Chapter 4: *SITE EVALUATION AND FIELD TESTING*

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Site Evaluation and Field Testing

Introduction

Finding a suitable site and soil is essential to the placement and proper functioning of any on-site system. This chapter is designed to provide information on determining the proper site and soil for the placement of on-site systems, and has been written specifically for ~~the~~ use ~~of~~ by environmental health specialists as a training guide.

As defined by the *Rules for Sewage Treatment and Disposal Systems*,

"Sewage" means the liquid and solid human waste and liquid waste generated by water-using fixtures and appliances, including those associated with food handling.

"Effluent" means the liquid discharge of a septic tank or other sewage treatment device.

Reference
15A NCAC 18A.1935(11),(39)

Section 4.1, ***Wastewater Treatment in Soils***, describes the constituents of wastewater, the chemicals and human pathogens, and how these potentially harmful constituents are treated and absorbed by the soil.

Section 4.2, ***Groundwater***, presents an overview of groundwater and how groundwater can be affected by improperly sited or malfunctioning on-site systems.

Section 4.3, ***Soils and Geology of North Carolina***, introduces the reader to the different soils and geology of North Carolina, and describes how they affect the siting and functioning of on-site systems.

Section 4.4, ***Basic Soil Concepts***, presents soil and landscape position concepts necessary to conduct a site and soil evaluation. This section then relates these concepts to the placement and functioning of on-site systems.

Section 4.5, ***Site and Soil Evaluation Procedures***, provides details on how to make a thorough site and soil evaluation. Site evaluation factors and classifications are discussed in detail, and the rules for determining the placement of an on-site system are described.

Section 4.6, ***On-Site Wastewater Loading Rates***, discusses the importance of calculating the proper on-site wastewater loading rates and then instructs the reader on making the calculations for conventional, modified, and alternative on-site systems.

Section 4.7, ***Site Suitability: Matching the Site Characteristics to Appropriate Designs***, introduces the reader to the *Soil Site Evaluation for On-Site Wastewater System* form used to permit on-site systems. Six *Soil Site Evaluation for On-Site Wastewater System* forms, which have been completed, are included to help the reader understand how the forms are used to determine site and soil suitability for on-site systems.

4.1 WASTEWATER TREATMENT IN SOILS

The purpose of wastewater treatment is to reduce the pollutants in wastewater that can contaminate ground and surface waters. Without proper treatment, wastewater can cause public health problems and environmental contamination from potential spread of bacteria, viruses, and pathogens.

Wastewater may contain bacteria, viruses, protozoa, nitrogen compounds, and toxic organic compounds which can cause disease in humans. Chemical constituents in wastewater: oxygen-demanding substances~~;~~, nitrogen~~;~~, phosphorus~~;~~, chloride~~;~~, sulfate~~;~~, sodium~~;~~, heavy metals~~;~~, toxic organic compounds~~;~~, detergent surfactants~~;~~, and suspended solids can adversely effect the environment.

Most on-site systems treat and dispose of wastewater. Depending on a number of factors, the soil can reduce or remove these pollutants. This section describes the process of wastewater treatment in soils. The health and environmental impacts of the constituents that may be released from on-site systems are also discussed in this section.

Treatment Processes in the Soil

Most of the organic solids in domestic sewage are removed by sludge settling in the septic tank. Some of these solids will partially biodegrade in the tank. Wastewater effluent that exits the septic tank and enters the soil receives most of its treatment in the unsaturated aerobic regions under the treatment and disposal field.

Wastewater treatment in the soil can be broken down into three different types of processes:

- *Physical processes* include soil filtration, sedimentation in the soil profile, dispersion, and dilution;
- *Chemical processes* involve cation exchange, adsorption, organic residue complex formation, and precipitation; and immobilization,
- *Biological processes* consist of biological oxidation, nitrification, denitrification and plant uptake, enzymatic inactivation, and predation.

All of these processes may occur independently or together for any given wastewater constituent.

Aerobic Treatment

The most rapid and complete soil treatment of wastewater occurs in an *aerobic* soil environment, where oxygen is present in the soil. The soil is sufficiently aerobic to treat sewage only when not saturated with water. Oxygen found in “unsaturated” soil conditions allows aerobic bacteria and other microorganisms to feed on the wastewater and break down contaminants into less harmful products. Because oxygen is a very powerful chemical, aerobic degradation proceeds much faster than similar *anaerobic* processes that occur in the absence of oxygen. The faster aerobic processes help increase the amount of treatment the wastewater receives before the wastewater enters the ground or surface water.

Aerobic conditions promote rapid die-off of many *pathogens*, or disease-causing~~,~~ microbes, that require anaerobic conditions to live. Additionally, oxygen in the soil favors the growth of aerobic bacteria microorganisms, and macro organisms over the anaerobic organisms. In some instances, aerobic organisms may feed on the anaerobic populations, further reducing pathogen numbers.

Table 4.1.1-A
Wastewater Treatment
Processes in Soils

	Process	Effect	Conditions
Table 4.1.1- A			
	Soil filtration	Remove organic and mineral particulate matter and pathogens (primarily bacteria) in small soil voids and biomat.	Unsaturated soil best; finer textured with moderate permeability most efficient.
PHYSICAL PROCESSES	Sedimentation in soil	Remove bacteria, some viruses, and particulates by settling out on soil particles where quiescent zones exist.	More likely where flow through macropores (visible soil voids) and channels is not extensive.
	Dispersion and dilution	Reduces the concentration, but not the overall mass of the pollutant.	Most important for chemicals such as NO_3-N & CI. Affected little by other treatment processes.
	Chemisorption	Involves ionic or covalent bonds. Rapid, temporary, weak binding of trace metals, virusws, bacteria, and organic substances to surface of soil particles.	Fine-textured soils with many fine voids show more adsorption. Unsaturated flow enhances chemical-soil contact and adsorption. Organic substances and viruses can later be eluted or "rinsed out" to groundwater.

Table 4.1.1.-B
Wastewater Treatment
Processes in Soils.

	Process	Effect	Conditions
Table 4.1.1-B			
	Cation exchange	Absorption of cations (positive ions) onto negatively charged exchange sites on clay minerals and organic matter. Temporary storage for later plant or microbial uptake of K^+, Na^+, NH_4^+, Ca^{++}, Mg++, and other metal cations.	Depends primarily on clay content, type of clay minerals, organic matter content, and pH of soil. Cations are only temporarily held.
CHEMICAL PROCESSES	Precipitation	Occurs when concentration of chemical elements in sewage exceeds solubility in soil, water, and groundwater. Especially important for soil fixation of P (Phosphorus) as Fe, Al, or Ca phosphates. Phosphorus is permanently retained unless soil particles are physically eroded from site.	Aerobic conditions and neutral or high pH enhance formation of insoluble oxides and hydroxides. Fine texture and presence of Fe and Al oxides favor P precipitation in acid conditions. Presence of Ca-minerals enhances phosphorus precipitation in basic conditions.
	Complexation with organic residues	Chemical complexes formed from organic decomposition residues that are strongly bound to trace metals through chelation, chemical coagulation, ion exchange, surface absorption, and other reactions. Chemical complexes not part of living biomass.	Chemical complex formation enhanced by accumulation of organic residues and near neutral or slightly basic pH. Very low pH releases chelated metals into water.

Table 4.1.1-C
Wastewater Treatment
Processes in Soils.

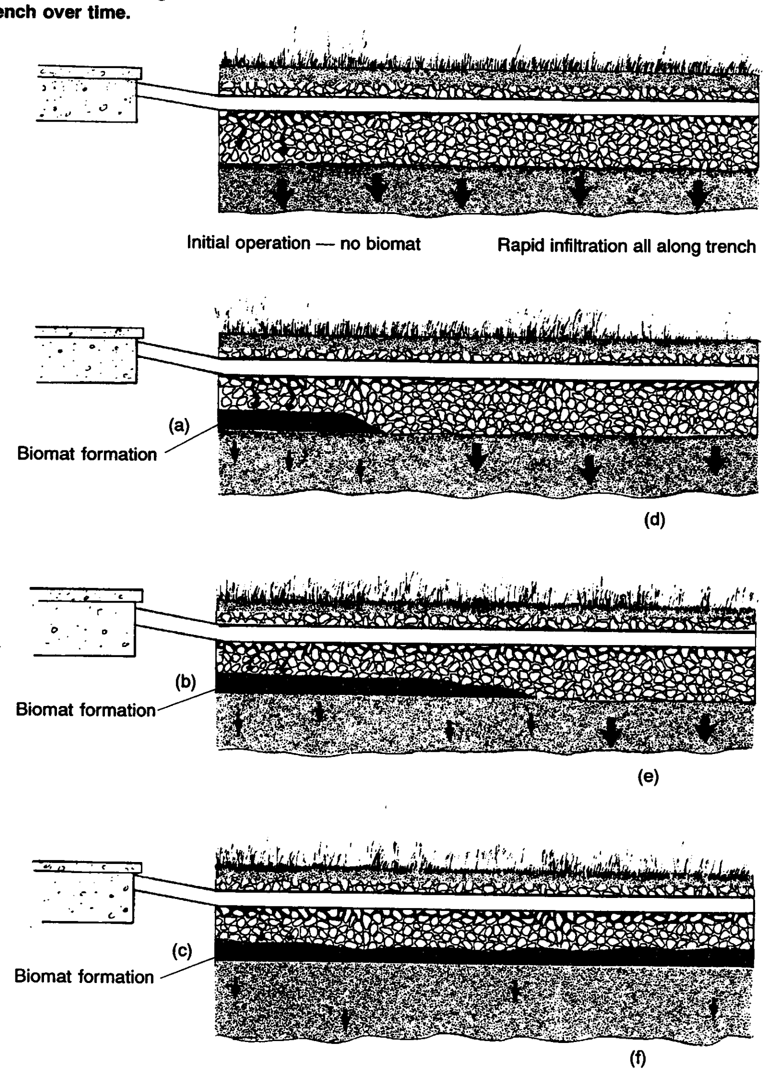
	Process	Effect	Conditions
Table 4.1.1-C			
	Biological Oxidation (Mineralization)	Oxidation and breakdown of micro-organisms and organic compounds by other micro-organisms. Mineralization of organic N to NH_4^+, and release of P, S, and other nutrients. Bacteria and fungi are most important microorganisms for biological oxidation.	Nutrients and carbon source in biomat, and aerobic conditions beneath mat enhance microbial degradation of compounds. Strongly affected by temperature. Also affected by dosing regime.
	Nitrification	A special case of biological oxidation of NH_4+ to NO_3^- by *Nitrosomonas* and *Nitrobacter* bacteria.	Only takes place under aerobic conditions.
BIOLOGICAL PROCESSES	Denitrification	Biological reduction of nitrate to nitrous oxide or dinitrogen gas (N_2) that escapes into the atmosphere.	Only takes place under anaerobic conditions with a suitable carbon source.
	Immobilization	Uptake of substance from inorganic state to organic form in microbial or plant tissues rendering the substance not readily available to other organisms. Incorporation of nutrients and heavy metals into biomass.	Immobilization and mineralization resulting from biological decomposition create the cycling of N, C, P, and S in soils. Carbon to nitrogen ratio has strong effect.
	Predation	Decreases viruses, bacteria, protozoa, and helminths.	Aerobic soil conditions necessary.
	Plant Uptake	Decreases the nutrient content (N, P, K, Ca, S, and Mg) of the wastewater by plant absorption. Also removes water from the soil.	Suitable to high yields of plant biomass.
	Inactivation	Many disease-causing bacteria cannot live without the high levels of nutrients and warm temperatures inside the human digestive tract; hence they do not compete well in a soil environment. Desiccation and enzymatic destruction of viruses, bacteria, and other pathogens (from other soil microbes) are also important.	Aerobic soil conditions and long travel times that allow natural environmental and enzymatic induced die-off to increase inactivation. High temperatures promote destruction of viruses and other pathogens.

Biomat

A significant degree of treatment occurs in the biomat in the treatment and disposal trenches. The *biomat* is a biologically active layer that covers the bottom and sides of the trenches. It is formed from complex bacterial polysaccharides and accumulated organic substances as a result of wastewater moving from the trench into the surrounding soil. A biomat is vital in obtaining a high degree of wastewater treatment and preventing the pollution of groundwater. However, excessive biomat formation may eventually clog the soil surface so that the trench can no longer absorb any wastewater. The best treatment occurs just before the biomat clogs. Figure 4.1.1 shows biomat formation over time.

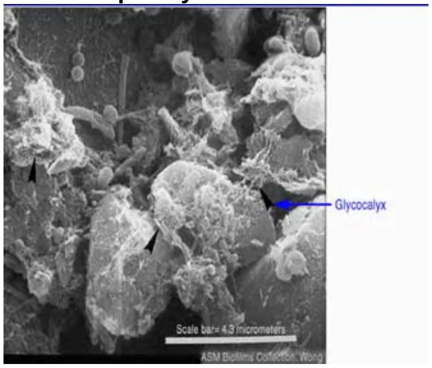
Figure 4.1.1
Biomat formation over time. Biomat forms initially at the beginning of the trench, and progresses along the entire trench over time.

Figure 4.1.1
Biomat formation over time. Biomat forms first at beginning of trench and progresses along the entire trench over time.



Architecture of Biofilm from Onsite System

Figure 4.1.2
(SEM scale bar 4.3 µm)
Biomat (biofilm)
From a septic system.



Center for Biofilm Engineering,
Montana State University
1990-present.

The architecture of biofilm (Figure 4.1.2) from an onsite system is a complex design of the base and towers. The base is a bed of dense, opaque slime ranging from five micrometers to ten micrometers in thickness. The slime is a sticky mix of polysaccharides and other polymeric substances which are produced by bacteria. Biofilm towers are colonies of bacteria shaped like mushrooms or cones that range from 100 micrometers to 200 micrometers and upward in size.

The following process describes the formation of a septic system trench over time: (Center for Biofilm Engineering, Montana Sate University, 1990-present)

- When the soil absorption system begins processing, there is no biomat present in the trench. The rate of wastewater flow out of the trench is determined by the soil;
- as the on-site system is used, the biomat forms in the trenches where the wastewater enters. The biomat progresses down the trench to eventually cover the entire length of the trench;
- the formation of the biomat begins immediately, but may take three years to eight years to form completely. The amount of time that it takes to form the biomat depends on a number of factors, including the hydraulic loading rate of the trench, the dosing schedule, the types of substances in the wastewater, and the temperature. A mature biomat will cause ponding in the trench. When ponding occurs, the upper portion of the biomat is anaerobic. If the soil under the trench is aerobic, the bottom portion of the biomat will tend to be aerobic, because oxygen will move toward the biomat from the well aerated soil;
- once formed, the biomat biologically and chemically removes or reduces many wastewater constituents. Further, it limits the rate that water can move into the soil, aiding the purification process by treating sewage with beneficial microbes;
- since the biomat limits flow from the system into the soil, the amount of wastewater loaded into the system can be no greater than the amount of wastewater that can move through the biomat into the soil. When the amount of wastewater entering the system is the same or less than the amount of wastewater exiting through the biomat and into the soil, the on-site system is considered to be at equilibrium; and
- the mature biomat of a properly functioning system is in equilibrium. The addition of organic matter by soil organisms supplies enough oxygen to maintain aerobic conditions.

Wastewater Movement Through the Soil

The rate of wastewater flow through the soil is critical. If wastewater moves too rapidly through the soil, the chemical, physical, and biological reactions that must occur to retard, reduce and transform the pollutants are impeded. Any condition that causes an increased rate of flow, high hydraulic loadings or shallow depth to seasonally high water tables can potentially cause groundwater contamination from inadequately treated wastewater.

Reference
15A NCAC 18A.1955 (m)

North Carolina soils with a Group II, II or IV soil texture require~~s~~ 12 inches of unsaturated soil between the bottom of the trench and any soil wetness condition, groundwater or other unsuitable soil condition. Research by Bauma and others has shown that 12 inches of unsaturated soil provides adequate sewage treatment in the soil groups.

Based on research performed by Cogger (1984), Group I soils (sandy soils), require an 18-inch separation distance between the trench bottom and any soil wetness conditions or the groundwater. Because the rate of wastewater movement through Group 1 soils is faster than Group II, III, or IV soils, a greater separation distance is needed to properly treat the wastewater before it enters the groundwater.

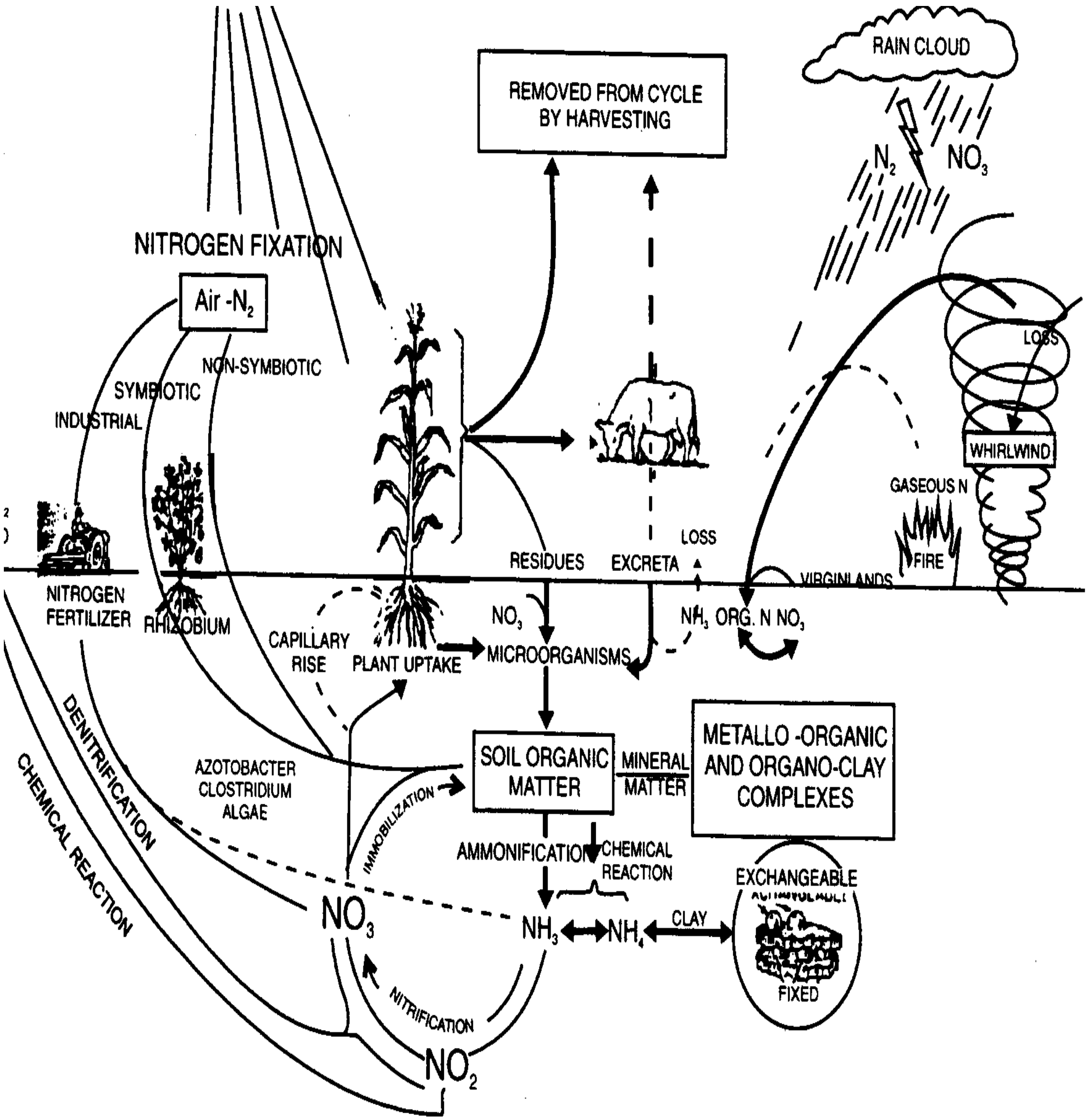
Nitrogen in On-Site Systems

Nitrogen enters domestic on-site systems mainly as organic nitrogen, which means the nitrogen is part of a large biological molecule such as protein. Bacteria and other microbes oxidize or mineralize the organic nitrogen to ammonium forms. The ammonium can be volatized to the atmosphere, used by bacteria and plants or absorbed into the biomat. The nitrate may then be released back to the atmosphere as harmless nitrogen gas through a process known as *denitrification*~~denitrification~~, if it encounters anaerobic conditions below or adjacent to the on-site system. ~~Under anaerobic conditions, nitrite can be transformed to nitrogen gas, a process known as *denitrification*.~~ Figure 4.1.3 demonstrates the nitrogen cycle: gains and losses of nitrogen in the atmosphere and soil.

Denitrification is often limited in a properly sited system because the aerobic soil conditions will not allow denitrification to occur. If nitrate is not lost through denitrification, it may cause groundwater problems. Because nitrate is not absorbed by soil it can move through the soil into the groundwater and adjoining surface waters. If there are too many on-site systems in one area, nitrate levels in groundwater may exceed the U.S. Environmental Protection Agency's Maximum Contaminate Level for nitrogen of 10 milligrams/liter (mg/l). Nitrogen levels above 10 mg/l may cause sickness or death to small babies, and other harmful effects on adults.

Denitrification is most likely to occur in anaerobic zones, such as wet soils and riparian areas next to streams.

Figure 4.1.3
The Nitrogen Cycle in Soil.
(Sauchelli, Fertilizer Nitrogen—
It's Chemisstry and
Technology, 1964.
Reprinted with permission
Of Van Nostrand Reinhold
Publishing Company,
New York, NY.)



Research by Bicki (et al., 1985) shows that of the total nitrogen produced from on-site systems, only 20 percent to 40 percent is adsorbed or removed during flow through unsaturated soils. Dilution and denitrification therefore, are the mechanisms that must be relied upon to reduce the groundwater nitrate concentrations.

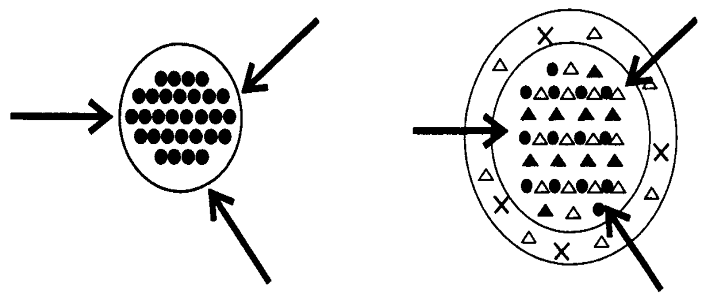
Phosphorous in On-Site Systems

Phosphorus can enter a wastewater system in a variety of forms. Organic and synthetic phosphorus are transformed by bacteria to the simple orthophosphate form. Because excess phosphorus can stimulate *eutrophication*—the excessive growth of algae and aquatic plants in streams, rivers, and lakes—it is important that phosphorus not enter water bodies in high concentrations. Fortunately, orthophosphate is usually immobilized by a number of processes in the soil.

Phosphate immobilization processes in the soil include adsorption to the soil particles or biomat, precipitation in the soil (Figure 4.1.4) or biological uptake. Most soils in North Carolina have high phosphorus fixing capacity. Reseach by Uebler (1984) has shown that phosphorus was reduced to undetectable levels 12 inches below the nitrification trench in a Cecil clay soil.

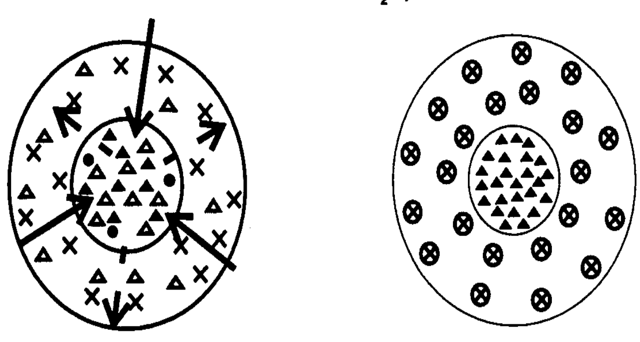
Figure 4.1.4
Phosphorus fixation in the soil.

- ● $Ca(H_2PO_4)_2 \cdot H_2O$
- ▲ $CaHPO_4 \cdot 2H_2O$
- △ H_3PO_4
- ✕ Soluble Fe, Al, Mn
- ⊗ Insoluble Fe, Al, Mn phosphates



1. Water enters a granule of water-soluble monocalcium phosphate — Ca $(H_2PO_4)_2 \cdot H_2O$.

2. As more water is absorbed by the granule and soil, phosphate (H_3PO_4) and dicalcium phosphate ($CaHPO_4 \cdot 2H_2O$) are formed.



3. The solution of phosphate (H_3PO_4) moves into the surrounding soil. The solution displaces soil elements such as iron (Fe), aluminum (Al), or manganese (Mn).

4. The iron (Fe), aluminum (Al), or manganese (Mn) react with the phosphate to form insoluble compounds. This reaction ties up the phosphorus, making it inaccessible to plants and further movement in the soil.

Other Chemical Pollutants in On-Site Systems

Wastewater from various facilities can contain a wide variety of contaminants. Common domestic sewage has at least minor levels of the pollutants as discussed below. Contaminants present in wastewater from other facilities, such as commercial and industrial establishments, vary widely and depend on the type of activities taking place in the facility generating the wastewater.

Sodium may be a problem if high levels are found in the wastewater. Sodium cations are adsorbed to the soil aggregates, which are held together by organic matter and clay. When sodium levels in wastewater are too high, the sodium may disperse the organic matter and clay in the soil. Such *soil dispersion* changes the soil structure and reduces the rate of water movement through the soil, which can cause failure of an on-site system.

Detergent surfactants—as we currently do not use many "soaps"—are removed from wastewater effluent by adsorption into soil particles and by biodegradation. Aerated soil conditions enhance biodegradation and increase the treatment of surfactants. Adsorption of surfactants not only removes them from the wastewater, but also increases the time for additional biodegradation to occur.

Toxic organic compounds, such as pesticides and non-biodegradable organic compounds degrade slowly. Since these compounds usually are not adsorbed by the soil, they may leak into and contaminate the groundwater. The best way to minimize the impact of these chemicals is to keep them out of the on-site system.

Heavy metals in high concentrations are usually toxic. Such metals can slow or stop the bacterial action in the septic tank and in the treatment and disposal trench. These metals should not be put in the on-site system. Also, these tend to be more commonly treated in the sludge layer or removed when the sludge is pumped out.

Pathogens in On-Site Systems.

Viruses, bacteria, protozoa, and worms, also known as pathogens, cause many human and animal diseases. Cholera, shigellosis, salmonella, and typhoid fevers are caused by bacteria. *Giardia* and *Cryptosporidium* are protozoa that cause dysentery. Hepatitis is caused by a viral contaminant. A properly sited soil absorption system keeps these disease organisms below the soil surface and out of contact with humans and animals. Once the disease organisms are absorbed into the soil, a variety of mechanisms described below are able to remove the organisms from the percolating wastewater prior to entering groundwater or surface water. The definitions listed below provide general information about how biological contaminants are removed by on-site systems.

Viruses – are not greatly reduced in number in the septic tank. Viruses can be removed by adsorption, filteration, precipitation, biological enzyme attack, and natural die-off in soils. Because of their smaller size, viruses may move much further in soils than other pathogens—in some instances, from meters to miles. Greater clay content, low pH, low soil moisture content, and low effluent loading rates are important factors that decrease the possibility of viral contamination of groundwater from on-site systems.

Bacteria – reside and often re-grow in the septic tank. Fortunately, bacteria are effectively removed in the soil, primarily through filtration, adsorption, and natural die-off. If the soil is unsaturated, bacteria are not usually transported more than 3 feet if the soil is aerobic. Aerobic soil does not favor the survival of anaerobic bacteria that may cause disease. If however saturated flow occurs, bacteria can move farther. Saturated flow, high wastewater effluent rates, shallow depth to soil wetness conditions or fractured bedrock may contribute to bacterial contamination from on-site systems.

Protozoa - cysts and worm eggs are largely removed by settling in septic tank sludge. Few disease outbreaks by microbes have been reported other than bacteria and viruses from subsurface wastewater disposal systems. It appears that these biologic agents are removed in the tank or treated in the soils.

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