UNIVERSITY OF FLORIDA
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SL118

Soils and Septic Systems [1]

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INTRODUCTION TO SOILS

Soils are naturally occurring or man-made, three-dimensional bodies of the earth's surface. They are highly variable as to their suitability for different uses. Historically, most of our emphasis in studying soils has been placed on those attributes of soil that affect plant growth; hence the close association between soil science and the agronomic and horticultural sciences. In recent decades, however, there has been increasing interest and emphasis on use of soils for nonagricultural purposes, including onsite wastewater disposal.

A soil consists of one or more layers, or horizons. These horizons are grouped into surface soil, subsurface soil, subsoil, and substratum:

- **Surface soil.** The surface soil, or "topsoil," is enriched in organic matter -- and usually darkened somewhat as a result -- from decomposing organisms.
- **Subsurface soil.** The subsurface horizon, if present, is a leached zone, beneath the surface soil, from which mobile soil constituents (clay particles, organic matter, iron and aluminum oxides, carbonates, and/or other constituents) have been removed in solution or suspension by downward-percolating rainwater and/or by a fluctuating water table.
- **Subsoil.** Underlying the surface soil and/or subsurface soil may be a "subsoil." The subsoil, where present, is a zone that has been influenced in some significant way by soil-forming processes. The processes may be subtle, consisting of simple alteration of chemicals and minerals, or very distinct, consisting not only of alteration but of enrichment of subsoil horizons by materials that have been leached from the overlying topsoil and subsurface soil. Where such enrichment has occurred, an "argillic" (relatively clayey) horizon, a "spodic" (enriched with organic materials and iron and aluminum oxides) horizon, or other horizons marked by some sort of accumulation may result. Occasionally, such horizons are so well developed that they act as "hardpans" and retard in some degree the downward movement of water.
- **Substratum.** Beneath the zone of soil formation is the "substratum," which is nonsoil material, ranging from bedrock to unconsolidated sediment. Substrata are largely unaffected by soil-forming processes other than deep weathering.

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In addition to the soil-forming factors of alteration, leaching, and enrichment, the stratification of soil or soil parent materials can have enormous impact on the behavior of water in soils. Stratification is the result of deposition of relatively fine-textured layers over and/or under coarser-textured layers. Behavior of water, including septic tank effluent, is a function of such layering, of the permeability of the various soil horizons, position in the landscape, the weather, and other factors.

SOIL SURVEY -- A VALUABLE RESOURCE INVENTORY

The many different processes of soil formation, acting in many different combinations on different types of parent materials, cause great variety in the soils we see in the landscape. Some, but not all, of the spatial variability that we see in soils is predictable and mappable. Much of this predictable, systematic variability is shown on the soil maps produced and published by the National Cooperative Soil Survey (NCSS). The lead agency for the NCSS in Florida is the United States Department of Agriculture (USDA) Soil Conservation Service. Other participating agencies are the Institute of Food and Agricultural Sciences (IFAS) of the University of Florida, the Florida Department of Transportation, the Florida Bureau of Soil and Water Conservation, the USDA Forest Service, and several other state and county agencies. These soil resource inventories being conducted by NCSS are published as soil survey reports for counties or for other similarly-sized jurisdictions in Florida and elsewhere.

A soil survey report is highly useful in understanding the three-dimensional landscapes of a region. One can obtain important information regarding systematic changes in morphology and behavior of soils across the landscape. The soil survey report should be a valuable reference for the septic system practitioner, complementing his or her own observations of local soils and landscapes.

There is, however, a great deal of variability in soils that is not captured and shown in soil survey reports. This sort of variability is either (1) poorly understood ("random"), and therefore unpredictable and unmappable, or (2) well understood and predictable but so intricate as to be unmappable at the published scale of the map. The result is that soil survey reports normally do not provide the precise detail necessary to understand and predict soil behavior on small parcels of land. So, while a soil survey report is highly useful in gaining broad understanding of landscapes, having such a report in hand does not remove the need for onsite investigation in determining suitability of soils for septic systems or other similarly intensive land uses.

The best qualified persons to conduct onsite investigations of soil for septic system suitability are those who understand: 1) soil profiles, i.e., the occurrence and effects of various sorts of horizons and layers, the dynamics of the water table, etc.; 2) the occurrence of soils in three-dimensional, variable, dynamic landscapes; 3) vegetative indicators of soil wetness and other soil attributes; 4) the value -- and limitations -- of soil survey reports; and 5) the use -- and limitations -- of percolation tests. Much of this kind of expertise and experience may be found in the profession of soil scientists. Soil scientists are available 1) to provide training for environmental health officials and others doing onsite investigations, and/or 2) to conduct onsite investigations, where appropriate, for private parties or public agencies.

Additional expertise relevant to onsite wastewater disposal may be found among geotechnical engineers, who design wastewater disposal systems based on information derived from onsite investigations of soils. They also consider other, nonsoil characteristics of the site, along with applicable state and local regulations.

BEHAVIOR OF EFFLUENT CONSTITUENTS IN SOIL

A wide range of constituents, with widely ranging behaviors, may be found in the wastewater of households, restaurants, and other facilities. Some of the important aspects of behavior of these various constituents are discussed in the following paragraphs.

Organic Substances

The concentrations of natural and synthetic organic compounds in effluent are generally expressed in terms of biological oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids content (TSS). A properly designed and maintained septic tank removes much of the organic substances from raw wastewater. Additional removal of these materials from the septic tank effluent occurs in the soil, where removal of organics is accomplished by filtration, decomposition, and incorporation into microbial cells.

Wastewater organics play an important part in the formation of a biologically active clogging layer or crust that can restrict movement of effluent and its constituents into the soil beneath and adjacent to a drainfield. Bacteria growing under conditions where effluent is plentiful store polysaccharides as slime capsules, which cover the soil particles at the boundary between the bottom of the disposal trench or bed and the underlying soil, causing a reduction in pore diameters in the soil. This clogging effect reduces the infiltrative capacity of the soil.

Formation of the clogging mat can lead to premature hydraulic failure of septic systems if pores become plugged entirely or nearly so. The clogging layer has been found to be beneficial, however, where it filters additional bacteria or suspended solids from the effluent and/or where it helps to maintain unsaturated conditions in the zone immediately underneath it, by slowing entry of effluent into the soil. Proper sizing and management of a septic system, so that the drainfield is not overloaded with effluent and with organic substances, can help to ensure that the clogging mat will not become thoroughly plugged.

Nitrogen

Forms of nitrogen present in septic tank effluent include ammonia, ammonium, organic nitrogen, nitrate, and nitrite. The types of nitrogen compounds and, to some extent, the total nitrogen concentration in effluent are functions of the treatment in the septic tank. Anaerobic conditions prevail in conventional septic tanks, and the resulting effluent contains dominantly soluble ammonium and significant amounts of nitrogen that is still in the organic form. Effluent from aerobic tanks, however, contains nitrogen primarily in the form of nitrate.

Only a small part, perhaps 10%, of the total nitrogen in raw wastewater is removed via sludge that accumulates in the bottom of the septic tank. Several other mechanisms exist in the soil for transformation, retention, and movement of nitrogen. The mechanisms include denitrification, adsorption, plant uptake, and volatilization. Some of the nitrogen in effluent may be removed by one or more of these mechanisms before the effluent reaches groundwater. But half or more of the nitrogen is likely to travel with effluent to groundwater.

Nitrification -- i.e., conversion of ammonium-nitrogen into the nitrate form -- occurs in the first foot or so of soil below a drainfield, provided the water table is not present and unsaturated conditions exist in that zone. Nitrate is very soluble and does not interact with soil components under aerobic conditions, travelling through the soil practically unimpeded. Unless conditions for denitrification (conversion to nitrogen gas in an anaerobic environment) exist, nitrate will not undergo further transformation in ground water. Dilution is therefore the best hope of reducing concentrations of nitrate from septic systems in ground water.

Phosphorus

Phosphorus in septic tank effluent originates from two main sources: detergents containing phosphates, and human excreta. Anaerobic digestion in conventional septic tanks converts most of the phosphorus into soluble orthophosphates.

In contrast to the highly mobile nitrate nitrogen, most phosphate reacts vigorously with soils. Phosphate ions are removed from the soil solution by several mechanisms, including adsorption, precipitation, plant uptake, and biological immobilization. Phosphorus transport through the soil is more likely to occur, however, in coarse-textured, noncalcareous soils that are low in organic matter with shallow depth to the water table and/or to bedrock. Where these conditions exist and/or where septic systems are close to surface waters such as drainage ditches or lakes, phosphorus transport to ground and surface waters is likely, although continued removal of phosphorus from ground water by adsorption and precipitation in water-transmitting soil/geologic strata may occur.

Detergent Surfactants

Mechanisms for removal of detergent surfactants from effluent in the soil include biodegradation and adsorption to soil particles. Any factors that promote aerobic conditions and unsaturated flow will promote such biodegradation and adsorption. Adsorption is influenced by several soil properties, including soil texture, mineralogy, organic matter content, soil solution chemistry, soil exchangeable acidity, and the formation of a clogging mat. Adsorption of detergent surfactants can retard their movement and allow more time for biodegradation to occur.

Toxic Organic Compounds

Toxic and nonbiodegradable organic compounds, such as chlorinated hydrocarbons, trichloroethylene (TCE), and methyl chloroform (MC) have been found in homeowner-administered septic tank cleaners or additives. TCE and MC have a higher density than water. If allowed to reach the saturated zone, they may sink to the bottom of the water phase, and are not readily biodegradable in this environment. These and other toxic materials such as pesticides, solvents, and compounds containing heavy metals have high potentials for contamination of soils and groundwater, and should not be put into septic systems.

Bacteria

Bacteria are single-cell organisms, and they may be trapped in the pore spaces between soil particles. This entrapment or filtration is an important mechanism for removal of enteric bacteria from effluent. A clogging mat occurs at the interface between the trench and natural soil. This mat is formed in part because of bacterial activity, and serves in turn to help trap enteric bacteria before they enter the soil. Other soil and biological factors influencing the attenuation of bacteria include bacterial numbers in the effluent, soil texture, soil wetness, loading rate, temperature, and bacterial type.

Unsaturated flow beneath a drainfield is important in ensuring slow travel, long residence time for bacteria in the unsaturated zone, good aeration, increased opportunity for contact between effluent and soil particles, opportunity for some adsorption of bacteria to soil particles, and eventual die-off of bacteria.

Viruses

Viruses are smaller than bacteria and have a behavior in the soil environment that is different from that of bacteria. Virus removal or inactivation in the soil may be by several mechanisms, including filtration, precipitation, adsorption, biological enzyme attack, and natural die-off. The small size of viruses, and their surface properties deriving from a protein coat that may or may not have an electrochemical charge (depending on the virus), cause removal of viruses to be controlled more by adsorption to soil particles than by filtration. Many of the soil properties that affect adsorption of bacteria also affect adsorption of viruses. Cation exchange properties of soils, mineralogy, texture, pH, and temperature are just a few of the soil properties that influence virus attenuation.

As with bacteria, unsaturated flow conditions in the soil beneath a septic system, resulting in good aeration, slow travel, long residence times, good effluent-soil contact, and opportunity for die-off, is very important in ensuring cleanup of viruses in effluent.

IMPORTANCE OF THE UNSATURATED ZONE

As we have seen, the behavior of effluent constituents in soil ranges widely, depending on the nature of the particular constituent, on the nature of the soil, and on the degree of saturation of the soil. The degree of saturation, or wetness, of the soil is influenced in turn by several factors, including the depth to the wet season water table. The water table fluctuates in elevation as rains come and go, as rates of evapotranspiration change with the seasons, and as human activities (drainage, irrigation, stormwater management, etc.) have their impact.

One of the keys to proper functioning of a septic system is ensuring that the vertical separation between the bottom of the drainfield and the water table is large enough so that unsaturated conditions will be maintained even during wet seasons. Water travels more slowly through an unsaturated soil (i.e., a soil whose pores are not entirely filled with water) than it would travel through the same soil were it saturated. The slower the velocity of flow, the longer is the residence time of the effluent in the unsaturated zone and the greater the opportunity for cleanup of the effluent as it travels through the soil. Maintenance of the unsaturated zone helps to ensure that good aeration and slow travel of effluent will be achieved. Good aeration is necessary to achieve decomposition of organic particles and compounds, biodegradation of detergents, and die-off of bacteria and viruses. Slow travel gives opportunity for good contact between soil particles and effluent, adsorption of effluent constituents to soil particles, extended opportunity for natural die-off of bacteria and viruses, and biodegradation of degradable materials.

To design a septic system such that an unsaturated zone will exist beneath the drainfield even during the wet season, one must know the depth to the wet season water table at the site. Normally, the investigator does not have detailed records of water table fluctuations for a site, and the onsite investigation usually does not take place during times of maximum height of water table. Therefore, depth to the wet season water table must be estimated at the site, by examining soil color patterns, other features of the soil profile, landscape position, the vegetation growing on the site, and such additional information on water table fluctuations in the local soil-landscape as may be provided in the soil survey report for the area.

The separation distance required between the bottom of the drainfield and the wet season water table varies widely from state to state around the United States, and the evidence is not yet completely assembled to say exactly what separation is adequate in the range of soil conditions, effluent qualities, and effluent loading rates that may be found around the country. The state of Florida requires a minimum separation of 24 inches.

Water table fluctuations in soils are one of the major pitfalls of the percolation test, in which the rate of fall of water in a standard-size hole is measured in order to estimate the ability of the soil to accept effluent. The percolation test has some value in estimating the "perk" rate of soils at a site, establishing appropriate loading rates, and predicting system performance. But a test performed at any time other than the wet season of a normal rainfall year, when the water table is at its maximum height, may be completely misleading. The test might indicate a rapid perk rate during dry times, but subsequent experience might prove otherwise if the wet season water table turns out to be close to or even above the bottom of the drainfield.

Soils containing impermeable or slowly permeable soil horizons commonly develop perched water tables during periods of high rainfall. Perched water tables can result in saturated flow of effluent, lateral flow, and/or transport of the effluent to the soil surface. Again, the site investigation needs to yield a good understanding of soil features (soil textures, cemented layers, aggregation of soil particles, and wet season water table), so that system performance can be predicted and appropriate designs executed. Alternative systems such as mounds may be employed to increase the separation distance between the bottom of the system and the wet season water table, bedrock, cemented soil, clay, or other unsatisfactory material.

Artificial drainage with ditches, canals, tile lines, French drains, etc., can increase the water-unsaturated soil depth below an absorption system, and has been shown in some instances to improve the hydraulic functioning of septic systems with slowly permeable horizons and/or with high wet season water tables. Caution is advised, however, in estimating the effects of drainage. The precise effects of drainage in any one locale can be estimated only by careful analysis of soil conditions at the site of concern. A single ditch across an equidimensional 100-acre tract of land, for example, is not likely to influence the water table beyond an area several tens of feet wide on either side of the ditch, unless the ditch is deep and wide and has a positive outfall leading to rapid removal of water from the site, and unless the soils are sufficiently permeable to allow removal. Adequacy of drainage works is a function of 1) permeability of soils and under-lying substrata, 2) presence or absence of restrictive layers such as hardpans, 3) depths of drainage devices (canals, ditches, tile lines, wells, etc.), 4) distance between drainage devices, and 5) the establishment and maintenance of adequate rates of flow from the site.

It should be recognized also that human activities might cause the water table to rise, rather than fall, in some circumstances, as where paving and buildings concentrate rainwater in smaller areas of land than would be available under natural conditions. And stormwater retention/detention facilities, designed to keep runoff from exiting urban watersheds too rapidly, might also serve to keep the water table from falling as rapidly or as far as it otherwise would. So could blockage of drainage works by debris or check dams. Performance of nearby septic systems can be affected by such artificially induced raising of the water table.

IMPORTANCE OF SEPTIC SYSTEM DENSITIES

Numerous researchers across the U.S. have studied the influence of septic system densities on water quality. Studies have employed actual measurements of water quality and/or computer modelling. It would be highly misleading to generalize from those studies, conducted as they were in a wide variety of soil, landscape, and climatic conditions, with different water quality parameters (nitrate in one study, viruses in another, etc.) employed among the different studies. It is generally known, however, that potential for ground water contamination with nitrate depends not only on septic system densities but on several other factors as well. These other factors include permeability of soils/substrata, gradient of the ground water (which together influence velocity of ground water), natural rates of recharge to the ground water, and concentrations of effluent constituents reaching the ground water. Appropriate densities and setback distances may therefore vary widely from region to region, due to variations in soils, geology, ground water velocities, and other factors.

CLASSES OF FAILURE OF SEPTIC SYSTEMS

The homeowner tends to think that the septic system is working as long as the toilet works and there's no smell in the yard or adjacent ditches. Shifts in our environmental awareness in recent years have led us to realize, however, that there are other ways to define failure of systems. We might categorize these types of failure as follows:

Class I -- Raw Sewage on the Bathroom Floor. This is the classic failure in which raw sewage is rejected by the disposal system. One county environmental health official in Florida has referred to this type of failure as a "Ten Phone Call Failure."

Class II -- Sewage in the Yard. In this class of failure the toilet and other facilities seem to function just fine, but untreated or poorly treated sewage is surfacing in the yard, in nearby ditches, in the neighbor's yard, or elsewhere in the immediate environment. It is probably going to be obvious to someone in the neighborhood that a failure has occurred.

Class III -- Decline in Water Quality. In this case the household plumbing and drainfield seem to be working perfectly. There is no smell in the neighborhood, and no excess wetness around the drainfield. But a research team, using monitoring devices, groundwater sampling, tracers, and/or other scientific techniques, demonstrates that the system or systems are causing degradation of ground water and/or surface water. The homeowner(s) may be skeptical, however, of the research findings. They may be doubtful because they think there's some other cause of the decline in water quality, because they don't trust the results, or for other reasons having to do with their own values and priorities.

Class IV -- Long Term, Gradual, Environmental Degradation. Here there is little if any scientific evidence that waters are being degraded at a rate likely to be a problem to this or the next generation of residents. But computer modelling and/or long term monitoring indicates that very gradual environmental degradation will happen as a result of septic system practices at a particular homesite, in a neighborhood, or in a region. This is the hardest type of "failure" to prove, especially if all we have to go on is a computer model, without benefit of actual measurements.

Note that Class I failures can easily be identified with facts. Class IV failures, on the other hand, often cannot be proved with facts, because the required facts are entirely lacking or nearly so. Most people are likely to have an opinion on the occurrence of Class IV failures, however, based in large part on their personal values. The intermediate Class II and Class III failures are identified using varying combinations of facts and values. In communicating with others and in trying to sort out the facts regarding septic system performance and environmental impacts, it is well for us to know where we are on this fact-value continuum. Our efforts in septic system research should always be toward improved assembly and understanding of the facts, so that decision-makers, be they homeowners, sanitarians, installers, or policy-makers, will use the facts, in the light of their own and society's values, to make informed decisions.

REASONS FOR FAILURE OF SEPTIC SYSTEMS

A septic system failure, of whatever *type*, might have one or more of several *causes* . Some of these causes might be:

- High water table.
- Slowly permeable subsoil (clay, cemented pan, etc.).
- Inadequate setbacks from open water or wells.
- Organic material in mound fill.
- Fine-textured material in mound fill.
- Improper design and/or installation.
- Failure of dosing pump.
- Use of system beyond its designed hydraulic capacity.
- Improper disposal of solvents, grease, etc., in the septic tank.
- Failure to pump out.
- Excessive BOD, TSS, or other constituents in effluent.

Note that some of the potential causes have to do with the nature of the site and the soils found there. These causes should be reckoned with before the septic tank permit is issued and the system is designed and installed. Other potential causes have more to do with design and/or with homeowner use, management, and maintenance of the system. It is hard to say which of the above are the dominant causes of homeowner inconvenience/expense in Florida. It is also unclear which of the above are the dominant causes of environmental degradation, if any, from septic systems. What *is* clear is that failures of onsite sewage disposal systems can be minimized by careful and informed planning, installation, maintenance, and use of the systems.

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This fact sheet is a modification of a paper entitled "Introduction to soils and the functioning of onsite sewage systems," by R.B. Brown, which appeared in a larger volume of related papers *(Onsite wastewater management and groundwater protection: Meeting the real challenge.* Proceedings of the 3rd Annual National Environmental Health Association Midyear Conference, held February 7-9, 1988, in Mobile, Alabama. National Environmental Health Association, Denver, Colorado). This information also has appeared in print as NOTES IN SOIL SCIENCE No. 41 (February 1990).