EB1475

CLEAN WATER FOR WASHINGTON

Septic System Waste Treatment in Soil

This bulletin provides basic scientific background on the role of soils in wastewater treatment. This information relates to the 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 part of 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 consists of 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. Most chemical and biological reactions in soil 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.

Soil Texture and 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 (0.0020.05 mm) or sand (0.05-2.0 mm) particles.

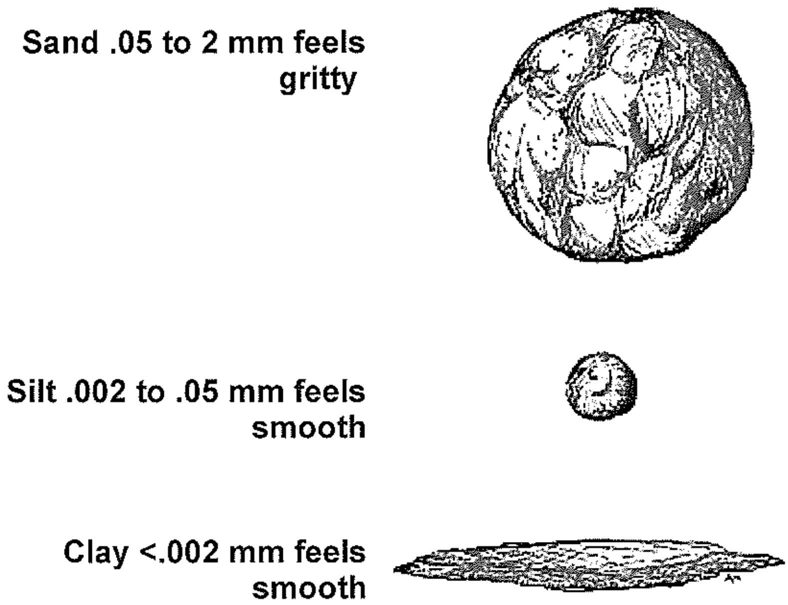


Fig. 1. Sand, silt, and clay particles. Magnification not proportional.

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 course sand (about $^1/_4$ teaspoon) is roughly equivalent to the area of a half dollar, while the surface area of 1 cm of fine clay is equavalent 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

Soil surfaces can be divided into four broad categories:

1___silicate clay 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 and resistance to crumbling when dry.

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. As a result of their negative charge, silicate clay minerals can attract 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. 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 topsoil, 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 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.

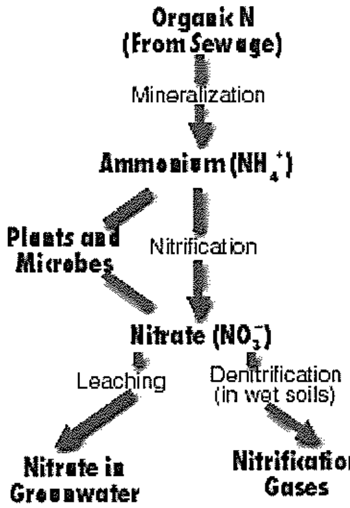
Oxygen functions as a biochemical electron acceptor for aerobic organisms. The biochemical processes that convert food into energy rely on the transfer of electrons from one molecule to another in the cells, and on the capture of energy released during those transfers. At the end of the biochemical pathway, 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, ferric iron, sulfate, or organic compounds as electron scavengers. Since these other substances only accept electrons from higher energy levels than oxygen can, the anaerobes must rely on less efficient biochemical pathways than aerobes do. Less efficient and less complete treatment of waste-water occurs under anaerobic conditions.

Chemical Components of Wastewater

The chemical substances of greatest concern in household wastewater are phosphate, nitrogen, and organic matter.

Phosphate. Phosphate ions are negatively charged ($H_2PO_4^-$ and HPO_4^{2-}). Phosphate is adsorbed strongly 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. 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.

Ammonium is soluble in water but is weakly retained in soil by attraction to negatively charged soil surfaces. The persistence of large amounts of ammonium in the soil usually indicates anaerobic conditions and an improperly operating septic system. Under aerobic conditions 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 some microorganisms. 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 groundwater. These factors have led to the great concern about nitrate pollution from septic systems.

In order to prevent methemo-globinemia, the Environmental Protection Agency has established a maximum acceptable level of 10 mg/L for nitrate-N in public drinking water systems. Lot size restrictions have been the main tool used to reduce nitrate accumulation beneath areas served by septic systems. Because lot size restrictions often conflict with growth management goals, different approaches to nitrate reduction are needed. These approaches include building dentrification and plant uptake into septic system designs and land use planning to take advantage of dilution and denitrification in greenbelts and wetlands.

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 methemoglob-inemia 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 also occur in household wastewater. The mobility and persistence of these compounds vary. Disposing of solvents or petroleum products down drains, or misusing solvent-based cleaners can increase the risk of organic leaching into groundwater.

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 more complex and less well understood than the reactions of nitrogen and phosphate. Pathogens in wastewater 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 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. Retained organisms are not necessarily inactivated, and may even be protected from inactivation. This is especially true when retention occurs by adsorption. 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 groundwater by alternate cycles of retention and resuspension.

Inactivation in soil. Sewage bacteria and viruses will persist in soil if they have favorable environmental conditions and protection from competition. Bacteria can survive under either aerobic or anaerobic conditions. Most soil bacteria are 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 inactive, and the 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 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. These cases of extreme movement probably 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 groundwater 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 in a conventional system.

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. Three of the most common alternative designs are mound, pressure-dosed, and sand filter 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 similarily, except that the additional mound fill is not used.

A sand filter has a bed of sand (the same type of sand as used for mounds) for pretreatment of the effluent, followed by a conventional or pressure-dosed absorption area.

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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