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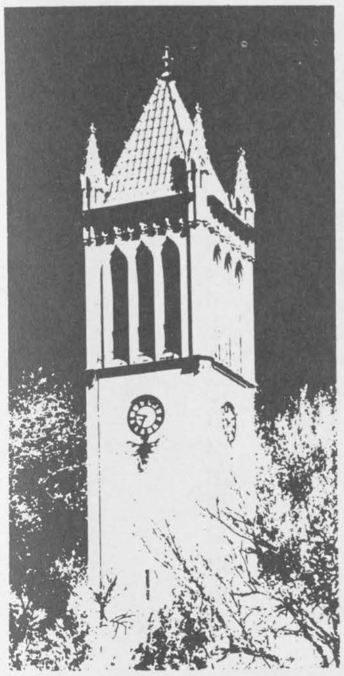

Site Evaluation, Design, Operation, and Installation of Home Sewage Systems in Iowa

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Site Evaluation, Design, Operation, and Installation of Home Sewage Systems in Iowa*

Edited by C. E. Beer

Introduction

The demand for on-site waste treatment systems for dwellings not served by sewer systems continues to grow in Iowa. On-site systems, when properly designed and maintained, provide a viable means of treating septic tank effluent. A research project was initiated at Iowa State University to provide information for solving problems associated with design, location, and maintenance of on-site systems in Iowa. This publication is designed to report the results of the interdisciplinary research and provide information for sanitarians, extension personnel, and contractors on waste treatment systems.

The subject matter is subdivided into three sections. The individual sections are written by the authors who were involved with the subject matter during the research project.

Section I contains information on the origin, description, properties, and classification of soils and on how the properties or characteristics relate to proper site evaluation for optimum waste treatment.

Section II covers the groundwater districts of Iowa. The geology and location of the water resources are discussed in relation to potential hazards of pollution as a result of waste treatment systems.

Section III provides guidance in selecting design criteria and construction methods for on-site waste treatment systems. Research results and an extensive review of literature are combined to provide the reader with the latest information on both conventional and alternative systems for waste treatment.

Section I: Soils and Soil Landscape Evaluation for Conventional Septic Tank Absorption Fields

by Gerald A. Miller, Thomas E. Fenton, and Thomas J. Bicki[1]

An Introduction to Soils

The term soil is used by many different individuals or groups of individuals. Each person or group has developed a definition of soil to meet the specific needs related to use and management of soil resources by that person or group. The average home owner has two definitions of soil: one positive and one negative. It is a positive definition if "the ground is dark brown or black, nice and mellow, and loamy." The opposite viewpoint is associated with "yellow-hard clay," which fails to make a good seedbed for a flower or vegetable garden.

Soil to a highway engineer is the unconsolidated material that is composed of solids, water, and air. If the combination of soil components is suitable, he can manipulate the material to build a roadbed. If the soil is unsuitable, it must be removed and replaced with rock and gravel or other soil material.

The farmer defines soil as a medium for plant growth. The farmer's livelihood is dependent on the productive capacity of the soil. In his framework, soils are defined in terms of color, depth, stickiness, and yield capacity.

The sanitarian and the home owner concerned with home sewage waste treatment define soil as a medium to absorb the effluent from a septic tank and to treat the organic constituents in the liquid. Soil is a medium for treatment and eventual disposal.

What Is Soil?

Soil may be broadly defined as the upper portion of the earth's crust. In a general way, soil is to the earth as a rind is to an orange, although soil is much less uniform in thickness and composition. However, this is a very general concept of soil and does not indicate the complexities associated with soil. Soil, defined on the

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basis of soil properties, is the unconsolidated material on the outermost portion of the earth's crust, ranging in thickness from a mere film to more than 10 feet. It differs from the underlying unconsolidated or consolidated material in color, texture, structure, physical constitution, chemical composition, biological characteristics, probably chemical process, and morphology (Marbut, 1951, p. 3).

Genetically, soil is a collection of natural bodies occupying portions of the earth's surface. Soils have properties that are a result of the integrated effect of climate and plants and animals that have acted on parent material, as conditioned by relief, over periods of time. These parameters are the factors that cause a soil to differ from an adjacent soil on the landscape.

The set of properties in a given soil determines how liquids are absorbed and move through soils as well as how effectively soil treats the organic constituents of liquid effluent. To understand the absorption and movement of liquids and the treatment of organic constituents in soils, sanitarians and others concerned with home sewage waste treatment need to have an understanding of the genesis and morphology of natural soil bodies.

Soil Constituents

Each individual soil has a unique combination of properties, but each individual soil also has properties common to all soils. All soils consist of solid materials and pores.

The soil solids consist of mineral and organic matter. The mineral fraction is composed of particles of rocks and minerals of various sizes. The particles are altered in size and composition by the physical and chemical alteration of rocks and minerals. In nearly all the different soils occurring in the State of Iowa, the dominant minerals present are quartz and feldspar and the weathered products from these minerals, clay minerals.

The organic component of the soil solids includes living organisms and the remains of dead organisms and plant residues in various stages of decomposition.

The volume composition of a typical mineral soil is shown in Figure 1. With increasing soil depth, the percentage of pores, solids, and organic matter changes in most soils. These changes will not occur in exactly the same proportion in adjacent soils.

Soil pores occur between individual soil particles or aggregates of soil particles (Figure 2). Pores contain air or water or both. Air and water move up, down, and laterally in the pore space.

Soil water and soil air that occupy pores differ from water and the air of the atmosphere. Water in the soil is a solution containing materials dissolved from the soil. The soil air is lower in oxygen and higher in carbon dioxide than the atmosphere. The carbon dioxide content of soil air is 10 to 100 times greater than in the atmosphere. Therefore, three phases—solid, liquid, and air—are present in all soils. However, as shown in Figure 1, the percentage of each phase will vary among soils as well as within a soil.

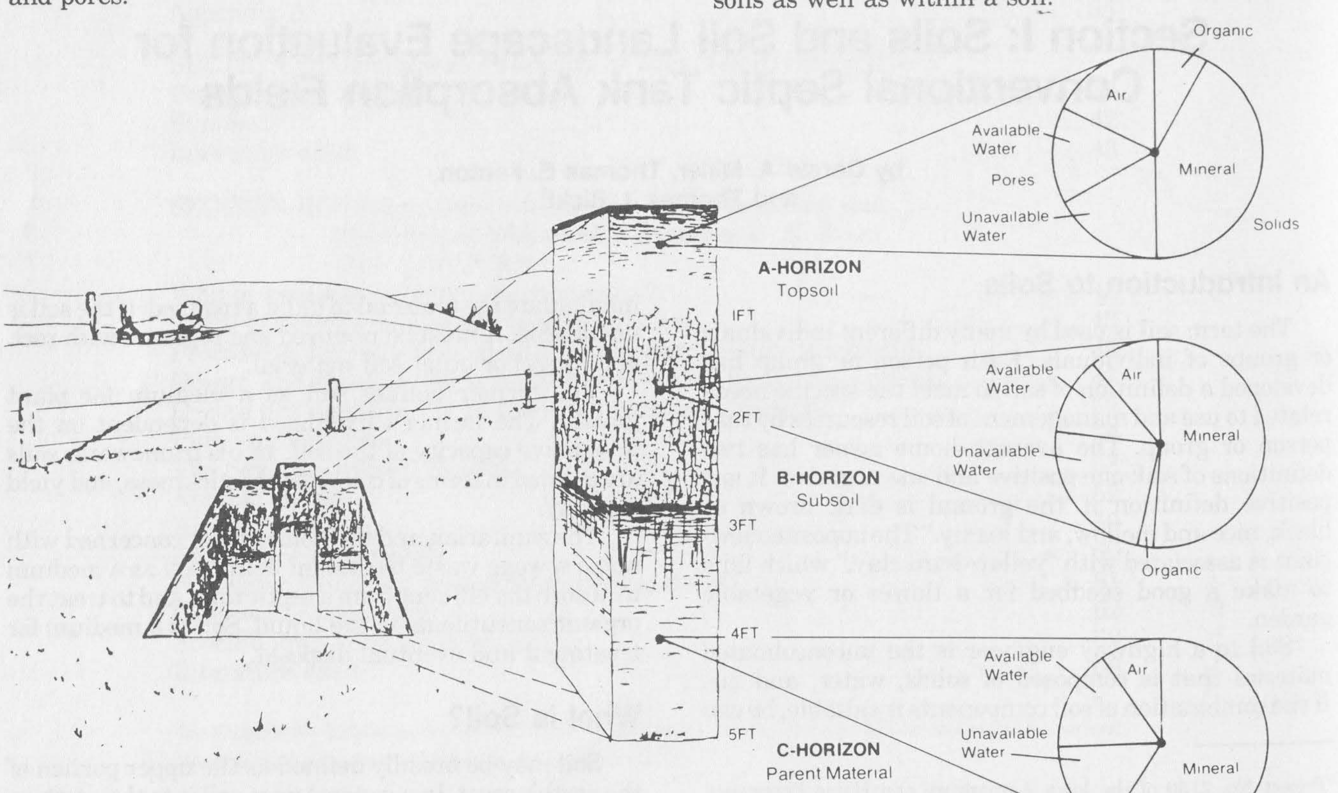


Figure 1. A soil profile showing the relationship of three major soil horizons and the changes in solid and pore distribution with depth (modified from Dunmire and Bidwell, 1960).

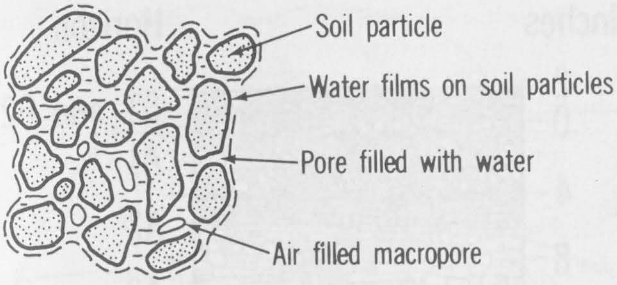


Figure 2. A schematic relationship of solids, liquids, and air in the soil.

Soil is a natural body that is the meeting place of the biological and physical forces that affect its development. The solid matter provides the framework or skeleton of the soil; the pores are analogous to a combination respiratory and circulatory system.

Soil Profiles and Soil Horizons

Individual soils are three-dimensional. Soils have depth and occupy space (Figure 3). A soil profile is a vertical section through the layers that make up a soil. It extends downward from the soil surface through the plant root zone. The depth may be as shallow as a fraction of an inch where bedrock is near the surface, or it may range to several feet where there are no restricting layers. Soil depths in Iowa are commonly between 3 and 5 feet.

Soil profiles are composed of various layers called soil horizons. The horizons form roughly parallel to the land surface under the influence of weathering and plant and microbial activity. The character of each horizon is a result of the nature of its parent material and the physical, chemical, and biological processes that have acted upon it. The changes are progressive with time, so the age of the soil is also a factor.

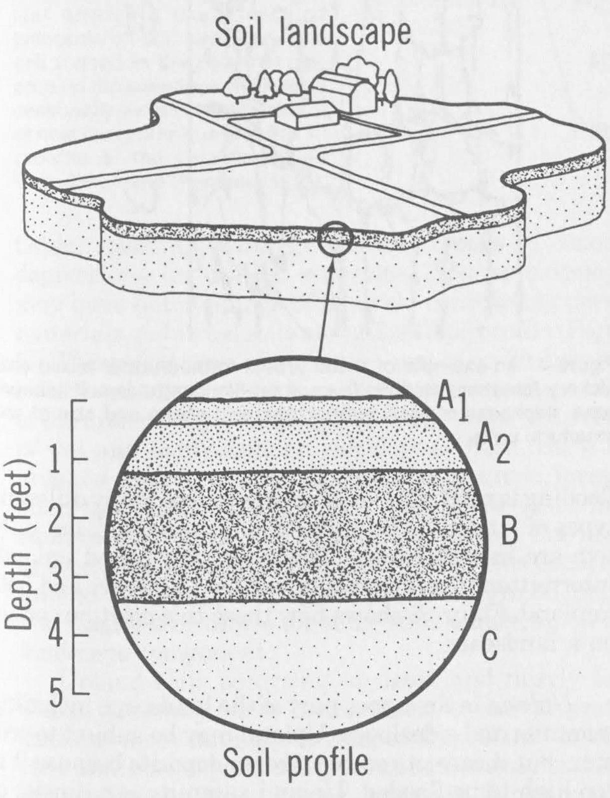


Figure 3. The relationship of a soil profile to the soil landscape.

The main horizons in soils are designated as:

- O horizon—organic layer
- A horizon—surface soil
- B horizon—subsoil
- C horizon—loose underlying material
- R horizon—bedrock

These horizons may be subdivided into parts such as A1, A2, and A3 where there are important differences within a main horizon. The various horizons can be distinguished because they differ from one another in such properties as color, texture, structure, and hardness. The change from one horizon to another may be abrupt or gradual. The thickness of soil horizons ranges from a fraction of an inch to perhaps 2 or 3 feet (Figure 4).

A horizon

The A horizon is commonly referred to as "topsoil" or surface soil. The thick, dark-colored surface probably is the best known horizon of Iowa soils. In fact, to many people this is their idea of "soil." The A horizon is the zone of the soil that has maximum biological activity. Bacteria, fungi, plant roots, insects, and small animals all contribute to the biological activity. Native prairie grasses with extensive root systems were important sources of organic matter for many Iowa soils. Well-decomposed organic matter (humus) coats the mineral particles in the A horizon and is responsible for the dark color. Layers having these characteristics are called A1 horizons unless they have been plowed.

Forest-derived soils and certain other soils commonly contain A2 horizons a few inches below the surface (Figure 4). An A2 horizon is lighter in color, lower in organic matter, and less fertile than an A1. The effect of percolating water removing clay from the A1 horizon and some organic matter from the 01, 02, and A1 horizons of the soil is most evident in the A2. Deposition of the clay in the B horizon helps produce a contrast in the clay contents of A and B horizons. Strongly developed A2 horizons commonly are underlain by B horizons with much greater clay contents than found in similar genetic-derived soils with a weak A2 horizon or lacking an A2 horizon. The greater clay content of the B horizon reduces the subsoil permeability and may cause a saturated or near saturated condition to occur for extended periods each year.

B horizon

The B horizon generally occurs immediately below the A horizon. It commonly is referred to as the "subsoil." The B horizon has less organic matter and biological activity than the A horizon. It usually is harder when dry and stickier when moist than the A horizon. These properties result from the lower organic matter level and the accumulation of clay that are characteristics of most B horizons. Color of the B horizon results primarily from the presence or absence of iron coating on the exterior of the mineral particles. The oxidation state of the iron compounds determines the color of the B horizon when iron coatings are present. When iron coatings are absent, the color of the B horizon is determined by the color of the uncoated mineral grains. In some soils, sufficient time has not elapsed for soil weathering to occur on the parent material, or the landscape has not been stable enough for a B horizon to form. These soils consist of an A horizon and a C horizon and are referred to as having A-C profiles.

C horizon

The C horizon is commonly referred to as "parent material." It occurs immediately beneath the B horizon or the A horizon in A-C profiles. The C horizon in many instances consists of material similar to that from which the A and B horizons developed, but it also may be a different geological material. The presence of two different geological materials in the same profile is called a *lithological discontinuity*. The second kind of geological material within a profile is indicated by a Roman numeral prefix, for example IIC. C horizons in general contain less clay than the B horizons. They also are lighter in color and have less organic matter than either the A or B horizons.

Additional horizons

The O horizons are layers that have high content of organic matter (generally 20 percent or more). They occur above the surface mineral horizon. O horizons consist of fresh and partly decomposed organic matter such as leaf litter or other types of forest residue. Disturbance of the soil by clearing, pasturing, or plowing will alter or destroy this horizon.

The letter "R" is used to designate underlying layers of consolidated bedrock such as limestone, sandstone, or shale. The R horizon designation is used if the overlying horizons are thought to have formed from similar rock material. If the R horizon is unlike the overlying material, however, the R is preceded by a Roman numeral, as "IIR."

Why Soils Are Different (or the Factors of Soil Formation)

A commonly accepted approach to understanding soil genesis is to examine the five soil-forming factors (Jenny, 1941): 1) relief or slope or landscape position, 2) parent material, 3) organism and native vegetation, 4) climate (rainfall and temperature), and 5) time.

Theoretically, whenever these five factors interact in a similar manner on any part of the landscape, the resulting soils will have similar characteristics. Conversely, whenever there is a significant change in any one of the factors, the soils will have different characteristics.

Landscape position and slope

Landscape position and slope are surface features that influence soil development. Position describes the location of the soil on the landscape. The potential for ponding, water erosion, or sedimentation from stream flooding is related to landscape position. Many different types of landscape positions can be described, but only five are included here. These five are called upland, intermittent drainageway, footslope, terrace, and bottomland. Figure 5 shows how these five positions occur on a landscape.

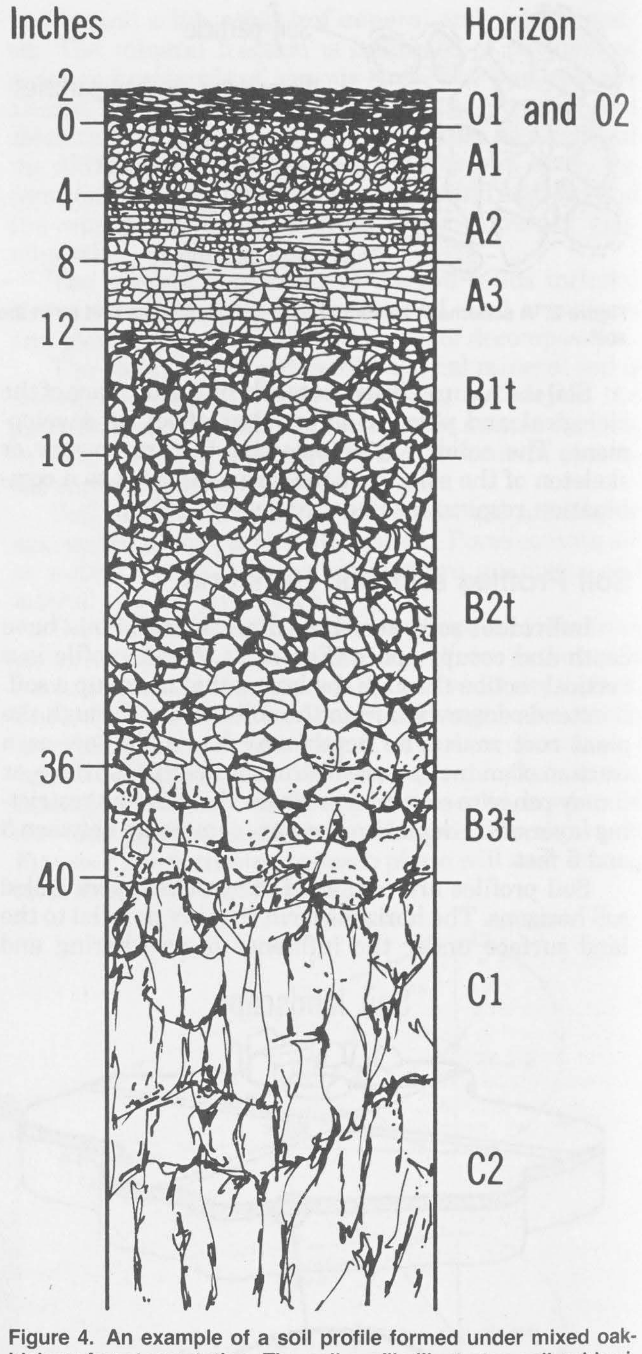
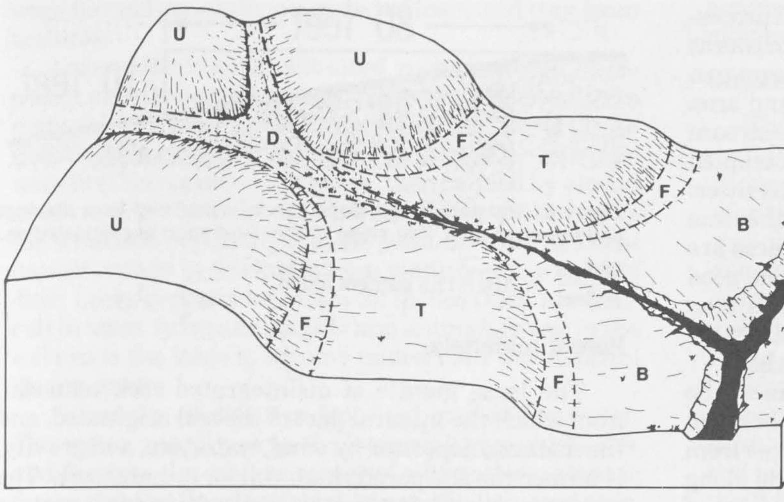


Figure 4. An example of a soil profile formed under mixed oak-hickory forest vegetation. The soil profile illustrates soil subhorizons, thickness of each subhorizon, and shape and size of soil structural units.

Upland is the upper part of the landscape including summits and sideslopes. Upland may be subject to erosion, but it cannot receive stream deposits because it is too high to be flooded. Upland summits can consist of microtopography with convex, level, and concave relief.



B = bottomland D = intermittent drainageway F = footslope T = terrace U = upland

Figure 5. A landscape diagram showing how landscape positions are related to each other (from Troeh and Miller, 1976).

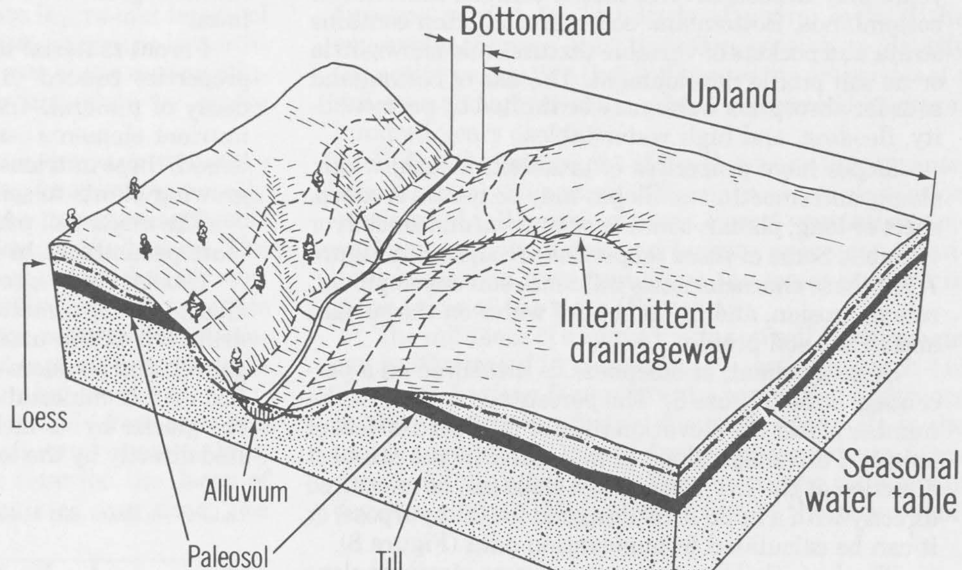


Figure 6. A diagram of a landscape and the soil parent material showing the effect of paleosols on soil formation. The soil formed in the paleosol outcrop on the sideslope will have a seasonally perched water table at or near the ground surface 8 to 10 months of the year (modified from Jones and Highland, 1971).

Often, standing water or ponding occurs in concave depressions on upland summits. Upland sideslopes may have outcroppings of bedrock, contrasting parent materials, or buried soils along the slope profile (Figure 6). These features often cause water to be perched, resulting in lateral water movement along the surface of the underlying material. The result is the occurrence of wet and seepy soils on sideslopes. Often, these are areas on the side of a hill. In these seepy areas, farmers often inadvertently bury their tractors or other farm equipment to the axles during a wet spring. The use of upland sites for septic tank absorption fields usually is limited by slope, permeability, ponding, runon, depth, and high water tables for some soils occurring on this landscape component.

Upland soils occurring on level and nearly level slopes generally have characteristics and properties that are more strongly developed than found in adjacent soils on steeper slope gradients. Some upland soils are shallow to bedrock, and some are flat enough to need artificial drainage.

Intermittent drainageway is an area where water flows through uplands and terraces during and after a rain. The water flows wide and shallow, often without a definite channel and banks. These areas become dry at other times, although tiling may be needed to achieve adequate drainage. Grassed waterways are sometimes used to protect these drainageways from erosion. The use of intermittent drainageways for absorption fields usually is limited by runon, permeability, flooding, seep, and seasonal high water tables.

Footslope is an area of moderate slope between a relatively steep area above and a relatively flat area below. The footslope is an area of accumulation of soil material that moves down from the steeper area above. The soils usually are deep. Footslopes are relatively moist sites because they receive seepage and runon water from above in addition to the normal precipitation. The use of footslope soils for absorption fields usually is limited by permeability, runon, and seasonal high water tables for some soils occurring on this landscape component.

A *terrace* is a landform developed by alluvial processes. It was a former bottomland when the stream was at a higher level. Downcutting by the present stream to a level now too low to flood the former bottomland area produces a terrace. Terraces are absent where stream levels have not changed. Some rivers have occupied various levels and thereby produced several terraces. Each terrace contains flood deposits related to the time when the stream was at that level. Many terraces are underlain by enough gravelly material to provide good drainage. On the other hand, some terrace soils may provide a potential for groundwater contamination because they have gravel layers at shallow depths.

Bottomland refers to the current floodplain of the stream, the land that may be covered with water when the stream overflows its banks. Its width ranges from narrow strips along small streams to miles wide along some major rivers. Successive floods over a period of years may deposit several feet of alluvial material in bottomlands. Bottomland soil material often contains strata and pockets of variable textures and shows little or no soil profile development. The use of bottomland soils for absorption fields may be limited by permeability, flooding, and high water tables.

Slopes have properties of gradient, length, width, shape, and smoothness. Slopes may be gentle or steep, short or long, planar, concave or convex, and smooth or variable. Some of these properties are shown in Figure 7. All these characteristics influence soil development, runoff, erosion, and movement of water on the surface and in the soil profile.

Slope gradient, or steepness, is measured on a percentage scale (Figure 8). The percentage scale tells the number of feet the elevation rises or falls per 100 feet of length. Percentage slope is measured in the steepest direction at the site. Percentage slope can be measured directly with a hand level designed for that purpose, or it can be calculated from elevation data (Figure 8).

The Iowa Soil Survey program uses standard slope classes in soil survey reports. These slope classes are listed in Table 1.

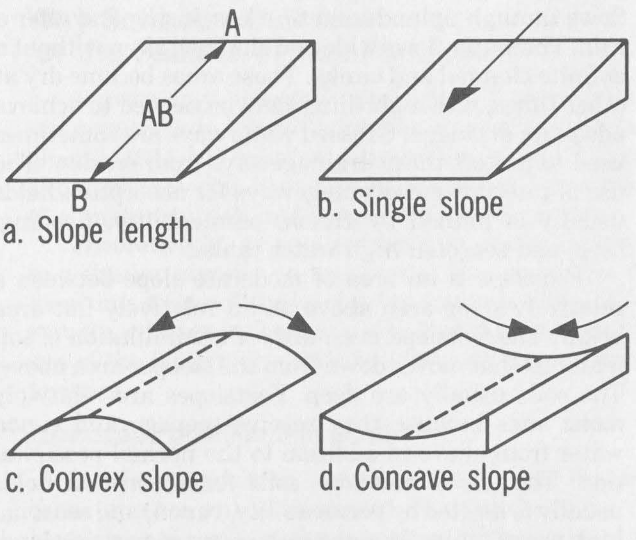


Figure 7. Slope length and typical slope shapes. (a) Slope length A to B, (b) single slope, (c) convex slope, (d) concave slope.

Figure 8. The percentage slope can be calculated from distance and elevation data. The slope in the illustration is calculated as:

$$\frac{10 \text{ feet}}{80 \text{ feet}} \times 100 = 12.5 \text{ percent slope.}$$

Parent materials

The loose mantle of disintegrated rock material, from which the mineral part of the soil originated, and the material deposited by wind, water, ice, and gravity, is termed the soil parent material for mineral soils. The parent material for organic soils is termed peat or muck. Organic soils cover only a few thousand acres in Iowa.

Parent material influences soil texture and all the properties related to soil texture. Also, the gradual decay of minerals from the parent material releases nutrient elements essential to plant growth. Once released, these nutrients may be cycled many times from growing plants to soil organic matter.

The major soil parent materials and their approximate percentages in Iowa are listed in Table 2.

Glacial drift—ground up material left by glaciers. Glacial drift is sometimes divided into till and stratified drift. Till is the unsorted mixture of clay, silt, sand, gravel, and boulders deposited by the ice sheet. Stratified drift is material that has been carried away from the glacier by its meltwater rather than being deposited directly by the ice. The tills from which Iowa soils

Table 1. Standard soil slope classes used in Iowa soil survey program.

Symbol	Slope group (percent)	Description
A or none	0-2; 0-1; or 1-2	Level and nearly level
B	2-5	Gently sloping
C	5-9	Moderately sloping
D	9-14	Strongly sloping
E	14-18 or 14-20	Moderately steep
F	18-25 or 20-30	Steep
G	>25 or 30-40	Very steep

Table 2. Parent materials of Iowa soils.

Parent material	Approximate percent of state
1. Glacial drift	40
a. Stratified drift	(8)
b. Till	(32)
2. Loess	40
3. Alluvium	15
4. Colluvium, residuum, and organic deposits	5

were formed generally consisted of loam and clay loam textures.

Loess—dominantly silt-sized rock material transported and deposited by wind. Loess is a rather uniform material with little or no obvious layering. The origin of most loess is related to glacial action. The particles were first transported by the ice, then carried by glacial meltwater to broad floodplains, and finally picked up by the wind and deposited at some point downwind. Loess deposits range in thickness from many feet to a layer of dust. Loess deposits less than 20 inches thick are difficult to identify because plants and animals living in the soil cause the loess to become mixed with the material that it covers.

Alluvium—sediments deposited by running water. The water usually sorts the material by particle size and deposits the coarser material where the current is faster and the finer material where the flow is slower. Variable flows and shifting currents cause most alluvial material to be stratified into layers and lenses of different textures. Many of the soils occurring in northern, northeastern, and eastern Iowa are formed on alluvial terraces and bottomlands underlain by coarse sands and gravels (Figure 9).

Colluvium—material that has moved down a steep slope with gravity as the driving force (water usually acts as a lubricant but not as the transporting agent) and accumulated on a lesser slope at the bottom. The movement may be either very fast (a landslide) or very slow (soil creep), but in either event, the colluvium is unsorted in contrast to the sorted nature of alluvium.

Residuum—material formed in place by the weathering of bedrock into a disintegrated mass.

Organic—organic parent materials from peat and muck have accumulated in small concave areas. Wet, poorly drained conditions have retarded the decay of organic matter that has accumulated over time. The accumulated organic matter, with small amounts of mineral matter, serves as soil parent material.

Organisms and native vegetation

The surface horizon or topsoil of most Iowa soils contains organic matter as part of the solid phase (Figure 1). Organic matter includes living organisms (plants and animals) and the decomposed remains of organisms. Therefore, the organic material in soil comes from the plants growing on the landscape as well as from the plant and animal residues that have been modified by the animals, insects, and microorganisms living in the soil.

Vegetation influences the chemical and physical properties of the soil as well as its biological characteristics. For example, a forested soil usually is more acid and has had more clay movement from the A horizon to the B horizon than a soil forming under similar conditions but with grass vegetation. The resulting soil differences persist for hundreds of years, even if the vegetation changes. It is, therefore, possible to identify the native vegetation that influenced the properties of a soil, even though the soil has been cultivated for several hundred years or more.

Before the settlement of the European immigrants, approximately 82 percent of the native Iowa vegetation consisted of tall prairie grasses. Forest vegetation consisting primarily of oak and hickory was more prominent in eastern Iowa and along the major streams in other areas of the state (Figure 10).

The influence of organic matter on soil development can be illustrated by comparing two soils for which 4 of the 5 soil-forming factors are the same. The difference in the soil-forming factors for these two soils is the native vegetation. One soil formed under native prairie grass, and the other soil formed under the influence of deciduous forest. The upper 4 feet of the prairie soil

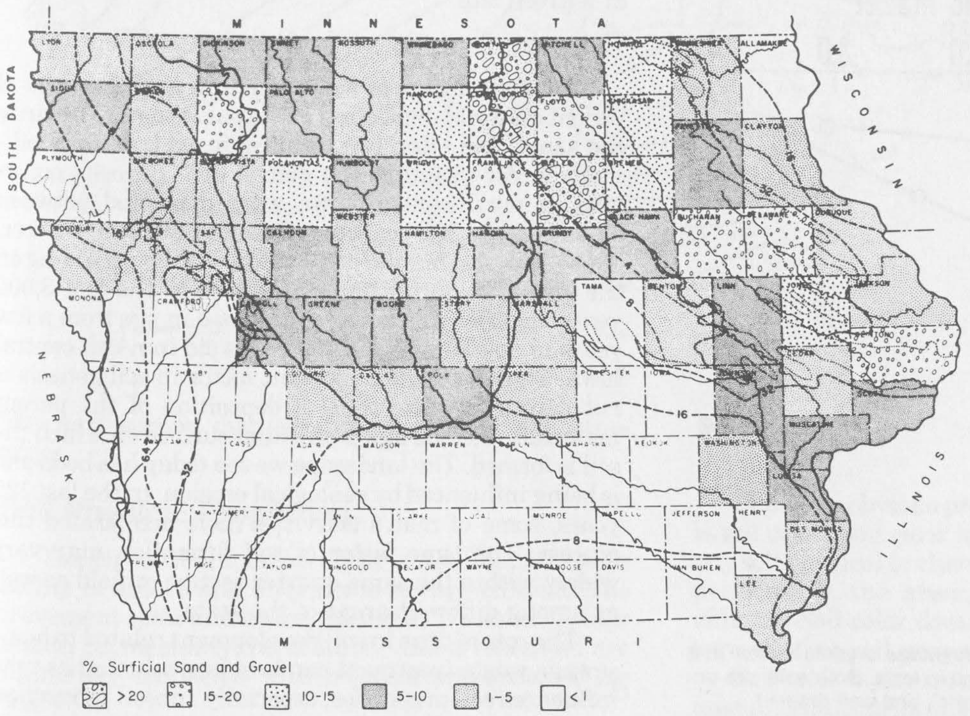


Figure 9. Distribution (%) by county of land area underlain with sand and gravels within 48 inches of ground surface. Dashed lines are isoliths denoting regional loess thickness pattern (modified from Simonson, Riecken, Smith, 1952; Hallberg, 1976).

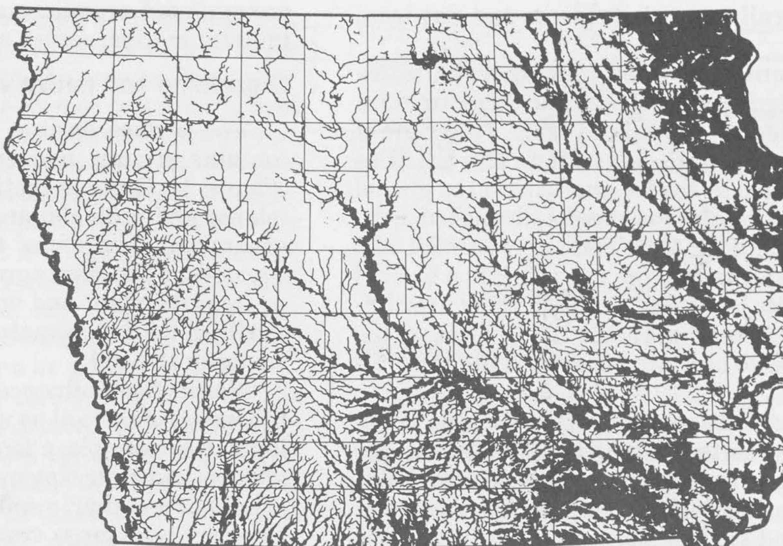


Figure 10. Map showing distribution of the original forest cover in Iowa (from Iowa State Planning Board, 1935).

contains approximately 68 tons of organic carbon per acre while the forest-derived soil has approximately 42 tons per acre in the same volume of soil. The soils differ, not only in the amount of organic carbon present, but also in its depth distribution (Figure 11). The annual addition of organic matter from the above-ground portion of trees and prairie grass is not greatly different, but the underground portion of the prairie vegetation contributes much greater amounts than do the tree roots (Figure 12). This fact helps to explain, not only the difference in amount of organic carbon present, but also the depth distribution.

Climate

Climate affects soils development both directly and indirectly. The influence of temperature and precipitation on the weathering of rocks and minerals is an example of direct effects. The speed of chemical reactions increases as temperature increases. High temperatures accelerate the weathering rate of rocks and minerals. Rainfall influences the soil directly through soil erosion and leaching losses. The average annual Iowa precipitation ranges from slightly more than 35 inches in southeastern Iowa to slightly less than 26 inches in northwestern Iowa. The direction of decreasing precipitation is, in general, a southeast to northwest vector across the state (Figure 13). The annual mean air temperature in Iowa ranges from 45°F in the northern part of the state to 52°F in the southern part. Annual average soil temperatures at a 20-inch depth are generally 2 to 5°F warmer than the air temperature at a given site.

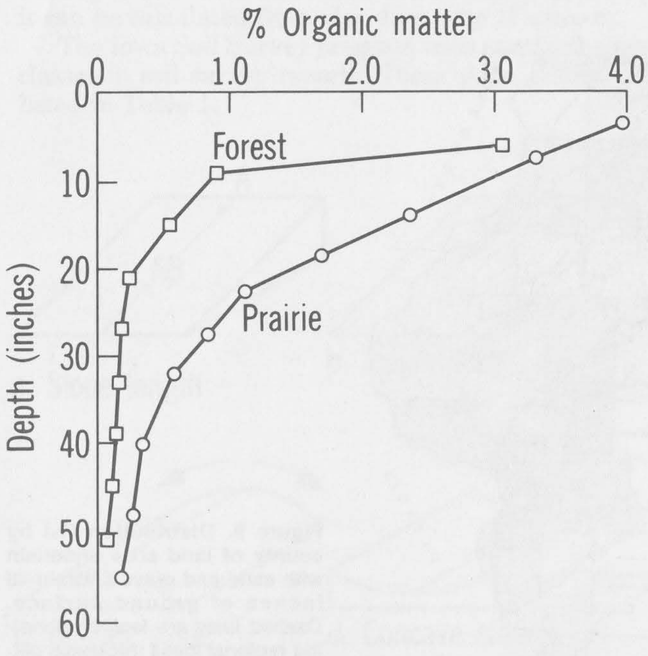


Figure 11. Depth distribution of percentage organic matter in a prairie-derived and forest-derived soil in Iowa. Both soils are uneroded, formed in loess parent material, and well drained.

Time

The time factor of soil formation and the time of parent material deposition in the past is not necessarily the same, and often has been confused by many individuals. For example, the glacial drift deposits occurring in north-central Iowa were deposited between 12,500 and 14,000 years ago. Research studies (Walker, 1966) indicate that the present soil profiles occurring on the glacial material have developed in the last 3,000 years. In other words, the soils range in age from a few years to no more than 3,000 years old in north-central Iowa. Therefore, the important factor in soil genesis is not necessarily the time of deposition of the parent materials, but the age of the land surface on which the soil is formed. The landscape we see today has been and is being influenced by geological erosion. In the last 125 years, some of man's activities have accelerated this process. The time factor of soil formation may vary widely within the same quarter section or field as well as among different areas of the state.

The role of time in soil development related to home sewage waste treatment can best be evaluated as time influences soil properties, especially subsoil properties.

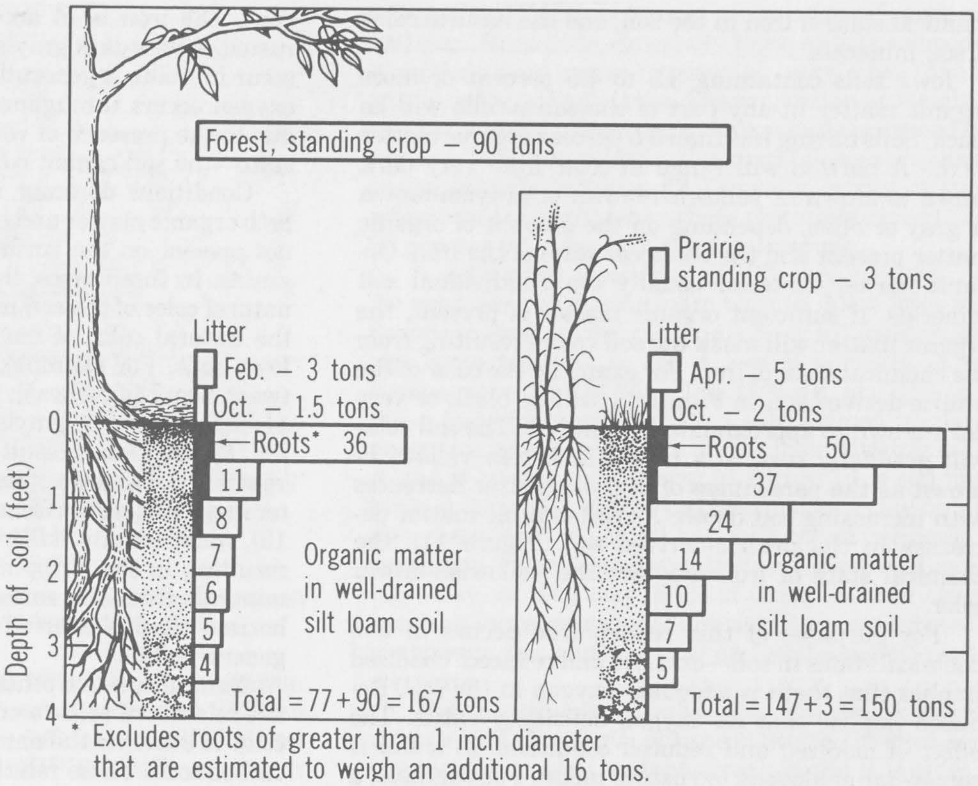


Figure 12. The distribution of organic matter in forest (white oak, black oak) and prairie (big bluestem, Indian grass) in loess-derived soils, south-central Wisconsin (from: Foth, Henry D., Fundamentals of Soil Science, 6th Ed., 1978, copyright ©. Reprinted by permission of John Wiley and Sons, Inc.).

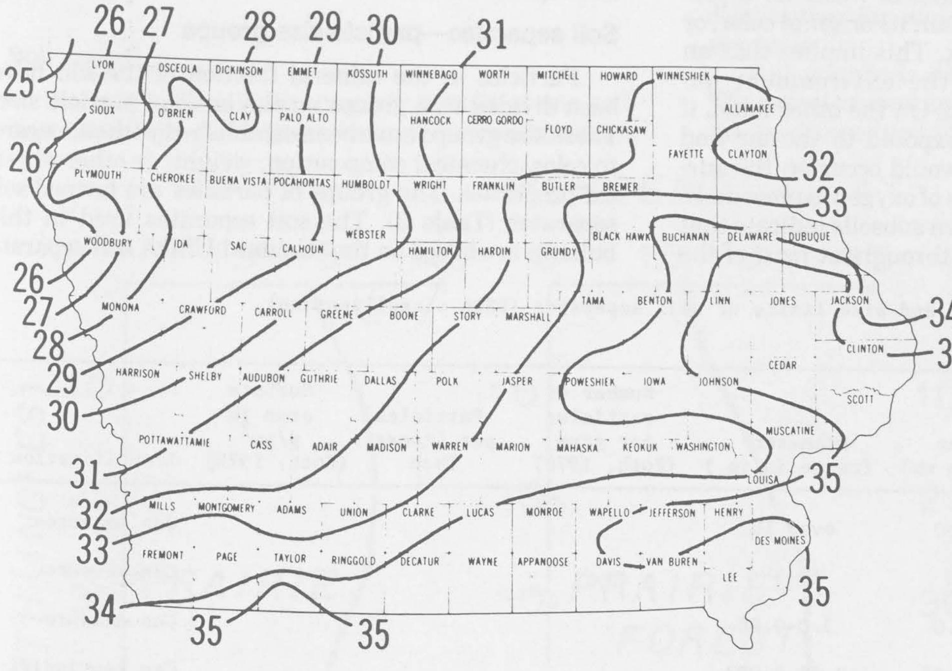


Figure 13. Average yearly rainfall, in inches, for the period 1941-1970 (information provided by the Iowa State Climatologist, Iowa Department of Agriculture).

The next section discusses many of these soil properties.

Soil Physical Properties

The physical properties of the soil influence a soil's ability to absorb and filter home sewage effluent. The movement of air and water, the depth to seasonal water tables, permeability, percolation, and aeration all are intimately connected with physical properties of the soil.

Soil color

The most obvious property of a soil to any observer is soil color. Soil color itself, however, has no effect on any soil physical or chemical properties or on how a soil performs in the absorption or filtration of sewage effluent. Soil color does provide an indication or measure of other soil properties.

Soil color is the result of three soil properties—the amount and distribution of organic matter present, the chemical state of iron in the soil, and the natural color of soil minerals.

Iowa soils containing 3.5 to 4.5 percent or more organic matter in any part of the soil profile will be black. Soils having less than 3.5 percent organic matter in the A horizon will range in color from very dark brown to brown or yellowish-brown or grayish-brown or gray or olive, depending on the amount of organic matter present and the chemical state of the iron. Organic matter material usually coats individual soil minerals. If sufficient organic matter is present, the organic matter will mask the soil colors resulting from the chemical state of iron. For example, the color of the prairie-derived soil in Figure 11 will be black or very dark brown to approximately 15 inches. The soil color will gradually turn to a brown and then yellowish-brown as the percentage of organic matter decreases with increasing soil depth. As soil organic matter decreases in the prairie-derived soil (Figure 11), the chemical state of iron provides the yellowish-brown color.

For purposes of this report, iron occurs in two chemical states in soil—oxidized and reduced. Oxidized implies that there is adequate oxygen in the soil. Reduced implies that an oxygen deficiency exists. The effect of oxidized and reduced conditions in a soil is somewhat analogous to rusting metal. For example, a piece of iron placed in a container of water for a prolonged period generally will retain its original color, or it will turn dark gray or black. This implies that an oxygen deficiency exists in the environment immediately surrounding the iron. On the other hand, if the same piece of iron were exposed to the air and allowed to dry, rust probably would occur on the surface. This implies that an excess of oxygen is present. In soils, yellowish-brown and brown subsoils indicate that an excess of oxygen is present throughout most of the year. The iron is in an oxidized state—the soil has rusted. Where dark grayish-brown, gray, or olive colors occur in a soil, it generally implies that a deficiency of oxygen occurs throughout most of the year, probably due to the presence of water. The iron is in a reduced state—the soil cannot rust.

Conditions do occur in some soil horizons where both organic matter and iron have been removed or are not present on the surface of individual soil mineral grains. In these cases, the soil color is a result of the natural color of the soil minerals. Light gray or gray is the natural color of most soil minerals occurring in Iowa soils. For example, the color of the horizon between 8 and 14 inches in the forest-derived soil (Figure 11) is light gray or grayish-brown. This is the A2 horizon (Figure 4) that resulted from the influence of forest vegetation. Because of the low amount of organic matter in the surface horizons of forest-derived soils (Figure 12), water readily infiltrates into the surface horizon, resulting in the stripping of organic matter and clay minerals from the surface of the soil minerals. This horizon often is referred to as an "ash" horizon by the general public.

Sanitarians and others interested in understanding the relation of soils to effluent absorption can use soil color to evaluate the natural drainage classes of undisturbed soils. These relationships will be discussed in a subsequent section.

Soil separates—particle-size groups

Particles in the mineral fraction of the soil have been divided into groups on the basis of particle size. These size groups have been established without regard to color, chemical composition, weight, or other physical properties. The groups of particles are termed soil separates (Table 3). The soil separates used in this bulletin are based on the standard USDA soil-separate

Table 3. Some characteristics and size limits of soil separates (USDA classification).

Soil separate	Diameter (range in mm)	Diameter (range in in.)	Number of particles per gram (Foth, 1978)	Particles per linear inch	Surface area in g/cm^2 (Foth, 1978)	Identification
Stone	over 250	over 10				Can measure
Cobble	250-70	10-3				Can measure
Gravel	75-2.0	3.0-0.08				Can measure
Sand	2.0-0.05	0.08-0.002				Can see individual grains,
Very coarse sand. .	2.0-1.0	0.08-0.04	90	12-25	11	feels gritty.
Coarse sand	1.0-0.5	0.04-0.02	720	25-50	23	Analogous to
Medium sand	0.5-0.25	0.02-0.01	5,700	50-100	45	table salt
Fine sand	0.25-0.10	0.01-0.004	46,000	100-250	91	crystals.
Very fine sand. . .	0.10-0.05	0.004-0.002	722,000	250-500	227	
Silt.	0.05-0.002	0.002-0.00008	5,776,000	500-12,500	454	Feels smooth like talc or flour.
Clay.	Less than 0.002	Less than 0.00008	90,260,853,000	more than 12,500	8,000,000	Sticky when wet Hard when dry

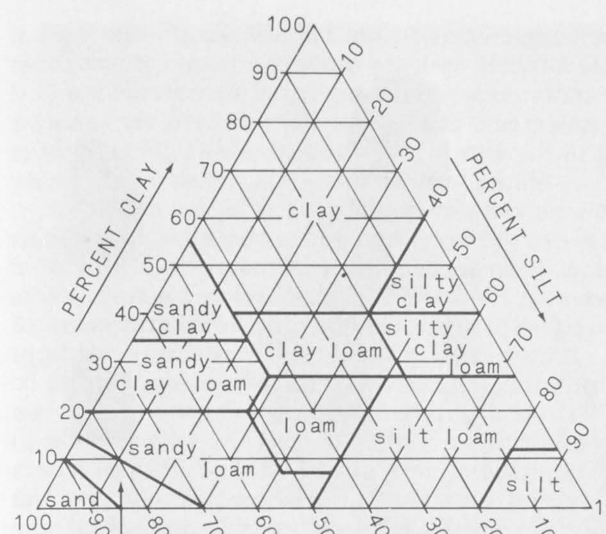


Figure 14. Standard USDA triangle for determining the 12 soil textural classes (modified from Soil Survey Staff, 1951).

categories (Soil Survey Staff, 1951). The soil-separate categories used by the American Association of State Highway and Transportation Officials (AASHTO) and the Department of Defense (UNIFIED) differ at certain size ranges.

Soil texture

Natural soils seldom or rarely consist of one soil-separate category in a given horizon or throughout the soil profile. Most soils consist of a mixture of sand, silt, and clay. Some soils, especially those soils developed in glacial-derived parent material, may also include gravel, cobbles, and stones. The proportion by weight of sand, silt, and clay that occurs in a sample is termed soil texture. The 12 standard soil textural classes are shown on the triangle in Figure 14. Gravelly, cobbly, or stony adjectives are added when these materials exceed 15 to 20 percent by volume of the total sample.

A soil horizon consisting of 30% clay, 67% silt, and 3% sand has a silty clay loam texture. Most Iowa soils formed in loess parent materials have silt loam or silty clay loam textures in the A and B horizons. A soil horizon consisting of 25% clay, 40% silt, and 35% sand has a loam texture. Most Iowa soils formed in glacial parent materials have loam or clay loam textures in the A and B horizons. As shown in Figure 14, a soil must have at least 40% clay to be classified as a clay or silty clay. Less than 5% of all the soils occurring north of Interstate 80 in Iowa have textural classes of sandy clay, clay, or silty clay. Soils of these textural classes covering large geographic areas in Iowa are limited to counties in the south-central and southeastern part of the state.

The percentages of sand, silt, and clay generally change over the length of the soil profile. In most soils, the maximum clay content occurs in the B horizon or subsoil. Figure 15 shows a typical clay content depth distribution for soils influenced by different native vegetation.

Soil texture is determined in two different ways. The actual percentages by weight of sand, silt, and clay can be determined by a laboratory procedure called a

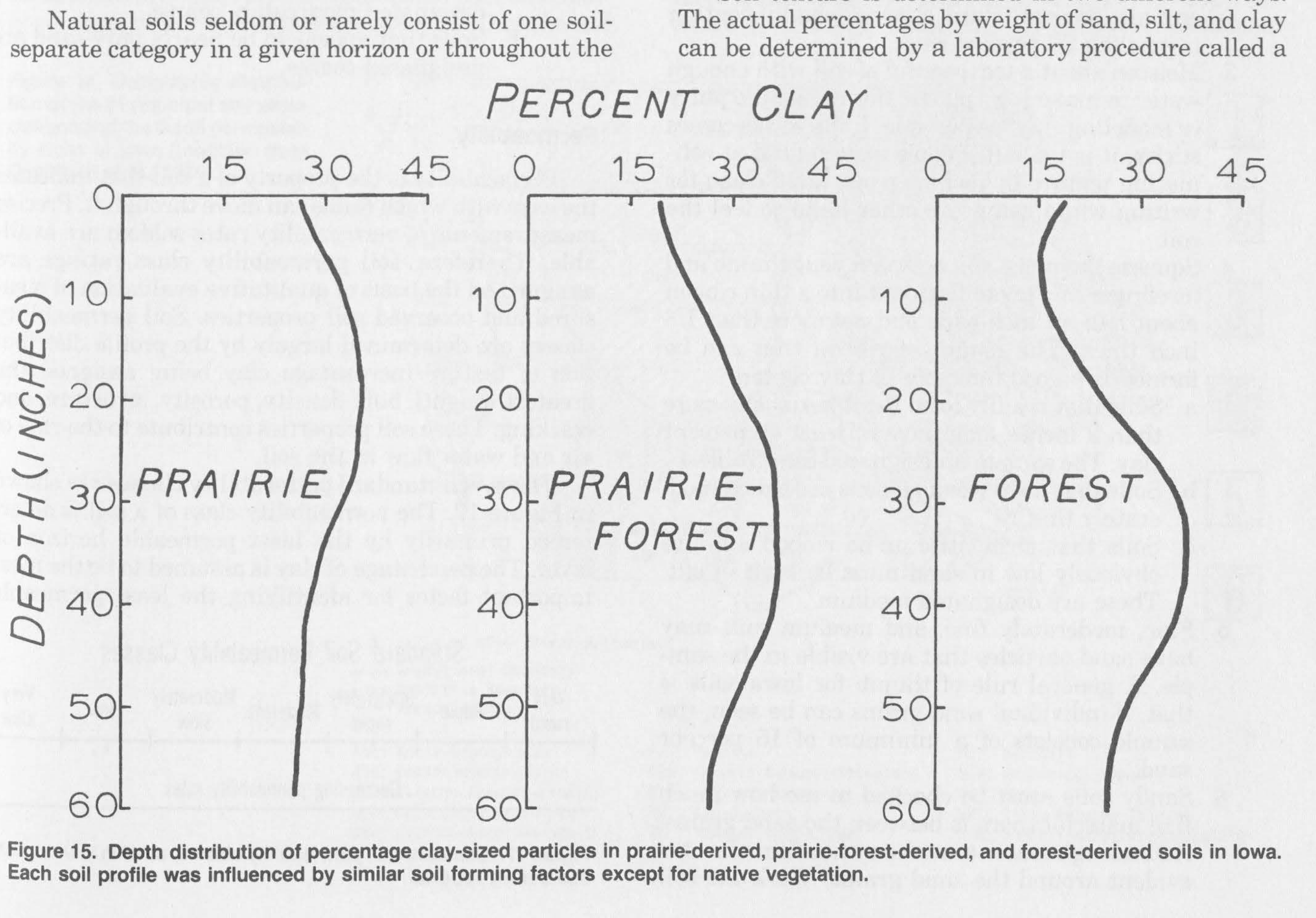


Figure 15. Depth distribution of percentage clay-sized particles in prairie-derived, prairie-forest-derived, and forest-derived soils in Iowa. Each soil profile was influenced by similar soil forming factors except for native vegetation.

Table 4. Textural groupings and range in percent of sand, silt, and clay of soil classes.

Textural group	Soil class	Range in percent of: Sand	Silt	Clay
Coarse	Sand	85-100	0-15	0-10
	Loamy sand	70-90	0-30	0-15
Moderately coarse. .	Sandy loam	43-80	0-50	0-20
Medium	Silt	0-20	80-100	0-12
	Loam	23-52	28-50	7-27
	Silt loam	0-50	50-88	0-27
Moderately fine. . .	Sandy clay loam	45-80	0-28	20-35
	Clay loam	20-45	15-53	27-40
	Silty clay loam	0-20	40-73	27-40
Fine	Sandy clay	45-65	0-20	35-55
	Silty clay	0-20	40-60	40-60
	Clay	0-45	0-40	40-100

mechanical analysis. In the field, however, it is necessary to estimate the soil texture by feeling it with the fingers. To facilitate field texture estimates, the 12 soil textural classes can be reduced to 5 textural groups (Table 4).

The field procedure for determining the five textural groups is summarized below and in Figure 16.

1. Look at the soil to see whether it seems sandy, silty (floury), or clumped into groups or masses of particles.
2. If the soil is dry, check the hardness of clumps if any are present. Hard clumps usually contain more than 20 percent clay.
3. Moisten about a teaspoonful of soil with enough water to make it as plastic (formable like putty or modeling clay) as possible. If the soil becomes sticky, it is too wet. People experienced at estimating texture by feel keep one hand clean for writing while using the other hand to feel the soil.
4. Squeeze the moist soil between your thumb and forefinger and try to flatten it into a thin ribbon about half an inch wide and not more than 1/8 inch thick. The length of ribbon that can be formed is a good indicator of clay content.
   a. Soils that readily form flexible ribbons more than 2 inches long have at least 40 percent clay. The sample is designated fine (Table 4).
   b. Soils that form weak ribbons are called moderately fine.
   c. Soils that form little or no ribbon and are obviously low in sand must be high in silt. These are designated medium.
5. Fine, moderately fine, and medium soils may have sand particles that are visible in the sample. A general rule of thumb for Iowa soils is that, if individual sand grains can be seen, the sample consists of a minimum of 15 percent sand.
6. Sandy soils must be checked to see how much fine material there is between the sand grains. Add enough water to make a thin film of water evident around the sand grains. Work the soil into a thin layer to see how much fine material there is.
   a. Sandy soils with obvious fine material abundant enough to make the hand dirty are designated moderately coarse.
   b. Soils that appear to be nearly pure sand are designated coarse.

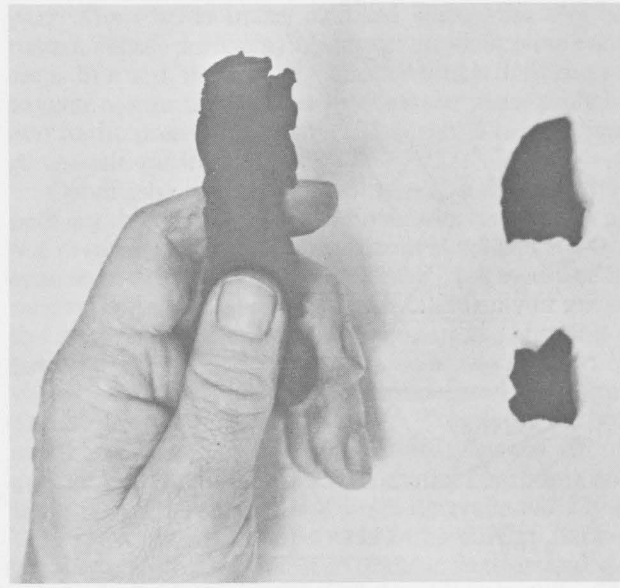


Figure 16. Ribbon test for soil texture. The ribbon formed on the left is soil of the fine textural group. The ribbon formed on the upper right is soil of the moderately fine textural group, and the ribbon formed on the lower right is soil of the medium textural group (modified from Troeh and Miller, 1976).

Permeability

Permeability is the property of a soil that indicates the ease with which fluids can move through it. Precise measurements of permeability rates seldom are available. Therefore, soil permeability class ratings are assigned on the basis of qualitative evaluation of measured and observed soil properties. Soil permeability classes are determined largely by the profile distribution of texture (percentage clay being assigned the greatest weight), bulk density, porosity, structure, and cracking. These soil properties contribute to the rate of air and water flow in the soil.

The seven standard permeability classes are shown in Figure 17. The permeability class of a soil is determined primarily by the least permeable horizon or layer. The percentage of clay is assumed to be the most important factor for identifying the least permeable

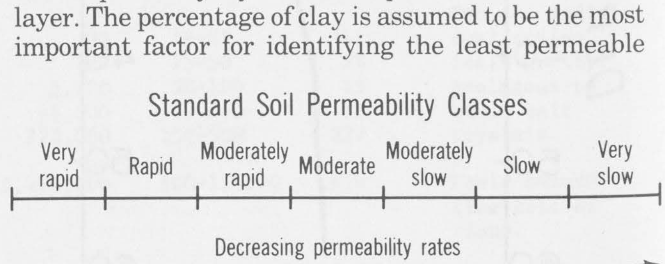


Figure 17. Standard soil permeability classes used in Iowa county soil survey reports.

horizon (see Figure 15), but bulk density and percentage porosity also are important factors. Because some Iowa soils are formed in more than one parent material, such as loess over till, loam over sand and gravel, or sand over till, these soils often have more than one permeability class assigned for the soil profile.

A general rule of thumb is that soils having a permeability class of moderate or greater will have satisfactory percolation test results. This assumes that seasonally perched water tables are absent or have been lowered by artificial drainage at the time the percolation test is performed.

Soils having moderately slow permeability ratings usually provide marginal percolation test results (assuming that seasonally perched water tables are absent or artificially lowered at the time the percolation test is performed). Soils rated as having slow or very slow permeability classes will, in nearly all instances, have unsatisfactory percolation test results.

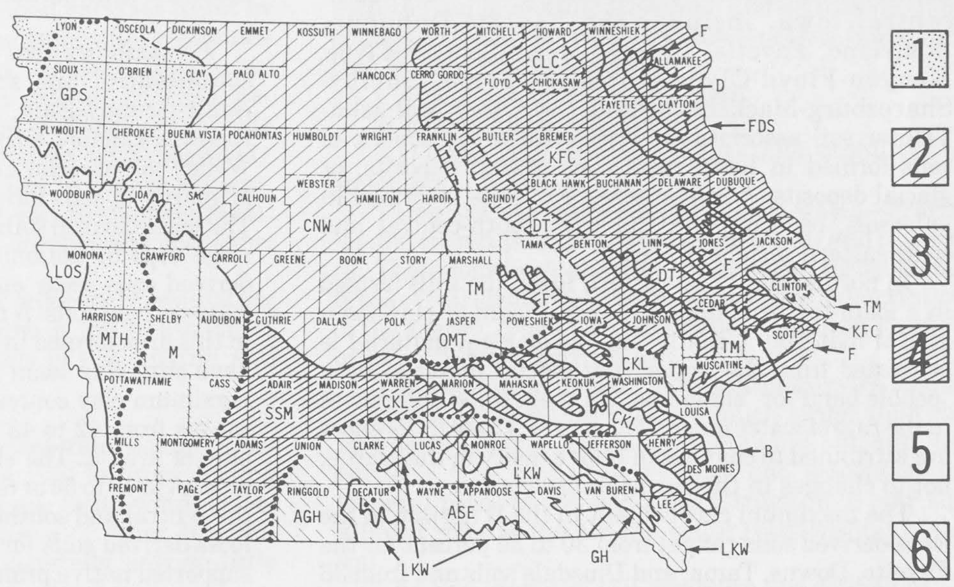
Figure 18 illustrates the general soil association areas of Iowa and their related permeabilities. On the basis of the dominant soil parent material and associated soil textural classes of the soil association areas, general comments concerning soil permeability are outlined. In this discussion, the 21 major soil association areas occurring in Iowa (Figure 18) are grouped into 6 soil permeability areas. These areas are ranked in increasing order of the total acreage in each area having permeability restrictions for conventional septic tank absorption fields. Comments concerning permeabilities are made on the assumption that seasonally perched, high water tables are absent or that the soil has artificial drainage systems installed for soils requiring drainage. Also, comments concerning the major soil parent materials of the area are not meant to imply that other soil parent materials do not occur in the area. The discussion addresses soils occurring on upland landscapes unless specific comments are made for other soils and landscape positions.

Permeability area 1. Area 1 (Figure 18), located in northwestern, western, and southwestern Iowa, includes the Moody, Galva-Primghar-Sac, and Monona-Ida-Hamburg soil association areas. The soil areas consist of soils formed primarily in loess deposits. In the northwestern sector of this area, some soils are formed in glacial deposits.

The soils formed in loess have silt loam and silty clay loam textures. Silty clay loam textures occur in the upper 20 to 35 inches of the soil profile in many of the soils occurring in the northwestern sector of area 1. These soils are characterized by moderate and moderately rapid permeable horizons. Approximately 95 percent or more of the soil acreage in this area will have moderate or greater permeability classes.

Permeability area 2. Area 2 (Figure 18), located in north-central Iowa, includes the Clarion-Nicollet-Webster soil association area. This soil area consists of soils formed primarily in glacial and lacustrine deposits. These soils are characterized by moderate and moderately rapid permeable horizons. Most of the soils have textures in the medium textural group (Table 4). Some of the soils occurring in upland depressions,

Figure 18. Geographic distribution of the 21 principal soil associations and the 6 soil permeability areas of Iowa (modified from Oschwald et al., 1965).



B: Soils of Miss. River bottomland

•••• Gradational Boundary
--- Tentative Boundary
—— Abrupt Boundary

AGH: Adair-Grundy-Haig
ASE: Adair-Seymour-Edina
CKL: Clinton-Keswick-Lindley
CLC: Cresco-Lourdes-Clyde
CNW: Clarion-Nicollet-Webster
D: Downs
DT: Dinsdale-Tama
F: Fayette
FDS: Fayette-Dubuque-Stonyland
GPS: Galva-Primghar-Sac
GH: Grundy-Haig
KFC: Kenyon-Floyd-Clyde
LKW: Lindley-Keswick-Weller
LOS: Luton-Onawa-Salix
M: Marshall
MIH: Monona-Ida-Hamburg
Mo: Moody
OMT: Otley-Mahaska-Taintor
SSM: Shelby-Sharpsburg-Macksburg
TM: Tama-Muscatine

however, will have silty clay loam textures in the upper 15 to 30 inches of the profile. Also, parts of southern Webster County and areas in Hamilton, Wright, Hancock, Winnebago, Kossuth, and minor acreages in all counties in this area have soils formed in lacustrine deposits. These lacustrine-derived soils have textures in the moderately fine and fine textural groups (Table 4). The permeability of many of the lacustrine soils is moderately slow and slow, depending on the amount of clay in the soil. Generally, the maximum clay in the B horizon of these soils is 44 to 47 percent. Overall, approximately 90 percent or more of the soil acreage occurring in area 2 has moderate or greater permeabilities.

Permeability area 3. Area 3 (Figure 18), located in west-central, southwestern, and east-central Iowa, includes the Marshall and Tama-Muscatine soil associations. These soil areas consist of soils formed primarily in loess. A minor acreage of soil formed in paleosols and glacial deposits and occurs on the lower sideslopes. Soils formed in loess in this area have silty clay loam textures in the A and B horizons. The maximum clay content in the B horizon of these soils is 30 to 36 percent. The permeability of the loess soils is moderate. Soils formed in glacial material and paleosols will have moderately slow or slower permeability rates. Overall, approximately 85 percent or more of the soil acreage occurring in area 3 has moderate or greater permeability classes.

Permeability area 4. Area 4 (Figure 18), located in northeastern, eastern, southeastern, and west south-central Iowa, includes the Fayette-Dubuque-Stonyland, Fayette, Downs, Cresco-Lourdes-Clyde, Kenyon-Floyd-Clyde, Dinsdale-Tama, Shelby-Sharpsburg-Macksburg, and the Otley-Mahaska-Taintor soil associations. These soil areas consist of soils formed in loess, loess over glacial deposits, or glacial deposits. A minor acreage of soils is formed in paleosols, especially in the west south-central and southeastern sectors of area 4.

In northeastern and eastern Iowa, the soils formed in a loam-textured material over a loam or clay loam glacial material. Usually, the upper loam material is separated from the underlying glacial material by a "pebble band" or "stone line." In these soils, differences in the rate of water movement occurs. These differences are attributed to changes in bulk density in the profile, not to changes in the permeability classes.

The maximum clay content in the B horizon of the loess-derived soils ranges from 30 to 36 percent for the Fayette, Downs, Tama, and Dinsdale soils and from 36 to 42 percent for the Sharpsburg, Macksburg, Otley, Mahaska, and Taintor soils. The permeability of the loess-derived soils is moderate. Most soils formed in glacially derived material have a moderate permeability. Some of the glacially derived soils have moderately slow permeabilities. Overall, approximately 75 percent or more of the soil acreage occurring in area 4 has moderate or greater permeability classes.

Permeability area 5. Area 5 (Figure 18), located in western, south-central, and south-eastern Iowa includes the Luton-Onawa-Salix soil association area of the Missouri River bottomland, the Clinton-Keswick-Lindley association in parts of south-central and southeastern Iowa, and the soils of the Mississippi River bottomland in southeastern Iowa. Soils of these associations include soils formed in loess and glacial deposits in parts of south-central and southeastern Iowa. A minor acreage of soils formed as paleosols in the Clinton association area of south-central and southeastern Iowa. Soils occurring in the Missouri River bottomland often have two-story profiles. That is, fine material over coarse material or coarse material over fine material. Some soils occurring in the Missouri River bottomlands have textures in the coarse textural groups (Table 4) while other soils are dominated by textures of the fine textural group.

The loess-derived soils in this permeability area occur on narrow, convex ridge tops. The glacially derived soils occur on the steeper sideslopes, downslope from the loess material. Most of the loess-derived soils, as well as the glacially derived soils, were supporting native forests at the time of European settlement. The maximum clay content in the B horizon of the loess-derived soils in south-central and southeastern Iowa ranges from 35 to 42 percent. Most of these loess-derived soils were formed under native oak-hickory forest. The soils formed in glacial deposits in these same areas also developed under a forest influence. The permeability of both the loess and glacially derived soils in this area is moderately slow. Overall, approximately 50 percent of the soil acreage occurring in area 5 has moderate to moderately slow or greater permeabilities.

Permeability area 6. Area 6 (Figure 18), located in south-central and southeastern Iowa, includes the Adair-Grundy-Haig, Adair-Seymour-Edina, Clinton-Keswick-Lindley, Grundy-Haig, and Lindley-Keswick-Weller soil association areas. These soil areas consist primarily of soils formed in loess and glacial deposits. The loess-derived soils occur on the broad flats forming ridge tops or summits in the upland. The glacially derived soils occur on sideslopes, downslope from the loess-derived soils. A minor, but sizable acreage of soils in this area formed in paleosols. The loess-derived soils have silty clay loam or silt loam A horizons, but the maximum clay content in the B horizon of these soils ranges from 42 to 48 percent for soils in the northern part of area 6. The clay content in the B horizon increases to 48 to 56 or 60 percent for loess-derived soils in the central and southern portion of area 6. Most of the loess-derived soils formed under an environment that supported native prairie grasses. The glacially derived soils generally have characteristics derived from a forest vegetative influence. Overall, approximately 80 percent or more of the soil acreage occurring in area 6 has a moderately slow, slow, or very slow permeability class.

Field and laboratory procedures have been developed to measure soil permeability rates. These procedures are time consuming and difficult to perform. Usually, the procedures are used only in research investigations. It is important to understand that permeability values obtained from these investigations, expressed in rate per time, have not been directly correlated with percolation test data for Iowa soils. Users of this publication are encouraged to use the qualitative permeability terms, very rapid, rapid, etc., and not to attempt to directly correlate percolation test data with quantitative permeability data listed in published soil survey reports.

Soil texture, permeability, and percolation rates

Sand particles are of comparatively large size and expose little surface area compared with the surface area exposed by an equal weight of silt or clay particles (Table 3). Sand-sized particles increase the size of spaces between particles, resulting in greater rates of movement of air and water than do silts and clays. However, the total exposed surface area of sands, when compared with fine silts and clay-sized particles, is small, and soil horizons having high sand content provide minimum potential for filtering and absorbing sewage effluents.

The great increase in surface area per gram of silt and clay, compared with sand, suggests that soils dominant in silt and clay such as loam, silty clay loam, or clay loam provide increased filtering and absorption potential. Clay-sized particles in Iowa soils are composed of minerals that differ greatly in composition and properties from the minerals that are silt- or sand-sized. The shape of individual sand- and silt-sized particles usually is described as spherical, and clay particles are described as platy. Clay-sized particles have a high surface area, and a large part of the water is held as a film on the surface of the clay particles. The chemical and physical properties of clay-sized particles result in the ability of these particles to adsorb water molecules and sewage effluent. In addition, the platy-shaped clay particles have edges that are negatively charged. Because of the negative charge, clay particles are capable of providing an exchange reaction with positively charged inorganic and organic ions in sewage effluent. This reaction allows the soil, not only to absorb effluent, but also to filter and remove organic and inorganic nutrients in sewage effluent.

Soil texture is an important property in evaluating a soil for its potential to perform in the treatment of sewage effluent. The interaction of soil texture and effluent can be summarized:

1. Soil texture has a significant influence on movement of water in soil horizons. Soil horizons having coarse textural groups tend to have faster water movement rates than do soil horizons of other textural groups. Coarse-textured soils generally provide little filtering or treatment of sewage effluents.
2. Soils high in silt content tend to flow and may clog soil absorption systems.
3. Research has shown that the best soil texture for percolation and removal of organic materials from effluent is moderately coarse and medium textural groups (Table 4).
4. Soil absorption systems in fine-textured soils usually fail sooner than systems in coarse-textured soils.
5. In many soils, the permeability of soil horizons changes throughout the depth of the soil profile as soil texture changes in succeeding horizons. The permeability potential of a soil profile seems to be limited by the least-permeable horizon. Research suggests that, as the size of pores becomes smaller and the size and shape of soil structural units change, there is an increasing tendency for water to move laterally (Bicki, 1977).

Soil particle size, the related soil texture, and the textural distribution in soil profiles are keys to understanding and evaluating soil water movement. Particle size and related soil textural terms—sand, silt, and clay—are standard terms based on the size of mineral solids. Color is not part of soil texture. Terms such as "yellow clay," "gumbo," "sugar clay," "white oak," and other colloquialisms are not standard soil terms. These terms are not used in soil survey reports or soil publications. Users of soils information should be careful in the use of these colloquialisms because they have many connotations and generally are used by individuals not trained as soil scientists.

Soil structure

Soil texture refers to the size of individual solid mineral particles. The arrangement of the solid particles into secondary aggregates or peds is termed soil structure. Soil structure is a grouping of single soil particles into compound particles. Just as soil texture usually changes with depth in a soil profile, so does soil structure. Soil structure of different soil horizons is an important characteristic of the soil.

Soil aggregates or peds are the result of sand, silt, and clay mineral particles adhering together, often with the aid of organic materials and iron oxide compounds, into definite shape and size patterns. Soil structure is classified in terms of:

1. Shape (or type) of aggregate,
2. Size of aggregate, and
3. Grade (the distinctiveness and stability) of aggregate.

There are four basic shapes of aggregates—granular and crumb, platy, blocky, and columnar and prismatic. These four basic shapes provide seven recognizable types of soil structure. Figure 19 provides a description of the shapes, types, size, and common horizon location of soil structure aggregates.

The macroscopic size of most soil aggregates results in interpedal openings that are much larger than the pore openings that occur adjacent to sand, silt, and clay particles. The size of aggregates and associated interpedal pores in the soil causes structure to play significant roles in the air and water relationships of the soil.

The five grades of soil structure are defined as:

1. Structureless—No observable aggregation; noncoherent sands are single grain; coherent (medium and fine) textures are massive.
2. Weak—Structure is poorly formed and will not maintain shape on handling. Difficult to see the shape and form of structural aggregates.
3. Moderate—Moderately durable on handling; evident but not distinct in undisturbed soil.

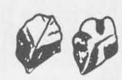
Structure Type	Aggregate Description	Diagrammatic Aggregate	Common Horizon Location
Granular	Relatively nonporous, small and spheroidal peds; not fitted to adjoining aggregates		A horizon
Crumb	Relatively porous, small and spheroidal peds; not fitted to adjoining aggregates		A horizon
Platy	Aggregates are platelike. Plates often overlap and impair permeability		A2 horizon in forest and claypan soils
Blocky	Blocklike peds bounded by other aggregates whose sharp angular faces form the cast for the ped. The aggregates often break into smaller blocky peds		Bt horizon
Subangular blocky	Blocklike peds bounded by other aggregates whose rounded subangular faces form the cast for the ped		Bt horizon
Prismatic	Columnlike peds without rounded caps. Other prismatic aggregates form the cast for the ped. Some prismatic aggregates break into smaller blocky peds		Bt horizon
Columnar	Columnlike peds with rounded caps bounded laterally by other columnar aggregates that form the cast for the peds		Bt horizon

Figure 19. Definition and location in the soil profile of types of soil structure (from: Foth, Henry D., Fundamentals of Soil Sciences, 6th Ed., 1978, copyright ©. Reprinted by permission of John Wiley and Sons, Inc.).

4. Strong—Durable on handling and visually distinct in undisturbed soil.

5. Massive—No observable aggregation; soil forms clods; clods are difficult to break apart when dry. Massive condition (lack of structure) is characteristic of the C horizon or parent material.

Soil structure and soil texture are closely associated, especially in the B horizon. Some of these correlations are:

1. Clay, some clay loam, and silty clay loam textures usually are associated with strong, fine, angular blocky structure.

2. Silt loam, some clay loam, and silty clay loam textures usually are associated with moderate, medium, subangular blocky, and angular blocky structure.

3. Sandy textures with some fines usually are associated with weak, large, subangular blocky structure, and sandy textures without fines usually are structureless and single grained.

4. The size of the aggregates may be related to the number of interpedal pores. As the size of the structural aggregate increases in a given unit area, the number of interpedal pores will decrease, and perhaps, the movement of air and water would be reduced (Bicki, 1977).

5. Structureless, massive soils generally will have slower rates of water and air movement than soils having structural aggregates. This relation will be more significant in soils of medium, moderately fine, and fine textural groups.

The rate of water movement through the soil profile is influenced by the aggregation of sand, silt, and clay into structural units. Structural units change from one type to another in the soil profile; therefore, the rate of water movement in one soil horizon may be different from the horizon above or below.

Soil texture and soil structure are primarily responsible for the size and number of pores in a soil horizon. The size and number of pores affect the rate of water and air movement, or the permeability of the soil. Sanitarians need a tool to interpret and evaluate pores in a soil horizon. One method involves the measurement of bulk density of a soil horizon.

Soil bulk density

Soil is composed of solids and pores. Mineral particles and organic materials are the primary solids, and air and (or) water fill the pores. In a given volume, say a 2-inch cube of a soil horizon, both solids and pores are present. The greater the amount of solids in the 2-inch cube of soil in comparison with the pores, the greater the weight of the 2-inch cube. The relationship is commonly referred to as bulk density. Bulk density is simply the mass of soil per unit volume. The relationship can be shown as:

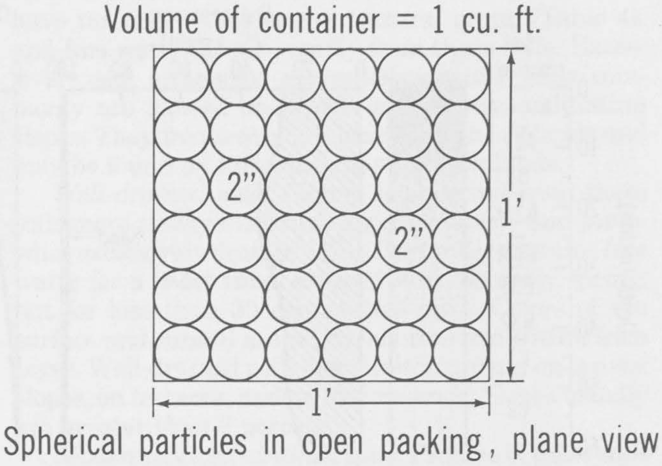
Bulk Density = Mass/Volume

Soil scientists express bulk density in grams per cubic centimeter. Most consulting engineers measure bulk density in pounds per cubic foot. In this discussion, bulk density will be referred to in terms of grams per cubic centimeter (g/cm^3).

The bulk density of the cultivated A horizon of most Iowa soils will range from 1.20 to 1.50 g/cm^3. This would equate to 74.9 to 93.6 lb/ft^3. The calculation of bulk density is demonstrated by the following example. Water weighs 62.4 lb/ft^3. If the soil is 1.2 times more dense than water, its bulk density would be 74.9 lb/ft^3 (62.4 lb/ft^3 x 1.2 = 74.9 lb/ft^3). The calculation in g/cm^3 expresses the weight of water as 1.0 g/cm^3. The bulk density of the B horizon or subsoil of most Iowa soils ranges from 1.25 to 1.75 g/cm^3.

Why do bulk density values vary among soil horizons in a soil profile? The basic components causing ranges in bulk density values are the mass or weight of the solid materials and the size, shape, and quantity of the pores in a defined volume of soil. First, in determining the particle density of soil, consideration is given only to the inorganic particles. In Iowa the dominant mineral particles are quartz, feldspar, mica, and clay minerals weathered from these primary minerals. The dominant particle density is 2.65 g/cm^3 for all mineral particles found in Iowa soils. Therefore, a constant value can be used for the particle density of most Iowa soil minerals. The amount of organic matter present and the nature of iron oxides affect the arrangement of the mineral particles in a soil horizon. Generally, soils having 3 or 4 percent or more organic matter content in the surface horizon will have larger pores than soils having lesser amounts of organic matter. These horizons often have moderate, medium granular structural aggregates. This, in turn, relates to lower bulk density values because of the increased number of large openings in the particle arrangement. Therefore, the variation or range in bulk density values is related to the size, shape, and quantity of pores in a soil horizon.

Soil texture (the percentage of sand, silt, and clay particles) affects the size, shape, and amount of pore space in a soil horizon and, in turn, the bulk density of the horizon. In addition, the size, shape, and stability of structural aggregates affect the size, shape, and amount of pore space in a soil horizon and, in turn, the bulk density of a soil horizon.



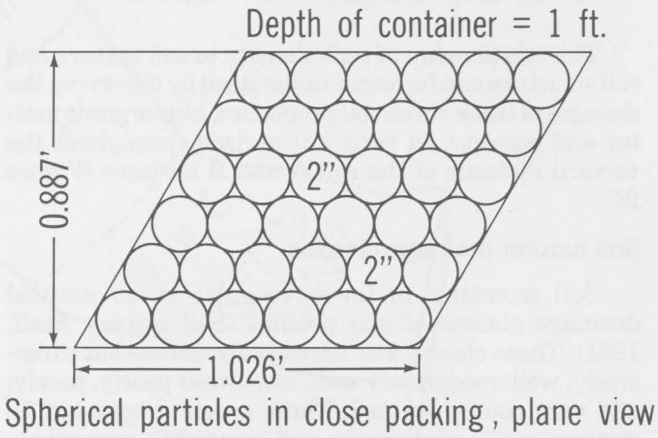


Figure 20. The effect of packing of spherical particles as related to void or pore ratio. The volume is reduced from 1.0 ft^3 in open packing to 0.91 ft^3 in close packing (modified from Spangler, 1960).

Sand and silt particles are assumed to be spherical. Spherical particles in close packing (Figure 20) result in 26 percent total pore space; particles in open packing result in 48 percent total pore space (Foth, 1978). Soil material with a textural classification of sand (Figure 14) has total pores of approximately 48 percent. This suggests (Foth, 1978) that sand particles are not perfect spheres and also that packing is not perfectly closed. Total pore space of sand and loamy sand soil horizons usually is low in comparison with soil horizons of most other textural classes; in turn, the sand and loamy sand soil horizons generally have bulk density values of 1.55 to 1.65 g/cm^3. In addition, these soil horizons generally have single-grain or weak granular structural aggregates.

Soil horizons having textures within the textural groups (Table 4) of medium, moderately fine, and fine usually have a wide range in particle sizes and shapes as well as stronger developed structural aggregates. A schematic relationship of soil texture and bulk density is shown in Figure 21.

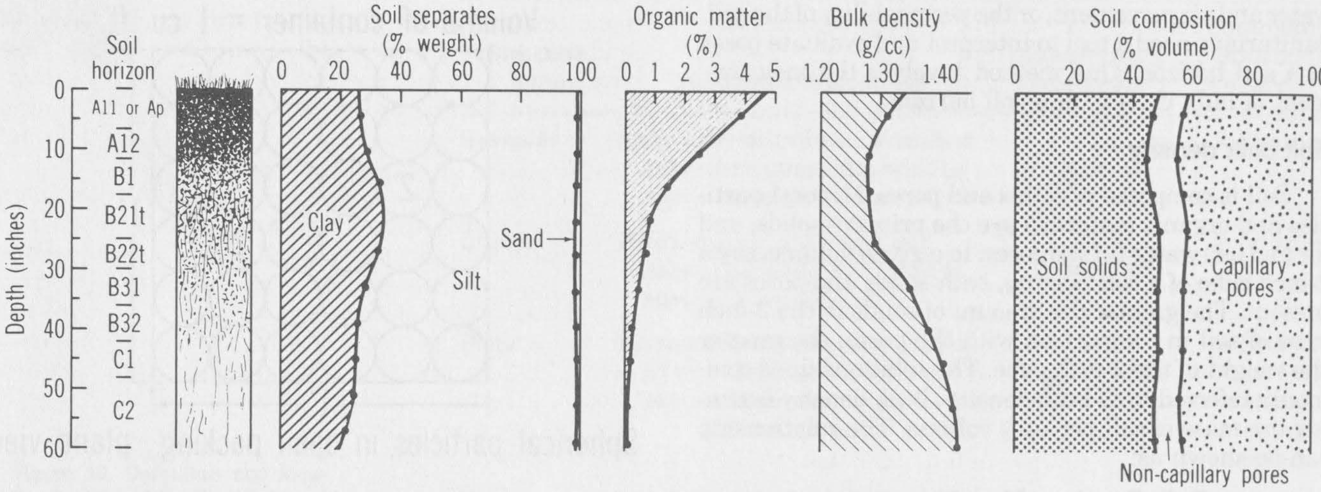


Figure 21. Schematic relationship of the depth distribution of soil structure, soil horizons, percentage clay content, bulk density, percentage organic matter, and percentage porosity for a well-drained, prairie-derived soil formed in loess. Closed dots on depth distribution curves indicate data points for a representative soil profile.

The relationship of bulk density to soil texture and soil structure can be better understood by observing the changes of these three soil properties, plus organic matter and porosity, in each soil horizon throughout the vertical distance of the soil A and B horizons (Figure 21).

Soil natural drainage classes

Soil scientists in Iowa recognize seven natural drainage classes of soil profiles (Soil Survey Staff, 1951). These classes are: excessively, somewhat excessively, well, moderately well, somewhat poorly, poorly, and very poorly drained. These seven classes can be grouped as: 1) excessively and somewhat excessively drained, 2) well drained, 3) moderately well drained, 4) somewhat poorly drained, 5) poorly drained, and 6) very poorly drained. These six groups are important because, for practical purposes, seasonally perched and (or) apparent water tables can occur: 1) below 6 feet in excessively and somewhat excessively drained soils, 2) below 5 or 6 feet in well- and moderately well-drained soils, 3) 2 to 5 feet in somewhat poorly drained soils, 4) 1 to 3 feet in poorly drained soils, and 5) at less than 2 feet in very poorly drained soils.

Natural soil drainage is one of the most important indicators of history carried within the profile. Determination of natural soil drainage is made by investigation of the soil colors, their intensity, and position in the profile. Soil drainage can be used to interpret and properly evaluate soils for potential use in soil absorption systems.

Iron is the main coloring substance of the subsoil, and the color of the iron in soil is closely related to the amount of free oxygen present. Free oxygen is absent or in short supply when soils become saturated or nearly saturated with water. When free oxygen is absent in the soil, iron exists in the ferrous or reduced state, which is gray. When adequate free oxygen is available, as in well-drained soils, the iron is in the ferric or oxidized state, which is yellowish or reddish. If, over a long time, a soil has been alternately wet and dry, a combination of the forms is found. This produces a mottled condition.

> *Mottling* is a mixture or variation of soil colors. In soils with restricted internal drainage, gray, yellow, red, and brown colors are intermingled giving a multicolored effect (Soil Survey Staff, 1951).

Soil scientists identify natural drainage classes by determining the presence or absence of mottles in the soil profile. Organic matter will mask colors and colors due to mottling caused by oxidation states of iron in the soil. Therefore, the area in the soil profile that the soil scientist looks at to determine whether mottles are present or absent for drainage groups 1, 2, 3, and 4 is in the soil horizon where soil color is no longer dominated by organic matter. This horizon occurs at the base of the surface horizon or A horizon. If mottles are present in this horizon, the drainage class is interpreted as being somewhat poorly drained. Poor and very poorly drained soils are easily identified by the generally thick and very dark or black surface and dark gray or very dark subsoil. A few rust-colored mottles may be present in the A horizon and in the lower part of the subsoil. In many poor and very poorly drained soils, the color of the soil material below the dark or black surface often is nearly uniform gray.

Adequate natural drainage provides for the development of well-drained soil profiles. The surface soil is dark, black and very dark brown, and the subsoil is a uniform bright, usually brown or yellowish-brown, color throughout. There is no gray or yellowish-orange discoloration or mottling in the upper 3 to 5 feet of the soil. The color pattern of moderately well-drained soils is similar to well-drained soils. In moderately well-drained soils, however, yellowish-orange and gray mottles may occur at 24 to 30 inches in a brown, yellowish-brown, brownish-yellow, or brighter soil matrix. Somewhat poorly drained soils have yellowish-orange and gray mottles in a grayish-brown, or dark grayish-brown, soil matrix. The mottling usually becomes visible at the base of the A horizon.

The six soil drainage groups are of major importance for the location of soil absorption fields. These six soil drainage groups are described in detail in the following paragraphs and Figure 22. The different drainage conditions are caused by seasonal variations in ground-water levels, seepage, rate of surface runoff, and soil permeability. The following comments assume that adequate tile or surface drainage has been installed for soils requiring drainage.

Excessively and somewhat excessively drained soils: These soils have bright-colored subsoils that are free of mottling, thus indicating that free water drains from the profile in a few days time. Colors of the surface soil vary widely but generally are less dark than those of poorly drained soils. Excessively drained soils usually have textures of the coarse textural group (Table 4), and free water drains rapidly from these soils. Excessively and somewhat excessively drained soils commonly are located on convex and gently undulating slopes. They frequently are located in the uplands and may be found on terraces and on bottomlands.

Well-drained soils: Water is removed from these soils more slowly than from the excessively and somewhat excessively drained soils. The profile contains free water for a short time, especially in the early spring, but for less than 30 consecutive days. Colors of the surface and subsoil are relatively uniform within each layer. Well-drained soils occur in the upland on convex slopes, on terraces, and on bottomlands. Slopes usually are greater than 2 percent.

Moderately well-drained soils: Profiles of these soils contain free water for short periods, especially in the

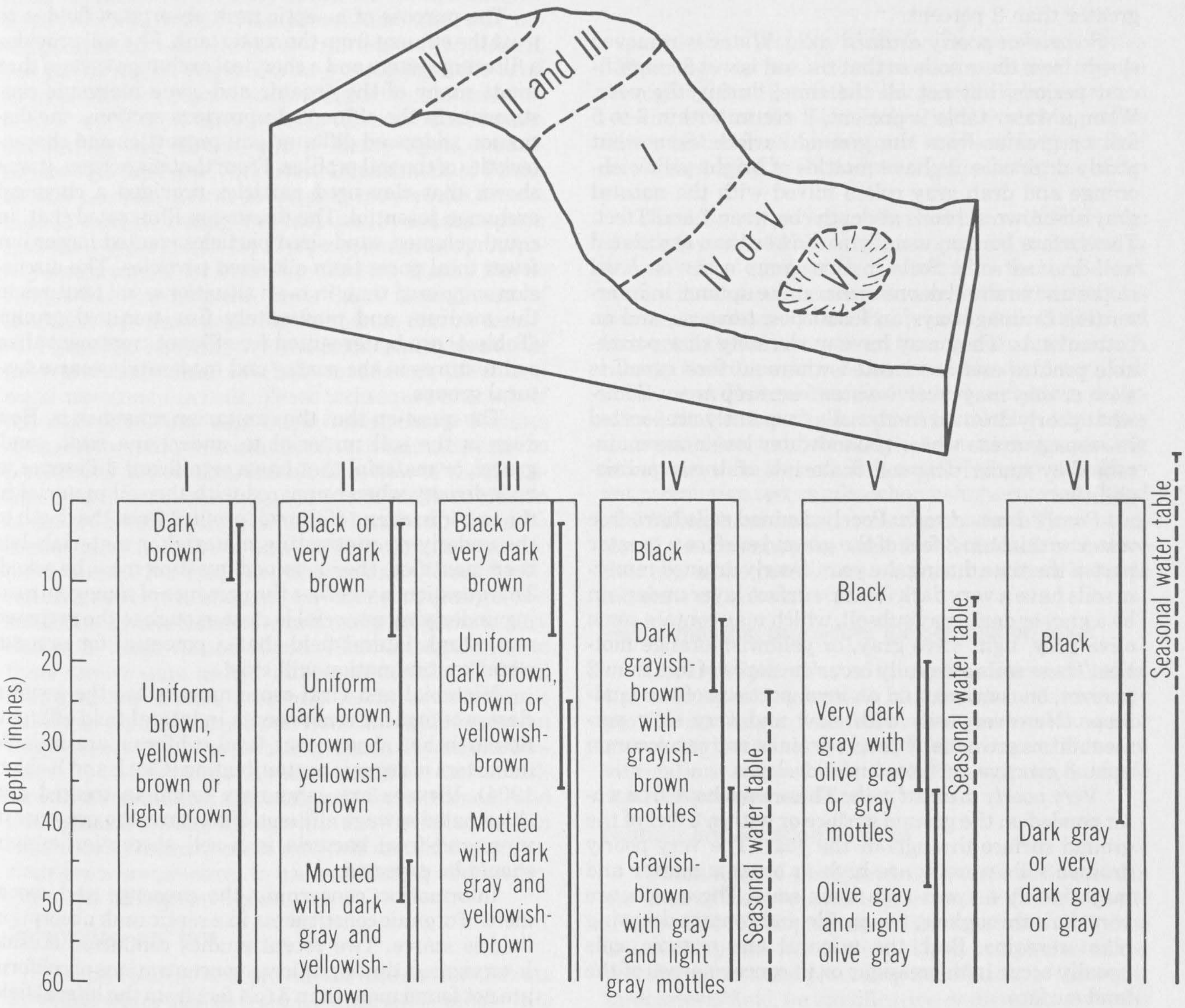


Figure 22. Schematic relationship of the natural soil drainage classes. I = Excessive and somewhat excessively drained; II = well drained; III = moderately well drained; IV = somewhat poorly drained; V = poorly drained; VI = very poorly drained. Solid vertical lines on drainage class profile indicate range of soil color in the soil profile. Dashed vertical line for seasonal water table indicates range to the fluctuating water surface. Solid vertical line for seasonal water table indicates that water table is present unless artificially drained.

early spring, but for less than 30 consecutive days. Moderately well-drained soils may have a layer or subhorizon with a moderately slow permeability immediately beneath the subsoil or in the subsoil. The moderately well-drained soils may have a perched water table, which rises to 3 or 4 feet below ground surface for short periods but less than 30 consecutive days, or seepage water, or some combination of these conditions. Colors of the surface and upper subsoil are relatively uniform within each layer. Mottling becomes noticeable in the lower subsoil, usually below 3 feet, but may occur at 2 to 3 feet, and normally consists of yellowish-orange flecks and blotches mixed in with the natural brownish color. Soils in this group commonly occur in the upland on convex slopes, on terraces, and on bottomlands. Some moderately well-drained soils occur at the base of hills (footslope) and on nearly level areas where surface runoff is slow. Slopes generally are greater than 2 percent.

Somewhat poorly drained soils: Water is removed slowly from these soils so that the soil is wet for significant periods, but not all the time, during the year. When a water table is present, it occurs within 2 to 5 feet or greater from the ground surface. Somewhat poorly drained soils have mottles of bright yellowish-orange and drab gray colors mixed with the natural grayish-brown subsoils at depths between 1 and 3 feet. The surface horizon usually is thicker than associated well-drained soils. Soils in this group occur on level slopes and in small depressions on the upland, in intermittent drainageways, in footslopes, terraces, and on bottomlands. They may have moderately slow permeable profiles and are located where surface runoff is slow, or they may receive water from seep areas. Somewhat poorly drained sandy soils frequently are located in seepage areas where groundwater levels are maintained by underlying soil materials of lesser permeabilities.

Poorly drained soils: Poorly drained soils have free water within 1 to 3 feet of the ground surface a greater part of the time during the year. Poorly drained mineral soils have a very dark (black) surface layer underlain by a gray or dark gray subsoil, which may contain some olive gray, light olive gray, or yellowish-orange mottles. These soils generally occur on slopes of less than 2 percent, on concave, and on level portions of the landscape. However, soils with slow and very slow permeabilities are usually poorly drained and can occur on upland concave surfaces and sideslopes.

Very poorly drained soils: These soils have free water ponded on the ground surface or within 2 feet of the ground surface throughout the year. The very poorly drained soils usually are high in organic matter and may classify as peat and muck soils. These soils are very dark throughout the profile and contain decaying plant remains. Both the mineral and organic soils usually occur in depressions or in concave areas of the land surface.

Soil depth

The depth of the soil profile is an important soil feature. The depth of the soil profile requires evaluation when considering the potential of a site for installation of a conventional septic tank absorption field.

Iowa soils generally are considered deep. This implies that many of the soils identified in Iowa have 6 feet or more of unconsolidated material in which the soil profile developed. Stated another way, this implies that the loess or glacial or alluvial materials usually are greater than 6 feet thick. A large acreage of Iowa soils, however, developed in loam-textured material, 20 to 40 inches thick, over sand and gravel. This is of special concern in areas of northeastern Iowa (Figure 9). Also, many acres of Iowa soils formed over limestone, shale, or sandstone. The occurrence of bedrock at a relatively shallow depth is greatest in northeastern and parts of south-central Iowa.

Soil Treatment

The purpose of a septic tank absorption field is to treat the effluent from the septic tank. The soil provides a filtering system and a chemical exchange system that treats many of the organic and some inorganic constituents in the effluent. In previous sections, the discussion addressed different soil properties and characteristics of the soil profiles. From that discussion, it was shown that clay-sized particles provided a chemical exchange potential. The discussion illustrated that, in equal volumes, sand-sized particles created larger but fewer total pores than silt-sized particles. The discussion suggested that, in most situations, soil textures in the medium and moderately fine textural groups (Table 4) are better suited for effluent treatment than soil textures in the coarse and moderately coarse textural groups.

The question that the sanitarian must ask is: How deep is the soil material to underlying rock, sand, gravel, or material that has a significant difference in bulk density when compared with the soil material in the upper horizons of the soil profile? Once the depth to the underlying contrasting material or materials has been identified, then a second question must be asked. This question is whether the presence of some contrasting underlying material is close enough to the proposed septic tank lateral field that a potential for groundwater contamination will exist.

Microbial and viral contaminants are the general classes of organic constituents in lateral field effluent. Research has shown that fecal coliforms are reliable indicators of organic contamination (Clark and Kabler, 1964). Viruses are commonly found in treated and chlorinated sewage effluent. Therefore, the presence of virus and fecal bacteria in a soil absorption system should be expected.

Information concerning the presence and movement of organic constituents in a septic tank absorption field is scarce. Two recent studies conducted outside Iowa suggest that significant concentrations of coliform are not found more than 3 to 4 feet from the lateral field distribution tile (Reneau and Pettry, 1975; Brown et al., 1979).

The evaluation of soil depth for septic tank absorption field construction can be conducted by sanitarians through the use of general guidelines. On the basis of empirical observations, it is suggested that a minimum of 3 feet of soil material be present between the base of lateral field trench or bed and surface of underlying bedrock or deposits of coarse sand and gravel. Limestone bedrock consisting of fractures and solution crevices may require additional soil material between the base of the trench or bed and the surface of the underlying rock material.

A more complete discussion of lateral effluent movement and potential for contamination of surface water supplies can be found in the section of this report concerned with groundwater resources of Iowa.

Soil Percolation Test

Percolation tests have been used for more than 50 years to assess the capacity of soil for sewage effluent disposal (Hill, 1966). The percolation test was developed through the efforts of sanitarians, physicians, and public health engineers who recognized the need for public health departments to supervise the installation of septic tank lateral fields for individual homes (McGauhey and Krone, 1967). Henry Ryon, a sanitarian with the New York State Department of Public Health, is credited with developing the percolation test in 1928 and calibrating it to field data in soil absorption systems (Frederick, 1948). The percolation test presently recommended by both the United States Public Health Service and the Iowa State Department of Health is not essentially different from Ryon's test.

Hydraulic conductivity and permeability are other more precise methods available to measure the rate of water movement in soils. These techniques are tools of the soil physicists and other researchers. Results obtained from these techniques do not relate directly to percolation test results. Indeed, a review of the literature on soil water flow suggests considerable confusion in the use of terminology. In many instances, hydraulic conductivity is referred to as percolation test rate or permeability. For example, Uhland and O'Neal (1951) referred to the rate of water movement in undisturbed soil cores as percolation rate and assigned permeability classes to those values. Klute (1965) later referred to those same values as hydraulic conductivity. The Soil Conservation Service presently refers to those same values as permeability in its Soil Survey Information Engineering and Interpretation sheets. Hydraulic conductivity and permeability measurements can be utilized for determining the adequacy for treatment and absorption of sewage effluent into a soil. As discussed in this report, however, other methods and field observations are more practical to use in selecting and designing a soil absorption system.

Percolation test rate

The percolation test provides a measure of the rate at which water moves from an uncased borehole into the surrounding soil under nearly constant head in both vertical and horizontal directions. Simply stated, percolation is the rate of water movement downward and laterally into a soil horizon. Percolation test rate is

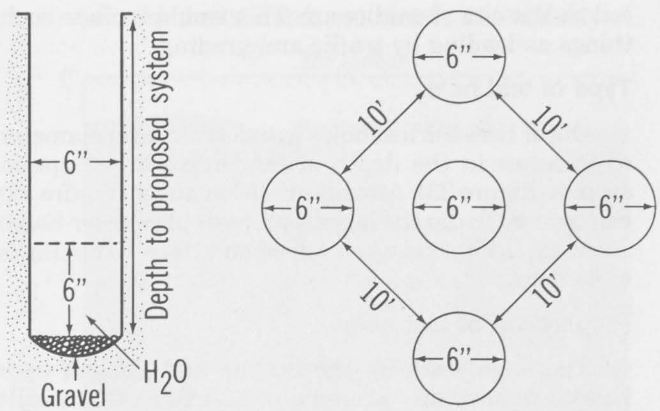


Figure 23. Recommended arrangement of soil percolation test holes and a cross sectional view of a percolation test hole (modified after Luce, 1973).

a quantitative property that can be measured. Rates will change as natural moisture conditions change throughout the 12 months each year. It is important to remember that the percolation test is nothing more than a test. It is a test designed to quantify the rate of water movement in the soil during a specific time of the year.

The *Manual of Septic Tank Practice* (U.S. Public Health Service, 1970) outlines a general procedure to follow when conducting percolation tests. Recent studies have shown a need for more refinement of this recommended procedure. Healy and Laak (1973) and Barbarick (1975) have shown the measured percolation rate to be a function of the test hole diameter. Hill (1966) and Franzmeier and coworkers[2] have determined that water moves out of percolation test holes under unsaturated flow and that extensive presoaking fails to saturate the soil. Bouma (1971) reported different percolation test results when using a constant-head and falling-head measurement procedure. These studies all demonstrate the need for a standard procedure that can make percolation test results a more reliable indicator of soil water flow.

Recommended procedure for percolation tests

Research data collected through independent investigations by soil scientists of Iowa State University provide an insight into techniques and procedures for measuring percolation rates. The findings of these investigations suggest that the following procedures be used for percolation tests.

Number and location of tests

A minimum of 4 to 6 test holes should be dug *within the area of the proposed septic tank lateral field site* (Figure 23). On sloping areas, the test holes should be oriented normal to the slope. Upon completion of the percolation test and preceding installation of the septic tank lateral field, no modification or disturbance to the

[2]D. P. Franzmeier, B. R. Brasher, and S. J. Ross, Jr. Soil percolation rates during sustained testing. Soil Survey Laboratory, Soil Conservation Service, United States Department of Agriculture, Beltsville, Maryland (mimeo). 1964.

soil at the site should occur. This would include such things as loading by traffic and grading.

Type of test hole

Dig or bore the test holes with a horizontal diameter of 6 inches to the depth of the proposed absorption system (Figure 23). A spade or bucket auger (Figure 32) can be used to dig the holes, or a portable (power-head) screw-type digger can be used when extensive testing is to be done.

Preparation of test holes

Thoroughly scarify the bottom and sides of each hole to remove any smeared soil surfaces that result from digging. This results in a natural soil interface into which water can readily move. This procedure also should be followed in the lateral field trenches when the absorption system is being installed. Carefully remove all loose soil material from the holes and line each hole with 10- to 15-mesh flexible metal screen. This prevents sloughing of loose soil from the sides of the hole during presoaking. Add 2 inches of noncalcareous pea-sized gravel to the bottom of each hole. This prevents sealing of the bottom of the hole when water is supplied.

Presoaking

Carefully fill the holes with clean water to a minimum depth of 12 inches above the gravel. Maintain this level in the test holes for a minimum of 8 hours by supplying a surplus reservoir of water by means of an automatic syphon or similar device. If a constant percolation test rate is not obtained after the initial presoaking, discontinue measurements and continue presoaking until such time as a constant rate is obtained.

Proper presoaking of the test holes is important in obtaining reliable and reproducible percolation test results. Green (1962) has shown that water movement in unsaturated soil is dynamically influenced by the initial moisture content of the soil.

Percolation rate measurement

The recommended procedure is a modified constant-head method, which yields a percolation test rate under an average of 6 inches of water.

After a minimum of 8 hours of presoaking, the water level is allowed to drop to a depth of 7 inches above the gravel. The drop in water level is measured for a period of 3 to 4 hours or until a steady rate is established. The time interval is adjusted to allow a water drop of less than 2 inches. If the water level drops below 5 1/2 inches above the gravel, water is added to return the water level to 7 inches, and readings are continued. Readings are taken to the nearest one-eighth of an inch.

The percolation test rate is calculated by averaging all readings taken during the final 3 hours. If a constant percolation rate is obtained before the conclusion of the 3-hour testing period, the constant rate is used to calculate the percolation test rate.

An acceptable percolation rate is not the only criterion necessary for the installation of a septic tank lateral field. The site must also be suitable in terms of slope gradient, depth to sand and gravel, bedrock, the seasonally high water table, and flooding potential.

If the percolation test rate is greater than 1 inch per hour (less than 60 minutes per inch) and soil characteristics are satisfactory, the site is rated as having a slight limitation for a septic tank lateral field. Once the site has been approved, the percolation test rate is then used to determine the required absorption area of the system.

Percolation test results, in some instances, can be misleading. Percolation tests conducted during the summer or during periods of extended dry weather can yield unreliable results. Sites that might otherwise have seasonally high water tables from 0 to 3 feet below the surface can yield satisfactory rates during dry periods.

An example of this relationship is illustrated in Figures 24 and 25. Figure 24a illustrates the water table conditions for a well-drained soil with a moderate permeability class. A well-drained soil generally does not have a seasonally high water table within 6 feet of the ground surface for more than 30 consecutive days during the year. The moderate permeability class implies that the soil has the ability to transmit water. The user, knowing the natural soil drainage class and permeability class, can predict that a satisfactory percolation test can be obtained for this soil condition (Figure 24b).

Figure 25a shows the water table conditions for a poorly drained soil with a moderate permeability class. A poorly drained soil generally has a water table 1 to 3 feet below the ground surface for most of the year. The moderate permeability class implies that the soil has the ability to transmit water if adequate artificial drainage is installed with a suitable outlet. If the water table is not lowered by artificial means, however, then a water table will be present (Figure 25a). Knowing the drainage class and the permeability class of the soil, the user can predict that a high water table can be expected. Figure 25b shows for this soil that satisfactory percolation test results are achieved only during a few months each year. During the other months of the year, the high water table will preclude satisfactory percolation test results even though the soil has the ability to transmit water. The percolation test results will be dependent on the presence of the water table. Engineering design and additional costs will be needed to overcome the water table limitation.

Soil profiles with well-, moderately well-, somewhat poorly, or poorly drained natural soil drainage classes and moderately slow, slow, or very slow permeability ratings will not, in most instances, provide satisfactory percolation test results. Soils with these permeability classes do not have the inherent ability to transmit air and water rapidly enough to achieve satisfactory percolation test rates. Increased size of the septic tank absorption field area and (or) alternative dosing may be useful to achieve satisfactory performance. Otherwise, little can be accomplished by engineering design to alter the permeability of the soil horizons.

Percolation tests conducted when the soil is extemely wet also can yield unreliable results. Digging the test holes in wet soil can result in smearing and compres-

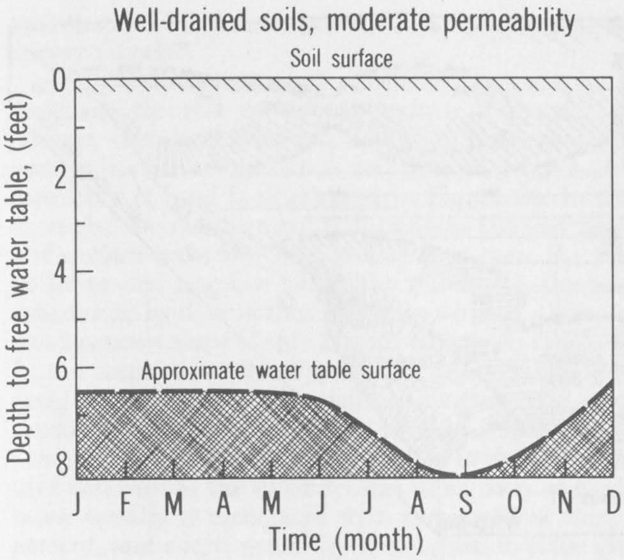


Figure 24a. Approximate water table depth for well-drained soils with moderate permeability.

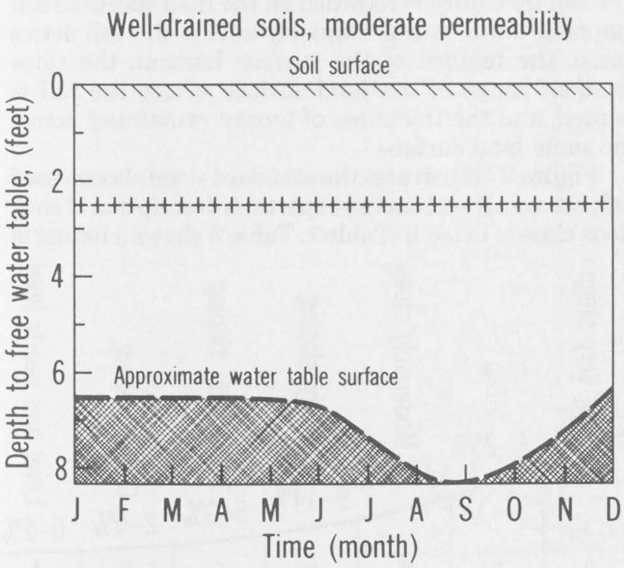


Figure 24b. Projected percolation test results at 30-inch depth for well-drained soils with moderate permeability; + indicates satisfactory.

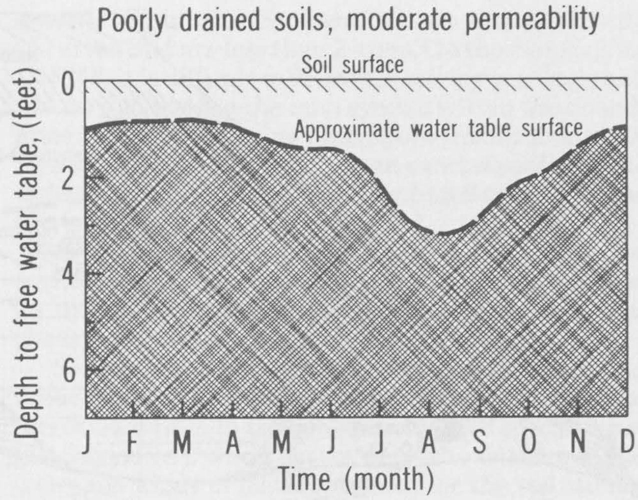


Figure 25a. Approximate water table depth for poorly drained soils with moderate permeability without artificial drainage.

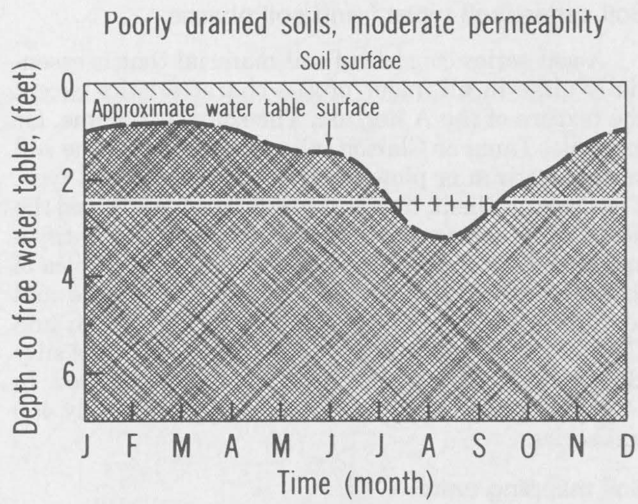


Figure 25b. Projected percolation test results at 30-inch depth for poorly drained soils with moderate permeability without artificial drainage; + indicates satisfactory; − indicates unsatisfactory.

sion of the soil around the test hole. Scarifying of sidewalls will do little to expose the natural soil surface through which the water would move.

Soil Survey and Soil Survey Terminology

The properties and characteristics of a soil profile result from the interaction of environmental factors on the soil parent material. In an earlier section, soil formation was described. The soil-forming factors include the landscape position and slope gradient, the native vegetation, the temperature and rainfall history, and the length of time the parent material has been exposed to weathering. Any one of these factors, as well as the soil parent material, can change across the land surface. The change in any one of the soil-forming factors causes the development of a different set of soil-profile characteristics. This results in a different soil being formed on the land surface (Figure 26).

The combintion of soil-forming factors occurring in the same manner on similar parent material in more than one location on the land surface results in similar soil-profile properties and characteristics being developed. The development of similar soil properties and characteristics allows soil scientists to classify soils.

The classification of soil involves the identification of the length, width, and depth of similar soil-profile properties and characteristics across the land surface.

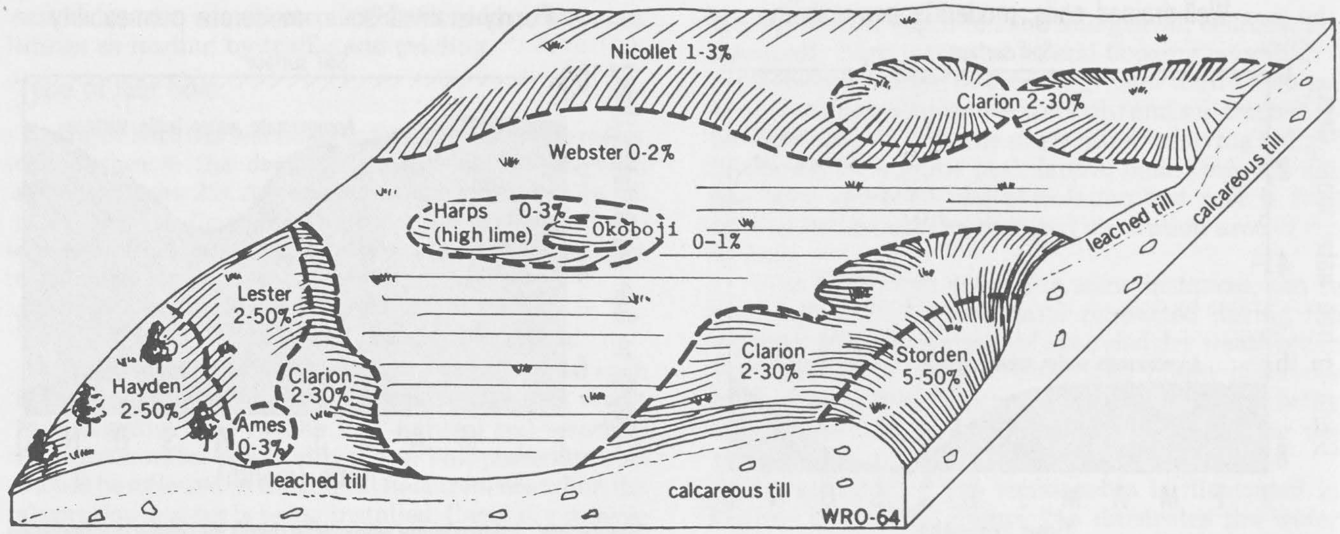


Figure 26. Relationship of soil series to soil landscape characteristics—% slope, parent material, and native vegetation—for selected soils occurring in north-central Iowa.

Soil series, soil types,[3] and soil phases

A soil series consists of soil material that is essentially alike in all major profile characteristics except the texture of the A horizon. The soil series name, for example, Tama or Clarion, plus the texture of the soil surface horizon or plow layer determine the soil type. The slope gradient, the thickness of the topsoil, and the depth of the soil are common features used to identify a subdivision of the soil type, a soil phase. Examples of different soil types defined on the series name and texture of the topsoil are Tama silty clay loam and Clarion loam. An example of a soil phase is Tama silty clay loam, 5 to 9 percent slope, moderately eroded. In Iowa, soil scientists have classified approximately 450 soil series.

Soil mapping units

Soil surveys provide for a systematic approach to classifying and recording soil properties and characteristics as these properties occur in nature. Soil scientists study and classify soils and delineate the soil boundaries on aerial photographs. The soil maps show the distribution of different soils across a landscape. This represents an inventory of the soil resources of the area surveyed. The soil inventory and other supporting studies are assembled and interpreted, with the results published in a soil survey report. The soil survey report is a summary of soil facts and a guide to land use alternatives.

Field mapping for soil surveys of Iowa counties prepared since 1938 have been on an aerial photograph base at a scale of 1:15840 (this represents 4 inches on the photograph equaling 1 mile on the land surface). The soil inventory is recorded on the map sheets as soil mapping units. A soil mapping unit is the soil series name, the texture of the surface horizon, the slope gradient range of the land surface where the soil is located, and the thickness of topsoil remaining across the same land surface.

Figure 27 illustrates the standard slope classes used in Iowa county soil survey reports. A description of each slope class is listed in Table 1. Table 5 shows a listing of

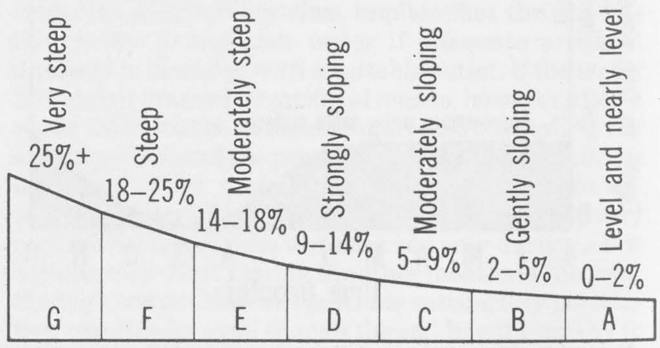


Figure 27. Standard slope classes and their respective slope gradients used in Iowa county soil survey reports.

Table 5. Erosion classes used in Iowa county soil survey reports.

Erosion class	Description
+	Recent deposition. 8 to 18 inches of recent overwash material.
(no symbol indicated--blank)	No or slight erosion. The plow layer consists of A horizon. Dark colored material or topsoil is greater than 7 inches. Little or no mixing of the subsoil material occurs in the plow layer.
2	Moderate erosion. Dark colored material is 3 to 7 inches thick. Some mixing of subsoil material in the plow layer.
3	Severe erosion. Dark colored material is less than 3 inches thick. Major part of the plow layer consists of subsoil material.

[3]The term soil type is no longer officially recognized as part of the standard USDA soil classification system (Soil Survey Staff, 1975). The definition of soil type now is included as part of the term, soil phase. The authors of this report have elected to use and define soil type because of the widespread use of the term by users of Iowa soil survey reports.

the standard erosion classes used in Iowa county soil survey reports.

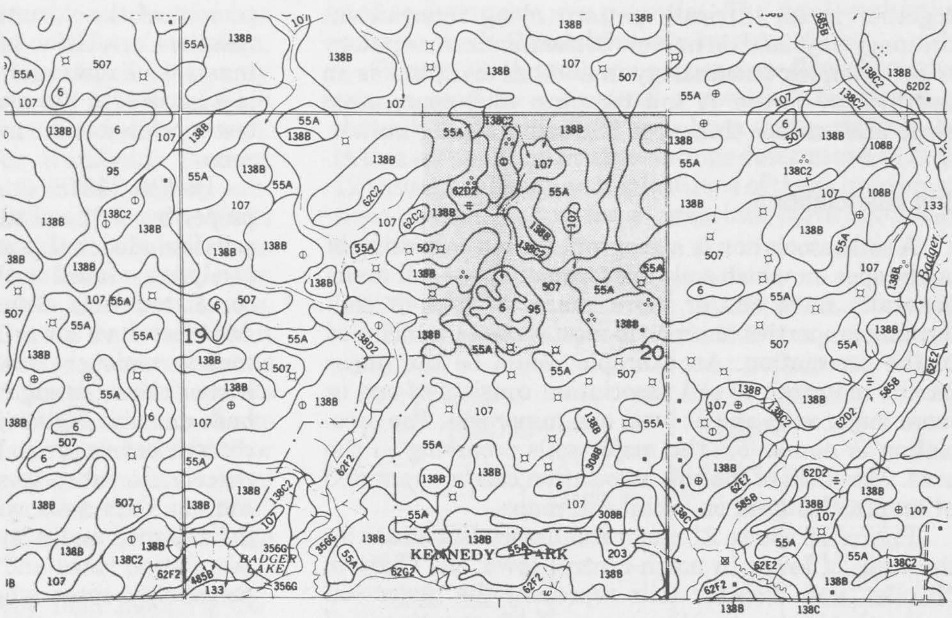
Map symbols are used on aerial photographs to designate the soil name and texture of the surface horizon, the slope gradient, and the thickness of the surface horizon or topsoil. A soil map showing a 160-acre tract of land is illustrated in Figure 28. In this example, the map symbol 6 designates the soil name and surface texture—Okoboji silty clay loam. Because no letter and number follow the number 6, the user determines by default that this soil occurs on a 0 to 1 or 0 to 2 percent slope (Table 1) with no erosion (Table 5). In the same example (Figure 28), the symbol 138B designates the soil name, surface texture, and slope gradient—Clarion loam, 2 to 5 percent slopes. In this example, no number follows the letter B; therefore, the user determines the erosion class to be none or slight (none usually is associated with slopes of less than 2 percent, and slight generally is assigned to slope gradients of 2 percent or greater) (Table 5).

Another feature of the soil map is the use of spot symbols (Figure 28). Spot symbols are used to identify soil areas that are less than 2 acres. On the map scale of 1:15840, it is difficult to delineate soil areas of less than 2 acres and include the map symbol within the boundaries of the soil mapping unit. Spot symbols should not be interpreted as representing an exact size of soil area unless so stated within the conventional symbol legend of a published soil survey report.

It is important to remember that the width of a normal pencil or ink line represents a ground width of 25 to 35 feet when the line is placed on an aerial photograph of the scale 1:15840.

Soil maps also show other landscape features and water features as well as some cultural features. The user should refer to the conventional and special symbols legend in the soil survey report to determine the types and kinds of features shown for the soil survey area.

An important feature shown on Iowa county soil survey map sheets is the drainageways. Soil survey map sheets show both perennial and intermittent



Map symbol	Soil phase
6	Okoboji silty clay loam, 0 to 1 percent slopes
55A	Nicollet loam, 1 to 3 percent slopes
62C2	Storden loam, 5 to 9 percent slopes, moderately eroded
62D2	Storden loam, 9 to 14 percent slopes, moderately eroded
95	Harps clay loam, 0 to 2 percent slopes
107	Webster silty clay loam, 0 to 2 percent slopes
138B	Clarion loam, 2 to 5 percent slopes
138C2	Clarion loam, 5 to 9 percent slopes, moderately eroded
507	Canisteo silty clay loam, 0 to 2 percent slopes

Spot symbols

(representing soil areas less than 2 acres in size)

- Gravel
- Okoboji soil
- Calcareous spot
- Severely eroded spot
- Drainageways crossable with farm implements

Figure 28. A completed soil survey map sheet including a 160-acre tract (shaded area) that shows the delineation of individual soil mapping units (from Koppen, 1975).

drainageways. In addition, in Iowa county soil survey reports, intermittent drainageways that are crossable with standard agricultural tillage implements are distinguished from intermittent drainageways that are not crossable with standard agricultural tillage implements. The uncrossable drainageway indicates that a channel has formed for conveyance of water. The banks adjacent to the channel may be stable or unstable. On-site investigation is required to determine bank stability. In addition, the sanitarian and land use planner can use this information to make a preliminary evaluation of the relative volume of water flowing in the drainageway in comparison with adjacent drainageways where an entrenched channel has not formed.

Soil complexes are used to define soil map areas where two or more soil series and their respective phases occur together in a more or less regular pattern. These patterns are so intricately mixed, or so small, that it is not practical or feasible to separate them at the standard mapping scale of 1:15840. An example of a soil complex is the Colo-Judson complex. These soils occur together in an intricate pattern along intermittent drainageways and on narrow bottomlands. An analogy to soil complex terminology in another discipline is an oak-hickory forest. A soil complex with appropriate slope and surface thickness is a soil mapping unit.

Soil associations

A soil association is a geographic area consisting of landscapes on which soils are formed. These soil areas generally have one or more characteristics or soil-forming properties common to most of the soils included in the association. An example would be the major parent material. A soil association consists of one or more major soils and at least one minor soil. The association is named for the major soils occurring in the area. Members of the soil association can be separated at map scales used on detail soil maps.

Figure 18 shows 21 major soil association areas for the state of Iowa. In north-central Iowa, the Clarion, Nicollet, and Webster soils represent the major soil series that occur in all or part of 29 counties. Soil scientists have classified approximately 50 additional soil series in this area, but in total, these soils do not occur in as great an acreage as does the Clarion, Nicollet, and Webster series. These additional soils are the minor soils of the association. Soil associations are used in conjunction with general maps or large-scale maps generally greater than 1:24000 scale.

Soil Research Results

Research data concerning the effect of selected soil properties on percolation test rate of Iowa soils indicate that the following properties are most closely related to variation in rates obtained: (1) soil textural class, (2) bulk density, (3) native vegetation, (4) soil natural drainage class, (5) soil consistence.

Luce (1973) in a study of 34 southern Iowa soils accounted for 75 percent of the variation obtained in percolation test results in a multiple-regression equation involving seven variables. These variables included the five soil properties listed in the preceding paragraph, plus soil chroma and soil parent material.

Fine-textured soils tended to have lower percolation rates than medium-textured soils. There was a general positive relationship between total porosity and percolation rate. Poorly drained soils had lower percolation rates than well-drained soils, and somewhat poorly drained soils had intermediate rates. Soils formed under forest vegetation had lower percolation rates than soils formed under grass vegetation. Soils with friable consistence had greater percolation rates than soils with firm or very firm consistence.

Bicki (1977) reported percolation test results for 12 Iowa soils. Sand content, clay content, soil textural class, bulk density, and the percentage of soil volume drained at 60 cm of water tension were found to be correlated with percolation rate. Significant relationships also were found between soil percolation rate and soil consistence, grade of structure, native vegetation, and soil drainage class. A multiple-regression equation involving these soil variables accounted for 98 percent of the variation obtained in percolation test results. Correlation of percolation rate with the maximum sand, minimum clay, and minimum bulk density of a horizon in the test zone suggests that percolation test is related to the most permeable horizon in the test zone.

DeWitt (1978) studied percolation rates and soil properties of 31 soil sites in north-central Iowa. For the soils included in this study, percolation rates were positively correlated with sand content and negatively correlated with clay content. Soils with high bulk densities had lower percolation rates, lower gravimetric moisture content, firmer consistency, and higher shear strength values than did soils with low bulk density. Soils with higher gravimetric moisture content before presoaking were shown to have slower percolation rates, less sand content, and greater clay content than soils with lower gravimetric moisture. Soils formed under native forest vegetation have lower percolation rates and greater within-site variation of percolation rates when compared with soils formed under prairie vegetation. Soils with limestone and sand and gravel strata at a depth of 20 to 50 inches had acceptable percolation rates, but pollution of groundwater from absorption fields could be a hazard.

Depth to a seasonal water table is an important characteristic reflected in the natural drainage class of a soil and was an important factor in all these studies in evaluating the suitability of a site for satisfactory percolation rates.

Soil Survey Reports

The first Iowa soil survey report was published in 1903 (Fippin, 1903). Between 1902, when the field work was completed for this first soil survey of the Dubuque area, and 1950, more than 90 Iowa counties had one or more soil surveys. These early soil surveys were an effort to inventory the soil resources of the county. Usually, the soil map was published on a colored map sheet at a scale of 1:63360 (1 inch on the map sheet equals 1 mile of ground surface). These maps provided a general, but not a detailed, inventory of the soil resources.

During the late 1920s and early 1930s, U.S. aviation technology was increasing at a rapid rate. Cameras were introduced and designed especially for aerial photography. Aerial photographs for soil survey purposes in Iowa were first made in 1938. The introduction of aerial photographs revolutionized the soil mapping program. Soil scientists no' longer were required to construct their own base maps. Aerial photography provided contrasts and tones on the finished photograph. Soil scientists soon learned to interpret map features in terms of relative slopes and general soil characteristics. In addition, the aerial photographs provided an insight to land cover.

The standard aerial photograph used today in the Iowa soil survey program has a scale of 1:15840 (4 inches on the map sheet equals 1 mile of ground surface). Soil maps at this scale show 16 times more area per square mile than the older soil maps having a scale of 1:63360. Since 1938, all soil mapping field work for standard soil survey publications of Iowa counties has been made at the 1:15840 scale, with one exception, Humboldt County. The field work in Humboldt County was recorded on map sheets at the 1:7920 scale (8 inches on the map sheet equals 1 mile on the ground). The published map sheets for Humboldt County, however, are at a 1:15840 scale. Some soil survey publications released for Iowa counties during the 1950s still used the color mat base background for soil maps instead of the now-standard aerial photograph base. This is the situation for Alamakee, Jefferson, Lucas, Monona, and Taylor counties. During the late 1950s it was decided to publish all future soil survey map sheets on an aerial photograph base. All published reports released for Iowa counties since 1960 have map sheets with an aerial photograph base at a scale of 1:15840 or 1:20000 (3.17 inches on the map sheet equals 1 mile of ground surface). Iowa counties published at a 1:20000 scale had the field work compiled on 1:15840 scale aerial photographs.

In the late 1960s, soil survey field mapping expanded at a rapid rate due to the systematic input of funds by the state and local governments. This resulted in all Iowa counties without post-1950 soil surveys becoming involved in conducting standard county soil surveys at a map scale of 1:15840. The completion of the field mapping for all 99 counties is scheduled for the late 1980s. Also, several counties that now have published soil reports where the field work was recorded on aerial photographs, but published on a colored mat base of 1:15840 scale or greater scale, have agreed to start the field work for an updated soil survey. Field mapping in these counties is also scheduled to be completed in the late 1980s.

Soil survey information is available in published reports or on map sheets awaiting publication in many Iowa counties. More than 60 percent of Iowa counties have the field mapping completed for an updated soil survey. Many of these same counties have published reports available. During the past 15 years, it has required 3 to 5 years after the completion of the field work to complete the writing and printing of the soil survey report. During this 3- to 5-year period, copies of the map sheets and interpretation of the soils for various land uses and management have been made available to local county offices.

Availability of soil survey information for any one of the 99 Iowa counties can be determined by contacting the local county extension office, soil conservation district office, or the Department of Agronomy, Iowa State University, Ames, Iowa 50011.

Soil and Landscape Site Evaluation

A specific location on the land surface has a potential for use as a site for home sewage waste treatment. The potential of this location for such use may be very poor or may be very good or may be between the two extremes. The potential of a site for future home sewage waste treatment will be dependent on the soil and landscape properties. The purpose of this section is to explain how soil and landscape properties can be evaluated to determine site potential. The final evaluation must be made through on-site investigations.

Figure 29 illustrates a sequence or flow chart that can be used in evaluating a specific site. Items 12 through 20 on Figure 29 have been discussed in detail in this section. The interpretations determined in steps 12 through 20 and the implications of these interpretations are outlined in the appropriate parts previously described.

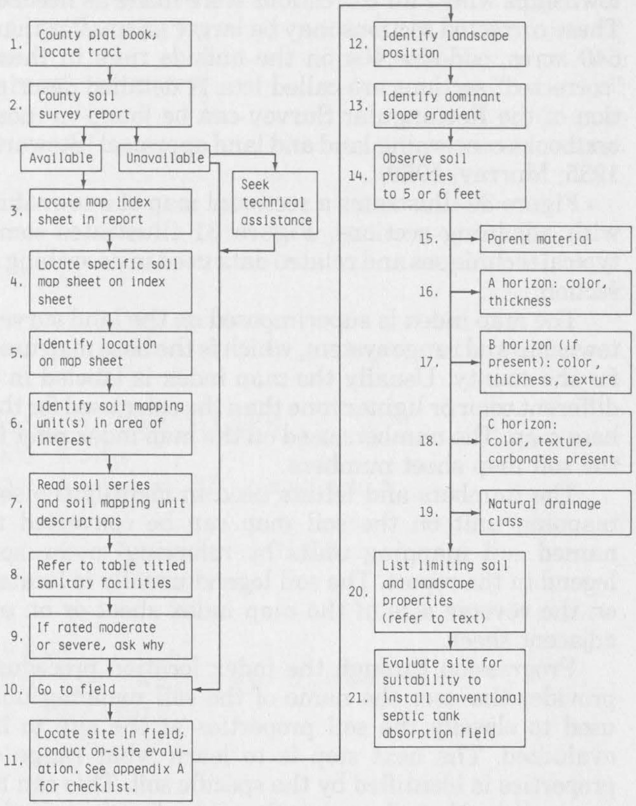


Figure 29. A flow chart to plan the evaluation of soil and landscape properties for septic tank absorption field sites.

Use of county soil survey reports

County soil survey reports were described previously in this section, but their use has not been discussed. County soil survey reports as used in this publication include those soil survey reports for Iowa counties that have been published since Jan. 1, 1955, as part of the National Cooperative Soil Survey, have soil survey field work completed as part of a cooperative soil survey, or have a standard soil survey in progress.

The first step in evaluating a site for its potential use for home sewage waste treatment is to geographically locate the site.

Soil map index sheets

A county plat book is an excellent document to use in locating a site. The plat book shows the geographic distribution of each township in the county and shows property ownership boundaries as well as listing the names of the property owners. Once the site is located in the plat book, it is necessary to transpose the information to the soil map index sheet of the county soil survey report. There are two index sheets. One is located in the report between the written material and the individual soil map sheets, and another is the last sheet in the county soil survey report. The map index sheet is based on the standard U.S. Rectangular Survey system for locating the township and range system.

A U.S. Rectangular Survey township is 6 miles square and contains 36 sections. Each section contains 640 acres except those on the north and west sides of townships where all corrections were made as needed. These corrected sections may be larger or smaller than 640 acres; odd-size 40s on the outside tiers in these "corrected" sections are called lots. A detailed description of the Rectangular Survey can be found in most textbooks concerning land and land appraisal (Stewart, 1935; Murray, 1969).

Figure 30 illustrates a sectional map of a township with adjoining sections. Figure 31 illustrates some typical techniques and related data used in describing a section.

The map index is superimposed on the land survey township and range system, which is the base map used for the county. Usually the map index is labeled in a different color or lighter tone than the color used for the base map. The numbers used on the map index refer to the soil map sheet numbers.

The numbers and letters used to identify the soil mapping unit on the soil map can be converted to named soil mapping units by referring to the soil legend in the report. The soil legend usually is located on the reverse side of the map index sheet or on an adjacent sheet.

Progression through the index location procedure provides the user the name of the soil mapping unit used to classify the soil properties at the site to be evaluated. The next step is to learn what range of properties is identified by the specific soil. This can be accomplished by referring to the table of contents in the county soil survey report and locating the description of the soil series and soil mapping unit. This is a very important step. Key information given in the soil series

Figure 30. Sectional map of a standard township showing adjoining sections.

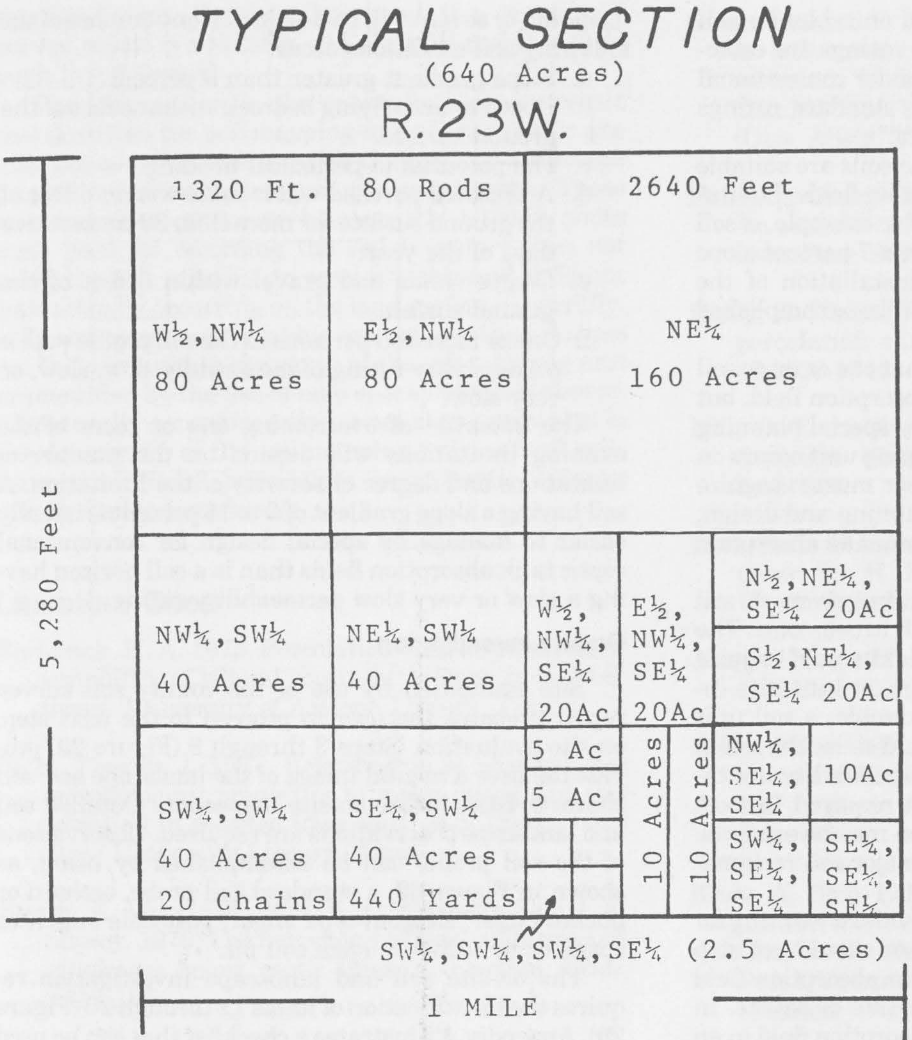
description is the soil-forming factors—description of the topography and the related natural drainage class of the soil, native vegetation, and parent material that contributed to the formation of the soil properties. In addition, the series description provides information concerning the color, texture, and thickness of each major horizon and the qualitative permeability rating. The soil mapping unit description provides additional information concerning properties and characteristics specific to the soil mapping unit.

The review of the soil series and soil mapping unit description is important because it provides a preliminary evaluation of the soil and landscape characteristics from the vantage of the user's office or other work location. This step provides an insight to likely limitations, if any. It does not, however, replace on-site investigation and evaluation.

Limitation ratings

Limitation ratings for suitability of a soil series and soil mapping unit for a conventional septic tank absorption field are provided as a soil interpretation. These ratings are listed on tables in most published Iowa county soil survey reports.[4] In counties not having this interpretation available in the published report or in counties where copies of the soil map sheets are available but not published, single-sheet soil interpretation forms are available at the county extension office and soil conservation district office. Soil interpretations for septic tank absorption field suitability are listed in published county soil survey reports on a table entitled "Sanitary facilities," "Engineering interpretation of the soils" or "Engineering interpretations."

[4]Published Iowa county soil survey reports *not* providing this soil interpretation include Allamakee, Adams, Cass, Humboldt, Jefferson, Lucas, Monona, Polk, and Van Buren counties.



1 Section = 640 Acres
1 Acre = 43,560 Square feet

1 Link = 7.92 Inches
1 Rod = 16.5 Feet
5.5 Yards = 25 Links
1 Chain = 66 Feet = 4 Rods = 100 Links
1 Furlong = 660 Feet = 40 Rods
1 Mile = 8 Furlongs = 320 Rods = 80 Chains = 5,280 Feet
1 Square Rod = 272.25 Square feet = 30.25 Square yards
1 Acre = 160 Square Rods
1 Acre = 208.71 Feet square
1 Acre = 8 Rods x 20 Rods (or any two numbers of rods whose product is 160)

Figure 31. A guide for land descriptions of a standard section of the U.S Rectangular Survey system (Reprinted by permission from Farm Appraisal and Valuation, Fifth Edition, William G. Murray, © 1969 by the Iowa State University Press, Ames, Iowa 50010.).

The limitation ratings are listed on tables by soil series and soil mapping unit. These ratings are established for use in evaluation of the soil for conventional designed soil absorption fields. The standard ratings are "slight," "moderate," and "severe."

A "slight" rating implies that the soils are suitable for installation of septic tank absorption fields. Limitations, if any, are easily overcome. For example, a soil mapping unit rated slight occurs on a 7-percent slope gradient. The management and installation of the lateral field on a 7-percent slope can be accomplished with limited engineering design.

A rating of "moderate" implies that one or more soil properties are unfavorable for an absorption field, but these limitations can be overcome by special planning and design. For example, a soil mapping unit occurs on a 12-percent slope gradient. The user must recognize the slope as a limitation. Proper planning and design, however, will allow the use of the site for an absorption field.

A "severe" rating implies that one or more soil properties are unfavorable or difficult to overcome. The use of the site for an absorption field would require major soil reclamation, special design, or intensive inputs in time and materials. For example, a soil unit having a slow permeability class could cause the soil to be rated severe. To overcome the permeability limitation, major soil reclamation would be required. In most instances the permeability limitation may be extremely difficult to overcome, even with major soil reclamation.

The limitation rating system provides a warning for the potential user. However, the user should not stop planning a site for installation of an absorption field because a specific soil is rated moderate or severe. In many instances, relocation of the absorption field to an adjacent soil may be a practical solution. The user must ask the question, "Why is the soil rated moderate or severe?" The limitation(s) must be identified for the planning procedure to continue. Generally, a rating of moderate or severe will be assigned if one or more of the following soil conditions occur:

a. Slope gradient greater than 9 percent.
b. Depth to underlying bedrock within 6 feet of the ground surface.
c. The potential of periodical flooding.
d. A seasonal perched water table within 5 feet of the ground surface for more than 30 consecutive days of the year.
e. Coarse sands and gravel within 5 feet of the ground surface.
f. One or more soil horizons in the soil profile with a permeability rating of moderately slow, slow, or very slow.

The potential of overcoming one or more of the existing limitations will depend on the number of limitations and degree of severity of the limitation. A soil having a slope gradient of 9 to 18 percent is usually easier to manage by special design for conventional septic tank absorption fields than is a soil horizon having a slow or very slow permeability rating.

On-site investigation

Site evaluation by use of the county soil survey report prepares the user to proceed to the next step, on-site evaluation. Steps 3 through 9 (Figure 29) provide the user a mental image of the landscape and soil characteristics before on-site inspection. Detailed soil and landscape observations are required. Observations of the soil profile can be accomplished by using, as shown in Figure 32, a standard soil probe, orchard or bucket auger, Belgian-type auger, post-hole auger, or spade or by using an open soil pit.

The on-site soil and landscape investigation requires the identification of items 12 through 20 (Figure 29). Appendix A illustrates a checklist that can be used to accomplish items 12 through 19 listed on Figure 29. Each item requires thorough evaluation and interpretation. If a county soil survey report is not available, it is at this phase where the soil and landscape inves-

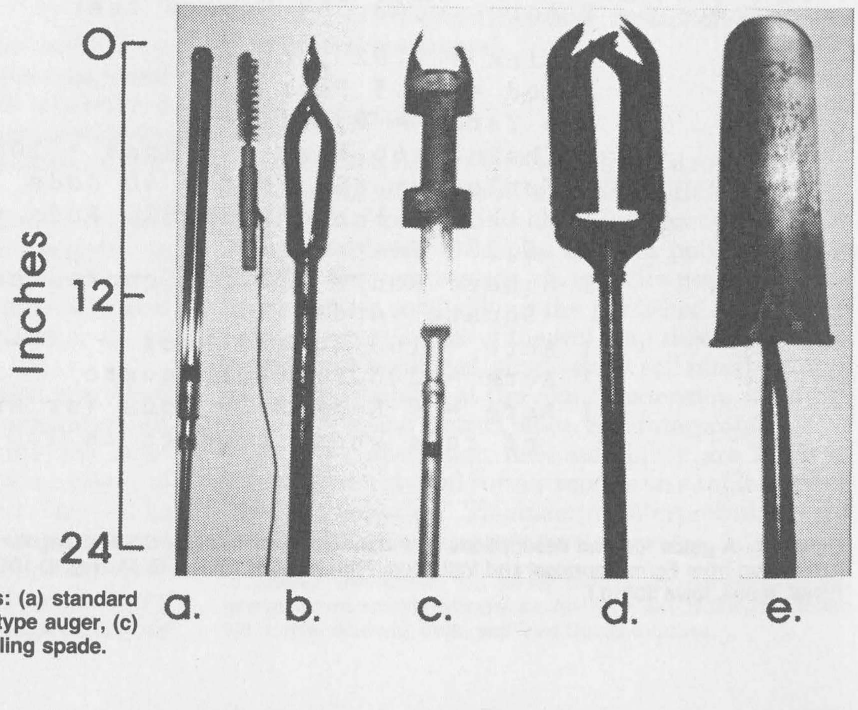


Figure 32. Hand equipment for soil investigations: (a) standard 18-inch soil probe and brush cleaner, (b) Belgian-type auger, (c) orchard or bucket auger, (d) post-hole auger, (e) tiling spade.

tigation begins. On the other hand, if a county soil survey report is available, the site still requires thorough investigation.

The information in the county soil survey report that describes the soil mapping unit at the specific site may not coincide exactly with the soil and landscape properties observed during on-site investigation. These circumstances can occur because the 1:15840 photo scale used for recording the soil inventory does not allow the soil scientist to precisely show all different soils actually occurring on the land surface. Generally, soils occupying a geographic area of less than 2 acres are included within the range of the soil mapping unit or identified by the use of map spot symbols. However, all naturally occurring soils are not always recorded in the description of the soil mapping unit, and all soils have gradational boundaries as properties change across the land surface.

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APPENDIX A

Soil and Landscape Site Evaluation for Home Sewage Waste Treatment

I. Surface features

A. Landscape position

1. Upland summit

   a. Level

   b. Convex summit

   c. Concave depression

2. Upland slope

   a. Head slope
   b. Side slope
   c. Nose slope

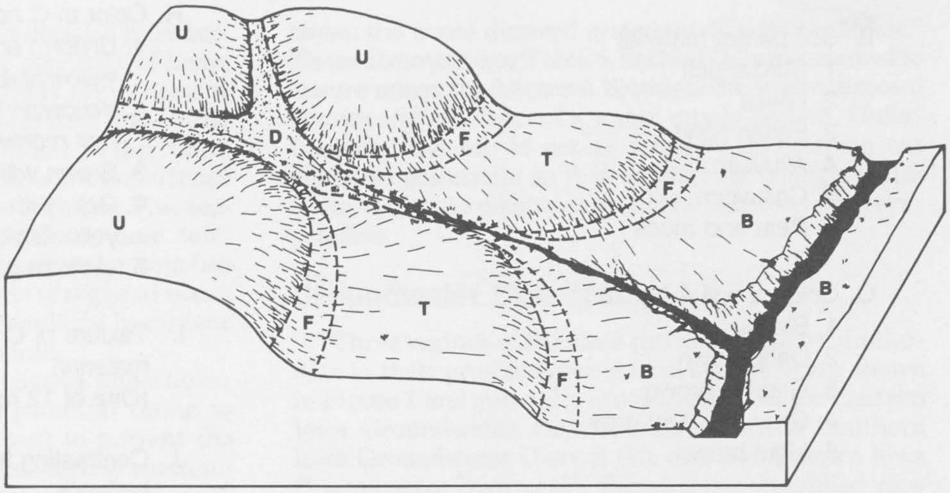
   } Shoulder
     Backslope

3. Upland intermittent drainageway

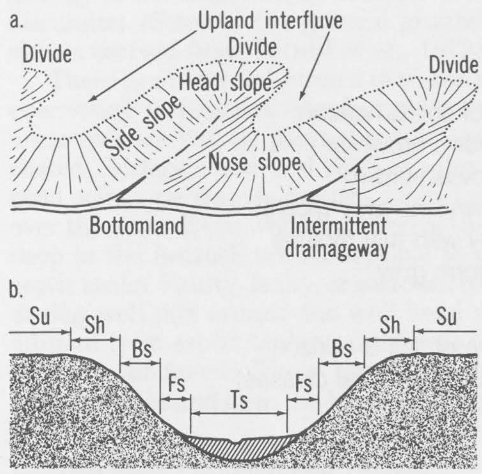
4. Footslope

5. Terrace or bench

6. Floodplain



B = bottomland D = intermittent drainageway F = footslope T = terrace U = upland

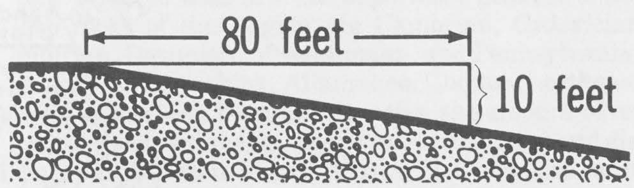


Su – summit
Sh – shoulder
Bs – backslope

Fs – footslope
Ts – toeslope

B. Slope gradient

1. Nearly level:	0-2%
2. Gently sloping:	2-5%
3. Moderately sloping:	5-9
4. Strongly sloping:	9-14%
5. Steep:	14-18%
6. Very steep:	>18%



Percentage slope can be calculated from distance and elevation data. The slope in the illustration is calculated as:

$$\frac{10 \text{ feet}}{80 \text{ feet}} \times 100 = 12.5 \text{ percent slope.}$$

II. Soil profile features

A. Soil depth (in inches)
1. <20
2. 20-32
3. 32-40
4. 40-60
5. >60

B. Soil parent material
1. Glacial drift
2. Loess
3. Eolian sand
4. Alluvium
5. Colluvium
6. Peat and muck

C. Color of soil A horizon
1. Black
2. Dark brown
3. Grayish-brown
4. Gray and light gray
5. Light brown

D. Thickness of soil A horizon (inches)
1. >12
2. 7-12
3. 3-7
4. <3

E. Color of soil B horizon
1. Uniform brown or yellowish-brown
2. Brown with gray mottles
3. Gray with rust mottles
4. Uniform gray

F. Texture of soil B horizon (One of 12 textural classes)

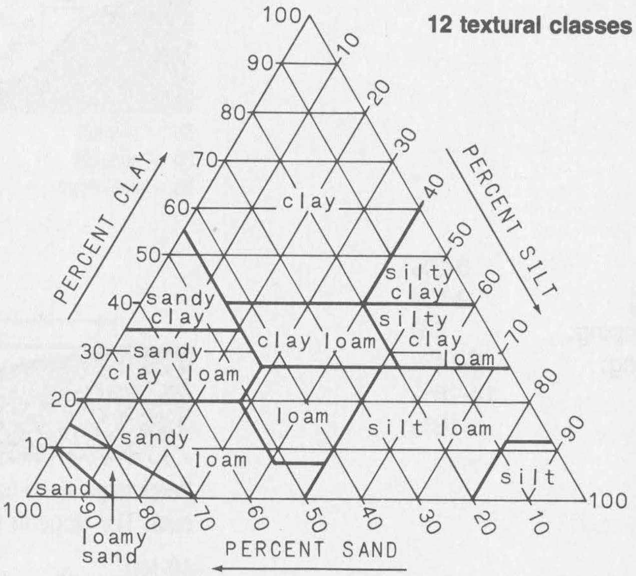
G. Natural drainage class
1. Excessively drained
2. Well drained and moderately well drained
3. Somewhat poorly drained
4. Poorly drained
5. Very poorly drained

H. Color of C horizon (parent material)
1. Uniform brown or yellowish-brown
2. Yellowish-brown with gray and rust mottles
3. Brown with gray mottles
4. Gray with rust and yellowish-brown mottles
5. Uniform gray

I. Texture of C horizon (parent material) (One of 12 textural classes)

J. Contrasting textures for B and C horizons
1. Yes
2. No

K. Carbonates present or absent
1. A horizon
2. B horizon
3. C horizon



12 textural classes

Section II: Groundwater Districts of Iowa

by George R. Hallberg[1]

Section I of this report provides a detailed introduction to soils and how soils affect the operation of home sewage systems. Proper soil conditions are necessary for the functioning of a home sewage system and for the treatment and attenuation of the effluent. In this sense, the proper soil conditions are of paramount importance for the protection of drinking water supplies. This section of the report will briefly expand on these relationships of home sewage systems and water supplies and will outline some general aspects of regional water resources in Iowa to point out particularly hazardous situations in various parts of the state.

Drinking water supplies are of obvious importance. Home sewage disposal presents a potential threat to potable water quality. It is important to prevent the effluent from a septic tank from entering and contaminating surface or groundwater resources. In Chapter 12 of the Iowa Administrative Code, the State Department of Health has set forth rules regulating sewage disposal. Several of the rules are designed for the protection of water resources.

It is prohibited to discharge sewage or household drainage into any type of surface water. Potential health hazards exist from bacteria, viruses, and chemicals, whether these surface waters form a water supply or recreational facility or are even unused. Also, the constituents of the effluent may contribute to increased eutrophication of lakes and ponds. This is discussed further in Section III.

Discharge into abandoned wells and sinkholes also is prohibited because the effluent could enter the groundwater system unfiltered and could readily contaminate groundwater supplies in nearby wells. For example, in 1931, Warrick and Tully published an article entitled "Pollution of abandoned well causes Fond du Lac typhoid epidemic." The title is self-explanatory. At present, no regulation requires the plugging of abandoned wells. Hopefully, this situation will change. (Optimal procedures for well abandonment are outlined by Van Eck, 1971.) These problems will be discussed in more detail later.

Groundwater is specifically mentioned in only one rule, which states that groundwater cannot be within 3 feet of the final grade. A leach field will not operate properly if it is devoid of free oxygen, as it would be when below the water table. The filtration of the effluent and the destruction of harmful bacteria depend on the maintenance of unsaturated-aerobic or oxidizing conditions in the soil. This is further discussed in the other sections.

There also are minimum distances required between the waste disposal system and "water supplies." These distances (see Table 4, Section III) are assumed to ensure adequate filtration between the waste disposal system and any facet of a water supply system. Unfortunately, the soil is not as effective at filtering out chemical pollutants as it is at filtering biologic pollutants, and these distances should be exceeded wherever possible.

Groundwater Districts

Three regions of the state can be defined by similarities in their groundwater resources. These are shown in Figure 1 and generally are referred to as the Eastern Iowa Groundwater District (A,B,C,D), the Southern Iowa Groundwater District (E), and the Western Iowa Groundwater District (F). Figure 2 is a simplified view of the surficial geology of the state. These regions do not correspond with the bedrock geology, which defines the Groundwater Districts (Figure 1). Both aspects of the geology of the state will be considered in this general discussion. (Some of the general groundwater discussion is derived from Tuthill et al., 1972).

There is a potential hazard to water supplies wherever waste is disposed. The hazard potential of these areas in Iowa will be pointed out as each area is discussed. Surface water and shallow alluvial wells with sand points, permeable casings, or enclosures occur all over the state. Even wells that derive their water from deep in the bedrock are susceptible to pollution from septic tanks. Faulty, leaky, or corroded casings on wells or dug well pits around the well head may allow the effluent from septic tanks to infiltrate deep wells (active or abandoned). These types of hazards occur all over the state and form the basis for the general hazard rating.

Eastern Iowa Groundwater District

This district, comprising roughly the eastern half of the state, is characterized in the eastern two-thirds of its area (Zones A and B) by the occurrence of fractured and sometimes cavernous limestone and dolostone bedrock aquifers that are the uppermost geologic units. The rocks of this region are Cambrian, Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian in age. In Winneshiek, Allamakee, Clayton, northeastern Fayette, and Dubuque counties, the amount of unconsolidated sediments, or soil materials (loess and glacial drift) is thin to absent (Figure 2). Elsewhere in the district, drift thickness is highly variable, ranging between 1 and 300 feet in the upland areas. Thickness of loess ranges from 0 to 32 feet. Many of the rivers flow directly upon bedrock and have banks developed in

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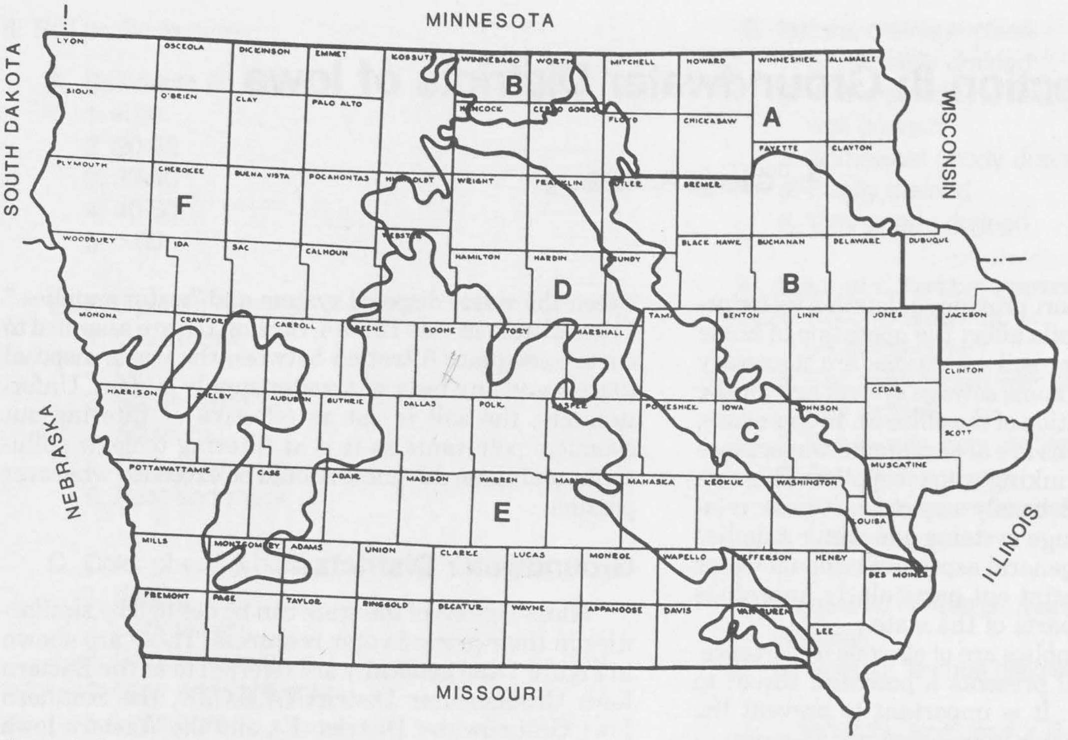


Figure 1. Groundwater regions in Iowa.

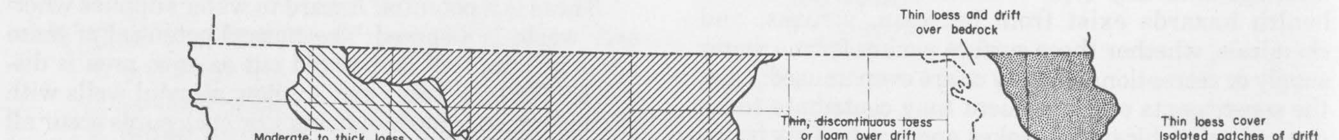


Figure 2. Quaternary terrain and surficial materials in Iowa (from Prior, 1976).

glacial drift. Generalized geologic cross sections typifying the relationship between the bedrock aquifers and the overlying unconsolidated materials in Zone A are shown in Figures 3 and 4. Similar relationships for much of Zone B are illustrated in Figure 5.

There is an abundance of good-quality bedrock aquifer water, which is used extensively as a water source in this area. The fractured nature of the limestone and dolostone bedrock aquifers, in conjunction with the existence of many rapid recharge points, such as sinkholes where drift is thin or absent, causes water from the surface to migrate into the bedrock aquifer at a rate that makes the contamination of the water in the aquifer readily possible. As an example of the severity of this problem, Tjostem et al. (1977) tested 147 wells in the limestone aquifer area of Winneshiek County. Altogether, 57.8 percent of the wells tested were found unsatisfactory for drinking water with respect to nitrate concentration, coliform bacteria, or both.

Open sinkholes are readily recognized and can be easily avoided. However, a related serious hazard exists—where large openings occur in the bedrock but are covered by moderate thicknesses of unconsolidated materials. These "buried" sinkholes may not always be recognized because bedrock is not exposed at the surface, and the holes are not evident. In the making of the modern soil surveys in this part of the state, the soil scientists are showing these features on the soil maps

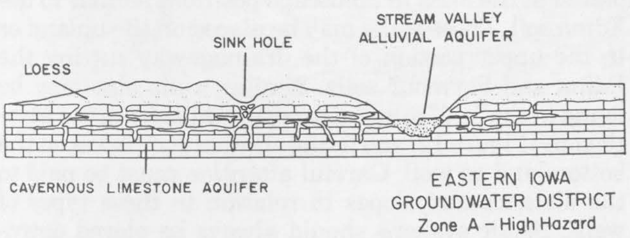


Figure 3. Northeastern Iowa loess-mantled karst area (after Tuthill et al., 1972).

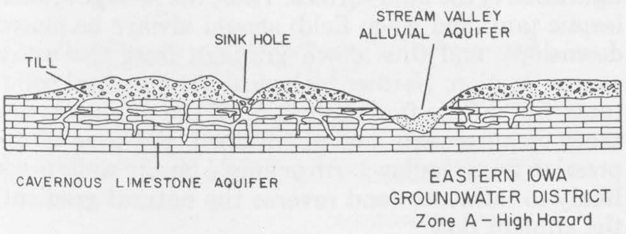


Figure 4. Northeastern Iowa drift-mantled karst area (after Tuthill et al., 1972).

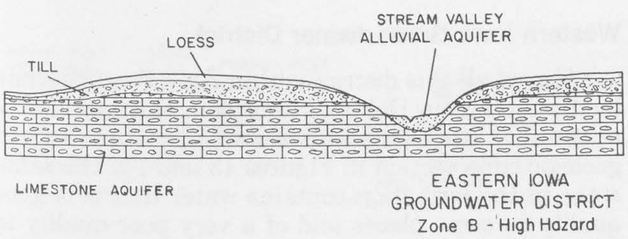


Figure 5. East-central Iowa porous dolostone mantled by thin loess and till (after Tuthill et al., 1972).

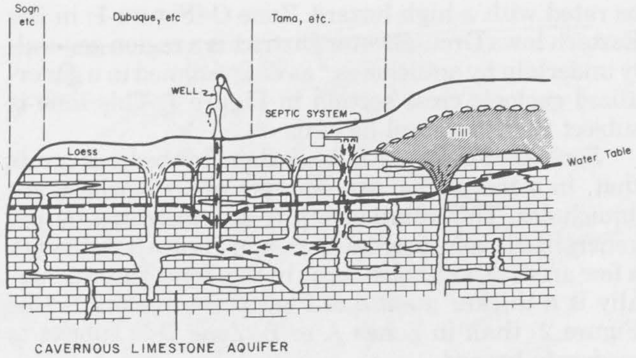


Figure 6. Potential groundwater hazard in karst region of northeastern Iowa.

wherever they are evident. These features often are evident in the soils because they form gentle depressions. Soils in depressions should be poorly or very poorly drained. Often, however, these depressions over cavernous openings in the limestone are well drained. Figure 6 shows this kind of situation.

The names at the top of the figure refer to soil series:

1. Sogn—4 to 20 inches of loamy material over limestone.
2. Dubuque—18 to 36 inches of loess over limestone.
3. Tama, Downs, Fayette, etc.—greater than 60 inches of loess.

Sogn and Dubuque soils would have severe limitations for septic tanks because of the shallow depth to rock and the potential for groundwater pollution. The Tama and related loess soils may have developed in up to 30 feet of loess—or, in the situation shown in Figure 6, in only 5 to 6 feet. The Tama series usually has only slight limitations because, in general, it does not overlie cavernous limestone at these shallow depths. The hazardous situation occurs when the Tama soil in this landscape situation is assumed to have no serious potential for groundwater contamination. The septic system placed as in Figure 6 might have only 1 or 2 feet of material between it and a large opening in the bedrock. Relatively unfiltered effluent could rapidly reach this opening in the limestone. When it does, it flows as if it were in a pipe; i.e., it is like the flow of the effluent through the drainage pipe or tile line that flows from the septic tank where no filtration occurs. If these solution openings interconnect with the openings intersected by the well, the effluent may be pumped up the well in essentially undiluted form (Figure 6). The minimum distance requirements have little bearing in this situation because, effectively, only 1 or 2 feet of soil filter material are between the leach field and the well.

Again, this situation can be foreseen by using the soil survey information. Careful attention must be paid to the soil landscape relations outlined in Section I. That Tama soils occur directly adjacent to Dubuque soils should be a clue that, in this case, limestone is at a shallow depth under the Tama.

Obviously, Zone A (Figure 1) represents a very high potential hazard situation. Sinkholes are not quite so common in Zone B (Figure 1), but this zone should also be rated with a high hazard. Zone C (Figure 1) in the Eastern Iowa Groundwater District is a region generally underlain by aquicludes,[2] as diagrammed in a generalized geologic cross section in Figure 7. This zone is subject to the general hazards.

Zone D (Figure 1) is underlain by bedrock units that, in some places, are aquifers and elsewhere are aquicludes. This relationship is demonstrated by the generalized geologic cross section in Figure 8. Although a few areas of sinkholes occur in this zone, there generally is a thicker mantle of Pleistocene materials (see Figure 2) than in Zones A or B. Zone D is subject to moderate hazard.

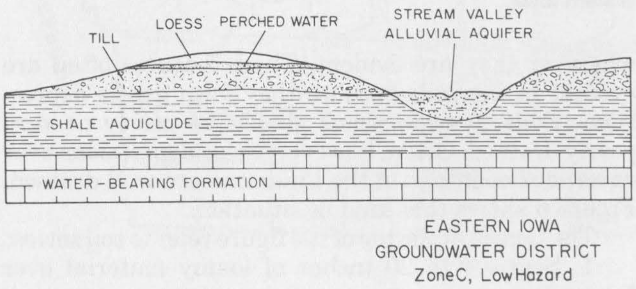


Figure 7. Central Iowa drift mantled shale terrain (after Tuthill et al., 1972).

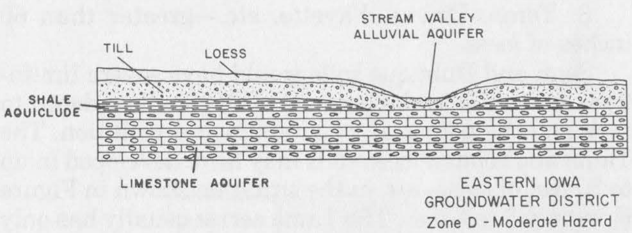


Figure 8. Central Iowa porous limestone or dolomite mantled by shale, till, and loess (after Tuthill et al., 1972).

Southern Iowa Groundwater District

Zone E is essentially without hazard to bedrock aquifers. The water in the Pennsylvanian-age bedrock generally is of very poor quality. Except for the southeastern portion of this district where Mississippian-age rocks subcrop as the uppermost bedrock unit and in the west where Cretaceous rocks are uppermost, this district is underlain by aquicludes as shown in Figures 9 and 10. Water-bearing channel sands occur in the Pennsylvanian and, locally, provide some better-quality water.

Heaviest reliance for sources of potable water is placed on surface water, runoff, and shallow river valley alluvium. Drift thickness in this district ranges from 0 to 400 feet and usually ranges between 50 and 400 feet. Loess thicknesses in the Southern Iowa Groundwater District range from 0 to more than 64

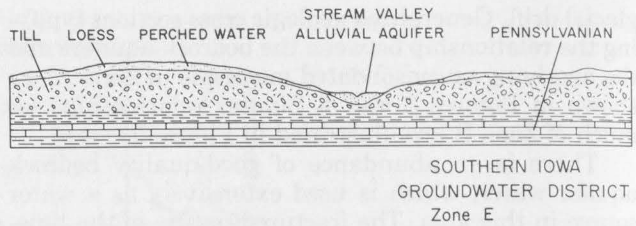


Figure 9. South-central Iowa thick till area (after Tuthill et al., 1972).

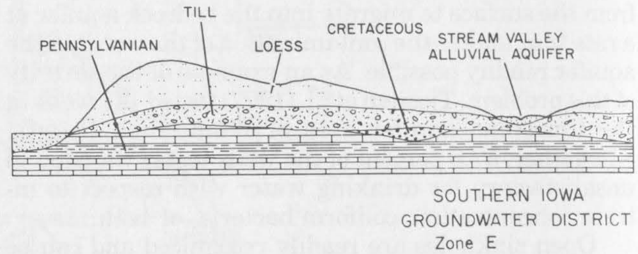


Figure 10. Missouri River area (after Tuthill et al., 1972).

feet. Well records in the files of the Iowa Geological Survey indicate that, in the uplands east of the Missouri River, loess thickness as great as 150 feet occurs (Figure 2). Many shallow wells are placed in the loess and "old" alluvium locally for homes or livestock.

Figure 11 shows soil-landscape relations in a portion of south-central Iowa (Lockridge, 1971). Shallow hand-driven or dug wells or tile wells will sometimes be placed in the loess in landscape positions similar to the Edina soil. These wells may be placed on the upland or in the upper portion of the drainageway cutting the Edina and Seymour soils. Similar wells also may be found in the "old" alluvial deposits underlying the Mystic soils (Figure 12) and in the alluvial complexes on the bottomland as well. Careful attention must be paid to the distance and slopes in relation to these types of wells. Septic systems should always be placed downslope ("downstream") from a well. In shallow groundwater systems, the water table will mimic the configuration of the land surface. Thus, the sewage system (septic tank and leach field) should always be placed downslope, and thus down gradient from the water source location. Neither biological nor chemical pollutants will diffuse far "upstream." If the minimum distance requirements are maintained, the cone of depression from shallow farm or single family wells is not likely to influence (and reverse the natural gradient) the effluent flow.

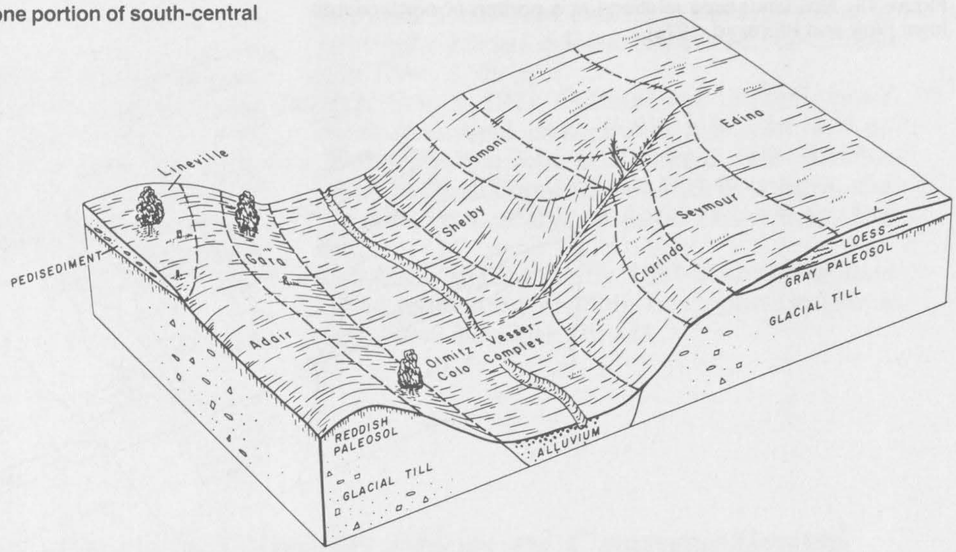
The dependence on shallow wells and surface water in Zone E rates a moderate to high hazard for this area.

Western Iowa Groundwater District

Almost all this district within Zone F is underlain by the Cretaceous Dakota Formation. This rock unit is of variable lithology and is shown in the generalized geologic cross section in Figures 13 and 14. The sandstone in the formation contains water that is of good quality in some places and of a very poor quality in others. Drift thickness in this district ranges from 250 to 600 feet. Rarely does bedrock crop out on the land

[2]An aquifer is a general term for a rock unit that will produce groundwater. It allows groundwater to flow readily enough that it can be pumped in a well. An aquiclude is a rock unit that does not readily transmit water. Water moves through an aquiclude very slowly and will not produce water to a well.

Figure 11. Soil landscape relations in one portion of south-central Iowa (Lockridge, 1971).



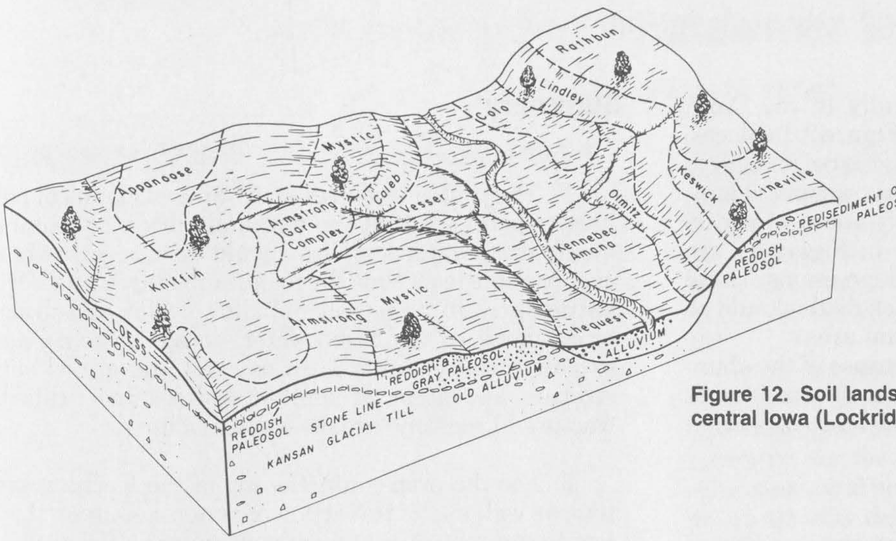


Figure 12. Soil landscape relations in another portion of south-central Iowa (Lockridge, 1971).

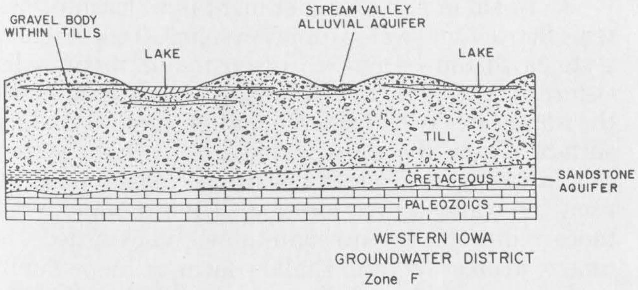


Figure 13. Wisconsin drift—"lakes" area (after Tuthill et al., 1972).

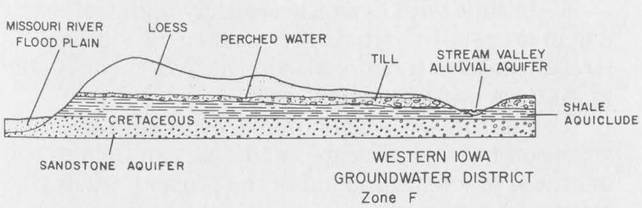


Figure 14. Missouri River area—thick loess mantled terrain (after Tuthill et al., 1972).

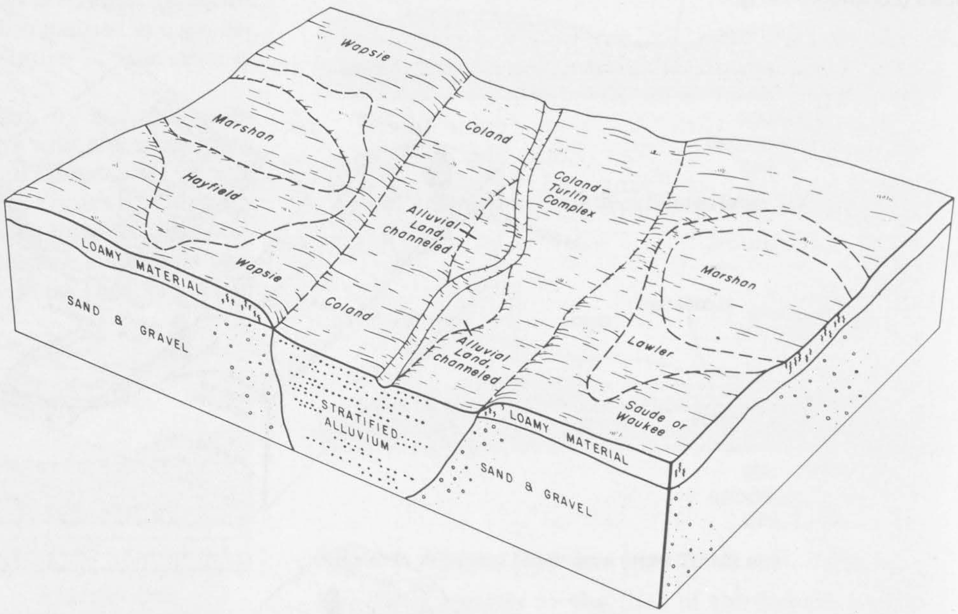
surface. Loess thickness ranges between 0 and more than 64 feet.

Surface water, river valley alluvium, terrace sands and gravel, upland sand bodies (where saturated), and the loess serve as aquifers. Although somewhat more plentifully endowed with usable water sources than the Southern Iowa Groundwater District, this district has few assured water resources distant from stream valleys. In almost all localities, save for the floodplain of the Missouri River, the quantity of water in an aquifer usually is a limiting factor, and protection of available water resources is of critical importance.

Figure 2 points out the overlap of the surficial geology between the Southern and Western Groundwater Districts. The problem of loess (and related upland sand) wells discussed for southern Iowa also occurs here.

Another particular type of problem occurs in northern Iowa and is frequently found in Zone F. Figure 15 is a soil-landscape diagram, which shows gravel terraces adjacent to (and interconnected with) the alluvial bottomlands (Voy and Highland, 1975). This situation

Figure 15. Soil landscape relations in a portion of north-central Iowa (Voy and Highland, 1975).



occurs across northern Iowa, generally in the Cary, Tazewell, and Iowan areas shown in Figure 2. In places, the gravel substratum of these soils is coarse enough to offer rapid flow and, potentially, could transmit chemical and even bacterial effluent long distances into nearby wells. The Marshan soils shown in Figure 15 are poorly drained—occurring in small depressions. These situations should be avoided, and leach fields should be directed away from these depressional areas.

Zone F has a moderate hazard because of the abundance of shallow wells. The coarse gravel areas across the northern part of the state should be considered a high hazard.

Groundwater summary

Much of the emphasis has been placed on shallow wells. The actual design of these wells as well as the water table relationship to the septic system make shallow wells more susceptible to serious contamination. *No matter how deep the well, however, effluent from a septic system can still affect the water supply.* The potential of water-supply contamination from home sewage disposal is generally a very localized problem. Consequently, it has not been discussed or dealt with as vigorously as other large-scale types of waste disposal problems, which may affect regional water supplies or large concentrations of people in urban areas. Where septic tank effluent affects surface waters used for water supply or recreation, or where it enters a karst system, it can indeed have wider reaching implications.

Home sewage disposal usually is considered the problem of an individual family. However, the actual magnitude of the problem may be brought out if we stop and realize that some 800,000 to 1,000,000 people in Iowa are dependent on septic systems to dispose of waste. Even if the water supply of only one family were in question, this problem must be considered seriously.

Summary

1. The problems of travel distance of chemical pollutants point out that the minimum distance requirements from water supplies should be exceeded wherever possible to provide the maximum margin of safety, particularly in areas with shallow wells, subsurface brick, stone, or tile cased water storage systems, and excessive permeability such as sand and gravel substratum and areas of shallow bedrock (particularly fractured limestone areas—karst regions).

2. For the proper functioning of the leaching system, as well as the protection of water resources, the 3 feet to groundwater requirement must be followed.

3. To aid in preventing effluent from leaching systems flowing into water supply systems, these leaching systems should be placed "downstream" from wells, cisterns, ponds, etc. In shallow groundwater systems, the water table will mimic the configuration of the land surface. Thus, the septic tank and leaching system should always be placed downslope (down gradient) from the water source location. If the minimum distance requirements are maintained or exceeded, the cone of depression from shallow farm or single family wells is not likely to influence the effluent flow (by reversing the natural gradient).

4. In soils with even a seasonally high water table and in areas with high pollution potential—gravel substratum and karst regions—alternatives to conventional systems must be considered.

Use of the soil survey maps, especially by paying attention to soil-landscape relations, can help to point out these problems and aid in the proper system placement and design.

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Section III: Design and Construction of Conventional and Alternative Wastewater Systems

by C. E. Beer and D. D. Effert[1]

Why Is Wastewater Treatment Necessary?

There are a number of reasons for treating household wastewater before final disposal. The original reason for sewage disposal, and later treatment, was for the protection of our health. Rural wastewater may contain a number of pathogenic bacteria, viruses, protozoa, and parasitic worms that can be spread by improper wastewater treatment. Indeed, it is not uncommon for certain epidemics to be directly linked to inadequately treated sewage. The number of health problems related to wastewater disposal has declined significantly in the last 60 years. One of the reasons for this change is because of improved wastewater treatment. This good record can continue and will improve with the installation of properly operating on-site wastewater treatment systems.

The protection of the environment is a more recent reason for proper wastewater treatment. The need for this type of protection is apparent, and of particular importance, in areas where a rural wastewater treatment system is located near a river or lake. The addition of untreated or partly treated wastewater to a receiving body of water will cause eutrophication, and fish kills may result in some instances.

Eutrophication, which may cause fish kills, is caused by two elements commonly found in household wastewater. They are nitrogen in the form of ammonia, nitrate, or nitrite and phosphorous in the form of orthophosphate. Both elements have the potential for causing eutrophication, and the amount of damage caused depends on the concentratin of the element in the lake or river. For example, nitrogen and phosphorous concentrations of 0.3 mg N/l and 0.02 mg P/l, respectively, are acceptable in most lakes. However, if the nitrogen or phosphorous concentrations become greater than 0.8 mg N/l and 0.1 mg P/l, respectively, algal blooms may result. In addition, nitrogen in the form of ammonia may kill some types of fish. Lethal concentrations will depend on pH, temperature, and the season, but it is recommended that ammonia concentrations in surface waters should not exceed 2.0 mg N/l.

From the previous discussion, it can be concluded that the discharge of rural household wastewater without treatment is not sufficient. Proper treatment is necessary for the protection of our health and the environment, and proper treatment can take place only in an adequately designed, constructed, and maintained on-site wastewater treatment system.

Rural Household Wastewater Characteristics

To properly design an on-site wastewater treatment system, it is necessary to make a site investigation to determine the topography of the area and characteristics of the soil (see Appendix A, Section I). It also is helpful to know something about the wastewater that will be treated. The following information will provide some background to help in understanding the amount and strength of the wastewater produced in a rural home.

Flow characteristics

Total household water use is dependent on many factors, including the number of full-time residents, their ages, occupations, and life styles. In addition, the number and types of household appliances also are important factors, and methods used to estimate the daily water use must include all these variables.

Total daily water use is only a part of the information needed to determine the hydraulic loading rate for

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a wastewater treatment system. The daily flow pattern or the time of day when the water is used also should be known. Although the flow pattern is not specifically used in designing a disposal system, it is important because a wastewater treatment system must be designed to handle the estimated maximum water flow in addition to the average daily water flow.

Studies have been made to indicate the average daily water use for a rural household and the times of the day that the water is generally used. These studies have shown that, although water consumption may vary from family to family, on the average, an individual uses between 40 and 45 gallons per day (gpd). If we assume a per-capita water consumption of 44.5 gpd, the distribution of the water use is estimated by the values shown in Table 1 (Bennett et al., 1974).

Table 1. An estimate of a rural household's water use

Appliance	Each use (gal)	Uses per Person per day	GPD per person
Toilet	4.1	3.6	14.7
Sink	1.7	4.5	7.6
Garbage Disposal	2.1	0.4	0.8
Bath or Shower	27.2	0.32	8.7
Dishwasher	7.0	0.15	1.1
Washing Machine	38.6	0.30	11.6
		Total	44.5

An hourly profile of water use is harder to determine because it is dependent on life style and the bathing habits of the occupants of the household. A typical daily flow pattern is shown in Figure 1 and is used to illustrate the variation in wastewater flow during different times of the day. Studies have shown that surge flows of 60 gallons of water in a 7-minute period are not uncommon. Wastewater treatment systems, particularly those using gravity settling methods such as a septic tank, must be designed to handle such sporadic water surges.

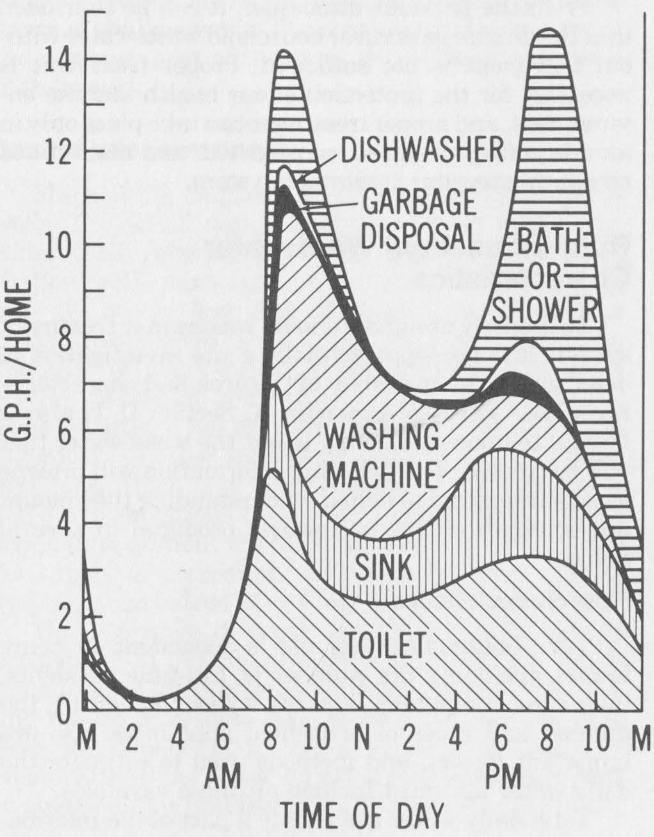

Figure 1. Typical daily household water use.

Strength characteristics

Although wastewater strength is not as important as the hydraulic loading rate in the normal operation of an on-site wastewater treatment system, it is an important concept. Table 2 (Bennett et al., 1974) shows the parameters in which the pollution-causing properties of wastewater, commonly called strength (mg/l), can be measured. An important concept that should be understood is that the strength of the wastewater is dependent on its source, not on the volume used for a particular function. This concept is illustrated in Figure 2 where a circle is divided into six parts, with the size of each part reflecting the percentage of 44.5 gallons of water used for each function. Figure 3 divides a similar circle into six parts also, but the size of each segment is related to the strength of the wastewater. A comparison of these two figures shows that although the toilet and garbage disposal use only 33 percent of the water, they are the source of 75 percent of the daily COD production.

It is helpful to have a basic understanding of the amount of wastewater produced in a rural home and its strength. With this information, a person can more accurately design a treatment system that will effectively handle the waste and, at the same time, not be unnecessarily overdesigned. In addition, the source of the wastewater also is important because, in special cases, some of the wastewater may be segregated from the rest and treated in a different manner. It is important to know the volume, flow characteristics, and strength of the segregated wastewater so that it also

Table 2. Characteristics of home wastewater sources

	Flow/Use (gal)	COD mg/ℓ	BOD mg/ℓ	TS mg/ℓ	SS mg/ℓ	PO_4 mg/ℓ	NH_3-N mg/ℓ
Sink							
Kitchen	1.0	1652	1082	1328	209	1	114
Bathroom	2.0	495	261	480	228	0	1
Average		850	533	760	215	1	-
Bath-Shower	27.2	220	100	339	27	0	0
Toilet							
Average	4.1	1300	124	1723	650	24	300
Washing Machine							
Cycle 1	17.2	1050	400	1185	128	30	8
Cycle 2	4.2	185	46	421	0	3	1
Cycle 3	17.2	130	39	527	46	1	1
Average	38.6	550	200	760	78	14	5
Garbage Disposal	2.1	11780	4065	10748	6672	24	285
Dishwasher							
Cycle 1	2.0	620	363	2207	83	15	0
Cycle 2	1.0	210	99	1083	16	1	0
Cycle 3	2.0	44	23	412	0	0	0
Cycle 4	1.0	35	6	75	0	0	0
Cycle 5	1.0	11	2	73	0	0	0
Average	7.0	225	125	920	26	4	0
Combined (mg/ℓ)		905	278	1180	396	12	120
Average (#/CD)[a]		0.35	0.11	0.45	0.15	0.005	0.05

[a]Pounds per person per day

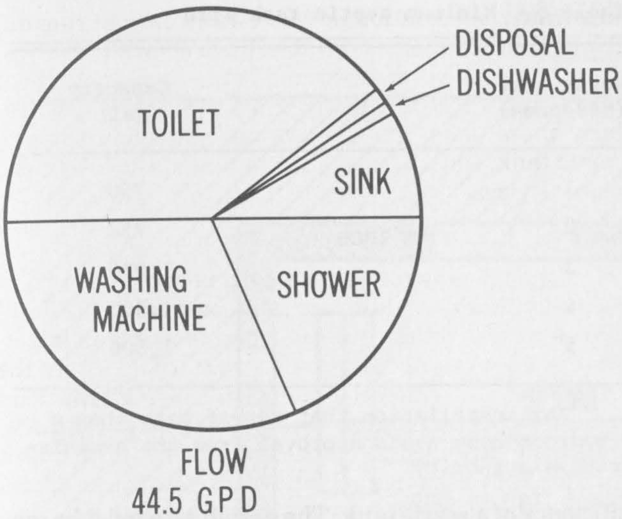

Figure 2. Distribution of the sources of wastewater flow.

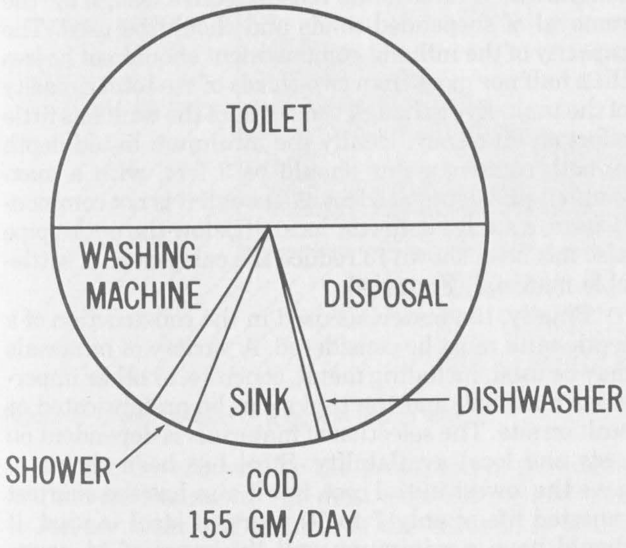

Figure 3. Distribution of the sources of wastewater strength.

may be treated by the most efficient and economical method available.

Procedures for Installing On-Site Wastewater Treatment Systems

The procedure for installing an on-site wastewater treatment system will vary from county to county in the State of Iowa. There is, however, a sequence of steps that can be followed to make the most efficient use of your time. They are:

1. Contact the county sanitarian if one is available. He will be able to answer your specific questions and give suggestions on what the next step should be.
2. Complete a soil examination of the proposed wastewater treatment site. In some counties, this service may be provided by the sanitarian. In lieu of this service, the procedure for the soil examination as outlined in Section I of this publication under "Soil Physical Properties" and "Soil Percolation Test" may be followed.
3. Obtain an on-site wastewater treatment construction permit if required. This permit is issued by the county sanitarian. If a conventional septic tank with soil absorption field, double sand filter, or mound is not appropriate for the area, the sanitarian will be able to suggest an alternative method of wastewater disposal.
4. A wastewater treatment system should be designed in cooperation with a local contractor, and the sanitarian if available. This system should fit the terrain and geological formations of the area, and its size must be based on the characteristics of the soil and number of bedrooms in the house as shown in this publication.
5. Construction may now begin. It is the responsibility of the sanitarian (if available) to inspect the system during and after construction to make sure that proper materials and construction techniques have been used.

Design and Construction of On-Site Wastewater Treatment Systems

Location selection

One of the most important considerations in the design and construction of an on-site wastewater disposal system is selecting the proper location. Several factors including the topography of the land, soil characteristics, and depth to and duration of the seasonal high water table as well as local ordinances must be considered. The legal restrictions must be fulfilled and should be considered first inasmuch as they normally are not changed or modified.

The location of the sewer line and the wastewater treatment system are both specified by regulations in the State of Iowa. The restrictions on the location of the sewer line are variable and depend on the material used to construct the sewer line. Current restrictions issued by the Department of Environmental Quality should be consulted (Table 3). Table 4 shows the minimum distance the treatment system must be from water supplies, buildings, and other potential problem areas. Because the location of the well is so important with respect to the sewer lines and the treatment system, it has become a common practice to drill the well before the location of the wastewater treatment system is chosen. This helps to eliminate future conflicts over minimum distances from the well to the treatment system. Finally, in a few instances, local zoning restrictions also may dictate where a wastewater system is to be installed.

The topography of the area is the next factor that must be considered when choosing the proper location for a wastewater treatment system. The relationship of landscape position to expected performance of a treatment system is discussed under Landscape Position and Slope in Section I in the part about Why Soils Are Different.

The septic tank

The function of a septic tank is to serve primarily as a settling chamber. It collects and holds wastewater

Table 3. Sewer line location

	Minimum Distance from Well Water Supply and Distribution Lines (ft) Private	Public
1. Extra heavy or centrifugally cast iron soil pipe with joints of caulked lead or preformed gaskets and encased with a minimum of 6 in of concrete.	5	10
2. Extra heavy or centrifugally cast iron soil pipe with joints of caulked lead or preformed gaskets.	10	20
3. Sewer pipe installed to remain water-tight and root-proof.	50	75

Table 4. On-site wastewater treatment system location

Minimum Distance in feet from to	Septic Tank	Absorption System
Private water well	50	100
Public water well (shallow)	200	400
Public water well (deep)	100	200
Lake or reservoir	50	100
Stream or open ditch	25	25
Dwelling or other structure	10	10
Side or rear lot lines	5	5
Front lot lines	10	5
Other type subsurface sewage treatment system	5	10
Water lines continually under pressure	10	10
Suction water lines	50	100

and allows some waste material to settle to the bottom while the rest of the waste is biologically converted to liquid and gas, which can then be easily disposed. The material that settles to the bottom of the tank (the sludge) decreases in volume with time because of compaction and additional degradation. Eventually, this material along with floating debris (scum) must be removed from the tank to maintain the efficiency of the tank to remove the settlable material.

The proper selection of a septic tank is very important to the overall operation of a conventional wastewater treatment system. Three factors govern the selection of the tank. They are capacity, design, and the materials used for the construction of the tank. All factors must be considered if the most efficient and economical tank is to be chosen. The capacity of the septic tank is specified by the State of Iowa (Table 5). The purpose of a large tank is threefold. First, a large tank helps to reduce the effect of a hydraulic surge, which can take place when the bathtub and the toilet discharge simultaneously. A large tank also reduces the amount of mixing that takes place and therefore is more efficient in removing solids. Finally, a large tank helps to maintain at least a 24-hour detention time, which allows for a more complete degradation of the nonsettlable material.

Capacity is not the only factor that controls the efficiency of a septic tank. The design also must be considered. For example, it has been shown that a two-compartment tank is the most effective design for the removal of suspended solids and should be used. The capacity of the influent compartment should not be less than half nor more than two-thirds of the total capacity of the tank. Even though the shape of the tank has little effect on efficiency, ideally the minimum liquid depth in both compartments should be 3 feet, with a maximum liquid depth of 6 feet. Although it is not commonly used, a sludge deflector located below the outlet pipe also has been shown to reduce the carry-over of settleable material (Figure 4).

Table 5. Minimum septic tank size

House size (bedrooms)	Capacity (gal)
1	750
2	750
3	1,000
4	1,250
5[a]	1,500

[a]Any installation that serves more than a 5-bedroom home needs approval from the administrative authority.

Finally, the materials used in the construction of a septic tank must be considered. A variety of materials may be used, including metal, concrete, or other impervious material, and the tanks can be prefabricated or built on site. The selection of materials is dependent on costs and local availability. Steel has been shown to have the lowest initial cost, but it also has the shortest expected life of only 7 to 10 years. If steel is used, it should have a minimum wall thickness of 14 gauge (5/64 inch) and be provided with an appropriate type coating both inside and out as specified in American National Standards Institute Specifications No. A162.1-1970.

Concrete or brick also are acceptable construction materials for a septic tank. Poured-in-place concrete lasts 10 years or more when properly built, but precast concrete, waterproof tile, or brick, although more expensive, has a life expectancy of more than 20 years. If concrete or brick is used, the walls and bottom of the tank should conform to the specifications listed in Table 6. In addition, tank tops should have a minimum thickness of 4 inches and be reinforced with quarter-inch reinforcing rod in a 6-inch grid or equivalent. Finally, to prevent a rapid deterioration of the concrete, all surfaces above the water line must be given a protective coating of a bituminous material.

Septic tank effluent disposal

The liquid that drains from a septic tank is dark, foul smelling, and as much of a potential health hazard as raw sewage. It therefore is necessary to fur-

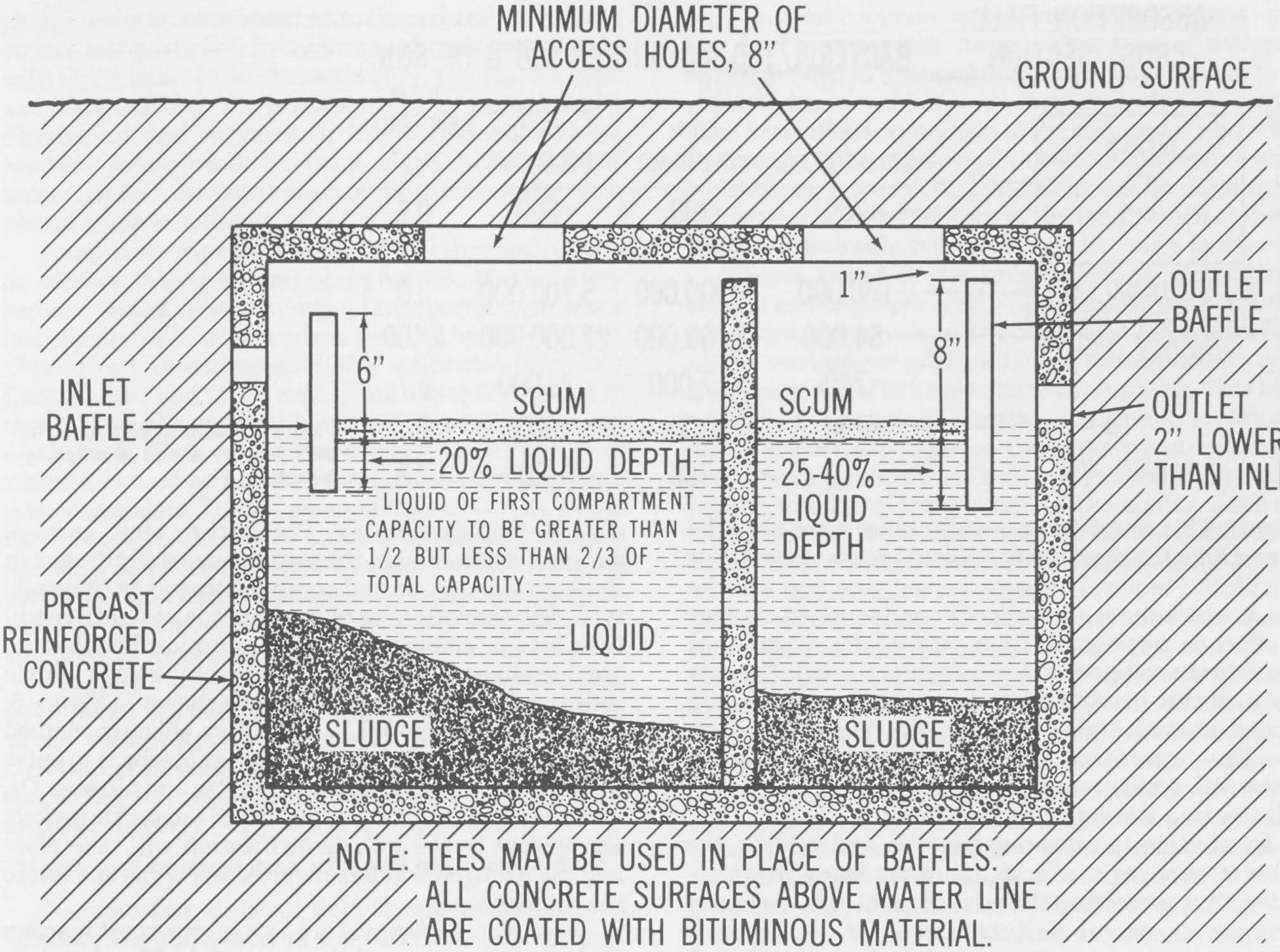

Figure 4. Cross section of a typical septic tank.

ther treat the effluent for the protection of the public and the environment. The most common method used to further treat and dispose of the effluent is to discharge the liquid under the surface of the soil. Soil is used because it is an available natural filter capable of trapping bacteria, viruses, and other indicators of pollution such as BOD_5 (5-day biochemical oxygen demand) and phosphates.

The efficiency of a soil to remove bacteria, viruses, and other pollutants is dependent on a number of conditions in the soil. A few of the major factors include soil characteristics, rate at which the liquid is applied, temperature, biological competition of the microorganisms for nutrients, and pH. Although many of these parameters are hard to control and the effects of others are hard to predict, it is accurate to say that wastewater that travels through an unsaturated soil at a slow rate of speed will be better treated than if it travels through a saturated soil at a fast rate of speed.

Table 6. Septic tank wall and bottom specifications

Material	Thickness (in)
Segmented block, brick	8
Poured concrete	6
Poured concrete, reinforced	4
Special concrete, vibrated and reinforced	2

The distance the wastewater travels also is a very important factor in the efficiency of the soil to remove bacteria, viruses, and other pollutants. A good example is the treatment that takes place in a typical absorption trench. Figure 5 shows that the removal of bacteria from septic tank effluent does not take place until the liquid has left the saturated conditions of the trench (McCoy and Ziebell, 1975). The bacteria count for the saturated zone is given in number/100 ml, and in the unsaturated zone, the count is expressed in number/100 g of soil. Other studies (Ziebell et al., 1974) have shown that this liquid must travel through at least 2 feet of an unsaturated soil if harmful bacteria and indicator organisms are to be removed.

Virus removal also takes place in the soil, but the mechanisms of virus removal are different from those for the removal of bacteria. Unlike bacteria removal, which takes place through filtration and biological antagonism, virus removal occurs when viruses adhere to the soil through sorption and are either inactivated or retained there. Sorption is the attraction of a virus to the soil much like iron particles are attracted to a

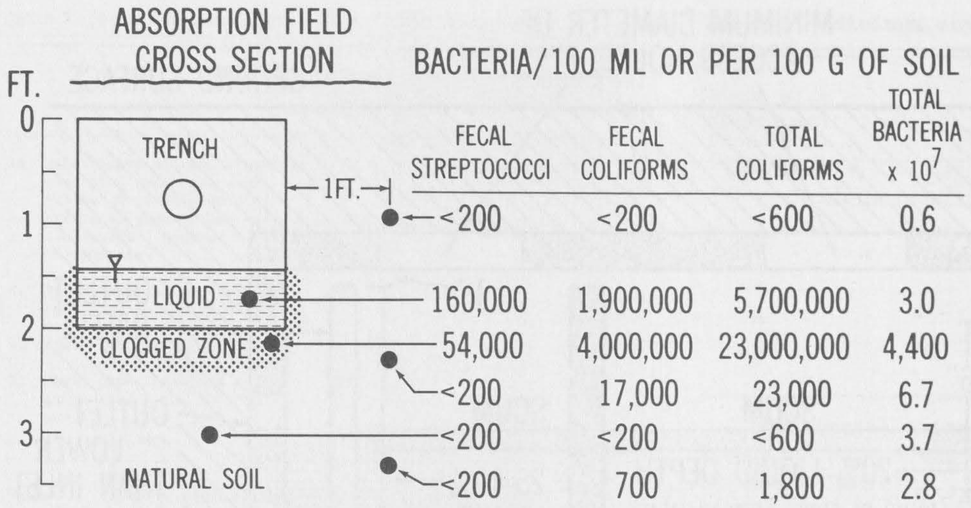

Figure 5. Bacterial population in and around a soil absorption trench.

magnet. This attraction generally takes place near the point where the septic tank effluent enters the soil, but as with the removal of bacteria, soil pore size and the rate at which the septic tank effluent is applied also has an effect on sorption. In time, most of the viruses that attach to the soil grow old and are inactivated. The rate at which this inactivation takes place is temperature dependent, with higher temperatures being more effective. The viruses that are not inactivated are retained in the soil, which removes them from the liquid, thus still treating the septic tank effluent.

In addition to removing bacteria and viruses, the soil also removes chemical pollutants found in wastewater, thus protecting the environment. The two most common chemical pollutants found in domestic wastewater are nitrogen and phosphorus, and both either change form or are partly removed in the soil.

Nitrogen enters the wastewater from a variety of sources and in a number of forms at a per-capita rate of about 6 pounds annualy. The kitchen sink, garbage disposal, and toilet are the major sources of nitrogen in the form of ammonia and organic nitrogen. In the septic tank, few changes take place, and it is not until conditions become aerobic in the soil absorption field that the organic nitrogen and ammonia are converted to soluble nitrogen. The change with depth is shown in Figure 6. Unfortunately, the soil is not a very effective method for removing nitrogen, and it is possible for it to enter the groundwater in the form of nitrites and nitrates. Or, under certain conditions when small anaerobic pockets are present in the soil, denitrification will take place and the nitrogen will be converted to N_2 gas and lost to the atmosphere.

Phosphorous removal is another important reaction that takes place in a soil absorption field. The phosphorous is added to the wastewater primarily in the form of polyphosphate from synthetic detergents, and it is removed by a mechanism similar to virus removal. The

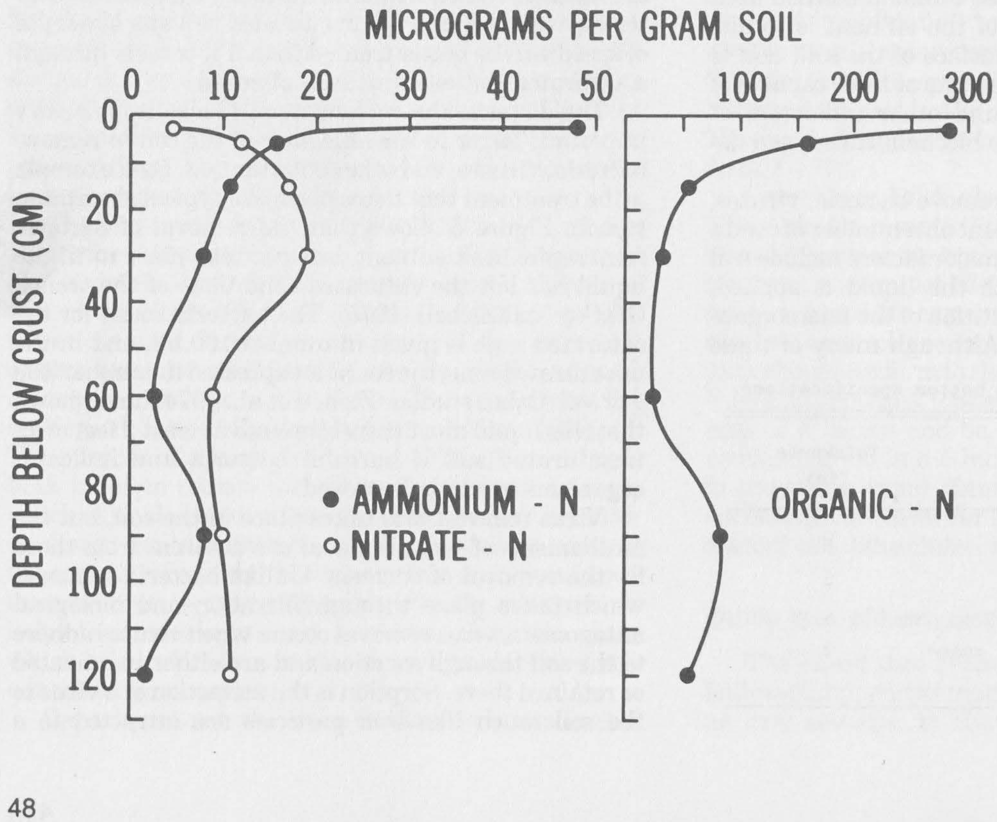

Figure 6. Distribution of nitrogen in a soil absorption field.

phosphorous become attached to the soil and is retained on the soil particles. In addition, phosphorous reacts with other ions of the elements of K, Ca, Na, Fe, Mn, and NH_4 and forms a precipitate large enough to be filtered out and retained in the soil. Because these reactions take place at the point where the wastewater enters the soil, contamination of the groundwater with phosphorous is unlikely.

A soil absorption field is capable of removing bacteria, viruses, nitrogen, and phosphorous. It does more because the soil also removes a large percentage of the biologically oxidizable carbon present in wastewater. This carbon, measured as BOD_5, originates primarily from kitchen and toilet waste, and about 30 percent of this biologically oxidizable carbon is removed in the septic tank. The rest enters the soil absorption field where it is used as a carbon and food source by the soil microorganisms. The efficiency of the soil to remove the carbon is dependent on a number of factors including soil type, temperature, and availability of oxygen. A soil absorption field is designed to optimize those factors and thereby remove the biologically oxidizable carbon present in domestic wastewater.

An on-site wastewater treatment system should be installed for the purpose of treating as well as disposing of the wastewater. The removal of bacteria, viruses, chemical pollutants, and BOD_5 can take place in the soil if the soil absorption field is designed and constructed properly.

Design and construction of a soil absorption field

A subsurface disposal field should be designed to optimize the conditions in the soil necessary for good treatment and disposal. These conditions include maintaining the structure of the soil and keeping the field as aerobic as possible. Both conditions are necessary for treatment and disposal of septic tank effluent, and they can be achieved if proper design and construction practices are followed.

One of the most important and often overlooked preconstruction procedures is the protection of the soil near the proposed soil disposal field. It is essential that heavy equipment be kept off the site because the weight of such equipment will compact the soil causing irreversible damage, and a compacted soil will not accept and treat septic tank effluent at its normal rate. To guarantee full protection of the soil, it may be necessary to rope off the entire lot until the location of the absorption field has been chosen. After the soil and landscape evaluation and percolation tests have been completed, the protected area may be reduced to the actual size of the field.

After the site has been protected from heavy equipment, the design, followed by construction of the soil absorption field, may proceed. The first step in design is to decide which type of soil disposal system should be installed in that particular area. The options include absorption trenches and absorption beds. Each design has a particular advantage, depending on soil characteristics and availability of construction equipment. Each design, if properly constructed, will use the soil to treat and dispose of septic tank effluent.

The most common type of subsurface disposal system is the absorption trench. This type of design is recommended in areas where the soil has up to 35 to 45 percent clay content because its installation causes the least amount of compaction of the soil, and it also offers the largest ratio of sidewall to bottom absorptive area. In addition, a trench disposal field can be designed to follow the slope and contour of the land, which makes it the most desirable type of design in many locations.

Proper sizing of the soil absorption trench is as critical as the proper sizing of the septic tank. Ideally, the trench system should be large enough to dispose of all the wastewater produced in the home and still be as small as possible to keep costs to a minimum. This ideal size can be determined if certain information is known. This information includes the anticipated volume of wastewater produced by the home (estimated by counting the number of bedrooms) and the ability of the soil to absorb and treat septic tank effluent (estimated by conducting a percolation test). It has been shown previously that, on the average, a person produces 44.5 gallons of wastewater per day. Experience has shown, however, that individual life styles vary, and a more reliable estimate of the amount of wastewater produced in a house should be based on the size of the home. Currently, on-site wastewater treatment systems are designed to dispose of 150 gallons of wastewater per bedroom per day. This figure allows for individuality of life styles as well as for those times when water use is great. A wastewater disposal system must be able to handle unpredictable surge flows in addition to the average daily flow, an undersized design of the soil absorption field is not an effective way of reducing costs. Therefore, a soil absorption field should be sized by using the information supplied in Table 7.

After the size of the soil absorption trench has been calculated, a decision must be made as to what configuration or shape of field is suitable for that particular location. There are two configurations from which to choose, and each has certain benefits associated with it. In actual practice, however, it usually is the topography of the land, in particular the slope, that suggests to the contractor whether he should use lateral or serial distribution.

Table 7. Required absorption area or length of trench per bedroom[a]

Percolation Rate (min per in)	Depth of Aggregate (in) 6: Area (ft^2)	6: Length (ft)	6: Rate (gpd per ft^2)	12	18	24
1/2 to 5	125	83	1.2	Decrease area and length 20 percent of 6 in depth requirement	Decrease area and length 33 percent of 6 in depth requirement	Decrease area and length 40 percent of 6 in depth requirement
6 to 15	190	127	0.8			
16 to 30	250	167	0.6			
31 to 45	300	200	0.5			
46 to 60[b]	330	220	0.45			

[a]Absorption area is defined as the square feet of trench bottom required. The equivalent length of trench is based on an 18-inch width bottom. For trench widths less than 18 inches, new trench length must be computed based on the required area. Each bedroom is assumed to produce 150 gallons of waste per day.

[b]Soils with percolation rates greater than 60 minutes per inch are unsuitable for installation of a soil absorption field.

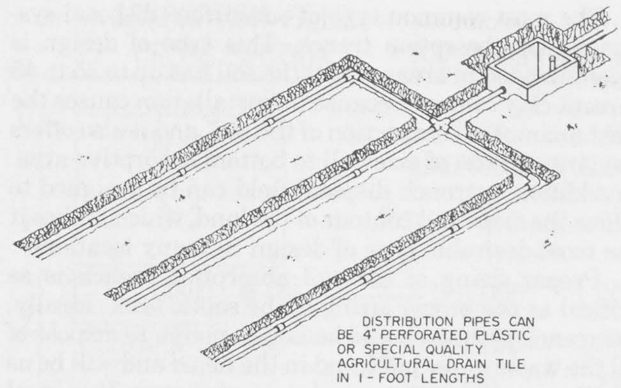

Figure 7. Schematic of a lateral distribution soil absorption field.

Lateral distribution (Figure 7) is the most common trench configuration used today. This type of design can be used in all locations where the soil has been classified as suitable for receiving and treating septic tank effluent and the slope of the land is less than 6 inches from one side of the proposed absorption field to the next. Lateral distribution is ideal for most situations and is the recommended configuration because the septic tank effluent is more equally distributed, and this contributes to aerobic conditions in the soil. A variety of designs can be used for a lateral distribution system as long as the flow lines follow the contour of the land and the installation meets the sizing requirements shown in Table 7.

For many years, distribution boxes were used to help equally distribute septic tank effluent to the various sections of pipe in a lateral soil absorption field. If properly installed and maintained, distribution boxes work well, and each lateral will receive an equal share of septic tank effluent. Research has shown, however, that proper installation is rare, and an improperly installed distribution causes inundation of some parts of a soil absorption field, which results in failure.

Serial distribution (Figure 8) may be used in areas where lateral distribution is not appropriate. Serial distribution must be used when the slope of the land is greater than 6 inches from one side of the proposed soil absorption field to the other side. The object of a serial distribution network is to allow each section of trench to become continually inundated before the septic tank effluent flows into the next section of trench. This allows each section of trench to be used to its full capacity before other sections are wetted. Unfortunately, this type of design causes a continuous inundation of the trench and does not provide for dry periods during which the soil pores can become aerobic. Because of this, serial distribution soil absorption fields should be used only when a lateral distribution network is not feasible.

After the soil absorption field has been properly sized and designed to follow the contour of the land, construction may not necessarily begin. Before construction is to proceed, the soil moisture must be tested to prevent soil structure damage due to high moisture content during construction. Ideally, the soil moisture should be at a level to give proper working conditions for a given textural class before construction may begin. Most contractors do not have the equipment necessary to determine this, however, so a good rule of thumb to follow is if the soil is wet enough to roll into a thread or wire, it is too wet to install an absorption field. A soil moisture determination is one of the few ways of determining if conditions are right for the installation of a subsurface disposal field, and a little extra time spent at this point is an almost sure way of extending the operating life of the disposal field.

The installation procedures and materials used for either lateral or serial distribution systems are similar, and the following discussion is intended to be used as a guide for the construction of either type of subsurface disposal field. Recall that the lightest construction equipment available should be used to dig the trenches. In most cases, a small backhoe is ideal because it is capable of digging a trench 18 to 36 inches wide and 36 inches deep. After the trenches have been dug, the sides should be scarified to remove the layer of smeared soil that develops during the digging. After the scarifying procedure has been completed, it is then necessary to remove any loose soil from the bottom of the trench to prevent the fine particles from clogging soil pores. Good construction procedures will help to keep the soil pores open and contribute to the desired state of aerobic conditions in the soil disposal field.

After the trenches have been dug and properly prepared, the gravel may be added. When the trench depth is not limited by required distance between the bottom and bedrock, water table, or other restrictive layer, a minimum 18-inch layer of 1/2 inch to 2-1/2 inch diameter gravel must be laid evenly in the trench, but a thicker gravel layer means that fewer linear feet of trench are necessary to handle the same amount of

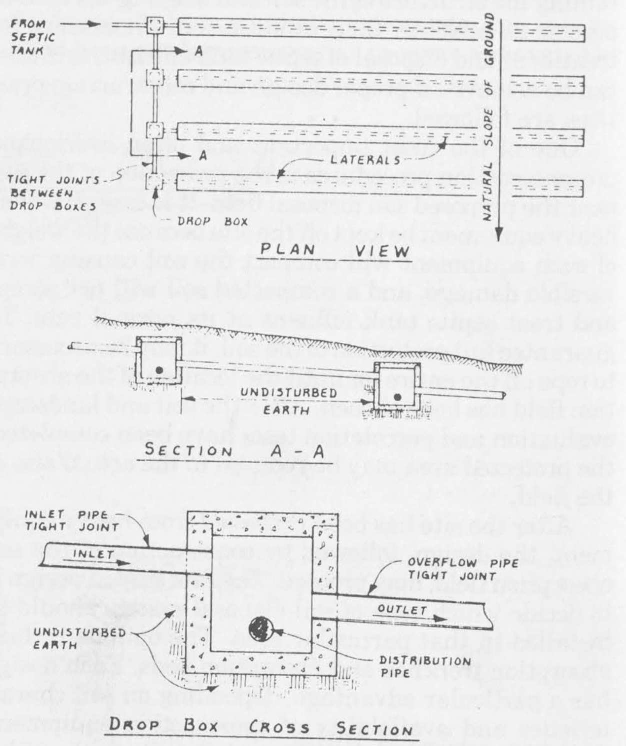

Figure 8. Schematic of a serial distribution soil absorption field with drop boxes.

septic tank effluent (Table 7). This may be of some importance if lot size is a problem. Therefore, a layer of gravel at least 18 inches thick is suggested, with a recommended thickness of 24 inches in a trench that is 36 inches deep.

The next step in the construction of a lateral or serial subsurface disposal field is the installation of the distribution pipe. For gravity-fed systems, the distribution pipe will consist of vitrified tile or nonmetallic pipe with a minimum diameter of 4 inches. Nonmetallic pipe is increasing in popularity because of its ease of installation, and, if this type of pipe is used, the perforated side of the pipe should be placed face down above the gravel. No matter what type of distribution pipe is chosen, however, it will be necessary to determine its slope before proceeding further. Ideally the distribution pipe should be level, but a maximum slope of 6 inches per 100 feet is permitted. After the slope of the pipe has been determined, it will be necessary to contact the local sanitarian (if available) so that he may inspect the disposal field before the area is covered.

The final step in the construction of a lateral or serial subsurface disposal field is to protect it from freezing. To do this, gravel must be added to the trench to a height of 2 inches above the distribution pipe. A barrier of straw, decomposable building paper, or hay should then be placed on top of this gravel layer to prevent the backfill from clogging up the spaces in the gravel. A decomposable material is used because once the backfill has settled, the barrier will decay, allowing evapotranspiration to take place and increase the effectiveness of the trench. Finally, 10 to 12 inches of soil are laid above the decomposable material (Figure 9). This backfilling process must be done properly so that excess soil is added to form a mound at the top of the trench (Figure 10). If this is not done, a depression will form above the trench collecting rain water and surface runoff, which will infiltrate into the soil and increase the hydraulic load on the absorption field. Under no circumstances should the contractor attempt to compact this mound by driving over it with heavy equipment to speed up this leveling process because damage to the distribution pipe and the soil structure may result.

After the soil has properly settled, a variety of landscaping techniques may be used to increase the aesthetic appearance above the subsurface disposal field. The most common technique is to plant grass above the field. Other foliage may be planted in this area if it is known that the root structure will not penetrate more than 12 inches below the surface. Trees or other deep-rooted vegetation should not be planted on or near the subsurface disposal field.

Seepage beds

An alternative subsurface disposal system is the

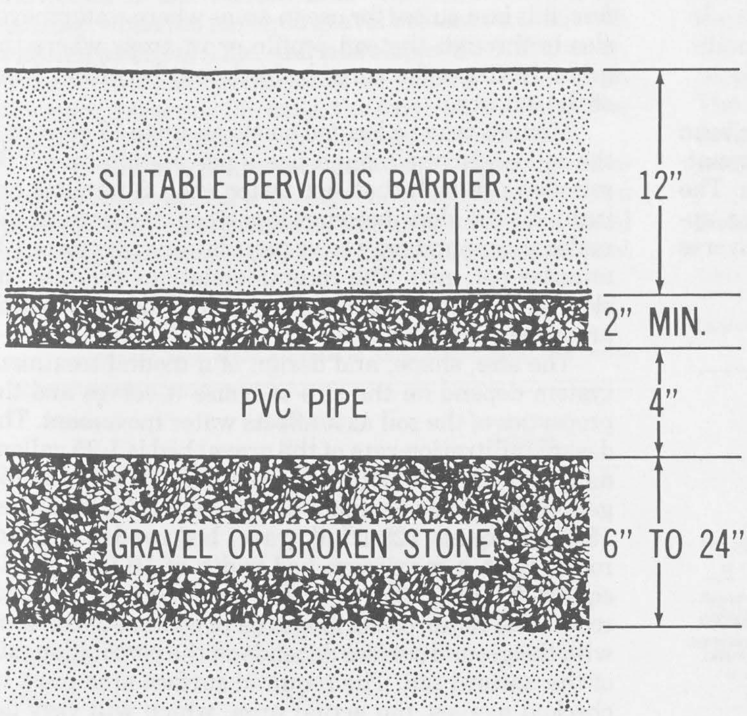

Figure 9. Longitudinal section of a soil absorption trench.

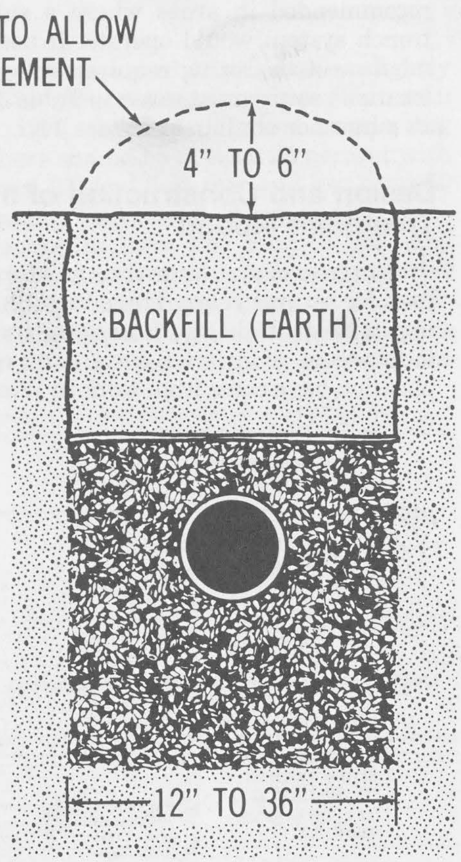

Figure 10. Cross section of a soil absorption trench.

seepage bed, which is defined to be a trench with a width greater than 36 inches (Figure 11). Although a seepage bed is not suitable in all locations, particularly where the clay content of the soil is from 35 to 45 percent, it can be an effective method for disposing of household wastewater. There are a few advantages to using a seepage bed under certain conditions. These advantages include the fact that a wide bed makes a more efficient use of a limited area of land available for a subsurface disposal field, and earth-moving equipment used to dig a basement also can be used to dig the seepage bed. Finally, because a seepage bed has a larger storage capacity than a trench, it is an effective field design for weekend or vacation homes that produce large volumes of wastewater in a short period.

Unfortunately, the disadvantages of a seepage bed outweigh the advantages for most installations. For instance, seepage beds have a smaller infiltrative sidewall area than trenches, which reduces the rate at which the septic tank effluent can be absorbed into the soil. Also, the large equipment needed to dig a bed causes compaction of the soil, which further reduces the absorption capacity of the soil. Finally, seepage beds usually are continuously inundated with septic tank effluent and therefore rarely dry out. All three conditions prevent the soil from becoming aerobic and contribute to premature failure of the subsurface disposal field.

Generally, the installation of a seepage bed is not recommended in areas where a subsurface disposal trench system would operate. If used, however, beds must meet the sizing requirements given in Table 8, location requirement given in Table 4, and be designed in a manner similar to Figure 11.

Design and Construction of a Sewage Treatment Mound

Variations of sewage treatment mounds have been used for several years. These include designs originating in North Dakota, Minnesota, and Wisconsin. The most recent criteria for design and constraints in application have come from work in Wisconsin (Converse et al., 1977).

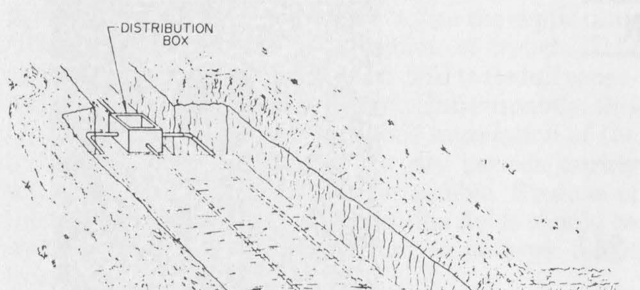

Figure 11. Schematic of a seepage bed with optional distribution box.

Table 8. Soil absorption bed sizing

Percolation rate (min/in)	Required absorption area (ft^2 per/bedroom)[a]
<10[b]	160
11-20	220
21-30	250
31-40	280
41-50	320
51-60[c]	330

[a]Minimum size, two bedrooms.

[b]In very permeable soils or in concentrated populations such as around lakes, additional precautions must be taken to present possible pollution.

[c]Soils with percolation rates greater than 60 minutes/inch are unsuitable for installation of a soil absorption field.

The principle of operation of sewage treatment mounds is that septic tank effluent is distributed uniformly by pressure on a gravel (rock) medium. From the gravel, the effluent is filtered through a sand medium and finally into the natural soil surface. Both the gravel and sand media are located above the existing natural ground surface, thereby permitting an aerobic environment for the treatment. The components and a cross section of a typical mound are shown in Figure 12.

Septic tank effluent undergoes a high degree of treatment as it flows through the mound. Research over a period of 2 years at Iowa State University (Effert, 1977) has given results shown in Table 9. The BOD_5 was reduced 90 percent from that of septic tank effluent while the total nitrogen and fecal coliform had a 30-percent and a fivefold reduction, respectively. Therefore, it is best suited for use in areas where water moves slowly through the soil profile or in areas where the groundwater or fractured bedrock may be within 2 feet of the surface.

Mounds may be located on slopes up to 12 percent if the soil under the mound has a percolation rate of 30 minutes per inch (but not faster than 5 minutes per inch). As the slope becomes less steep, the natural soil under the mound may have percolation rates up to 120 minutes per inch. The recommendations relating the slope of the land to percolation rate under the mound are shown in Table 10.

The size, shape, and design of a mound treatment system depend on the size of house it serves and the properties of the soil as it affects water movement. The design infiltration rate of the gravel bed is 1.25 gallons daily per square foot of surface area. If we use 150 gallons daily per bedroom as the hydraulic load, then 150/1.25 equals 120 ft^2 of gravel bed needed per bedroom. With a maximum bed width of 10 feet, 120/10 equals 12 linear feet of gravel bed required per bedroom. The required surface area of contact of the sand with the ground surface depends on the percolation rate of the natural soil. The required surface area must be checked against the actual area, which will vary depending on bed length, mound height, and slope of the natural ground. The guidelines in Table 11 have been established to give the required soil surface area.

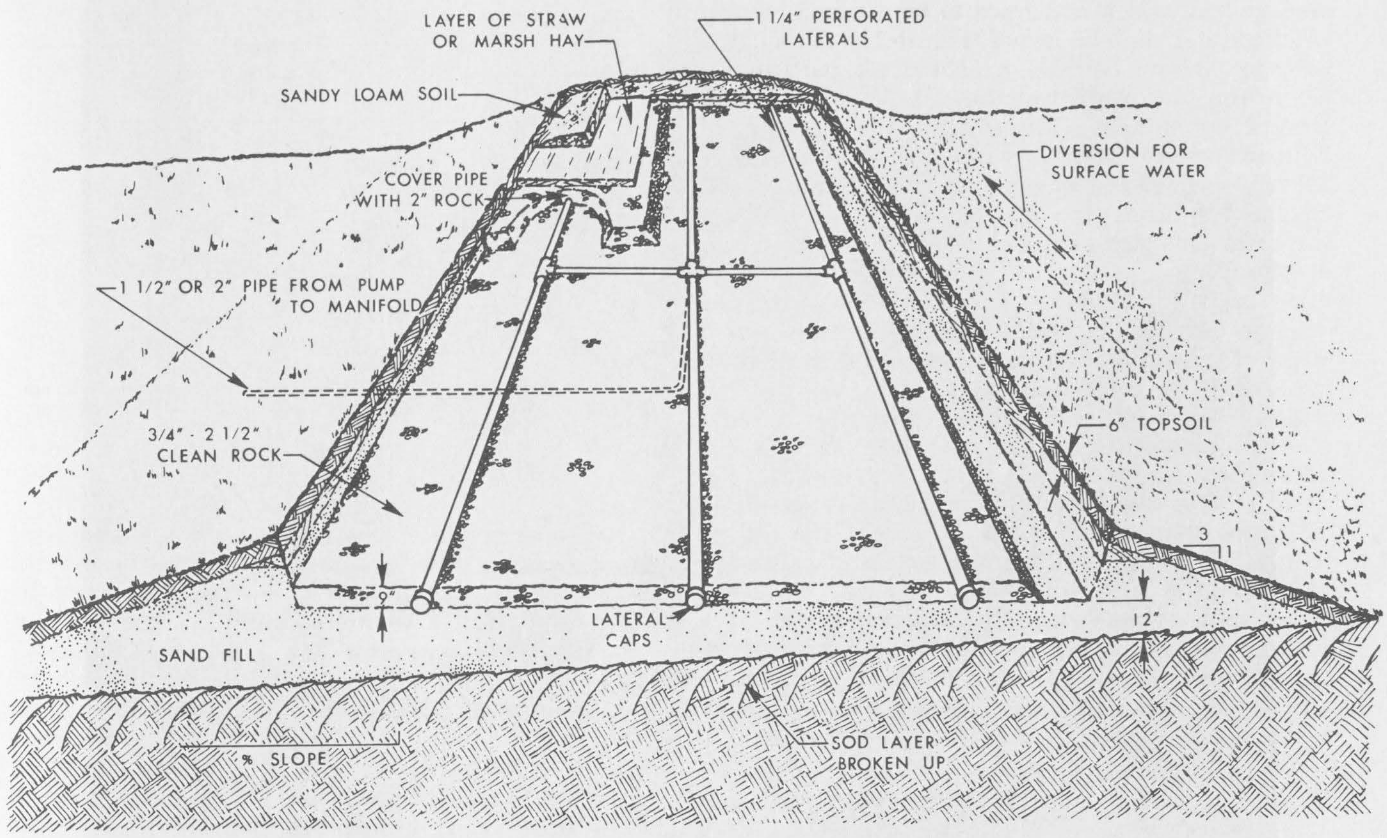

Figure 12. Components and cross section of a sewage treatment mound.

Where mounds are constructed on level land and on soils with percolation rates of 5-60 minutes per inch, the required soil surface area will automatically be satisfied when the required gravel bed area is used with a design height of 3 feet and side slopes of 3:1. However, when mounds are constructed on sloping land and on the more impermeable soils, the final design should be checked by an engineer or other qualified person.

It is important to select and use the proper materials in constructing a sewage mound. The gravel bed material may be the same as that used in conventional soil absorption trenches; i.e., 3/4 to 2-1/2 inches of clean rock that will not deteriorate when subjected to slightly acidic effluent. The recommendations from Wisconsin (Converse et al., 1977) should be followed for selecting the sand size. There should be at least 25 percent with diameters between 2.0 and 0.25 mm and less than 50 percent with diameters between 0.25 mm and 0.05 mm. The normal practice in Iowa has been to use sand designated for use in concrete. Avoid using mortar sand, which could have too many fines.

The pressure distribution system includes the line from the pump sump to the manifold pipe and the

Table 9. Values of parameters measuring degree of treatment of septic tank effluent treated in a sewage treatment mound

Parameter	Mean Value mg/l	Number of Samples
BOD_5	2.6	25
COD	75.0	25
Ammonia	0.12	25
Nitrite & Nitrate	32.03	25
Organic N	1.27	25
Total N	33.41	25
Orthophosphate	0.7	22
Fecal coliform	2.4×10^1(count/100ml)	19

Table 10. Maximum ground slope for different percolation rates

Landslope, percent	Percolation rate (min/in)
0-3	120
3-6	60
6-12	30

The above rates are guidelines designed to prevent side hill seepage.

Table 11. Required soil surface area for mounds at the sand-soil interface

Percolation Rate min/in	Rate, GPD/ft^2	Area Required ft^2/bedroom
5-29	1.24	121
30-60	0.74	203
60-120	0.24	625

Figure 13. Placing the sand during construction of a mound.

Figure 14. Mound is nearly completed with distribution system in place.

perforated laterals that connect to the manifold pipe. Rigid PVC pipe is used for the distribution system (see Figure 12). For satisfactory operation of the mound system, it must be constructed properly, including site preparation, use of proper equipment, correct soil moisture conditions, and correct placement of the sand and gravel (rock) materials. The original soil surface on which the sand is to be placed should be tilled to provide a good bond for the sand and to maximize the intake capacity of the soil. The best method is to use a moldboard plow, turning all the furrows up slope at a time when the soil is dry enough for usual agricultural plowing.

Install the 2-inch diameter discharge pipe from the pump to the center of the mound area before preparing the surface soil. Back fill the trench carefully, and compact the soil to prevent effluent seepage along the trench. The pipe should have sufficient slope back to the pump sump to drain into the sump after the pump stops. This will prevent stoppage by freezing in the winter.

Start the mound construction on a day when there is a low probability of rain. Cover the prepared soil surface with sand fill as soon as possible. A rubber-tired tractor can be used to prepare the soil surface, but do not use this type of equipment after the soil surface is prepared. Always use a crawler or track-type tractor for placement of the sand and gravel (rock) materials.

The sequence of construction steps is illustrated in Figures 13 and 14. The outside dimensions of the mound should be staked. Begin by placing the sand with a crawler tractor, keeping a 6-inch depth of sand between the tractor tracks and the prepared soil surface. The depth of sand will vary according to the land slope, but the minimum depth is 12 inches under the gravel (rock) bed at any point.

After the proper depth of sand is placed and leveled, with a 3:1 side slope established, place 9 inches of gravel (rock) on the sand according to the previously determined dimensions of the gravel bed. Bring the sand up to the top edge of the 9-inch layer of gravel (rock). With the completion of the gravel (rock) bed, the manifold pipe may be laid and connected to the previously installed line from the sump. The perforated laterals are then attached to the manifold pipe. The perforations should be 1/4-inch drilled holes spaced 36 inches on center in a straight line.

Lay the perforated pipe laterals on the level gravel (rock) bed with the holes down. Three laterals are required for a 10-foot-wide bed, placing them 40 inches on center with the outside laterals 20 inches from the edge of the bed. Cap the ends of the laterals and insure that all joints in the distribution systems are correctly glued with PVC cement. For proper effluent distribution, no perforated lateral should be more than 25 feet long, which permits a maximum bed length of 50 feet.

Place 2 inches of gravel (rock) over the distribution systems. A 3- to 4-inch layer of straw or coarse hay is next placed over the rock to prevent soil backfill from filtering down into the rock. Place a medium textural group soil (Table 4) on top of the hay or straw, but do not allow any equipment tracks on the bed. Place the soil 12 inches deep at the center of the gravel (rock) bed and 6 inches deep at the sides. This will permit surface water to drain off to the sides of the mound. A final layer of 6 inches of topsoil completes the construction of the mound. Establish a grass cover as soon as possible.

In the sewage treatment mound system, the effluent flows by gravity from the septic tank into the pump sump. Although design criteria for sump and pump selection are covered elsewhere (see Pumping Stations), the amount of effluent pumped into the mound each time must be adequate to fill all the lines (approximately 30 gallons) under pressure and, in addition, to supply a reasonable quantity to the entire gravel (rock) bed area. One application of effluent to the bed is called a dose. It is recommended that the sump be sized and the pump designed to dose the bed area twice daily. Thus, the quantity of effluent delivered during a pump cycle should be at least 200 gallons or 50 percent of 1 day's sewage flow, whichever is greater. The pump curve (head vs. discharge) has to be examined when a pump is selected. The pump must have the capacity to deliver at least 25 gallons per minute for a three-bedroom home against an 18-foot head.

Pumping Stations[2]

Some on-site sewage treatment systems require a pump installation to lift the septic tank effluent for gravity flow or to force the septic tank effluent under pressure to a distribution system. Examples of systems that require a pump installation are the sewage treatment mound and soil absorption systems where a given volume of effluent is applied under pressure at specified intervals (dosed). Wastes from basement facilities also may require a pump to lift them to the house sewer for gravity flow to the septic tank. Schematics of typical installations are shown in Figure 15.

A pumping station consists of two parts, a pumping tank and a pump. The purpose of the pumping tank is to act as a reservoir to collect the effluent from the septic tank and to serve as a settling basin for any carry over of solids from the septic tank. The choice of the pump will depend on whether it will be required to pump solids (from basement facilities) or whether septic effluent, which is a relatively clear liquid, will be the fluid to be pumped. Select a quality pump of a reliable manufacturer from a reputable dealer who will provide any needed service.

Pumping tank

The pumping tank must be water-tight and constructed of materials that will not corrode or decay. Provide an access to the tank by using a 20-24 inch diameter manhole to the ground surface. Follow safety precautions including a securely fastened cover on the manhole, and never go down into the pumping tank (also applies to a septic tank) unless you have provisions for obtaining air while in the tank and safety ropes for removing you from the tank if necessary.

The size of the pumping tank depends on the

[2]Abstracted from Town and Country Sewage Treatment, Extension Bulletin 304, University of Minnesota, by Roger E. Machmeier.

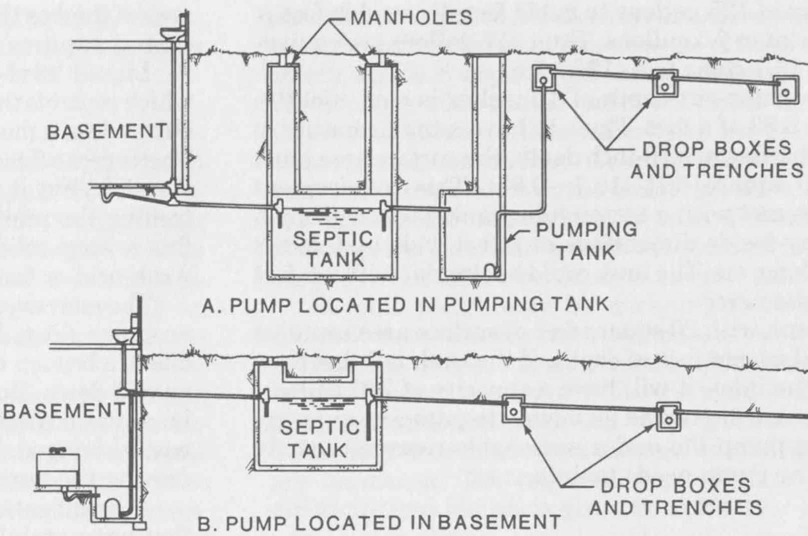

Figure 15. Pump locations to permit sanitary facilities in the basement.

amount of daily sewage flow and the amount of reserve tank capacity needed in case of pump failure. The diameter of the tank or surface area combined with the depth of fluid pumped each time the pump is actuated will give the volume pumped. The volume of the dose or amount of effluent pumped per pump cycle is important. A minimum dose may be required for the soil treatment unit to function properly. Also, a minimum dose size is required to control the number of cycles of the pump per day. Pump experts suggest that the pump should start only 3 or 4 times a day to maximize pump life. For the average three- or four-bedroom home, this is equivalent to 150 to 200 gallons per pump cycle.

A cross section of a typical pumping tank and pump installation is shown in Figure 16. A pump also will not pump a tank completely dry; pump operation requires a minimum liquid depth. Thus, a liquid depth of 6 to 8 inches must always remain in the tank. This may amount to approximately 100 gallons and is part of the required tank capacity.

Thus, the pumping tank capacity for a three-bedroom home may total 600-700 gallons: 100 or more gallons to be pumped, 450 gallons reserve capacity, and 100 gallons remaining in the botton of the tank.

As an example, assume the pump-out depth is 10 inches and the desired pumping quantity is 125 gallons. The required surface area of the pumping tank can be determined from these values. First, convert the

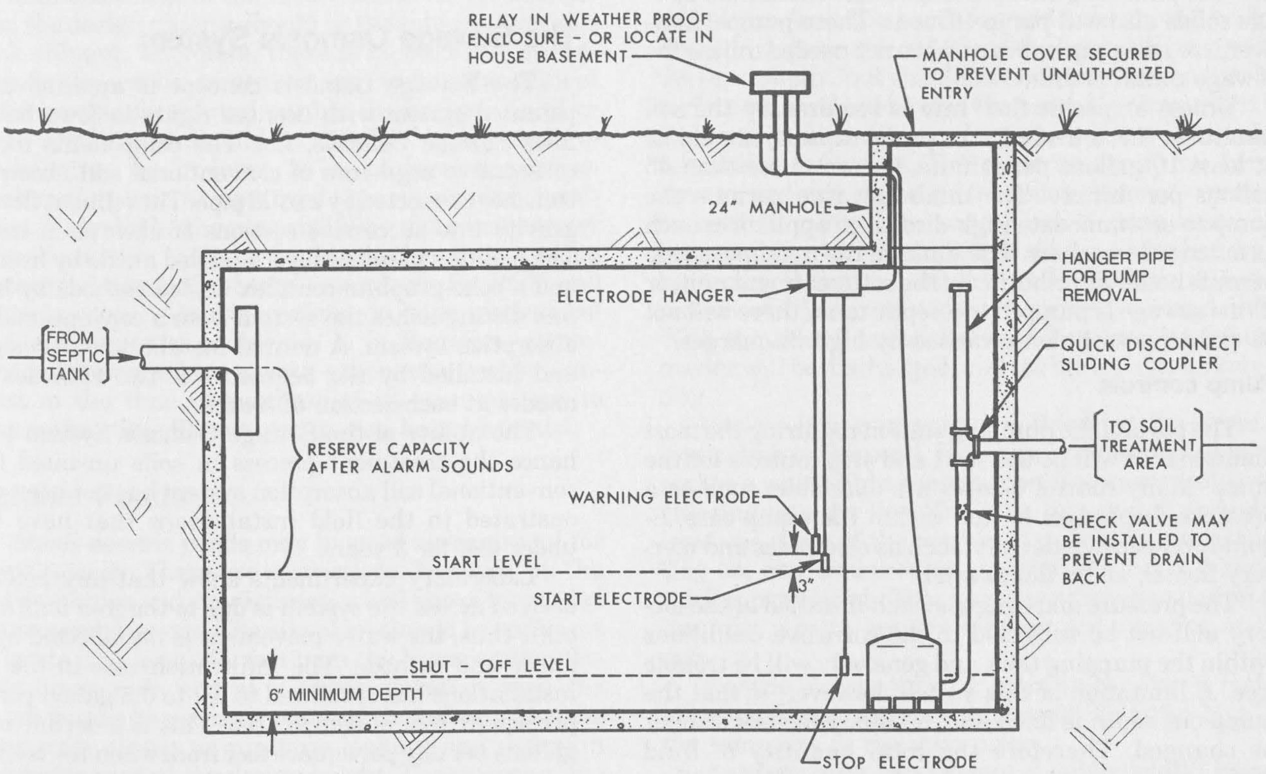

Figure 16. Diagram of pumping station.

quantity of 125 gallons to cubic feet. One cubic foot is equivalent to 7.5 gallons. Thus, 125 gallons are equivalent to 16.7 cubic feet ($125 \div 7.5$).

The pump-out depth of 10 inches is equivalent to $^{10}/_{12}$, or 0.83 of a foot. Thus, to have a tank capacity of 16.7 cubic feet in a 10-inch depth, the surface area must be 20.0 square feet ($16.7 \div 0.83$). This requirement could be met with a rectangular tank 4 feet wide by 5 feet long inside dimensions or 3 feet wide by 6 feet 8 inches long, etc. The tank could be circular with a 5-foot inside diameter.

A tank with 20 square feet of surface area contains 150 gallons per foot of depth. If the tank is 5 feet deep below the inlet, it will have a capacity of 750 gallons. This tank will provide an adequate pumping quantity for long pump life and a reasonable reserve capacity when the pump needs maintenance.

Pumps

The pump should be constructed of materials that are durable and corrosion resistant. A cast iron or bronze-fitted pump with stainless steel screws will not be corroded by sewage effluent. Plastic can be a suitable material if the pump is properly designed and constructed.

There are a number of pumping situations, and a specific pump is needed for each application. Whenever possible, pump settled sewage. The most trouble-free pumping situation is to pump the sewage effluent after the solids have been separated in the septic tank. If a flush toilet is located in the basement, a sewage ejector pump will be needed to handle the solids. The sewage ejector pump must be installed in a sealed sump vented into the plumbing stack. Pumps that will handle sewage solids also will pump effluent. These pumps, however, are more expensive and are not needed unless the sewage contains solids.

Unless a specific flow rate is required by the soil treatment (i.e, a mound), the pump capacity should be at least 10 gallons per minute, but not more than 45 gallons per minute. The minimum rate permits the pump to accommodate high-discharge appliances such as automatic washers. The limit on the maximum rate permits better distribution in the soil treatment unit, or if raw sewage is pumped to a septic tank, there will not be excessive turbulence caused by high discharges.

Pump controls

The parts of the pumping station requiring the most maintenance will be the start and stop controls for the pump. Many control devices are available, such as a pressure diaphragm switch within the pump case, liquid-level-sensing devices (such as electrodes and mercury floats), and a float switch.

The pressure diaphragm switch installed at the factory will not be subjected to the corrosive conditions within the pumping tank and generally will be trouble free. A limitation of this switch, however, is that the pump-out depth is fixed and, on many models, cannot be changed. Therefore the total quantity of fluid pumped at each pump cycle is a function of the surface area of fluid or the size of the tank. Repair of this pump control requires removal of the entire pump.

Liquid-level-sensing devices connect to a relay, which controls the pump. The sensing device may be an electrode or a mercury switch enclosed in a plastic float. The current flow in the electrode or mercury switch is very low, but it is adequate to activate the relay controlling the pump. If the electrode becomes fouled by fine sewage solids, it can be cleaned by dipping into a weak acid or toilet bowl cleaner.

The mercury switch is totally enclosed in a plastic or neoprene float. Malfunction of the switch may occur due to a broken wire at the point where the float flexes up and down. Both the electrodes and mercury switch have the advantage that the pump-out depth can be easily changed. They also can be serviced without removing the pump.

A modification of the mercury float switch is one that has a stainless-steel float attached to a stainless-steel wire, which is attached to a sealed switch. This is a new control on the market; thus, the "track record" is not known. The pumping depth also can be changed by adjusting the amount of weight attached to the stainless-steel wire.

Never locate the relay, electrical plug-in, or socket inside the pumping tank. The environment will corrode the devices and cause failure. Locate these devices in an above-ground weatherproof box or in a smaller underground enclosure adjacent to the pumping tank. Use all water-tight or soldered electrical connections within the pumping tank.

Install an alarm to warn if liquid depth exceeds that normally controlled by the pump. A buzzer or an easily visible light often are used for the alarm signal.

The Sewage Osmosis System

The Sewage Osmosis concept is an innovative, patented system with licensee rights in Iowa held by Iowa Sewage Osmosis, Inc. The components include consecutive segments of conventional soil absorption trenches connected by a solid pipe. The effluent flows by gravity into successive sections of absorption trench. The addition of mineral rock (called anode by licensee) and a coke-graphite complex (called cathode by licensee) distinguishes the system from a conventional soil absorption system. A normal installation as designed and installed by the licensee has two cathodes and anodes at each section of trench.

The ability of the Sewage Osmosis System to enhance the treatment process in soils unsuited for a conventional soil absorption system has not been demonstrated in the field installations that have been under test for 3 years.

Laboratory experiments show that any potential derived across the system is due to the iron ions in the coke; thus, the water movement is not affected by the anode and cathode. The infiltration rate in the field installations has stabilized to 0.2 to 0.3 gallon per day per square foot of trench area. This is a decline of 2.0 gallons per day per square foot from when the trenches initially were put into service. The data from the field installations show the benefit of good trench construction, including a depth of 24 inches of gravel below the distribution pipe.

Aerobic System

The designation "household aerobic sewage treatment system" means that one may replace the conventional septic tank with a tank or a multicompartment tank in which air is introduced by mechanical means. Many times, these systems are referred to as "mechanical systems" because of the necessity of having an electrical motor to drive a device to introduce air (oxygen) into the tank.

A septic tank treats the domestic waste by bacteria that live in an anaerobic (without air or oxygen) environment, but in an aerobic system, the domestic waste is treated in a tank in which the bacteria must have air to live. Because of the different environment, the amount of treatment given the waste is greater in a properly operating aerobic system. Nevertheless, the fluid discharged from an aerobic system is not of sufficient quality to be discharged directly on the soil surface without further treatment. Depending on local or state regulations, several ways exist to dispose of the treated fluid from an aerobic system.

1. Discharge into a conventional soil absorption field (trench or bed).
2. Discharge into a sand filter.
3. Disinfect and discharge on the surface of soil or into a receiving stream.

A aerobic treatment system will have higher initial cost, will cost more to operate, and will likely have more maintenance problems than the septic tank.

If either a soil absorption field or a sand filter is used for final treatment of the effluent from an aerobic system, the design criteria should be the same as for septic tank effluent. Therefore, there is no economic advantage for an aerobic treatment unit unless the effluent could be disinfected and surface-discharged. Local or state regulations should be checked before surface-discharging, for in Iowa, it is not legal to surface-discharge without an approved type of secondary treatment. It should be the responsibility of the homeowner to make certain that the quality of the effluent being discharged meets the State's standards for BOD and bacteria count. Aerobic systems do have mechanical and maintenance problems. It is therefore recommended that the homeowner purchase a service contract at the time of purchase of the aerobic unit to insure that the effluent quality can be maintained.

Aerobic Ponds

Small aerobic ponds may be used as treatment for home sewage. There are restrictions, however, on the soil properties and characteristics and size of lot needed to use aerobic ponds. The size of lot should be sufficient to locate it at least 200 feet from the house and preferably downgrade and at a lower elevation than the house. It may be necessary to treat the soil or to line the pond with plastic to minimize leakage and maintain the water level at the design height. The surface of the pond should not be in the shade so as to give exposure to sunlight during the day. The absence of trees also will permit a good sweep of wind across the pond's surface. The location also should permit a berm to be constructed to divert surface water from the site. In the midwest, evaporation may not be sufficient to maintain a constant water level in the pond; therefore, an overflow pipe should be provided. In case of overflow, the discharge should not flow on the surface across adjoining properties before reaching a natural watercourse.

Aerobic ponds may be designed to receive the domestic waste directly from the house sewer or be used to treat the effluent from a septic tank. Because the organic loading is greater when the pond is used as a primary treatment unit, the water surface area required is greater than when the pond is used for secondary treatment. The required water surface area for different sized houses is given in Table 12.

Table 12. Design requirements for aerobic pond

No. of Bedrooms	Required water surface area, ft^2	
	House sewer waste	Septic tank effluent
2	900	470
3	1050	700
4	1400	935

The shape of the pond, which will provide the required surface area, will vary depending on the terrain or topography. The shape may vary from circular to rectangular, but the length should not exceed three times the width.

A bulldozer is the best equipment for building a pond. The pond should be constructed with a 4-foot berm around the perimeter. See Figures 17 and 18. The side slopes from the berm to pond area should be 3:1. The side slope on the outside of the berm will vary with the topography, but should not be steeper than 2:1. No surface water should enter the pond. It is important to place a diversion terrace above the pond to divert surface water around it. The construction of the berm, terrace, and side slopes must be such that a mower may be used to control the vegetation. If some areas are inaccessible, the vegetation could be controlled by a herbicide. Provide a suitable outlet such as a 4-inch section of PVC pipe with a 6-inch submerged inlet. With the inlet 6 inches below the surface, no floating matter will be discharged, and the outlet is less likely to clog.

Use a 4-inch minimum-size line from the house or septic tank to the pond. PVC pipe with cemented joints makes a water-tight construction to prevent roots from entering into the line. The inlet line should extend at least one-third of the way on the pond bottom, outletting on, and anchored to, a 3-feet x 3-feet x 4-inches thick concrete slab. This provides a firm foundation for the inlet pipe to prevent settling and clogging at the end.

Provide a cleanout at a point in the line 6 inches above the water surface in the pond. This may be a "T" the same size as the inlet pipe.

Aerobic ponds can present a public health hazard

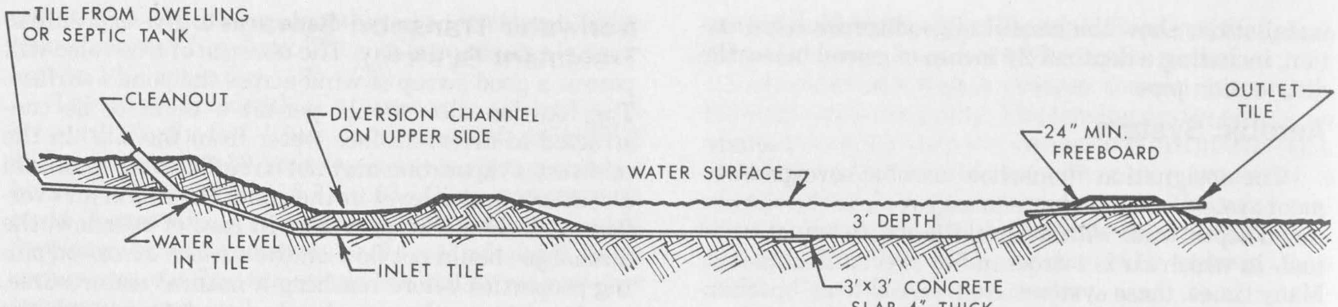

Figure 17. Cross section of an aerobic pond.

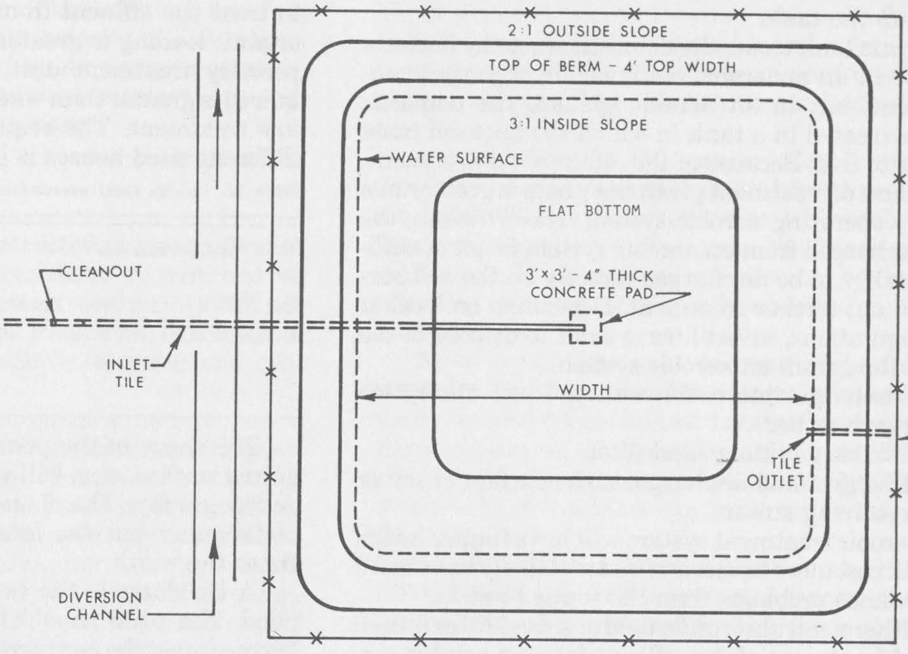

Figure 18. Plan view of an aerobic pond.

when accessible to children or pets. It is strongly recommended that ponds not be located in areas frequented by the public and that they be enclosed with a woven fence to minimize the hazard.

Subsurface Sand Filters

When the results of a site evaluation indicate that a conventional soil absorption field may not be used, a subsurface sand filter may be constructed to provide treatment to the septic tank effluent before it is discharged into a stream, ditch, or ravine. The successful operation of a sand filter requires that floating material from the septic tank be prevented from entering the filter. Therefore, it is important that the baffle in the outlet compartment of the septic tank function properly and the septic tank be inspected and pumped when the sludge and scum accumulations dictate cleaning. The position on the landscape may require the effluent from the septic tank to be pumped to the filter. As with an absorption field, mechanical pumping to the sand filter will result in more even distribution over the filter bed. The even distribution combined with dosing should maximize the effluent treatment and provide a long life for the sand filter.

Sand filters may consist of a single filter bed or two or more filtering beds connected in series and separated by a minimum of 6 feet of soil. When a single sand filter is used, Iowa regulations require that it be mechanically dosed and the effluent monitored to determine the degree of treatment. The size of a filter is calculated on the basis of the volume of sewage application permitted per square foot of filter area. The maximum permitted

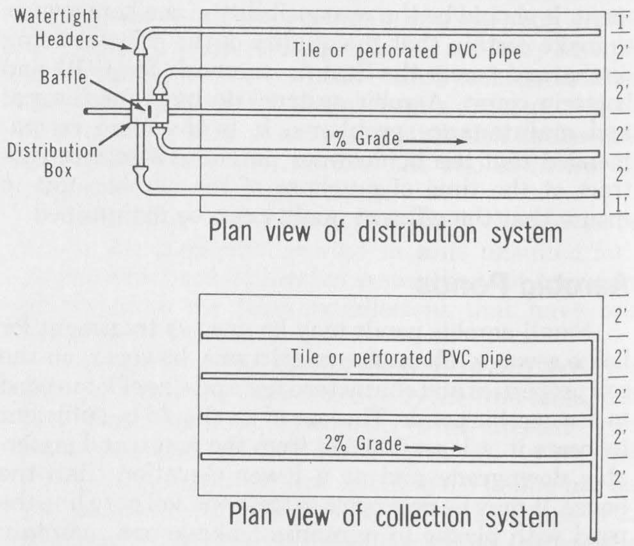

Figure 19. Plan view of a sand filter.

rate is 1.5 gallons per day per square foot in each filter for filters in series and 1.0 gallon per day per square foot for a single filter. The size for each filter in a double sand filter recommended by the Iowa State Department of Health (1976) is 200 square feet (10 x 20), 360 square feet (12 x 30), and 490 square feet (14 x 35), respectively, for a 2-, 3-, and 4-bedroom house.

The details of a double sand filter are shown in the cross section and plan views in Figures 19 and 20. The following sequence of steps illustrates the construction procedure.

1. The lower collector lines (tile or rigid-perforated PVC pipe) are laid on the bottom of the excavation on 24-inch centers with a grade of 2 percent.

2. Place a minimum of 4 inches of gravel over the collector lines.

3. Place a minimum of 3 feet of coarse washed sand over the gravel covering the collector lines.

4. Place 6 inches of gravel over the top of the sand in the bed.

5. Lay the distribution lines (tile or rigid-perforated PVC pipe) on the upper layer of gravel, centered vertically between the lower collector lines, on 24-inch centers with a grade of 1 percent.

6. Cover the distribution lines with 1-2 inches of gravel followed by a layer of treated paper (tar paper) and a final layer of 12 inches of soil.

For a single sand filter, all these steps are applicable except the distribution lines. Because the single sand filter must be dosed (under pressure), the distribution lines would be 1-1/2 or 2-inch PVC pipe with 1/4-inch holes drilled on 30-inch centers. As with other treatment facilities, minimum horizontal separation distances as given in Table 4 should be met with sand filters. To prevent hydraulic overload, surface runoff water should be diverted from the location of the sand filter.

Nonwater Transport Sewage Treatment Systems

Application

The mode of operation of most of the nonwater transport systems involves either composting, incineration, or chemical treatment. These facilities normally are used in areas of short water supply or where site and soil conditions prohibit the use of large quantities of water as in a conventional system. These toilets are suitable and economical for weekend cottages as well as for residences located in the watershed of a lake where no central sewer system is available. In areas where the percolation rate of the soil precludes the use of conventional septic tank/soil absorption field, these toilets could be an acceptable alternative. Although composting and incinerating toilets have been available for a number of years, no massive move has been recorded toward the installation of these units in any local areas. Where water is in short supply or tight soils and congested developments occur, it is possible that the installation of some of these systems will be more readily accepted by persons encountering these restrictions.

Composting

Composting toilets such as the Clivus Multrum or the Muhlbank operate with very little expense after installation. Some electrical costs are encountered in maintaining the proper operating temperature in these units. A small amount of electricity also is required to operate the exhaust fan. Decomposed wastes must be removed from these units at specified intervals. Aesthetic objections or constraints on bathroom placement could retard general acceptance of these units where the usual flush toilet has been used for many years.

Incineration

Incinerating toilets (Incinolet, Little John, Destroilet, etc.) use gas or electricity to incinerate the

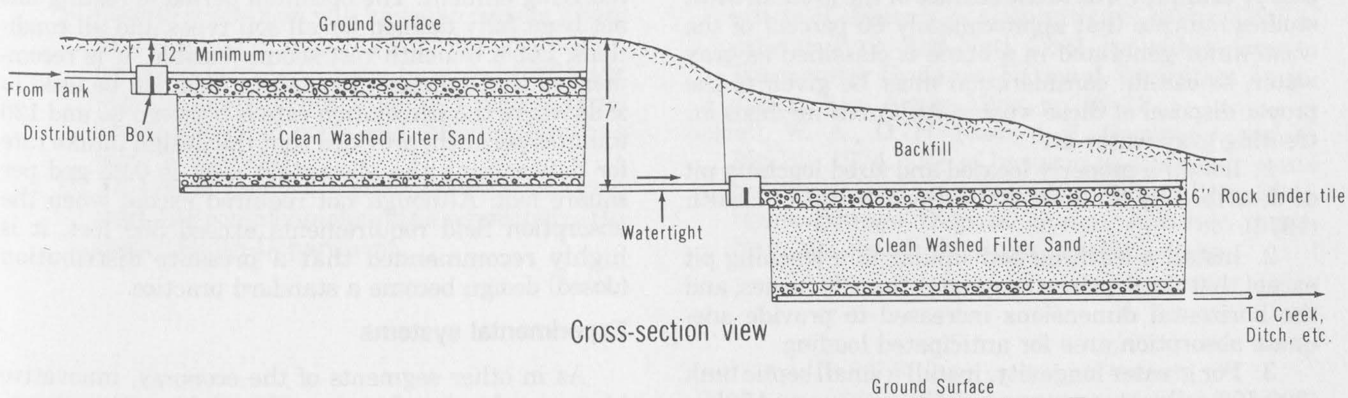

Figure 20. Cross-section view of a sand filter.

wastes. They consume energy, thereby increasing the cost of operation. Incinerated waste by-product (i.e., ash) must be removed periodically from these units. Most of these facilities also require an exhaust fan to move vapors and odors out through a vent. Aesthetic qualities and a general reluctance to install a mechanical unit are deterrents to widespread installation of units of this nature.

Privy

The conventional privy (outhouse, Chic Sale, etc.) has been an acceptable method of waste disposal for many years and has no equal insofar as simplicity and economy of operation. Well-constructed privies have been heated and lighted and even provided with decorative landscaping to increase their aesthetic value. Also, deodorizing chemicals have been developed (Hiotroo) to reduce or eliminate the odor, which has been the principal objection.

Chemical

Chemical toilets (Poly Jon, Kybo, Forest, Tufway, etc.) of varied design and cost are being advertised in increasing numbers. It would seem that this type facility is more adaptable to construction sites, temporary camps, mass gatherings, and other applications of this nature than to more permanent installation. Routine maintenance must be available and provided to users of this type of toilet.

Gray Water Treatment

When privies, chemical toilets, composting, or incinerating toilets are provided for the disposal of human wastes, the gray water (water from showers, baths, dishwashing, handwashing, clothes washing, and general cleaning operations) must be disposed of in a sanitary manner. It must not constitute a nuisance on the property where it originates or to the neighboring properties. Gray water cannot be discharged to surface waters, land drain tiles, abandoned wells, waterways, county drain tiles, or to the surface of the ground. Most studies indicate that approximately 60 percent of the wastewater generated in a home is classified as gray water, so careful consideration must be given to the proper disposal of these wastes. Approved methods for treating gray water are:

1. Install a properly located and sized leaching pit as described by the Iowa State Department of Health (1976).
2. Install a leaching bed similar to a leaching pit except that the depth be no greater than 30 inches, and the horizontal dimensions increased to provide adequate absorption area for anticipated loading.
3. For greater longevity, install a small septic tank (300-500 gallon) to remove any grit or grease and follow with a standard lateral field with about two-thirds the normal capacity that would be required for the disposal of all wastes from the residence.
4. To recycle the gray water for lawn or garden watering or for discharge to the surface, install a small septic tank (300-500 gallon) followed by a single sand filter. A sand filter for this purpose could be sized approximately two-thirds as large as required for treating all the wastewater from a residence.

Specific Iowa Recommendations

The design and type of on-site sewage treatment systems for use in Iowa are controlled by the Health Engineering Section of the Iowa State Department of Health. At present, the approved systems include the septic tank for the primary treatment, followed by a soil absorption field or a sand filter for secondary treatment. The design criteria are given in the "Residential Sewage Disposal Systems: Rules and Regulations" available from the Iowa State Department of Health.

Research has generated new technology for sewage treatment and disposal that should be examined for application to Iowa's conditions. The mound system, now is an approved system for Iowa, provided that it is designed and constructed correctly. If the local sanitarian or plumber needs additional information to complete a design for the mound system, they should contact the Agricultural Engineering Extension Service at Iowa State University or the Iowa Department of Health.

There is a definite benefit that results from a modification of the conventional septic tank soil absorption system. In the conventional soil absorption system, effluent from the septic tank flows by gravity into a distribution or drop box from which it is discharged to a perforated pipe or tile in the absorption field. Under these conditions, the entire linear length of the field does not receive effluent simultaneously. Research has shown that the life of the field can be lengthened if the entire absorption area receives effluent simultaneously. This can be accomplished by pumping the effluent (dosing) from a sump and distributing it under pressure to the field. (See discussion of "Pumping Stations" in this Section). A further modification may include the division of the field into two parts whereby half of the absorption area may alternate with the other half in receiving effluent. The optimum period of resting has not been fully defined for all soil types and all conditions, but a 6-month rest seems feasible. It is recommended that a dosed-alternating field can be used in soils where the percolation rate is between 60 and 120 minutes per inch, provided that the design intake rate for determining the absorption area is 0.25 gpd per square foot. Although not required except when the absorption field requirements exceed 500 feet, it is highly recommended that a pressure distribution (dosed) design become a standard practice.

Experimental systems

As in other segments of the economy, innovative ideas are developed and marketed for sewage treatment and disposal. Where a system has not been fully tested in a field application, it may be installed as an experimental system. Guidelines for receiving approval and installation of experimental systems have been developed and are available from the Iowa State Department of Health.

Experimental systems that are not specifically addressed by Iowa State Department of Health (1976) should be presented to the Health Engineering Section of the State Health Department for review and approval in the following manner:

I. Plans and Specifications
   A. Prepared by a registered engineer (3 sets).
   B. Show detailed designs of system components.
   C. Show location and layout of system in relation to buildings, lot lines, roads, wells, streams, lakes, etc.
   D. Show details of topography.
   E. Show location and results of percolation tests. Test to be accomplished as specified in Section I.
   F. Conduct a soil and landscape evaluation as outlined in Appendix A, Section I.
   G. Show sampling and observation ports (see item V, Monitoring).
   H. Indicate estimated daily water consumption for proposed facility.

II. Agreement
   Provide copy of agreement between property owner and county board of health indicating that owner will replace system in the event of failure.

III. Service Contract
   Provide copy of service contract with local firm capable of repairing malfunctions of system components.

IV. Installation
   A. County construction permit must be obtained preceding installation and subject to all other local regulations and requirements
   B. County sanitarian is to observe installation of system on the site and certify in writing that the system has been installed in accordance with the approved plans and specifications.

V. Monitoring
   A. Sampling and observation ports to be provided as recommended by the State Health Department and the Local Board of Health.
   B. County sanitarian will have the responsibility for collection of monthly samples or other interval as specified. (Note: Because of different types of experimental systems, different types and locations of ports and different analyses may be specified).
   C. All sample analysis reports as well as observations and comments should be submitted to the State Health Department.

The Sewage Osmosis System should not be continued as an experimental system. There is conclusive evidence that it has no merit over a conventional soil absorption system.

Experience with field installations of the general class of aerobic mechanical systems indicates that the effluent quality is extremely variable, and *no surface discharging should be permitted.* The mechanical systems should be continued in the experimental group insofar as installation is concerned. For all approved installations, the homeowner should show evidence of a service agreement with the dealer whereby the unit will be checked monthly or upon call for performance and any needed maintenance. The secondary treatment shall consist of a soil absorption system or a single-stage sand filter.

Sewage treatment systems dependent on removal of the effluent by evapotranspiration (ET) will not function as ET systems in Iowa. Solar energy distribution and intensity do not provide sufficient energy to evaporate both precipitation and effluent throughout the year. This type of system should not be permitted to be installed in Iowa.

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