainfields may be removed, but more experience and testing will be needed.

In pressure systems, the pipes are 1 to 2 inches in diameter with the drainfield portion perforated with 3/16 inch diameter, or larger, holes. The septic tank effluent is distributed relatively evenly throughout the drainfield area under low pressure (1 to 4 psi). Pressure is usually supplied by a pump with its associated float switches. Occasionally a dosing siphon is used.

b. Trenches/Bed

The standard infiltrative surface is created by excavating a level trench (< 3 feet wide) or bed (> 3 feet wide), placing a minimum of 6 inches of washed gravel (3/4 to 2 1/2 inch diameter) in the excavation, laying the piping, and then placing enough additional gravel to cover the piping by 2 inches. The trench bottom must be level to avoid ponding of the effluent in one area.

The gravel functions (1) to provide access to the infiltrative surface, (2) to provide storage for effluent, and (3) to maintain the trench or bed and hold back the backfill.

c. Replacement Area

The part of the onsite system that occupies the largest area is the drainfield. Development of properties with onsite systems includes a 100% replacement area for the drainfield. This practice insures a viable option for repair if the primary drainfield fails due to biological, hydraulic or particulate overload. All new lots in Washington

State are required to have a 100% replacement area. This area must be preserved from physical damage (e.g. excavation, vehicle traffic, construction over the area, large animal grazing, etc.)

3. Soil

The soil is where the wastewater receives its final treatment and where it is returned to the environment. In order for the soil to do the required job, it must have a texture of type 2-6, have an acceptable structure, and have sufficient unsaturated depth. The several features of the soil treatment system are discussed in the following paragraphs.

a. Infiltrative surface

The place where the septic tank effluent begins soaking into the soil is the infiltrative surface. The rate at which this occurs depends on the texture, structure, compactness and moisture content of the soil. It is also influenced by the degree of development of a biological "clogging mat" at this surface. This surface is where treatment of the sewage begins in earnest.

b. Clogging mat

The clogging mat is a complex mat of microorganisms and polysaccharide secretions, filtered suspended solids and even inorganic precipitants. It effectively slows the infiltration of liquid into the soil so that flows beneath the drainfield are unsaturated. It also provides some direct treatment of the sewage, removing much of the BOD and sewage microbes. This mat can form as quickly as 1 week, but usually requires months or even several years.

The clogging mat usually forms in a gravity system only after several months of continuous use. It can only form under continuous flooding which will create anaerobic conditions.

c. Treatment zone

This part of the system begins at the clog (infiltrative surface if there is no clog) and includes the unsaturated zone that extends for a minimum of two feet downward. It is in this unsaturated zone where treatment occurs and the minimum of 2 feet in depth provides treatment to an acceptable level. As mentioned previously unsaturated flow occurs when water moves through the micro pores and along surfaces of the soil particles by capillary forces (matric potential). Water moves from the wetter to drier areas and moves much slower than in saturated flow conditions. In addition, the larger pores are filled with air, thus promoting aerobic conditions in the soil. It should be noted that there is a continuum from unsaturated to saturated flow, and the definitions here are the extremes of the continuum.

d. Disposal

Disposal means the return of the treated effluent to the environment, usually to the groundwater. In conventional systems, this is also accomplished in the drainfield area. Properly designed and installed systems treat the wastewater to a degree that will not cause disease or environmental degradation, and then place the treated liquid back in the natural environment. The treated wastewater must move away from the site in order to make room for more treated wastewater.

B. Alternatives to the conventional systems

1. Types

There are a number of approaches to on-site sewage treatment and disposal other than the conventional system. These alternative systems are utilized where site conditions would prevent a conventional system from working properly. The three major alternatives in Washington are: pressure distribution to standard trenches, mound systems, and sand filters. Other alternatives include: gravelless drainfields, aerobic treatment devices, incineration toilets, composting toilets, and vault and pit privies.

2. How they accomplish treatment and disposal

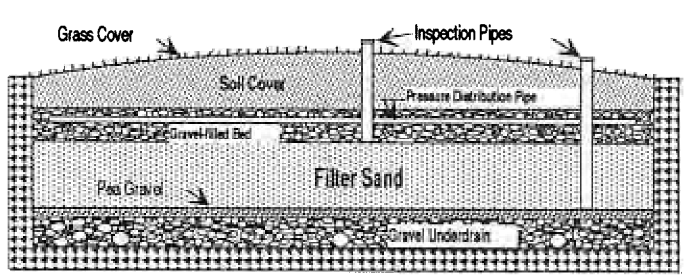
a. Pressure distribution

Pressure provides fairly even distribution of the effluent throughout the drainfield from the first use, without having to wait for a mature biomat to form. Conditions favoring the use of pressure distribution are: medium sands that are on the coarse end of the spectrum, shallow soils or high water table that reduce the vertical separation to less than 3 feet, during part or all of the year, or where the drainfield is a single trench (>100 feet) on a slope.

Pressure distribution accomplishes treatment under the above conditions by spreading the septic tank effluent over the entire infiltrative surface and in doses that promote unsaturated flow conditions. This regime promotes aerobic conditions, unsaturated flow and extended contact between the soil and the wastewater. Pressure distribution enhances the treatment and tends to slow formation of a clogging mat (This latter item not necessarily beneficial).

b. Sand filter

At present there are two basic types of sand filters, single-pass and multiple pass. The single-pass sand filter is used where the soil is too shallow to provide adequate treatment or where the soils are excessively permeable. Treatment is accomplished by applying doses of wastewater to a bed of specified media, collecting the treated wastewater at

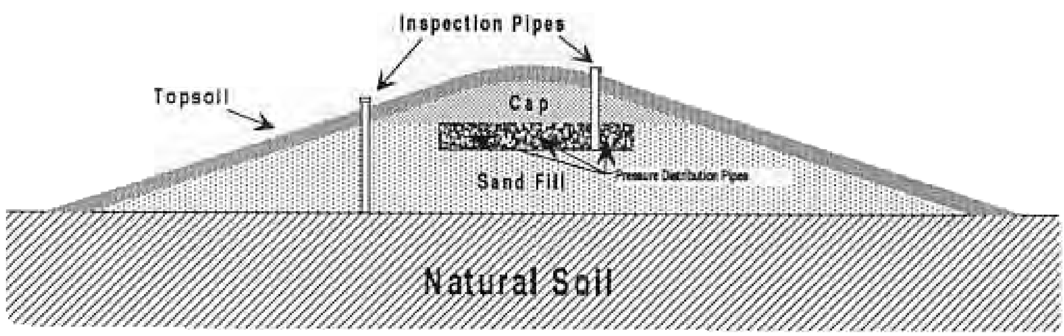


the bottom and sending it to disposal. The effluent from a sand filter must still be discharged to a subsurface soil absorption system. A special type of sand filter is a sand-lined trench or bed. For these special sand filters, the filtrate is not collected for disposal, but instead infiltrates into the soil at the bottom of the trench. These systems provide a high degree of treatment of BOD, TSS, microorganisms, and some nitrate reduction.

The multiple pass sand filter is used when the wastewater strength is higher than typical household sewage, i.e. a $BOD_5 > 230$ mg/l or where the daily flows are high. Treatment is accomplished by dosing the wastewater through a specified medium (coarser than single-pass filter media) multiple times. The biological activity in the media treats the higher strength effluent to a level that can be handled in a soil absorption system. These filters can produce effluent quality similar to single pass sand filters except for fecal coliform bacteria, which will be in significantly higher numbers compared to a single-pass filter.

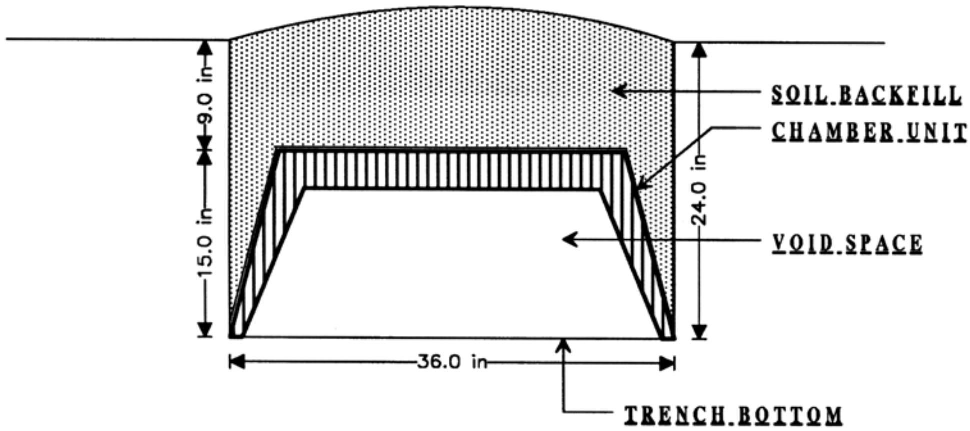
c. Mound system

Mound systems are used when the soil depth is insufficient to provide 2 feet of vertical separation or where the soil is excessively permeable. Mound systems are sometimes selected to meet other concerns on a site, such as a repair on a small lot. Treatment is accomplished in a manner similar to intermittent sand filters, except the effluent is discharged directly to the upper layer of the native soil.



d. Graveless drainfields

This system uses plastic or concrete channels or large diameter pipe instead of gravel to provide access to the infiltrative surface, storage volume above the infiltrative surface and to keep the overburden from collapsing into the trench. Treatment occurs in the biomat and the underlying soil, as it would in a standard drainfield.



VII. Subsurface Absorption Fields

A. Trenches vs beds

The difference between a trench and a bed is the width. Trenches are 3 feet or less wide and beds are greater than 3 feet wide. Good design practice limits beds to 10 feet wide, to allow air to diffuse into the soil beneath the center of the bed. In Washington, beds can be used only with soil types 1, 2, and 3 (soil type 1 will require enhanced treatment, such as a sand filter or a sand-lined bed). Beds are often used in order to provide the required bottom area on lots with limited space.

B. Sidewall vs Bottom Area

Sizing a drainfield in Washington is based on the bottom area only, except for some eastern Washington counties, where some consideration is given to sidewall area. Where credit for part or all of the sidewall is allowed, there can be a reduction in the overall length of trench required. Such reductions are not useful in Western Washington because of the long periods of very damp soil, which reduces the matric potential available for drawing the water through the sidewalls.

C. Deep vs Shallow vs At-grade Infiltrative Surfaces

Deep trench bottoms are sometimes proposed in order to reach more permeable soils. Optimum treatment occurs in the upper layers of the soil, as they have greater aeration. Standard practice should place the bottom of the trench no deeper than 3 feet from the final surface grade. Use of deep trenches is advised only when the trenches are lined with medium sand up to within 3 feet of the surface, where treatment can readily occur. Final disposal can then ensue at the deeper level after the treatment. When sand-lined trenches are proposed in Washington, they should follow the guidelines for them in the Washington State Sand Filter Guidelines. To achieve the required vertical separation under limiting site conditions, trenches can be placed as shallow as 6 inches, with final cover mounded over the top. At-grade infiltrative surfaces are sometimes proposed when the soil is shallow, but has an acceptable texture. These systems are not currently permitted in Washington.

VIII. Elements of Proper Design

A. Site evaluation

Proper design begins with a thorough and accurate site evaluation. This activity includes measurement and preparation of a plot plan which shows the property boundaries, wells, springs, surface water, roads, buildings, cuts, banks, fills, topography, drainage patterns, and any other feature which would affect the location, performance, design and installation of an on-site treatment and disposal system. The site evaluation also includes soil logs in all areas being considered for the drainfield in order to evaluate the suitability of the soil for an on-site system. In addition, there is a need for area-wide knowledge of groundwater flows and direction of flows so some calculations can be made as to short term and long term accumulative effects. The site also needs to be evaluated for its ability to handle any effects of groundwater mounding beneath drainfield, and to handle the ultimate disposal and dispersal of the wastewater.

B. System sizing

On the basis of the proposed size of the house (and therefore the design flows the system would need to handle) and on the soil texture in the proposed drainfield area, the amount of drainfield area is calculated. It should be noted that the design flow is not to be considered the average daily flow, but rather an attempt to factor in peak flows on an occasional basis. The system should be designed using a minimum design flow of 360 gallons per day. A plot plan showing a silt loam at the infiltrative surface and proposing a 4 bedroom house should show a minimum 1067 sq. ft. of drainfield area (120 gal per bedroom x 4 bedrooms divided by .45 gal per sq. ft. per day).

C. System location

Once the size of system is determined, an area must be chosen in which to place this size of system. It also must meet all the necessary setbacks from water supplies, property lines, buildings, etc. The soil texture and depth in this area should be confirmed by assuring that soil logs were performed there. A 100% replacement area is also a part of the system design and should be included in the design and located where acceptable soil logs were performed.

D. System selection and design

The type of system selected will depend on the site conditions. Where 3 feet of vertical separation and adequate horizontal setbacks can be maintained, the system of choice is the standard septic tank and drainfield. Shallow soils, high water tables, small lot size and excessively permeable soils dictate the use of an alternative system. The system design should specify the location and size of the septic tank and the location, depth and length of each drainfield trench. The design should specify in detail the location and size of all components of an alternative system. Construction details such as proper orientation and leveling of the septic tank, assurance of level drainfield trench bottoms, etc. should also be included. The system that is selected should be compatible with the site conditions.

IX. Elements of Proper Installation

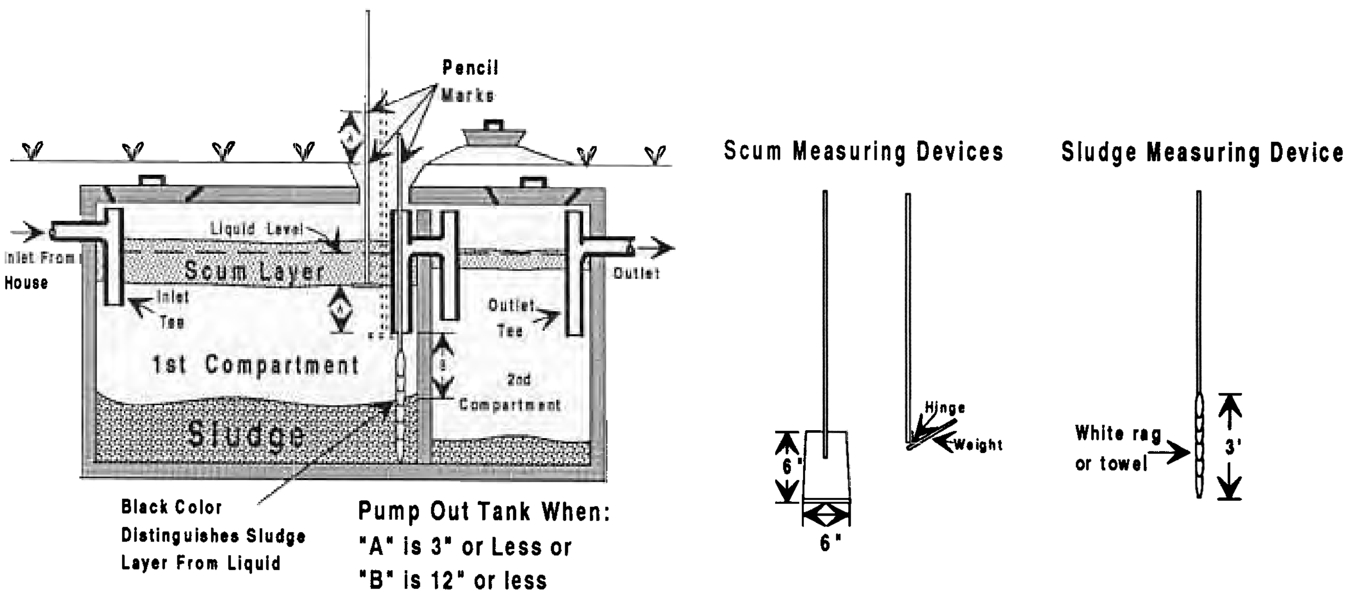
In order for a properly designed system to provide long-term service, it must also be installed properly. Correct installation practices include construction only when soil moisture conditions are right and excavating trench bottoms level. Other correct installation practices are: not compacting the soil, not scraping away the upper layers of the soil during lot preparation, and not smearing the infiltrative surfaces. They also include using washed gravel, using certified ASTM C-33 sand when specified, and installing water tight septic tanks and leveling and orienting them properly.

X. Elements of Proper Use

Users of on-site sewage systems are well advised to use a number of system-saving practices. These include avoiding excessive water usage and spreading out over several days heavy water using activities such as laundry. They also include avoiding use of garbage grinders, emptying grease or other high strength waste down the drain, not adding solvents or other chemicals which will kill the biological action, and not putting items like disposable diapers, tampons, or paper towels into the system. Another element of proper use is not building over, driving over or grazing animals on the drainfield or downslope of a mound.

XI. Elements of Proper Maintenance

Maintenance of on-site systems is often overlooked, but is just as important as the other elements already discussed. The depth of sludge accumulating in the septic tank should be checked each year or two, and at the same time the integrity of the baffles should be inspected. The septic tank should be pumped when the solids are within 6 inches of the bottom of the outlet baffle in the first compartment. (See illustration below.)



If a filter is installed on the outlet of the septic tank, it should be cleaned whenever the tank is inspected. Pump chambers should be checked regularly for accumulation of solids on the floats, proper function of the alarm system, pump operation within the designed pumping period, and evidence of water infiltration. Drainfields should be inspected for surfacing moisture, lush growth of plants, and odors. Septic tank additives are of no known value and some can be very harmful to the system and the receiving groundwater. Such products can deceive homeowners into forgoing the necessary maintenance by use of a relatively cheap off-the-shelf item. Washington State Health Department recommends against their use while urging that routine maintenance and repairs be carried out to prolong and protect the life of onsite sewage systems.

With proper siting, design, installation, use and maintenance, onsite systems can provide high quality treatment to domestic sewage. The treatment and disposal furnished by these systems are both long-term and cost-effective.

APPENDIX A

WHY DO COARSE SOILS HAVE LARGER PORE SIZE AND LESS SURFACE AREA?

WHY DO FINER SOILS HAVE SMALLER PORE SIZE AND MORE SURFACE AREA?

By definition, coarse soils have larger particles. Imagine some objects of similar size and having a round shape. When placed together in a container, they will touch each other in places and leave voids or spaces in other places. The larger the particles, the larger these spaces. Similarly the smaller the objects, the smaller the spaces that are left. Particles of soil lying together in the ground also leave void spaces, with the coarser soil textures having the larger void spaces.

A simple geometry example can illustrate how finer textured soils have larger surface areas. Imagine a cube that measures 1 inch on each side. The surface area of that cube is 1" x 1" to get the surface area of one face, time 6 faces in the cube, equals 6 square inches total surface area. Now if that same cube were cut into 64 smaller, equal sized cubes of .25 inches on a side, the total area of those smaller cubes is .25 x .25 x 6 x 64 = 24 square inches. "The actual surface area of 1 cubic centimeter (about 1/4 teaspoon) of coarse sand is roughly equivalent to the surface area of half dollar, while the surface area of 1 cm^3 of fine clay is equivalent to the area of a basketball court."[1]

For other relevant discussion on soils as they relate to onsite sewage disposal, see Appendix B.

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[1] Cogger, C.G. 1987. "Septic System Waste Treatment in Soil", Washington State University Cooperative Extension, Publication EB1475.

Cooperative Extension

College of Agriculture & Home Economics

Washington State University

EB1475

Septic System Waste Treatment in Soil

Craig G. Cogger

This bulletin provides basic scientific background on the role of soils in wastewater treatment. This information relates to the basic principles behind Washington's rules and guidelines on issuing permits for and designing on-site wastewater treatment (septic) systems.

A household septic system properly designed, installed, and maintained on suitable soil is as effective as a sophisticated sewage treatment plant. A conventional septic system consists of three parts: septic tank, absorption trenches, and surrounding soil. Household wastes flow into the septic tank, where the wastewater purification process begins. In the septic tank, solid wastes settle to the bottom of the tank as sludge, and grease floats to the top as scum. Bacteria (called anaerobes because they live without oxygen) begin to slowly digest the solid wastes. The remaining wastes flow out of the tank into the trenches as liquid effluent.

The absorption trenches distribute the effluent to the soil, where final treatment and disposal occur. This bulletin will focus on wastewater treatment in the soil, the most complex and limiting factor in septic system operation. A system designed and installed to provide proper wastewater treatment in the soil will also provide adequate wastewater disposal.

Soil contains roughly 50% pore space. The pore space is broadly subdivided into macropores (larger pores) and micropores (smaller pores). Macropores transmit water rapidly under saturated or nearly saturated conditions, while micropores transmit water more slowly by capillary flow. Many chemical and biological reactions in soil, including those which are important in wastewater treatment, occur on surfaces adjacent to soil pores.

The ability of a soil to treat wastes depends on four factors:
1) the amount of accessible soil particle surface area;
2) the chemical properties of the surfaces;
3) soil environmental conditions, such as temperature, moisture, and oxygen (O_2) levels; and
4) the nature of the particular substances in the wastewater.

Surface Area

The amount of surface area depends on the texture or particle-size distribution of the soil. Clay particles (< 0.002 mm in diameter) have a much greater surface area per unit volume than silt (0.002–0.05 mm) or sand (0.05–2.0 mm) particles.

To visualize the relative sizes of sand, silt, and clay particles, consider magnifying the largest clay particle to the size of a penny. A silt particle would then range upward to the size of a basketball, and the largest sand particles would approach the size of a house. The actual surface area of one cubic centimeter (cm^3) of coarse sand (about ¼ teaspoon) is roughly equivalent to the area of a half dollar, while the surface area of 1 cm of fine clay is equivalent to the area of a basketball court. Because fine-textured soils have more surface area, their chemical activity is generally much greater than that of coarse-textured soils.

Soil surfaces play a role in wastewater treatment only when wastewater contacts them. Massive clay soils, for example, often have few pores that are readily permeated by water, so the usable surface area is quite small. Heavy clay soils are not suitable for septic systems because they are too impermeable to treat or dispose of the wastewater. In very coarse soils, water can travel so rapidly through the profile that it does not contact enough surfaces to provide good wastewater treatment. Coarse soils allow rapid disposal of wastewater, but treatment may be inadequate. Soils with even a small amount of fine particles can provide excellent waste treatment if the wastewater contacts the particle surfaces.

Better contact occurs between wastewater and soil surfaces under conditions of unsaturated flow. The soil pores are partially filled with air, and wastewater moves by capillary flow along soil particle surfaces. In saturated flow, gravity pulls water through the macropores. Flow is faster, but there is less contact with the soil surfaces; wastewater treatment is less efficient.

Chemical Properties of Surfaces

Chemically different soil surfaces can be divided into four broad categories: 1) silicate clay

Fig. 1. Simplified structure of a silicate clay mineral, showing substitution in the silica layers and resulting negative charges on the surface. (O^{-2} and OH^- ions in the structure are not shown.)

minerals; 2) hydrous oxides of iron (Fe), aluminum (Al), and manganese (Mn); 3) carbonates; and 4) organic matter.

Silicate clay minerals often comprise much of the clay fraction of soils. They give soil its stickiness and plasticity when moist, and hardness or resistance to crumbling when dry. The molecular structure of silicate clays is much like a sandwich, with silica layers (silicon (Si^{4+}), oxygen (O^{2-}) and hydroxyl (OH^-)) bonded to alumina layers (aluminum (Al^{3+}) and O^{2-}) as shown in Figure 1.

Different types of clay minerals vary in structure and properties, but all have some permanent negative charge. This charge is usually due to imperfections in the crystal structure (isomorphous substitution), where ions of lower charge replace silicon or aluminum during crystal formation, so that the oxide ions are not completely balanced by positive charges. As a result of their negative charge, silicate clay minerals can attract and sometimes bond cations (positive ions) to their surfaces. This surface bonding is called adsorption. Potassium is more permanently held by some clay minerals through a stronger bonding mechanism. Since most of the inorganic pollutants from septic tanks are anionic (negatively charged), they are not attracted to clay minerals. These minerals do adsorb bacteria, viruses, and many organic compounds, however.

Hydrous oxides. The next important constituents are the hydrous oxides of iron, aluminum, and manganese. These are clay-sized minerals made of iron (III), aluminum, or manganese (IV) ions bonded to oxide ions. They often occur as poorly formed crystals or as coatings on other particles. Iron oxides are the source of the reddish or brownish coloration characteristic of well-drained soils.

The hydrous oxide surfaces combine with water molecules and form a mixture of positively and negatively charged sites. In acid soils the positive sites predominate, and the oxides have a net positive charge. Thus, oxides have the ability to attract and hold anions. Nitrate (NO_3^-) and chloride are weakly attracted to these oxides, but their movement through soil is only slightly inhibited. Phosphate ($H_2PO_4^-$ and HPO_4^{2-}), however, can bond directly to iron and aluminum at oxide surfaces, resulting in rapid removal of phosphate from solution. The movement of phosphate through soils containing large amounts of hydrous oxides is therefore limited. Oxide surfaces also adsorb and possibly inactivate some viruses.

The edges of silicate clay minerals are chemically similar to the hydrous oxides, and the surfaces of many soil particles may actually be coated with oxides. In such cases, particle interactions with wastewater may mimic those of the hydrous oxides of iron, aluminum, and manganese.

Carbonates. Calcium and magnesium carbonates (lime) are primarily important in arid regions or in soils developed from limestone-rich parent materials. In humid regions, however, they are dissolved and leached from soils. Soils containing calcium carbonate ($CaCO_3$) will fizz (release carbon dioxide) in the presence of acid, and sometimes have visible carbonate accumulations which look like white threads. In extreme cases, carbonates can form impermeable hardpans called caliche. The carbonates are important because they can adsorb phosphate in much the same way that iron and aluminum oxides do.

Organic matter. Organic matter is chemically very complex and has a large reactive surface. Soil organic matter can provide an energy source for microbial growth and can bind many substances, although its capacity to bind viruses appears limited. Since most soil organic matter is confined to the upper part of the soil profile, it is usually not of major importance in septic waste treatment.

Soil Microorganisms and Soil Environment

Soil surfaces are also important because they are the home for soil microorganisms which carry out many wastewater treatment processes. Soil microorganisms play important roles in the breakdown of organic matter, the treatment of nitrogen, and the removal of bacteria and viruses from wastewater. These microorganisms are sensitive to environmental conditions within the soil, including temperature, moisture levels, and oxygen availability. Cold temperatures will slow all biological reactions in the soil, reducing the rate of wastewater treatment.

Oxygen availability affects microbial populations and waste treatment. Excess water (as from a high water table) saturates soil pores and greatly decreases diffusion of oxygen into the soil. Once the existing oxygen is depleted, the soil becomes anaerobic; the rates and types of microbial processes that occur in the soil will change greatly.

Oxygen functions as a biochemical electron acceptor for aerobic organisms. The biochemical processes which convert food into energy rely on the transfer of electrons from one molecule to another in the cells, and on the capture of energy released during those transfers. At the end of the biochemical pathway, the electrons, at a very low energy level, have essentially become a waste product. They are removed by oxygen—an excellent electron scavenger—which plays the role of a garbage collector. When no oxygen remains to scavenge electrons, the energy-producing pathways shut down, resulting in death or dormancy of the aerobic organisms.

Some organisms can survive under anaerobic conditions. They can function without oxygen by using substances such as nitrate, iron (III), sulfate, or organic compounds as electron scavengers. Since these other substances only accept electrons from much higher energy levels than oxygen can, the anaerobes must rely on much less efficient biochemical pathways than aerobes do. Less efficient and less complete treatment of wastewater occurs under anaerobic conditions.

Chemical Components of Wastewater

Phosphate. The chemical substances of greatest concern in household wastewater are phosphate, nitrogen, and organic matter. Phosphate ions are negatively charged ($H_2PO_4^-$ and HPO_4^{2-}). Phosphate is adsorbed strongly, although not completely irreversibly, to hydrous oxide and carbonate surfaces. It can also be biologically incorporated into organic matter. Although phosphate is not a toxic substance, excess levels in lake waters can promote eutrophication, the excessive growth of aquatic plants and eventual depletion of oxygen in the water.

The capacity of most soils to hold phosphate is large compared with the phosphate load from a septic system, so there is usually little concern over this substance. An important exception occurs when septic systems are located in coarse-textured soils surrounding a lake. Because of limited surface area, these soils may eventually become saturated with phosphate. Phosphate will then move through the saturated soils, posing a threat of eutrophication to the lake.

Mounds and sand filters also have a limited capacity to adsorb phosphate, and in time their effluent will contain nearly as much phosphate as the influent from the septic tank. Once the mound or sand filter effluent comes in contact with native soil, however, the phosphate is usually removed quickly.

Nitrogen. Nitrogen is much more mobile than phosphate, and its reactions in the soil are considerably more complex. In raw wastewater, nitrogen is primarily associated with organic matter in substances such as proteins. Beginning in the septic tank, organic nitrogen compounds are broken down (mineralized) and inorganic ammonium (NH_4^+) is released.

$$\text{Org-N} \xrightarrow{\text{mineralization}} NH_4^+ \xrightarrow{\text{nitrification}} NO_3^- \xrightarrow{\text{denitrification}} N_2, N_2O$$

Ammonium is soluble in water but is weakly retained in soil by attraction to negatively charged soil surfaces. The persistence of large amounts of inorganic ammonium in the soil usually indicates anaerobic conditions and an improperly operating septic system. Under aerobic conditions inorganic ammonium is rapidly oxidized to nitrate (NO_3^-) through a microbial process called nitrification. Nitrate is very soluble in soil solution, and is often leached into the ground water. If nitrate is leached to an anaerobic zone in the soil, it can be used as an electron acceptor by denitrifying organisms. This process is called denitrification, which reduces nitrate to gaseous forms of nitrogen (N_2 and N_2O). Nitrification and subsequent denitrification can occur when aerobic and anaerobic zones alternate in the soil. This provides a good mechanism for nitrogen removal, but unfortunately the potential for denitrification is limited in many soils which otherwise provide excellent wastewater treatment.

Nitrate is considered a pollutant in drinking water because elevated levels have caused methemoglobinemia, or oxygen deprivation, in infants. Since nitrate is produced from inorganic ammonium under oxidizing conditions, it is usually the end product of nitrogen metabolism in a properly functioning septic system. Because nitrate is so soluble in soil solution, it will often leach to ground water. These factors have led to the great concern about nitrate pollution from septic systems.

In order to prevent methemoglobinemia, the Environmental Protection Agency has established a maximum acceptable level of 10 ppm for nitrate-N in public drinking water systems. Since nitrate removal is incomplete using current septic system technologies, lot size restrictions have been the main tool used to prevent nitrate concentrations from exceeding standards in ground water beneath areas served by septic systems.

Although recognition of the effects of nitrate, the establishment of drinking water standards, and the increased use of breast feeding and liquid infant formula concentrates have almost eliminated reported cases of methemoglobinemia in the United States, nitrate will continue to be an important indicator of subsurface pollution.

Organic compounds. Organic matter comprises the bulk of the solids in wastewater. Chemical and biological oxygen demand (COD and BOD), total organic carbon, and suspended solids are water quality analyses commonly used to indicate the amount of organic matter present in wastewater. Nearly all organic matter in household wastes is biodegradable, and it does degrade readily in soil. Aerobic conditions beneath the absorption field increase the rate of degradation, while anaerobic conditions slow degradation.

Trace amounts of toxic, synthetic organic compounds appear in the organic matter from household wastewater. Existing research indicates that levels of these compounds are so low that they pose little threat to ground water quality. There is little data available, however; this subject merits additional research.

Microorganisms in Wastewater

While most microorganisms in wastewater are harmless, many pathogenic (disease-causing) organisms may be present. The interactions of these organisms with soil are much more complex and less well understood than the reactions of nitrogen and phosphate. Pathogenic organisms in wastewater can include bacteria, viruses, protozoa, and helminths (worms). Helminths are approximately the size of sand particles, protozoa the size of silt particles, bacteria the size of fine silt and coarse clay, and viruses the size of very fine clay. Due to the relatively large size of helminths and protozoa, their movement from septic systems through soil pores is usually limited. Bacteria and viruses have a much greater potential for movement and have been the principal causes of disease outbreaks related to ground water contamination by septic systems.

To minimize the risk of disease transmission, pathogenic organisms must be removed from the soil before they reach drinking water aquifers. The transport of microorganisms through the soil depends on two main processes—retention and inactivation (die-off). Retention slows the movement of microorganisms while inactivation results in final removal. Soil properties, environmental conditions, and the nature of the microorganisms themselves control both processes.

Retention in Soil. Protozoa and helminths are retained in soil primarily by entrapment in soil pores or settling from soil solution. Viruses, which are small enough to move easily through soil pores, are retained primarily by chemical or physical adsorption to clay or oxide surfaces. Bacteria, which are intermediate in size, are retained by both entrapment and adsorption processes. Retained organisms are not necessarily inactivated, and may even be protected from inactivation. This is especially true when retention occurs by adsorption processes. Retention slows the movement of bacteria and viruses through the soil, but may also prolong their survival.

Viruses and bacteria are adsorbed by clay minerals and hydrous oxides, while organic matter appears less effective at microbial adsorption. Soil acidity affects virus adsorption; increased retention occurs in more acid soils (lower pH). The amount of viral adsorption to soil also depends on the ability of the virus surface to bind to soil surfaces. Scientists have observed a wide range of adsorption even among different strains of the same virus, apparently due to differences in the chemical charge on the protein coat of the virus.

Retention is not necessarily permanent. During periods of heavy rainfall, retained viruses become resuspended in the soil water, and are transported rapidly by saturated flow through large soil pores. When retention protects viruses from destruction, they may reach ground water by alternate cycles of retention and resuspension.

Inactivation in Soil. Bacteria and viruses need favorable environmental conditions and protection from competition or predation in order to persist. Bacteria in sewage are predominately facultative—that is, they can survive under either aerobic or anaerobic conditions. Most soil bacteria are obligate aerobes, active only in the presence of oxygen. Sewage organisms are rapidly destroyed in aerobic soils, because they compete poorly with the natural soil microoganisms. Under anaerobic conditions most soil bacteria are inactivated, and the facultative sewage organisms can survive for a much longer time. Virus survival shows similar patterns. Survival decreases under aerobic conditions and increases under anaerobic conditions. Both bacteria and viruses from sewage survive longer at low soil temperatures, because natural soil microbial activity is reduced.

A number of other factors also affect the survival of bacteria and viruses in soil. Survival varies significantly among types of bacteria and viruses, which show widely varying resistance to hostile conditions. Soil adsorption tends to protect microorganisms from destruction, although adsorption to certain hydrous oxides may speed the inactivation of some viruses. Many bacteria die off more rapidly in acid soils, while viral persistence often increases, probably due to increased adsorption under acid conditions. Both sunlight and drying decrease microbial survival, but neither of these are likely to be factors in septic systems.

In general, removal of viruses and bacteria is rapid under aerobic conditions and unsaturated flow; a number of researchers have found nearly total removal of bacteria and viruses in 2 feet of soil. Several monitoring studies, however, have suggested bacteria and viruses can sometimes move many feet, even under supposedly hostile conditions. It is probable that the cases of extreme movement involved factors such as improper septic system design or operation or inadequately protected wells. These occurrences underscore the importance of proper design, installation, and maintenance of septic systems and wells in protecting ground water quality.

Practical Considerations

The two factors most important in the treatment of septic system wastes are 1) maintaining adequate contact between the wastewater and the surfaces of soil particles; and 2) maintaining aerobic conditions beneath the absorption field. The rules and guidelines for designing and installing septic systems are based on these factors.

To maintain aerobic conditions beneath the absorption field, the soil must remain unsaturated. Under unsaturated conditions, oxygen can diffuse through the soil air and replenish the oxygen consumed by microbial activity.

Aerobic conditions are not maintained in saturated soil because water slows oxygen diffusion through soil pores. Septic systems are permitted only where a specified vertical separation can be maintained between the absorption trenches and the water table, providing unsaturated conditions. In Washington, the vertical separation requirement between the trenches and the water table is 3 feet, although it may be reduced to as little as 1 foot in certain situations.

Vertical separation also plays an important role in maintaining adequate contact between wastewater and soil particle surfaces. Increased vertical separation to the water table, bedrock or an impermeable zone increases the volume of soil available for wastewater treatment and the potential amount of soil-wastewater contact.

Loading rate, drainfield size, and distribution system design should be specified to allow unsaturated flow beneath the trenches without overloading the system. Unsaturated flow provides both aerobic conditions and good contact between soil particles and wastewater.

In soils where vertical separation or loading requirements cannot be met using a conventional septic system, an alternative design may provide a solution. Two of the most common alternative designs are mound and pressure-dosed systems. The purpose of both is to increase vertical separation and improve distribution of effluent through the absorption area.

A mound system consists of a 1- to 2-foot-deep mound of carefully selected sand, and a pressurized distribution system which doses effluent into the sand. The mound provides additional vertical separation by using the fill and surface soil for wastewater treatment. The mound is dosed by a pressurized distribution system to produce more uniform unsaturated flow of effluent.

Pressure-dosed systems placed at shallow depths in natural soil perform similarly, except that the additional mound fill is not used. While alternative systems can improve effluent treatment on some soils, many soils are too wet, too shallow, too impermeable, or too steep for any type of system.

Although soil is not the only factor involved in septic system operation, it is a very important one. It is important to locate systems on suitable soil, design them to fit the soil, and install them to maintain vertical separation and to disturb the soil as little as possible.

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