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A FIELD STUDY OF SOME MAJOR SOILS IN WISCONSIN

UNIVERSITY OF WISCONSIN-EXTENSION
GEOLOGICAL AND NATURAL HISTORY SURVEY
G. F. HANSON, DIRECTOR AND STATE GEOLOGIST

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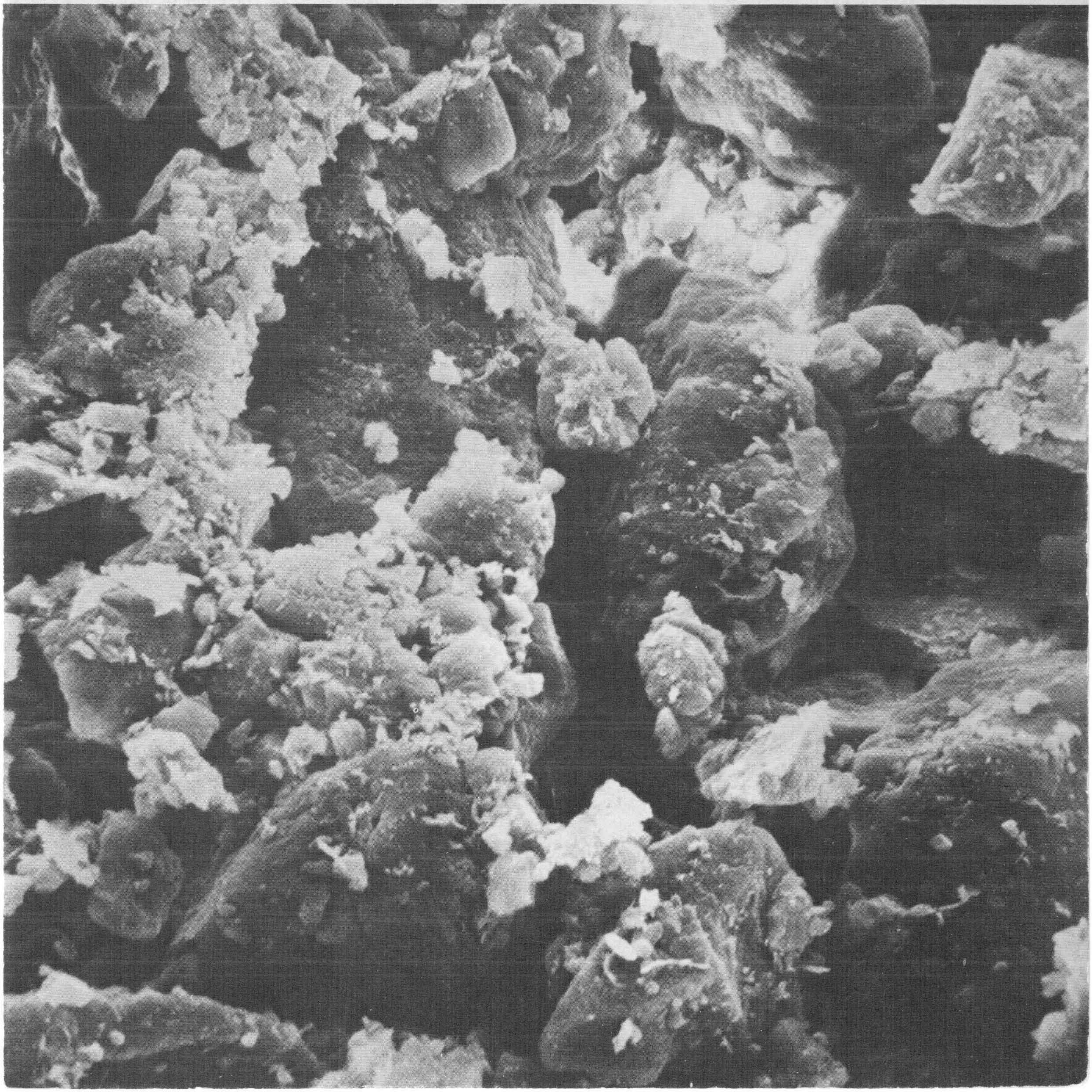

WIS. GEOL. & NAT. HIST. SURVEY

UNIVERSITY OF WISCONSIN-EXTENSION
GEOLOGICAL AND NATURAL HISTORY SURVEY
SOIL SURVEY DIVISION
G. F. HANSON, DIRECTOR AND STATE GEOLOGIST
F. D. HOLE, In charge, SOIL SURVEY DIVISION
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A FIELD STUDY OF SOME MAJOR SOILS IN WISCONSIN

By:
J. Bouma, W. A. Ziebell, W. G. Walker, P. G. Olcott, E. McCoy, and F. D. Hole

In Cooperation with:
DEPARTMENTS OF SOIL SCIENCE AND BACTERIOLOGY,
COLLEGE OF AGRICULTURAL AND LIFE SCIENCES
and
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The picture on the cover, of a sandy loam glacial till soil material (see Chapter 5.2.4.), was made with a Scanning Electron Microscope (Linear magnification approximately 6000x). Photo courtesy of Dr. I. Sachs and Mr. D. Kenny, Forest Products Laboratory, USDA, Madison, Wisconsin.

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Bouma, J., W. A. Ziebell, W. G. Walker, P. G. Olcott, E. McCoy and F. D. Hole.

SOIL POTENTIAL FOR DISPOSAL OF SEPTIC TANK EFFLUENT
A field study of some major soils in Wisconsin

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ABSTRACT

Soil disposal of septic tank effluent was studied in 20 systems in 12 major types of soil in Wisconsin. Processes of soil absorption of effluent from gravel-filled seepage beds and of ground-water flow were characterized by physical and hydrological methods. Purification of effluent during soil percolation was investigated by bacteriological and chemical methods.

Ponding of effluent was observed in seepage beds over 9 months old, in the entire range of soils, including the most permeable, at the same time that the surrounding soil remained unsaturated. This phenomenon apparently results from the presence of hydraulically resistant crusts a few centimeters thick at the interface between the seepage bed and the surrounding soil. The effect of such crusts is to reduce the hydraulic head of the ponded effluent, thereby allowing unsaturated conditions to persist in the soil below the bed, and reducing infiltration rates 20 to 100-fold, as compared with those into uncrusted, saturated soil. A new field method, the "crust test", was developed to characterize hydraulic conductivity (K) values of unsaturated soil *in situ*. Measurements obtained by this method and by the double tube method for determination of K in saturated soil *in situ* were compared with those obtained by the mandatory percolation test. The latter test, although useful as a simple, general indicator of soil permeability, was found to be more variable and less well defined than K_{sat} values. In addition, a single percolation rate does not apply to real flow conditions around operating seepage beds, which can more realistically be expressed by different K values as a function of crust resistance. The occurrence of unsaturated flow is very significant for the filtration of effluent, because it means that liquid will occupy only part of the voids and will move relatively slowly through the smaller pores in a soil material in which aerated conditions prevail.

Three types of disposal systems could be distinguished in the different soils:

1. Systems with a crusted seepage bed surrounded by highly permeable sand, as studied in the C horizons of the Plainfield, Sparta and Vilas loamy sands. Only the bottom area of the seepage bed, adjacent to the effluent inlet, was crusted and used for infiltration in three relatively new systems, varying in age between 6 weeks and 9 months. The crusted zone progressively extended farther into the bed until the whole bottom area and part of the sidewalls were crusted, as was observed in four older systems, varying in age between 9 months and 12 years. Crusts in different systems had a remarkably constant hydraulic resistance, as evidenced by subcrust tensions in the sand varying only between 20 and 25 millibars (mbars). The corresponding K values could be derived from the K-curve. Sizing of new beds in sands may be based on such values. It was suggested to size seepage beds in sands according to a flow rate corresponding with a tension of 30 mbar (approximately 5 cm/day). Unsaturated flow induced by crusts was very effective in removing fecal indicators from the percolating effluent within a few centimeters depth of soil. Absence of unsaturated flow, as observed in one system where the seepage bed was submerged in the ground water, resulted in considerable

lateral movement of fecal indicators in the ground water. A detailed study of four systems in Adams County revealed that nitrification of effluent, containing only NH_4-N and organic-N, occurred in the aerated subcrust soil. Contents of NO_3-N in ground water directly below some of these systems was relatively high, but concentrations decreased strongly at increasing distances from the systems as a result of ground-water movement and dilution.

2. Systems with a severely crusted seepage bed surrounded by permeable loamy soil materials, as observed in the IIC horizon (sandy loam glacial till) of the Saybrook silt loam. In this instance the twelve year old system had a crust that induced a tension of 80 mbar in the adjacent soil, corresponding with an infiltration rate of only 8 mm/day, which was insufficient to absorb average quantities of effluent in a seepage bed sized according to the State Code. A field experiment in manipulation of effluent flow showed that absorption by the soil in this system could be increased threefold if effluent were applied ("dosed") only once daily, rather than in a continuous trickle. Dosing allowed a rest period between applications, during which partial oxidation of accumulated crust materials at the infiltrating surface produced a lower crust resistance, effective at the next application.

3. Systems that did not function for a variety of conditions, other than severe crusting, as follows: a) the soil surrounding the seepage bed had a low permeability that did not allow adequate absorption of effluent even in uncrusted soil. Seepage beds that had failed because of this condition were observed in subsurface horizons in the Withee silt loam, Hibbing loam and Tustin fine sandy loam; b) bedrock, either creviced (under Summerville loam, Door County) or massive (under Arland silt loam, Clark County), was too close to the soil surface to allow construction of a subsurface seepage bed; c) a seasonally very high ground water table flooded the subsurface seepage bed and made it ineffective in the Humbird sandy loam (Clark County).

An alternative to a conventional subsurface seepage bed in these areas is the "mound system", consisting of a seepage bed built inside a mound of sandy soil fill material on top of the original soil surface. Six experimental mound systems were investigated in this study. Soil physical data were used to calculate required dimensions of mounds for different soils. Monitoring results indicated that some systems worked well. However, an improved system of effluent distribution needs to be developed that spreads the liquid more evenly over the seepage area during dosing. The current system, using conventional 4-inch highly perforated pipe, gave a very poor distribution and resulted in overloading of the parts of the bed in the mound near the inlet. Other recommendations for system construction and management are made, based on the experimental data obtained to date. Monitoring will be continued of the six mound systems and other recently constructed ones.

The general problem of small scale liquid waste disposal has more aspects than those associated with soil absorption of septic tank effluent as discussed in this report. For example, there are different methods of mechanical treatment of wastes, not necessarily followed by soil absorption. Economical and institutional questions arise when the liquid waste disposal problem is discussed in a broader context. These questions, technical aspects of mechanical treatment, and continued monitoring of mound systems, are being pursued now in an interdisciplinary project funded by the State of Wisconsin, the Upper Great Lakes Regional Commission, and the Geological and Natural History Survey, University Extension.

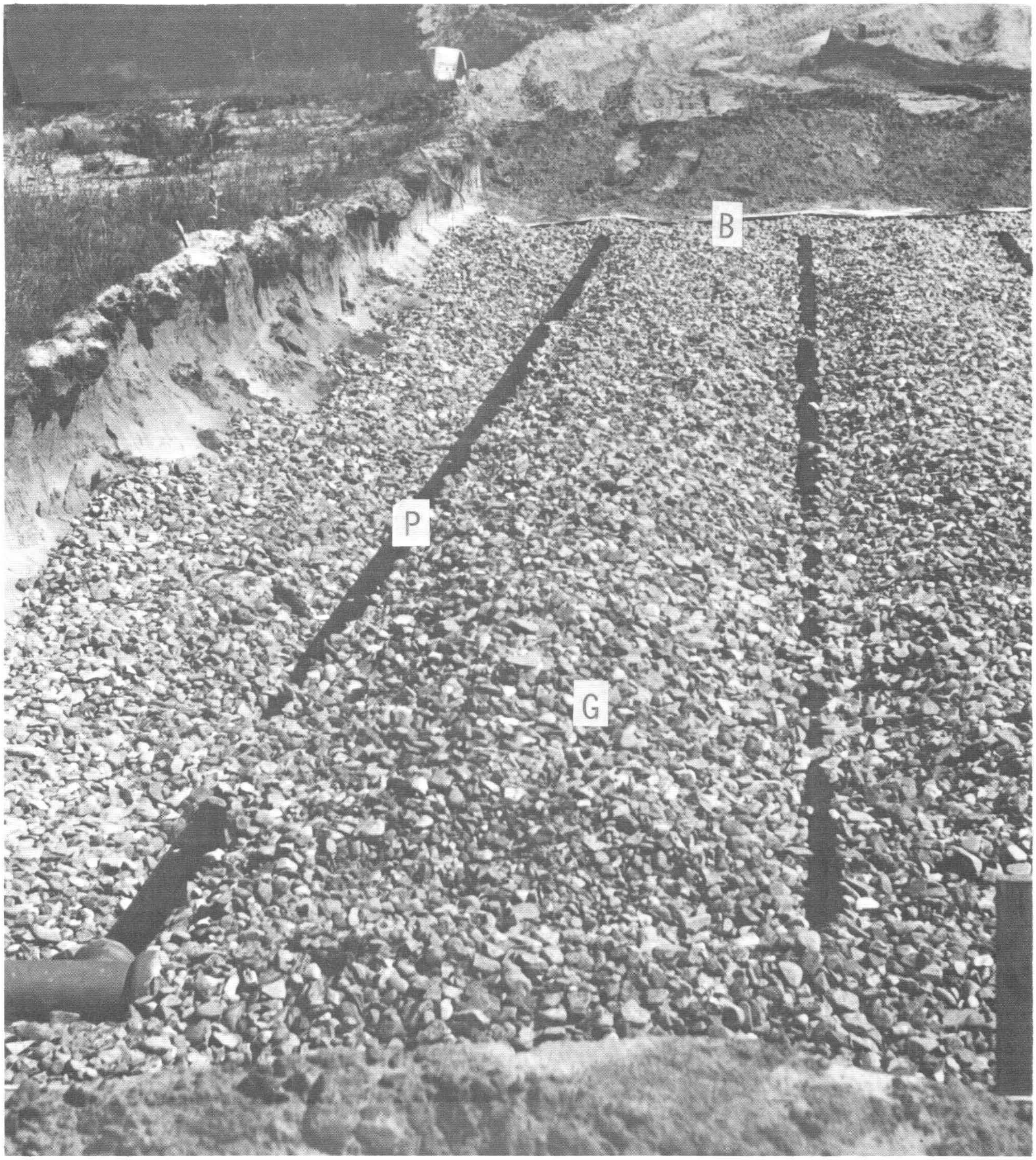

Photo 1. Steps in the construction of a subsurface seepage bed. Perforated pipes (P) were laid on top of 30 cm (12") of gravel (G) in an excavation, which was 4 feet deep at this location. A few inches of gravel are to be applied on top of the pipes and then soil is backfilled into the excavation. Soil fill and gravelbed are separated by a decomposable paper barrier (B) to avoid initial movement of fill material into the gravelbed.

1. INTRODUCTION

Soil absorption of septic tank effluent has been the usual process by which domestic liquid waste is disposed in areas beyond the reach of municipal sewerage facilities. In some places the process has worked well for decades, but at many sites in rural settings and in post World War II suburban developments, soil absorption systems have been discharging effluent to the surface before purification was completed. This all-too-common failure of the method may be correctable, but then only after a thorough scientific study of particular septic systems functioning in place in the soil. Such a study was begun by the Soil Survey Division of the Geological and Natural History Survey, in 1969 and the present report summarizes the findings of three field seasons and two winters of work. Acknowledgment is made elsewhere of the cooperation of agencies and individuals without whose participation and cost-sharing the project could not have been brought to its present stage.

Soil absorption systems are being installed at an increasingly rapid rate, not only in suburbia, but also in recreational developments around both natural and man-made lakes. In 1970, 14,000 permits were issued for private septic systems by the Wisconsin Department of Health. In 1971 the number increased to 19,400 representing an investment of at least $20,000,000 in this state.

The septic tank - soil absorption system (Photo 1) is relatively simple and, when used under proper conditions and management, has been entirely satisfactory. The diagram (Fig. 1) shows major components and pathways. Liquid wastes flow into a septic tank which should have a storage capacity equal to the accumulation over a three-day period. Processes of anaerobic digestion go on in the tank, producing on the bottom a sludge of decomposition products which should be pumped out periodically. The liquid flowing out of the tank has a high biological oxygen demand (B.O.D.), contains many fecal microorganisms and is therefore unsuitable for discharge into open water or onto the soil surface. Health hazards are created wherever this premature discharge is permitted. The necessary final treatment of the effluent is accomplished by leading it into a perforated pipe in a subsurface seepage bed filled with gravel. The effluent moves into the soil below the bed and through the substratum to the ground water. As it moves the liquid is purified by processes of absorption, filtration, and microbiological decomposition. Once the liquid has merged with the ground water, it moves laterally and is suitable after some time for pumping and reuse. The hydrologic cycle is then complete (Fig. 1).

Soil materials can be very effective filters, both with respect to fecal microorganisms and to chemical compounds where conditions are suitable (Bouwer, 1968, 1970; Parizek _et al._, 1967). Errors in placing septic systems in soils where conditions are unfavorable for their operation has resulted in failure, in many cases within the first year. Improper construction and system maintenance may also result in system failure, even in potentially very suitable soils.

Field procedures for determining soil suitability for liquid waste disposal were devised as early as 1928 in New York State by Ryon, who

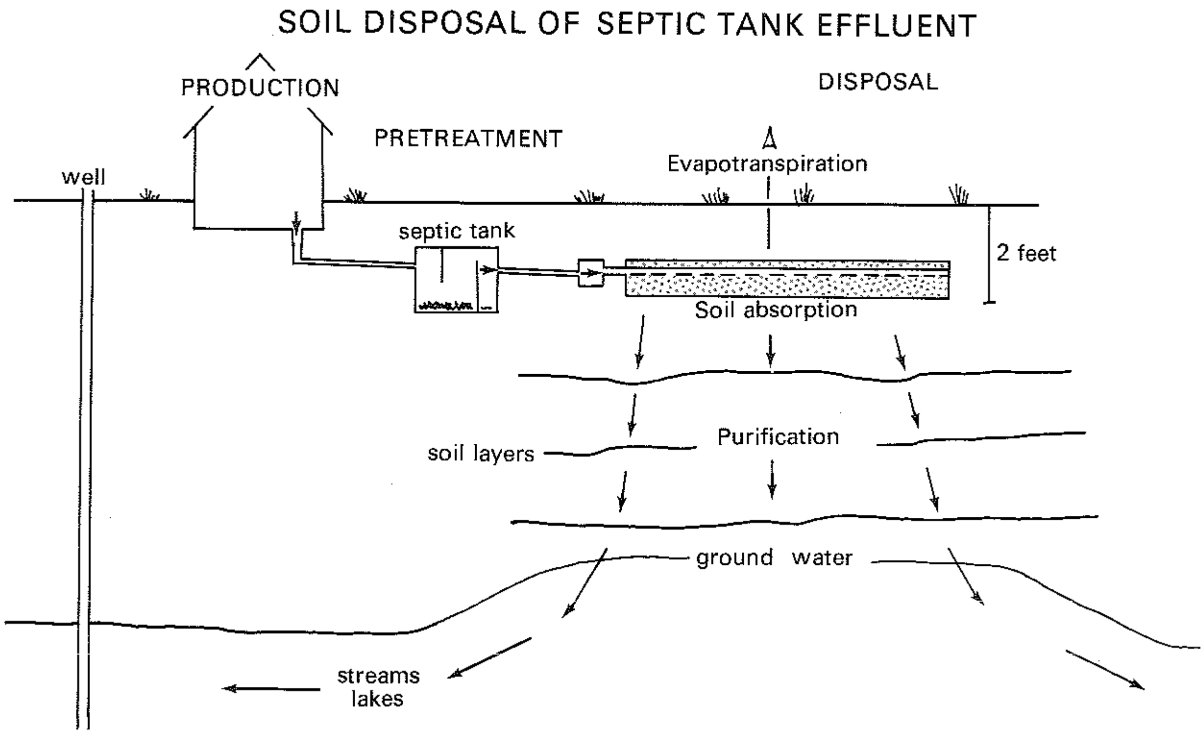

Fig. 1. Recycling of liquid wastes by soil absorption of septic tank effluent.

introduced the soil percolation test (McGauhey and Krone, 1967). This test, with some modifications, is still widely used, and is the basis for calculations of sizes of seepage beds for a given loading rate. However useful the percolation test may be as a simple indicator, it is from the scientific point of view incapable of precise definition and of yielding reproducible results.

In recent years pedological criteria have been included in regulations developed by the Wisconsin State Board of Health (H 62.20, 1969) for private domestic systems of sewage treatment and disposal. A planner using these criteria, including depth of soil over bedrock or water table, and soil slope can eliminate consideration of areas of unsuitable soils with the aid of a detailed soil map (Cain and Beatty, 1965).

Failure of soil absorption systems has been largely described in terms of a loss of infiltrative capacity. This ignores the serious bacteriological and chemical pollution of ground water, lakes and streams that may be caused by rapid movement of effluent through coarse, porous soils including sands. Fortunately, an inhibiting organic crust forms on the surfaces of seepage trenches even in sands, so that within the first year of operation of a well loaded system the rate of movement of effluent from the trenches decreases and purification improves before discharge to ground water or streams. In cases of extreme crusting, systems in initially permeable soils may overflow and unsafe effluent escapes to the surface.

Soil crusting or clogging has been discussed by McGauhey and Krone (1967) and Popkin and Bendixen (1968), who have suggested relevant adjustments in construction of systems as well as in their management, that may include mechanical pretreatment of effluent and its intermittent release (dosage) into the the seepage field. These recommendations were based on laboratory experiments with columns randomly filled with sand and various aggregates which could not duplicate many natural soil structures and field conditions that profoundly influence movement of liquid wastes. Comprehensive investigations of the soil-liquid system <u>in situ</u> have not been reported.

The objectives of the research program reported here were, therefore, to:

1. Investigate the performance in terms of absorption and purification of septic tank soil absorption systems under field conditions in major horizons of representative soils of Wisconsin;

2. Develop criteria and field methods that will provide reproducible quantitative data from which realistic estimates can be made of the capacities of soil units of Wisconsin landscapes to absorb and purify waste-bearing liquids;

3. Explore methods of satisfactory liquid waste disposal in soil materials at sites which by present criteria are unsuitable for soil absorption systems.

Attainment of these objectives is possible only by efforts of a multidisciplinary team of workers, in view of the operation of physical, chemical, and bacteriological processes in a liquid waste disposal system. The present project has involved microbiologists of the Department of Bacteriology, soil chemists and soil physicists of the Department of Soil Science, of the College of Agricultural and Life Sciences, and hydrogeologists and soil morphologists of the University Extension Geological and Natural History Survey, all based on the University of Wisconsin campus at Madison. This cooperative research program has developed through 1970 and 1971, with attention being focused most recently on movement and transformation of nitrogen and phosphorus compounds in soil and ground water.

The field season of 1969 (July 1 - Nov. 1) was used to test field procedures for measuring hydraulic conductivity and to compare results with those obtained by the soil percolation test. Work was done at the Charmany and Mandt Experimental Farms, of the University of Wisconsin, in Madison and at field locations near Omro and Oshkosh (Bouma and Hole, 1971a). Results were reported in a progress report (Bouma and Hole, 1970). The field season of 1970 (April 15 - Nov. 1) was used to further test these field procedures at the same locations. In addition, operating septic tank disposal systems were monitored at the Marshfield, Arlington and Hancock Experimental Farms of the University of Wisconsin and at field locations near Ashland and Friendship. Experimental "mound" systems were studied in Clark County. A field method was developed to measure unsaturated hydraulic conductivity <u>in situ</u>. Results were reported in a second progress report (Bouma and Hole, 1971a). The field season of 1971 (April 15 - Nov. 1) was used to monitor a series of five systems in sandy soils in Adams County and systems in sandy soils in Stevens Point and Black River Falls. Several septic systems near lakes were investigated in cooperation with the Inland Lake Renewal Project, University Extension. Study sites were near Kelly Lake (in a silty clay soil), Dardis Lake, and Pickerel Lake (the latter two systems in sandy soil). Several "mound" systems were designed for sites in the Ashland area (in a clay soil). Four existing mound systems on shallow loamy soils over creviced bedrock, were monitored in Door County.

The overall scope of the problem extends beyond technical aspects closely associated with the soil. New technical developments in small scale mechanical waste-treatment facilities may prove so effective in the future that soil materials are no longer needed. In addition, socio-economical and environmental considerations will most probably influence and direct future developments. These two aspects, in addition to continuing soil studies, are part of a recent larger research project of the University of Wisconsin on small scale waste systems in Wisconsin. This report is restricted to soil aspects of absorption and purification of septic tank effluent as studied in the period July 1969, through November, 1971.

2. SOME PHYSICAL AND MORPHOLOGICAL ASPECTS OF INFILTRATION AND MOVEMENT OF LIQUID THROUGH SOIL MATERIALS

2.1. Introduction

Flow of liquid through pores in soil materials is a physical process, governed by characteristic physical constants, which have been studied in great detail in the recent decades. Some current reviews and textbooks provide an excellent picture of the present state of soil physical knowledge (Rose, 1966; Childs, 1969; Hillel, 1971). Recently an attempt was made to relate morphological soil structure data, as assembled during soil survey studies, to flow phenomena (Bouma and Anderson, 1972).

The central problem of this study, which is soil absorption and percolation of liquid waste, is directly related to, and can be predicted by using, the hydraulic characteristics of the soil. In addition, filtration and purification of wastes, while moving in soil materials, will be a function of travel-path and travel-time through the very complex soil pore geometry. Physical and morphological techniques can be used to predict those characteristics. The purpose of this chapter, then, is to broadly review some basic concepts of the occurrence of liquid in and flow through soil materials, and to relate those processes to some major soils of Wisconsin. Only some general principles will be discussed. The reader is referred to the literature for a more in-depth analysis.

2.2. Morphological and physical characterization of soil porosity

Soil pores, contributing the non-solid phase of a soil material, have a wide variety of sizes and shapes due to the varying arrangement of the solid soil particles. The term soil structure in this context refers to the physical constitution of a soil material as expressed by size, shape, and arrangement of the solid particles and voids (Brewer, 1964). Two levels of soil structure can be distinguished when considering soil porosity: 1. The basic structure, which is the structure of the primary particles of clay, silt and sand,and 2. The secondary structure, which is the structure of aggregated soil materials in which primary particles are combined into larger natural units, called peds, that are separated by natural voids. Fig. 2.2.1. illustrates these structures schematically. Fig. 2.2.1a. depicts an apedal soil material, that is, without peds. Sizes and shapes of pores between individual grains, packing pores, are determined by sizes and shapes of the solid particles and their arrangement as shown in the inserted picture. Larger pores, with a size and shape not determined by the packing of elementary grains, may occur in this matrix. These can be tubular channels, formed by roots or animals, that usually have a regular configuration of the walls and a certain continuity, and vughs, that are defined as irregularly shaped discontinuous pores. This theoretical model is substantiated by observation of actual soil materials as illustrated by subsequent figures. Fig. 2.2.2. shows a natural apedal structure as exposed in a horizontal soil peel (Bouma and Hole, 1965) from the C horizon of a Plainfield loamy sand that exhibits packing voids. Sizes and shapes of such pores can be measured with microscopic techniques using

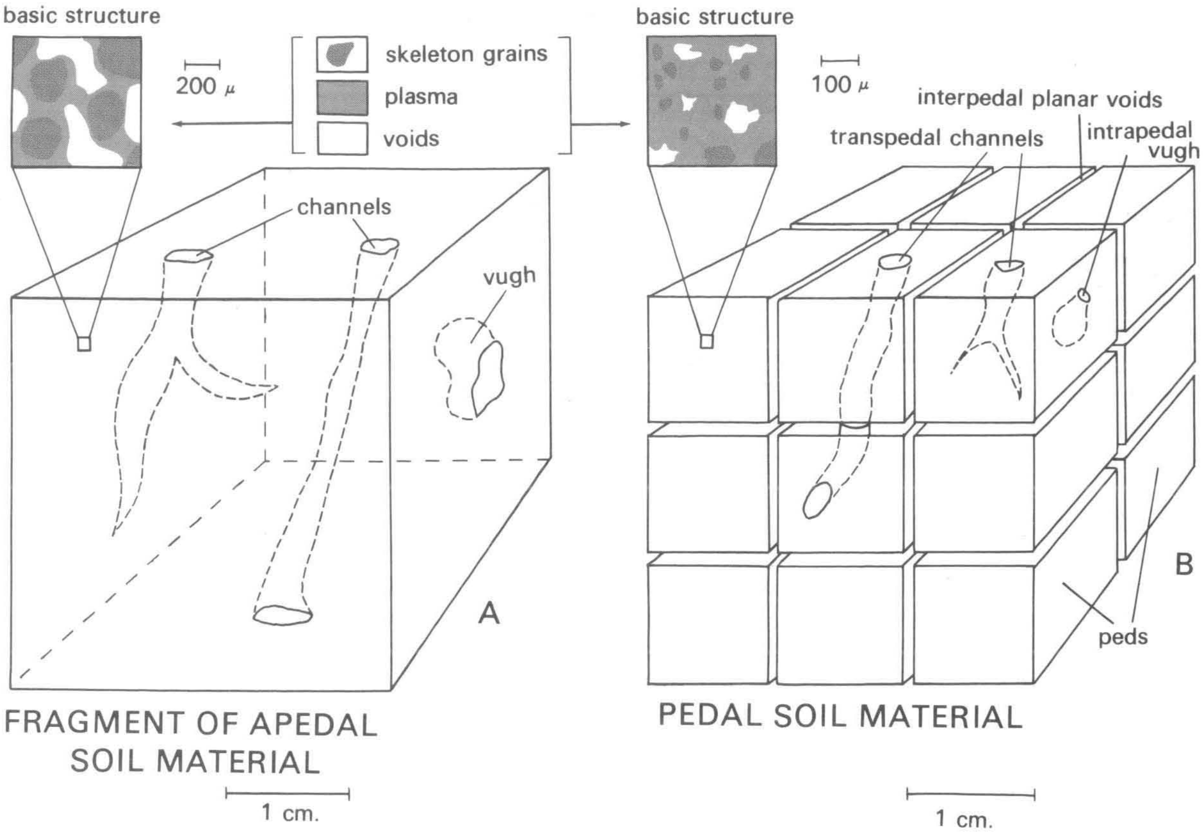

Fig. 2.2.1. Schematic representation of a pedal (right) and apedal soil material (left).

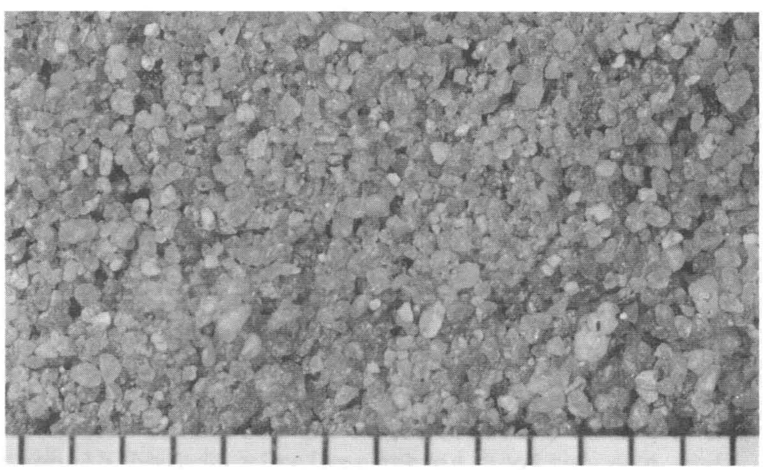

Fig. 2.2.2. Single grain, apedal soil structure in a horizontal soil peel from the C horizon (sand) of a Plainfield loamy sand.

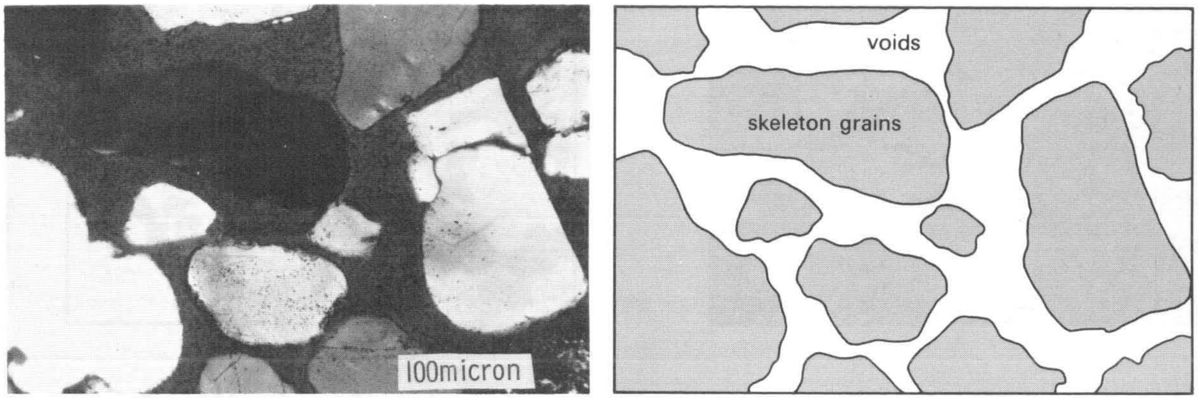

Fig. 2.2.3. As Fig. 2.2.2. but at larger magnification as seen in a thin section.

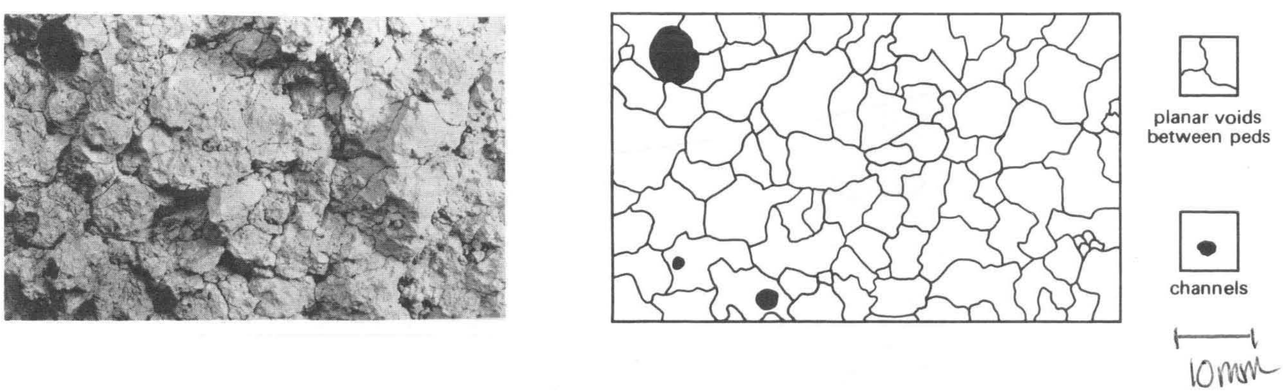

Fig. 2.2.4. Fine pedal soil material in a horizontal soil peel from the B2t horizon (silty clay loam) in a Plano silt loam.

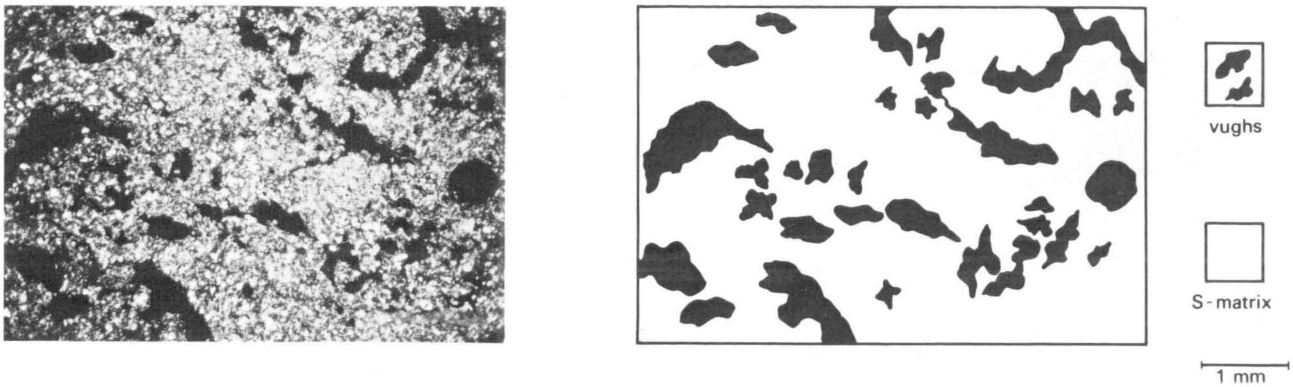

Fig. 2.2.5. As Fig. 2.2.4. but at a larger magnification as seen in a thin section. Note vughy S-matrix.

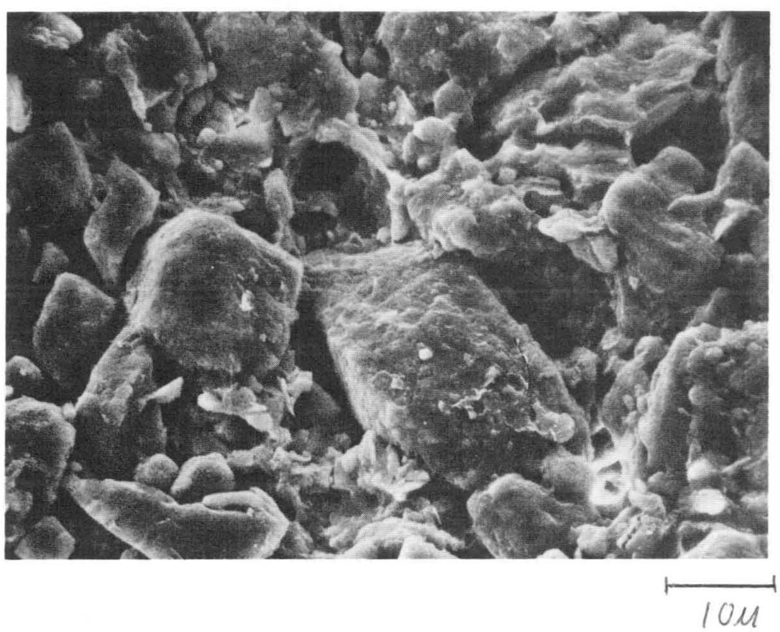

Fig. 2.2.6. As Fig. 2.2.4. but at much larger magnification as seen with the Scanning Electron Microscope (photo courtesy of Dr. Sachs, USDA Forest Products Laboratory).

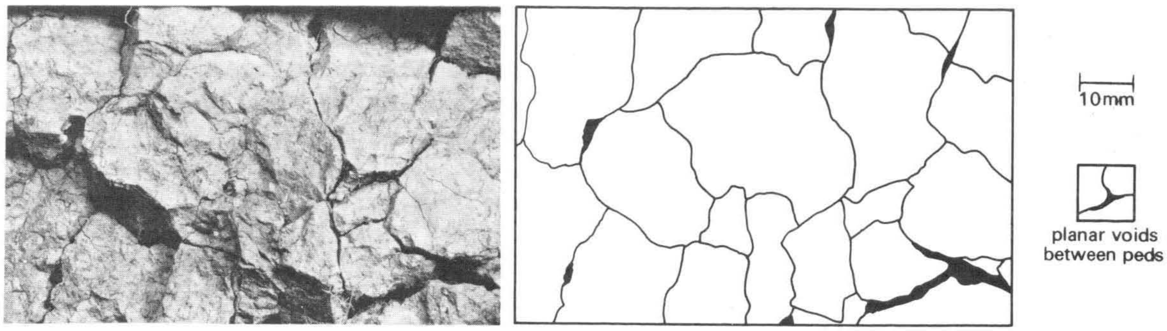

Fig. 2.2.7. Coarse pedal soil material in a horizontal soil peel from the B2 horizon (clay) in a Hibbing loam.

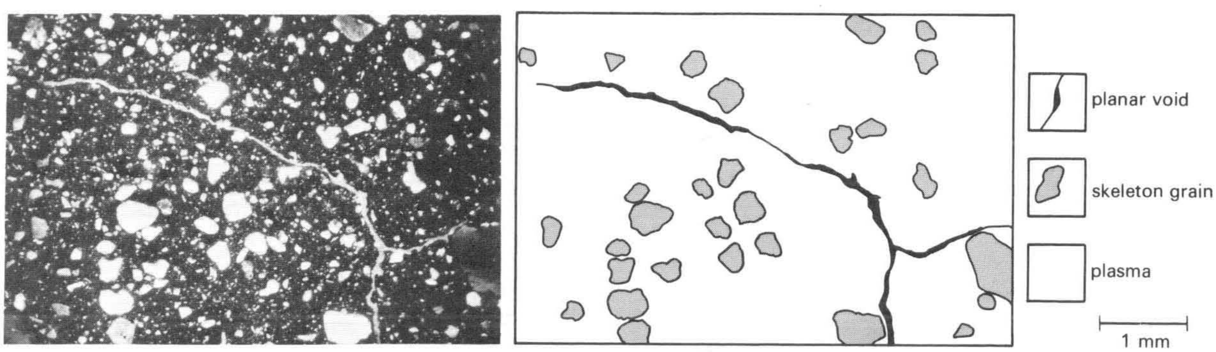

Fig. 2.2.8. As Fig. 2.2.7. but at a larger magnification as seen in a thin section.

thin sections of soil materials, which are slices 0.02 mm thick of plastic-impregnated and hardened soil (Buol and Fadness, 1964). Fig. 2.2.3. is a photograph and tracing of a thin section of a sandy soil as seen through a microscope. Fig. 2.2.1b. presents a model of a pedal soil material. The compound units, called peds, are separated by voids, commonly planar voids. Channels and vughs may occur inside peds (intrapedal) or between peds (transpedal). Note that dimensions of small pores inside peds are determined, as always, by the packing of the elementary grains. The photograph and tracing in Fig. 2.2.4. show the natural pedal structure in a horizontal section through the B2 horizon of a Plano silt loam, where peds are separated by planar voids. The basic structure inside a ped made from a thin section of the same horizon is pictured in Fig. 2.2.5. Many irregular vughs occur in the matrix (S-matrix of Brewer, 1964), which has very fine pores due to the small size of the primary silt and clay particles. A better view of this microfabric is obtained with the scanning electron microscope (Fig. 2.2.6.). Peds in clay soils are coarser. A section of the B2 horizon in a Hibbing loam (Fig. 2.2.7.) shows medium prisms. The basic structure inside the peds is dense and interpedal planar voids are the dominant type of larger pores, as shown in a view of a thin section of this horizon (Fig. 2.2.8.).

All the morphological pictures were by necessity made of dry soil, since wet soil is not used for making soil peds and thin sections. Under natural conditions at least some of the pores are filled with liquid. The basic physical characteristics mentioned in the following chapters have been determined on both dry and moist soil. A soil sample consists of solid particles and voids, a fraction of which may be filled with liquid (Fig. 2.2.9.). If we assume that the weight of solid particles is M , that of the water M_w, and that total weight is M_t grams, the corresponding volumes are: V_s, V_w and V_t. Here also the volume of pores filled with air (V_a) has to be included, which contributes negligibly to weight but constitutes an important part of the total soil volume. The volume of the pores is then $V_p = V_a + V_w$. The following characteristics are most commonly distinguished (see also Hillel, 1971), methods of determination of which are discussed later in Chapter 3.

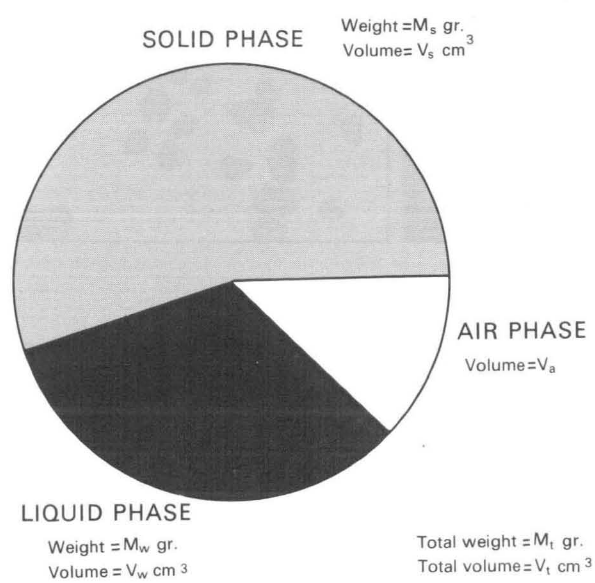

Fig. 2.2.9. Schematic diagram of the soil as a three-phase system.

1. Particle density ρ; which is defined as:

$$\rho = \frac{M_s}{V_s} \ (gr/cm^3)$$

This value is used to calculate the volume of a certain dry weight of soil. Values are usually about 2.6-2.7 gr/cm3.

2. Bulk density $B.D. = \frac{M_s}{V_t} = \frac{M_s}{V_a+V_s+V_w}$ (based on dry soil weight).

This value is always smaller than ρ, because V_a and V_w are also included. Sometimes bulk density is determined, including water:

$$B.D.(wet) = \frac{M_s+M_w}{V_t}$$

We will use B.D.(dry) exclusively because this is the value used to calculate θ_v from θ_w (see Point 3 below).

Porosity is defined as:

$$p = \frac{V_p}{V_t} = \frac{V_p}{V_p+V_w+V_s}$$

and is normally expressed as a percentage. This value uses the total volume of all pores. Thus, no distinctions can be made between different types of pores with different functions in the soil fabric. Here, morphological analyses can be helpful.

3. Soil wetness can be expressed in two ways: 3.1. Percentage by weight:

$$\theta_w = \frac{100 \cdot M_w}{M_s}$$

where M_s is determined after drying the soil at 105°C. 3.2. Percentage by volume:

$$\theta_v = \frac{100 \cdot V_w}{V_s+V_a+V_w}$$

These two characteristics are interrelated as follows:

$$\theta_v = \frac{\theta_v \cdot B.D.(dry)}{\rho}$$

where ρ = density of water.

Soil volume is a relevant factor in several of the characteristics defined above. This may change when dry soil is wetted. Most soil materials containing clay will expand upon wetting which is mainly due to the mineralogical and chemical nature of the clay minerals and to chemical characteristics of the wetting liquid. Thus, it follows that B.D., and θ_v values will be affected. The saran-method has been developed to measure the amount of swelling at different moisture contents (Section 3).

2.3. Physical characterization of liquid in soil materials

Soil wetness, as considered in the previous section, refers solely to the total amount of liquid in a soil sample. In addition, it is important to ascertain the distribution of water in the soil at different moisture contents, and to understand the natural laws that govern it. As the moisture content decreases, water leaves the larger soil pores but remains in the finer ones. This can be explained by considering the basic phenomena of liquid surface tension and capillarity. Surface tension occurs typically at the interface of a liquid and a gas. Molecules in the liquid attract each other from all sides. In the surface areas the molecules are attracted into the denser liquid phase by a force greater than the force attracting it into the gaseous phase. The resulting force draws the surface molecules downward, which results in a tendency for liquid to contract. Surface tension has the dimension of dynes/cm. Increased salt concentrations tend to increase the surface tension of water, whereas organic solubles like detergents tend to decrease it. Capillarity refers to the well known phenomenon of the rise of water into a capillary tube inserted in water, due to its surface tension. The finer the tube, the higher the capillary rise and the greater the negative pressures below the water meniscus in the tube. This negative pressure (p) is a result of the curvature of the meniscus, which increases as tubes become smaller, and can be calculated (in dynes/cm^2) as follows:

$$p = \frac{2\delta \cos\alpha}{r} \tag{1}$$

Where δ = surface tension of the water (dynes/cm), α = the contact angle of liquid and solid (see Fig. 2.3.1.) and r = radius of the capillary. The height of capillary rise is:

$$h = \frac{2\delta \cos\alpha}{\rho g r}$$

where ρ = density of the water (gr/cm^3) and g = gravitational constant ~~(gr/cm^2).~~ (cm/sec^2)
Function (1) can be pictured as a continuous graph, relating capillary radius to corresponding pressure (Fig. 2.3.1.). To represent the porosity of a certain soil material as a bundle of capillaries, with a characteristic size range is, of course, an unrealistic model as real pores in the soil have a much more complex configuration with varying sizes and discontinuities. This representation can nevertheless be helpful to visualize flow phenomena in soils, particularly when soil moisture contents are relatively close to saturation, as will be the usual case in this study. Different pressures of water, as introduced in equation (1), indicate different levels of energy. This is important as movement of water results from energy gradients in the soil. Of the two principle forms of energy, kinetic and potential, the latter, which is due to position or internal condition, is of primary importance in determining the state and movement of water in the soil. The total potential of soil water is defined as (Aslyng, et al., 1963): "The amount of work that must be done per unit quantity of pure water in order to transport reversibly and isothermally an infinitesimal quantity of water from a pool of pure water at a specified elevation at atmospheric pressure to the soil water." The potential can be best expressed as energy per unit weight (hydraulic head, in cm water). This total potential is composed of several separate potentials because soil water is subject to a number of force fields, which cause its potential to differ from that of pure, free water. Such force

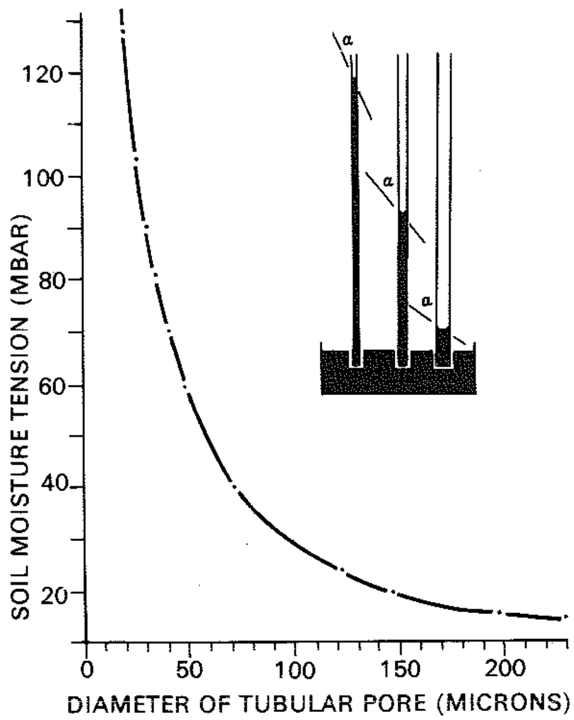

Fig. 2.3.1. Graphical expression of the relationship between tubular pore size and corresponding soil moisture tension.

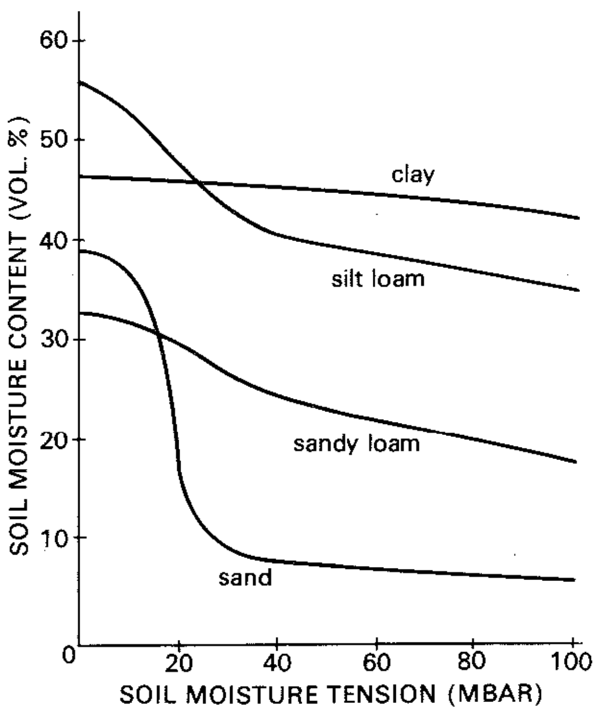

Fig. 2.3.2. Soil moisture retention curves, relating soil moisture content to moisture tension, for four different soil materials.

fields result from the attraction of the solid matrix for water (matric potential), as well as from the presence of gravitational forces (gravitational potential). In addition, the presence of solutes (osmotic potential) and the action of external gas pressure may contribute to total potential. Matric potential refers to the potential of water under negative pressure, which results from capillary forces (Equation 1) and adsorptive forces due to the soil matrix. Such soil is said to have a certain "suction" or "tension" which can be expressed in a positive figure as centimeters water or in millibars (1 mbar = 10^3 dyne/cm^2 = pressure of 1.022 cm water). As our study is confined to relatively "wet" soils (matric potentials ranging from 0 to around 100 cm), capillary forces will be dominant. The matric potential can be measured in the field as a soil moisture tension, using tensiometers (Chapter 3). The gravitational potential is due to the attraction of every body on the earth's surface towards the center of the earth by a gravitational force equal to the weight of the body. To raise this body against this attraction, work must be done, and this work is stored by the raised body against this attraction, work must be done, and this work is stored by the raised body in the form of gravitational potential energy, which is determined at each point by the elevation of the point relative to some arbitrary reference level. Therefore:

$$Eg = M.g.z. \tag{2}$$

where Eg is the gravitational potential energy of a mass M of water at a height z above a reference and g = acceleration of gravity. This potential, expressed per unit weight, becomes: Eg = z (in cm).

At zero tension all pores in the soil are filled with water (assuming that isolated air pockets do not exist). With increasing soil moisture tension progressively smaller pores will empty as the capillary force they can exercise becomes insufficient to retain water against the tension applied (see Equation 1). The rate of decrease of water content in a soil sample upon increasing tension is characteristic, as it is a function of its pore size distribution. Moisture contents in the same soil sample are different at corresponding tensions when the soil is gradually wetted to saturation, rather than desorbed, starting at saturation. The difference is the so-called "hysteresis" phenomenon, which is discussed elsewhere (Hillel, 1971). All our curves are based on a desorption process. Techniques are available (Chapter 3) to experimentally determine this so-called "soil-moisture-retention-curve". Fig. 2.3.2. shows such curves for a sand, a silt loam, and a clay soil, demonstrating the effect of their different pore types. These pore types are schematically represented in Fig. 2.4.3., which is used in the discussion of soil permeability in Section 2.4. The sand has many relatively large pores that drain at relatively low tensions, whereas the clayey soils release only a small volume of water, because most of it is strongly absorbed in very fine pores. The silt loam has more coarse pores than does the clay soil.

2.4. Physical characterization of liquid movement in soil materials

The amount of flow through a soil sample is proportionate to the potential gradient. This, basically, is Darcy's law as stated for a one dimensional steady-state condition of flow:

$$q = K \cdot \frac{\Delta H}{L} \tag{3}$$

where q = flux ($cm \cdot sec^{-1}$) of water [= $Q/(A \cdot t)$], which is the volume (Q) of water flowing through a cross-sectional area A per time t, K is the hydraulic conductivity ($cm \cdot sec^{-1}$) and $\Delta H/L$ is the hydraulic gradient, which is the drop of the hydraulic head per unit distance in the direction of flow (dimensionless). This equation applies to both saturated and unsaturated soils, although hysteresis effects may offer problems in the latter case (Hillel, 1971). In this context we will only consider steady state conditions of flow, in which the flux remains constant and equal along the conducting system. Field measurement of moisture tensions, around operating crusted seepage beds, has indicated the occurrence of basically steady state conditions. Unsteady-flow processes, in which the magnitude of the flux and the potential gradient vary with time, require additional mathematical expressions (Hillel, 1971, Childs, 1969).

The flux q is measured per unit cross-sectional area. Part of that area (at least 40%) is occupied by the solid phase, which implies that the real velocity of flow in the soil pores itself is larger than q. If the soil would be composed of simple capillary tubes, with a specific size, calculations of the real flow velocity in those pores would be easy. However, pores vary in shape, width and direction, and the actual flow velocity in the soil is variable. At best, therefore, one can refer to some "average" velocity (v) that can be calculated on the basis of the water-filled porosity at each tension. The miscible displacement studies of Biggar and Nielsen (1962) indicate the practical significance of this approach.

$$V = \frac{q}{\epsilon_w} \tag{4}$$

where ϵ_w is the water filled porosity, as derived from the moisture retention curve. At unit hydraulic gradient, we find:

$$v = \frac{K}{\epsilon_w}$$

According to Equation (3), flow rates can vary considerably with varying hydraulic gradient. The hydraulic conductivity (K), however, is defined as the flux at unit gradient, and can, therefore, be considered as a characteristic value for the soil. This basic difference between flow, or infiltration rates and hydraulic conductivity (K) values will be further discussed in Chapter 6.1. K values can be measured with physical techniques (Chapter 3).

Physical equations have been developed for certain types of pores to relate pore size to flow rates (Childs, 1969). For a cylindrical pore of radius r we find:

$$Q/t = \frac{\pi g \rho r^4}{8\eta} \cdot \text{grad } \phi \text{ (Fig. 2.4.1.)} \qquad (5)$$

For a plane slit of width d, and unit length:

$$Q/t = \frac{g \rho D^3}{12\eta} \cdot \text{grad } \phi \text{ (Fig. 2.4.1.)} \qquad (6)$$

where Q/t = flow rate ($cm^3/cm^2/sec$), ρ = density of water (gr/cm^3), g = gravitational constant (cm^2/sec), η = viscosity (dyne/cm), grad ϕ = hydraulic gradient (cm/cm). These equations are graphically expressed in Fig. 2.4.2., that demonstrates the great effect of pore size on flow rates. Morphological studies (Section 2.2.) attempt a classification of pore types, among which cylindrical channels and planar voids figure prominently. It appears possible, at least for some soils, to calculate K values from morphometric data, using Equations (5) and (6) that relate pore size to permeability (Bouma and Anderson, 1972). A physical method was introduced by Marshall (1958) to calculate K values from moisture retention data, following an equation which relates pore sizes to K values, including a pore interaction model. Pore sizes are indirectly derived from the moisture retention curve, using Equation (1). Green and Corey (1971) have revised the method and their procedure has been applied in this study (Chapter 3). The dominant effect of pore sizes on permeability is evident when K values of a soil material are compared, that are measured at different degrees of saturation. Unsaturated soil below an infiltrating surface may have different causes, such as the occurrence of a physical barrier to flow or an inflow rate which is lower than the saturated hydraulic conductivity. We may assume three different soil materials, with pore size distributions schematically represented in Fig. 2.4.3. The uppermost "soil" is coarse porous like a sand, the lowest one is finely porous (like a clay). Without any physical barrier (a "crust") on the soil surface and with a sufficient supply of water, all pores are filled and each will conduct water downward as a result of the potential gradient of 1 cm/cm, due to gravity. The larger pores will conduct much more water than the smaller ones (see Equation 5 and Fig. 2.4.3.). Suppose a weak crust now forms over the top of the tubes. Pores will only fill with water if the capillary force they can exercise is strong enough to overcome the resistance of the crust. The larger the pore, the smaller the capillary force that can be exercised (Equation 1). Therefore, larger pores will empty first at increasing crust resistance, creating unsaturated soil and soil moisture tensions (Section 2.3), and leading to a strong reduction in the hydraulic conductivity of the soil.

With no crusts present, similar processes can occur, when the rate of application of water to the capillary system is reduced. With abundant supply, all pores are filled. As this supply, which is supposed to be divided evenly over the infiltrating pore system, is decreased, insufficient water is available to keep all pores filled during the downward movement of the water. Larger pores will empty first, as they conduct most liquid while

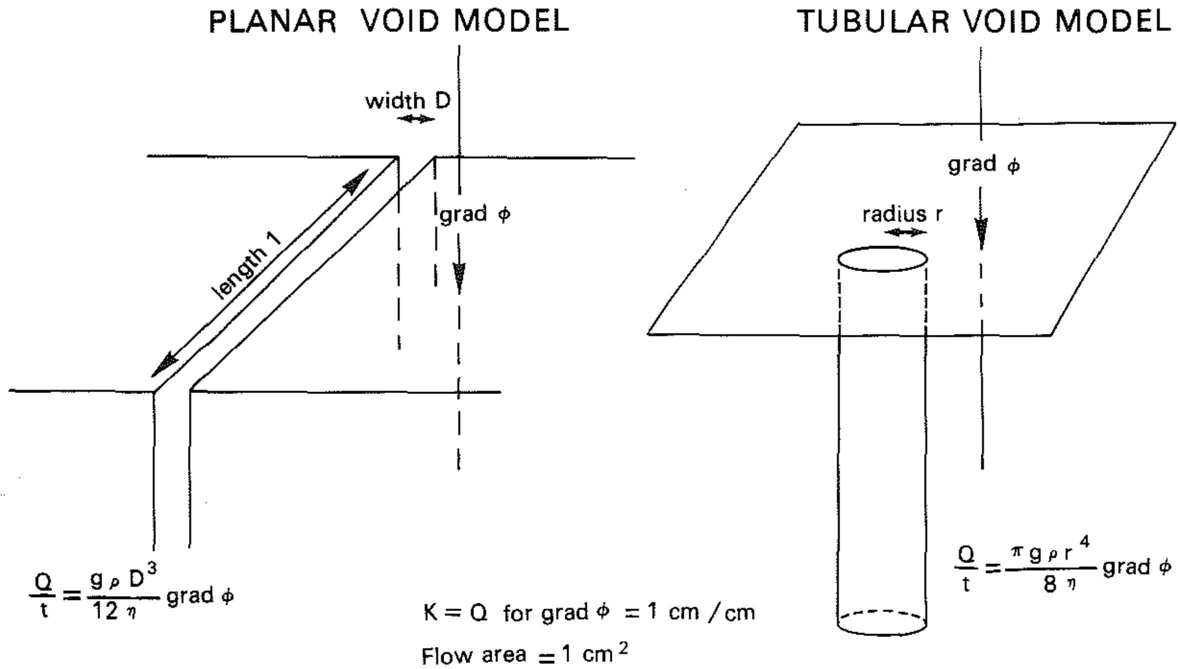

Fig. 2.4.1. Relationships between sizes of tubular and planar voids and flowrates at defined hydraulic gradients.

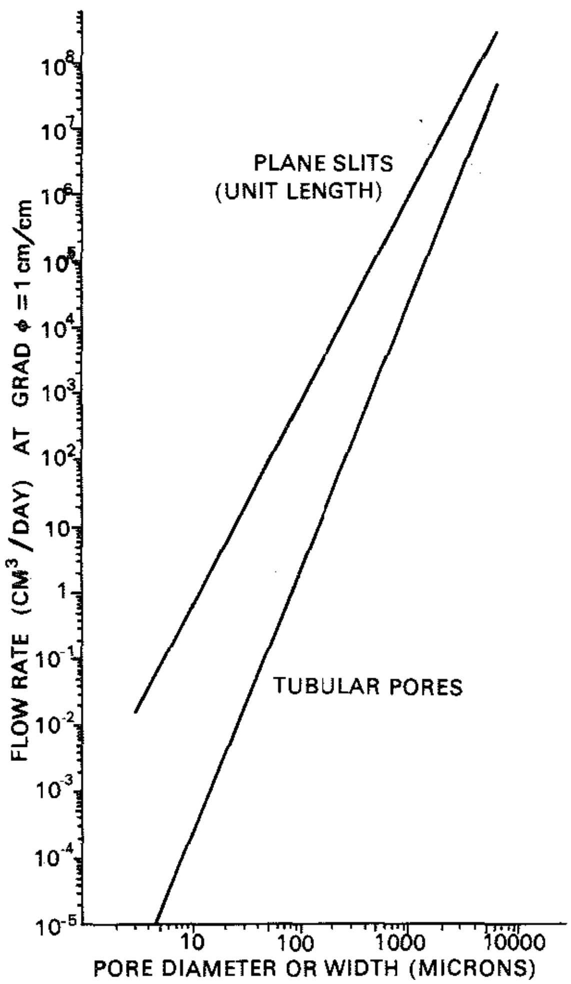

Fig. 2.4.2. Graphical expression of flow rates through tubular or planar voids as a function of pore size at a hydraulic gradient of 1 cm/cm.

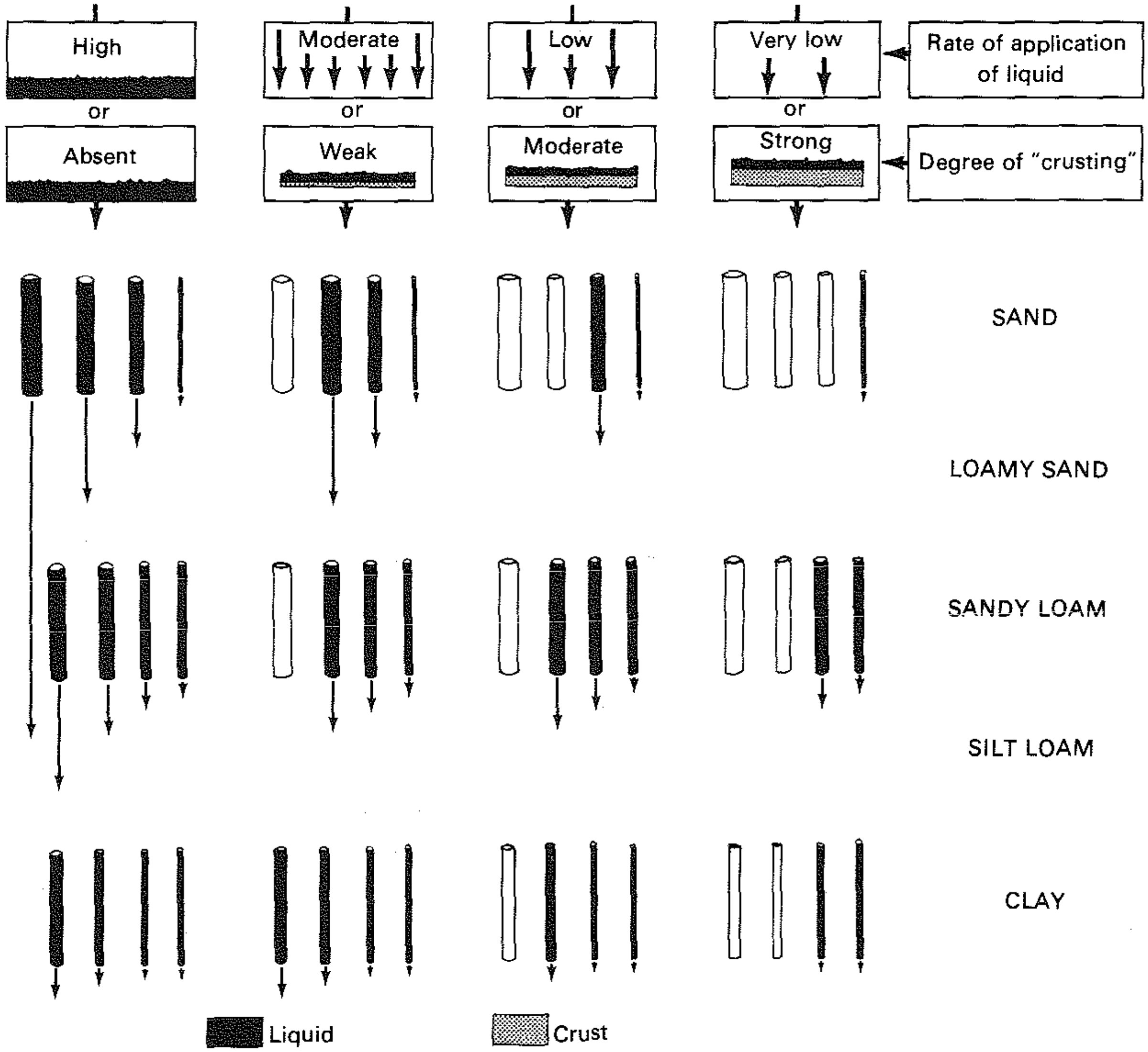

Fig. 2.4.3. Schematic diagram showing the effect of increasing degree of crusting or decreasing rate of application of liquid on the rate of percolation through three "soil materials".

at the same time, they exercise only relatively small capillary forces. Thus in this system, a certain size of pore can only be filled with water if smaller pores have an insufficient capacity to conduct away the applied water.

The degree of reduction in K upon desaturation and increasing soil moisture tension is characteristic for the pore-size distribution, as is graphically demonstrated in Fig. 2.4.3. Coarse porous soils have a relatively high saturated hydraulic conductivity (K_{sat}); but K drops strongly with increasing tension. Fine porous soils have a relatively low K_{sat}, but K decreases more slowly upon increasing tension. Experimental curves, determined in the field with the crust test (see Chapter 3) show such patterns for natural soil. Fig. 3.2.4.1. shows curves for a sand, a sandy loam, a silt loam and a clay soil, relating K and soil moisture tensions in unsaturated soil.

In summary, then, the higher the "crust" resistance, or the lower the rate of application of water, the higher the soil moisture tension in the underlying soil, and the lower the relevant hydraulic conductivity (K). These characteristics were described here for steady state, equilibrium conditions in a one-dimensional system, where, at a hydraulic gradient of 1 cm/cm, flow rates are equal to the hydraulic conductivity. More complex two-dimensional flow systems with curved flow lines can be characterized with numerical (Amerman, 1969) or analytical techniques (Raats, 1971).

3. METHODS

3.1. Introduction

Soil disposal of septic tank effluent can only be considered satisfactory if effluent is absorbed in sufficient quantities and if processes of filtration and absorption will purify the liquid before it can be recycled. Physical methods were used to study flow of liquid and bacteriological and chemical methods were used to investigate aspects of effluent purification. However, processes of filtration and absorption are strongly related to the flow processes in the soil. For example, relatively slow liquid movement through fine soil pores in unsaturated soil will result in a prolonged and closer contact between soil and effluent as compared with flow under saturated conditions when liquid will move much faster. Although discussed separately in this chapter, further discussion of experimental results in Chapters 5 and 8 will demonstrate the close functional relationship between the different methods.

3.2. Physical methods

3.2.1. Introduction

Physical aspects of soil absorption of septic tank effluent from subsurface seepage beds were studied with different methods. Soil moisture tensions in the soil around the beds were determined with tensiometry to characterize the water potentials in the actual flow systems (Chapter 3.2.5.). Basic hydraulic properties of the soil were determined in situ with the double tube method for measurement of K_{sat} (Chapter 3.2.3.) and the newly developed crust method for measurement of K of unsaturated soil, the latter to relate soil moisture tensions to specific K values (Chapter 3.2.4). Moisture retention characteristics, used to "translate" moisture tensions into volumetric moisture contents were determined in the laboratory using undisturbed soil cores (Chapter 3.2.5). Each of these methods were used not only to describe the actual flow conditions in the soil, but also to predict a range of potential conditions resulting from possible different flow regimes in the system. The State Percolation Test, required by State law to be performed at any prospective disposal site that is not disqualified for other reasons, is described in Chapter 3.2.2.

3.2.2. The Percolation Test (from Chapter H 62.20: State Board of Health, 1969)

Percolation Test Procedure.

"(a) Type of hole. The hole shall be dug or bored. It shall have vertical sides and have a horizontal dimension of 4 to 12 inches.

(b) Preparation of hole. The bottom and sides of the hole shall be carefully scratched with a sharp pointed instrument to expose the natural soil interface. All loose material shall be removed from the bottom of the hole which shall then be covered with 2 inches of coarse sand or gravel when necessary to prevent scouring.

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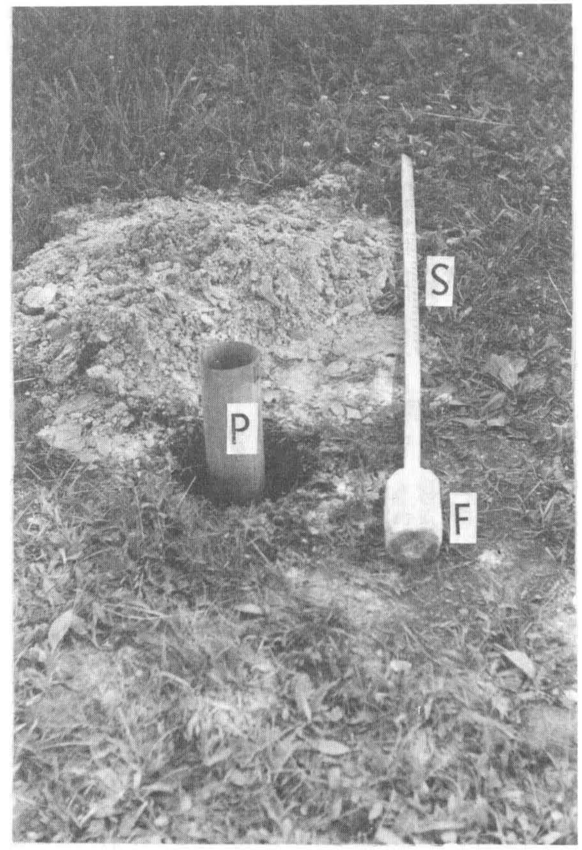
(c) Test procedure, sandy soils. For tests in sandy soils containing little or no clay, the hole shall be carefully filled with clear water to a minimum depth of 12 inches over the gravel and the time for this amount of water to seep away shall be determined. The procedure shall be repeated and if the water from the second filling of the hole at least 12 inches above the gravel seeps away in 10 minutes or less, the test may proceed immediately as follows: Water shall be added to a point not more than 6 inches above the gravel. Thereupon, from a fixed reference point, water levels shall be measured at 10-minute intervals for a period of one hour. If 6 inches of water seeps away in less than 10 minutes, a shorter interval between measurements shall be used, but in no case shall the water depth exceed 6 inches. The final water level drop shall be used to calculate the percolation rate. Soils not meeting the above requirements shall be tested as in subsection (d) below.

(d) Test procedure, other soils. The hole shall be carefully filled with clear water and a minimum water depth of 12 inches shall be maintained above the gravel for a 4-hour period by refilling whenever necessary or by use of an automatic siphon. Water remaining in the hole after 4 hours shall not be removed. The soil shall be allowed to swell not less than 16 hours or more than 30 hours. Immediately following the soil swelling period, the percolation rate measurements shall be made as follows: Any soil which has sloughed into the hole shall be removed and water shall be adjusted to 6 inches over the gravel. Thereupon, from a fixed reference point, the water level shall be measured at 30-minute intervals for a period of 4 hours unless 2 successive water level drops do not vary by more than 1/16 of an inch. The hole shall be filled with clear water to a point not more than 6 inches above the gravel whenever it becomes nearly empty. Adjustment of the water level shall not be made during the last 3 measurement periods except to the limits of the last measured water level drop. When the first 6 inches of water seeps away in less than 30 minutes, the time interval between measurements shall be 10 minutes and the test run for one hour. The water depth shall not exceed 6 inches at any time during the measurement period. The drop that occurs during the final measurement period shall be used in calculating the percolation rate." (Photo 3.1)

The percolation rate, measured with the State Percolation Test, is based on the rate of downward movement of the water level in the test hole in specified time periods. The varying water level makes the test rather complicated, and increases the variability of test results (see Chapter 6.1). We decided, therefore, to also use a modified test with a constant water level in the hole. Test holes were similar to those used for the State Percolation Test. A mariotte device was used to maintain a constant water level in the hole (Photo 3.1). Water flowed into the hole through a plastic tube from an otherwise sealed 5 gallon container that was mounted on a stake driven into the soil. Outflow from the container was measured regularly by observing the water level in a small external transparent sealed plastic tube connecting the upper and lower parts of the container.

Photo 3.1. Percolation test procedures

Percolation test constant level (CLPT)
The water level in the container (C) as visible in gauge (G), is measured frequently to monitor rate of infiltration into the soil. The constant level of water in the hole is maintained by a mariotte device, that bubbles air (A) into the entirely closed container.



State Percolation test (SPT)
The water level in the hole is measured with a scale (S) calibrated in inches, that is attached to a float (F) that moves up and down with the water level in the hole. The stovepipe (P) is used for pouring water in the hole and as a support for the float.

3.2.3. In situ measurement of saturated hydraulic conductivity: The Bouwer double tube method

This method is a standard procedure for measuring hydraulic conductivity of saturated soil, well above the ground water table (Boersma, 1965, in: Methods of Soil Analysis, Part 1, p. 234). With the double tube method, two concentric tubes are inserted into an auger hole and covered by a lid with a standpipe for each tube (Fig. 3.2.3.1.). Water levels are maintained at the top of the standpipes to create a zone of positive water pressures in the soil below the bottom of the hole. The hydraulic conductivity (K) of this zone is evaluated from the reduction in the rate of flow from the inner tube into the soil when the water pressure inside the inner tube is allowed to become less than that in the outer tube. This is done by stopping the water supply to the inner tube (closing valve a) and measuring the rate of fall of the water level in the standpipe on the inner tube while keeping the standpipe on the outer tube full to the top. This rate of fall is less than that obtained in a subsequent measurement in which the water level in the outer tube standpipe is allowed to fall at the same rate (by manipulating valve b) as that in the inner tube standpipe. The difference between the two rates of fall is the basis of the calculation of K.

Procedure:

The different stages of the method will now be explained in more detail with reference to the numbers on the included pictures (Photo 3.2). A large auger, with a diameter of 10 inches (1) is used to make a cylindrical hole (2) to the desired depth. A bottom scraper (3) is used to obtain a flat surface at the bottom. Loose soil is removed from the hole. Before using the hole cleaner (4) the outer tube (8) is forced down in the hole. It is often necessary to widen the hole locally to make this possible. This is done with a scraper, not pictured here. When the outer tube is found to fit well it is temporarily removed again. The hole cleaner (4) is gently forced into the soil at the bottom of the hole. If the soil is dry, premoistening of it may be necessary. The thin metal fins of the hole cleaner should penetrate about 2 cm into the soil. Next, the hole cleaner is pulled out of the hole with an upward cork-screw movement that prevents smearing the soil surface, as would happen if the cleaner were turned without being pulled up at the same time. The detached mass of soil is up-ended for observation of the natural broken surface of soil held between the fins. A corresponding natural broken soil surface is left at the bottom of the hole.

The outer tube (8) is forced down as evenly as possible about 5 cm into the soil at the bottom of the hole (13). This may require careful blows of a sledge hammer on a wooded cross-piece. Control of the distance is by measurement from a fixed horizontal reference rod (15). With a vacuum cleaner (5), powered by a portable electric generator (6), loose soil fragments are removed from the bottom of the hole. This bottom surface is then covered with a thin (1 cm) layer of coarse sand (7) on top of which a baffle is laid (12), with attached strings looped over the top

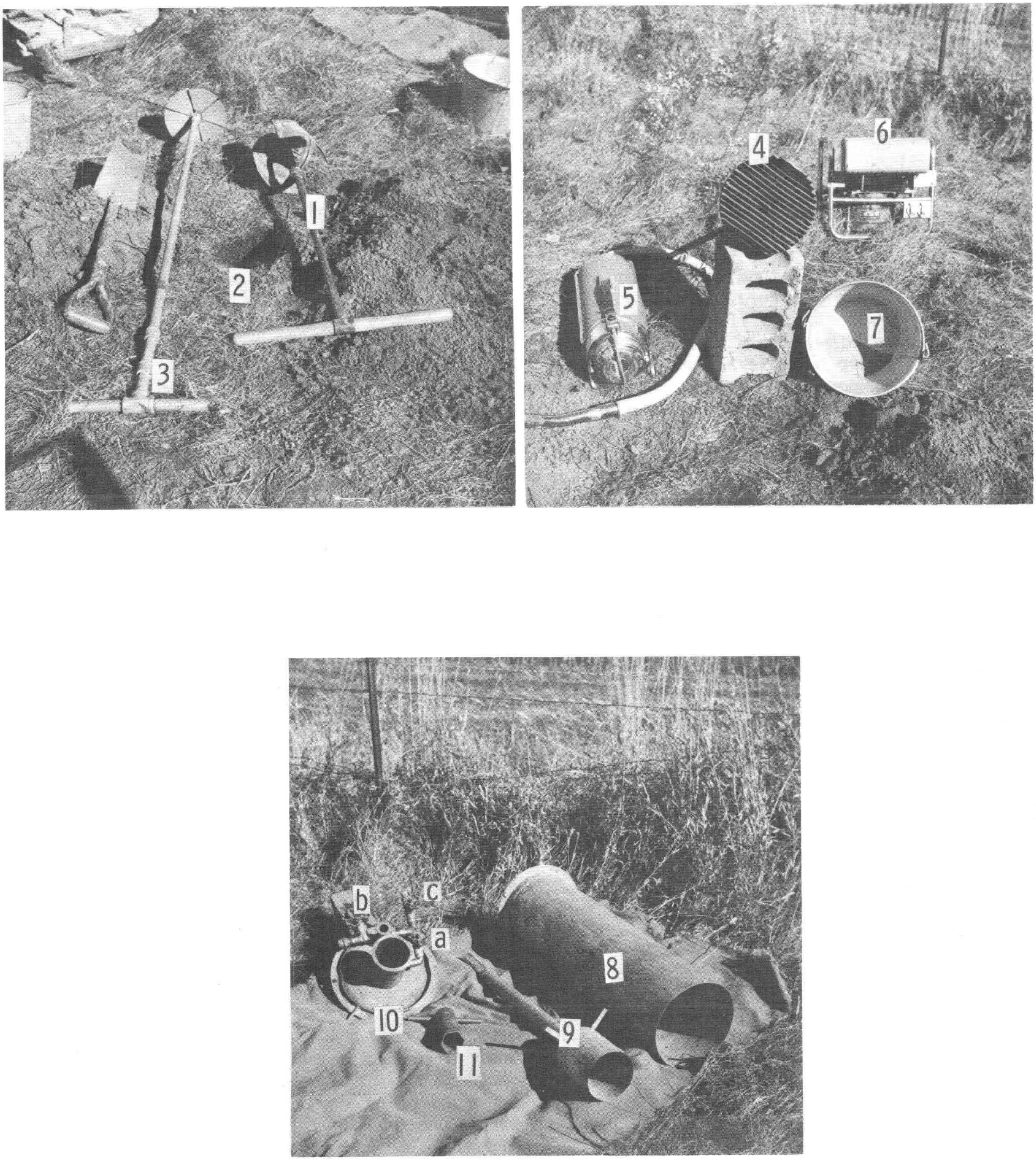
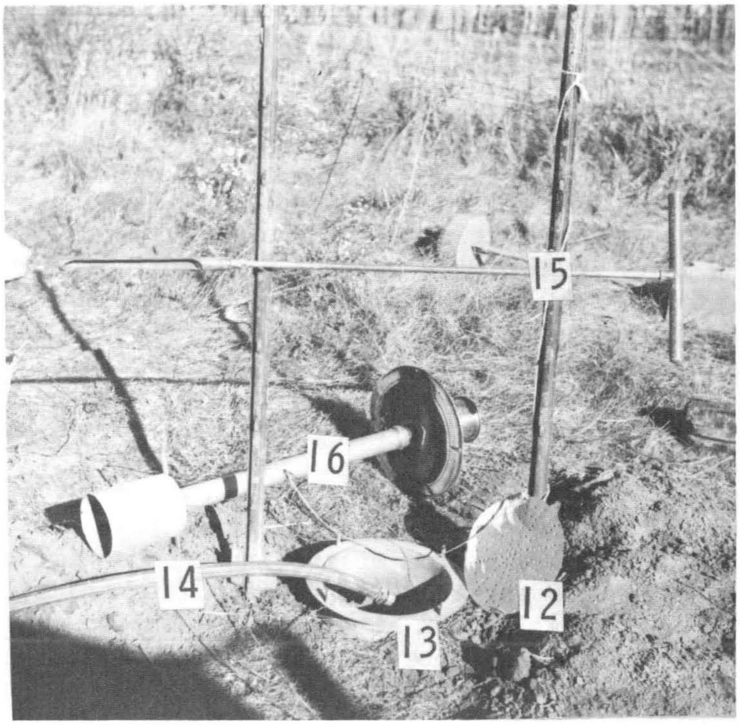


Photo 3.2. Measurement of the hydraulic conductivity with the Bouwer Double tube apparatus.



Abbreviated explanation of numbers:

1 = soil auger, 2 = test hole, 3 = bottom scraper, 4 = hole cleaner, 5 = vacuum cleaner, 6 = generator, 7 = bucket with sand, 8 = outer tube, 9 = inner tube, 10 = top plate, 11 = wrench to attach top plate to inner tube, 12 = energy breaker, 13 = outer tube in test hole, 14 = water-hose, 15 = reference rod, 16 = assembled inner tube - top plate, 17 = OTS-full measurement, 18 = equal level measurement.

of the tube. The outer tube is slowly filled with water (14). The energy breaker and sand layer protect the natural soil surface from erosion by the turbulent water. Then the inner tube (9) and the top plate (10) which has two basal standpipes leading to the inner tube and outer tube, respectively, and three valves (a, b and c)* are assembled into one fixed unit (16). A special wrench (11) is used to tighten a ring with washer inside the inner well of the top plate (10). This binds the inner tube to its standpipe.

The distance of the bottom of the inner tube from the top plate should be so spaced that the bottom of the inner tube will be only a few cm above the sand when the assembly (16) is set into and attached to the outer tube. The hose (14) is then attached adjacent to valve c on the top plate (1). When the outer tube is brim full and water starts streaming between the loose top plate and the upper rim of the outer tube, the bolts are tightly screwed, closing down on the gasket. This procedure flushes out air, avoiding its entrapment on the under side of the top plate. Valve a is now opened to admit water to the inner tube basal standpipe. Then the connection between the top plate and the inner tube is loosened again. The inner tube slides downwards to the soil surface. The sliding distance should not exceed a few cm in order to avoid turbulence that might disturb the soil surface. The inner tube is pushed down about 2 cm into the soil. In the meantime water is continuously entering the system in such a quantity as to keep both tubes filled all the time. Overflow water that spills onto the top plate from the outer tube basal standpipe (near valve b) is drained off the top plate through a brass tube and hose extension into a bucket nearby. The depth of penetration of the inner tube is accurately measured using the reference level (15). Next, the plastic standpipes for the inner and outer tubes are fastened to the two openings in the top plate. For slow infiltrations, a smaller inner tube standpipe (ITS) is used (R = 0.6 cm); for larger infiltrations a larger one is used (R = 1.85 cm). Valve c is then opened enough to ensure a slight overflow at the top of the standpipes.

Two types of readings are made, usually starting one hour after application of the water: 1. The outer tube standpipe (OTS) - full measurement (17). Valve a is kept closed, as is, of course, valve b. 2. The equal-level measurement (18). Valve a is closed and valve b is opened, but with obstruction by the fingers at the open end of the pipe, in such a way as to synchronize the drop of the water level in the OTS with that in the ITS. Eight stop watches are started simultaneously at the beginning of a reading. One watch at a time is stopped as the water level in the ITS reaches a mark on the tube. The marks are spaced 5 cm apart over a total distance of 60 cm. Elapsed time is recorded in tenths of a second.

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*The functions of the three valves are explained as follows: Starting with the valves closed, they can be manipulated in the course of the experiment to control the flow of water. Opening valve c allows water to flow into the outer tube basal standpipe which is situated between valve c and valve b. Opening valve b bleeds water from the outer tube standpipe, which can be isolated from the water supply by closing valve c, and from inner tube standpipe by closing valve a.

The readings over a distance of 40 cm should yield a difference of at least 6 seconds between two measurements; that is, between one OTS-full measurement and the average value of the preceeding and the next equal-level measurements. If the time difference is less than 6 seconds, measurement should be extended to, say, 60 cm and readings made within the lower 40 cm interval thereof. The measurements are to be repeated at regular time intervals until the ratio $\Delta t/t^2$ eq. level becomes constant (Bouwer, 1962). Here, Δt is the time difference between the OTS-full and the average value of equal level measurements before and after this OTS-full measurement.

A constant ratio may occur after a period varying from one to four hours. The constant ratio is supposed to indicate sufficient saturation of the soil below the tubes. The intervals between successive measurements should be approximately ten times as long as the time required for each separate reading, or 15 minutes (Baumgart, 1967), which is the shorter, to allow reëstablishment of equilibrium. The two final curves obtained (Fig. 3.2.3.1) differ because of flow of water from the outer tube into the inner, during the OTS-full measurement.

K is calculated according to the equation:

$$K = [R_v^{\,2}/(F_f \cdot R_c)] \cdot (\Delta H/\int H dt)$$

where: H = difference in hydraulic head H between both curves at any time t.

Hdt = surface below OTS curve (to be determined graphically)

F_f = flow factor, to be read from tables, expressing the influences of the dimensions of the system and the depth D to a layer with a much smaller or higher permeability. When D is several times larger than the diameter of the inner tube (R_c) a general set of curves may be used to estimate F_f (see Bouwer, 1961). The flow factor deviates usually only slightly from unity.

A more convenient method of calculation was suggested by Bouwer (1962) using the ratio: $2\Delta t/t^2$ eq. level instead of $\Delta H \int Hdt$.

The ratios obtained for the final set of data are extrapolated to zero, to correct for the decrease in infiltration that occurs during the equal level reading, due to the gradual decrease of hydraulic head (see example of data sheet and calculation in Table 3.2.3). The calculation of K values, according to this procedure may be difficult sometimes because of the rather inaccurate procedure of extrapolation (see left part of Fig. 3.2.3.2). Problems can be reduced when the total drop H of the water level in the inner tube standpipe (ITS) is varied for different measurements, so as to create a difference between the equal level and OTS-full times of approximately 8 sec. For example, in soils with a high infiltration, it may be necessary to extend the measurement to H = 80 cm, instead of the usual 40 cm. Baumgart (1967) made a study of the Bouwer method and suggests a somewhat modified procedure of calculation, that is based on the Bouwer calculation with an available H_b value.

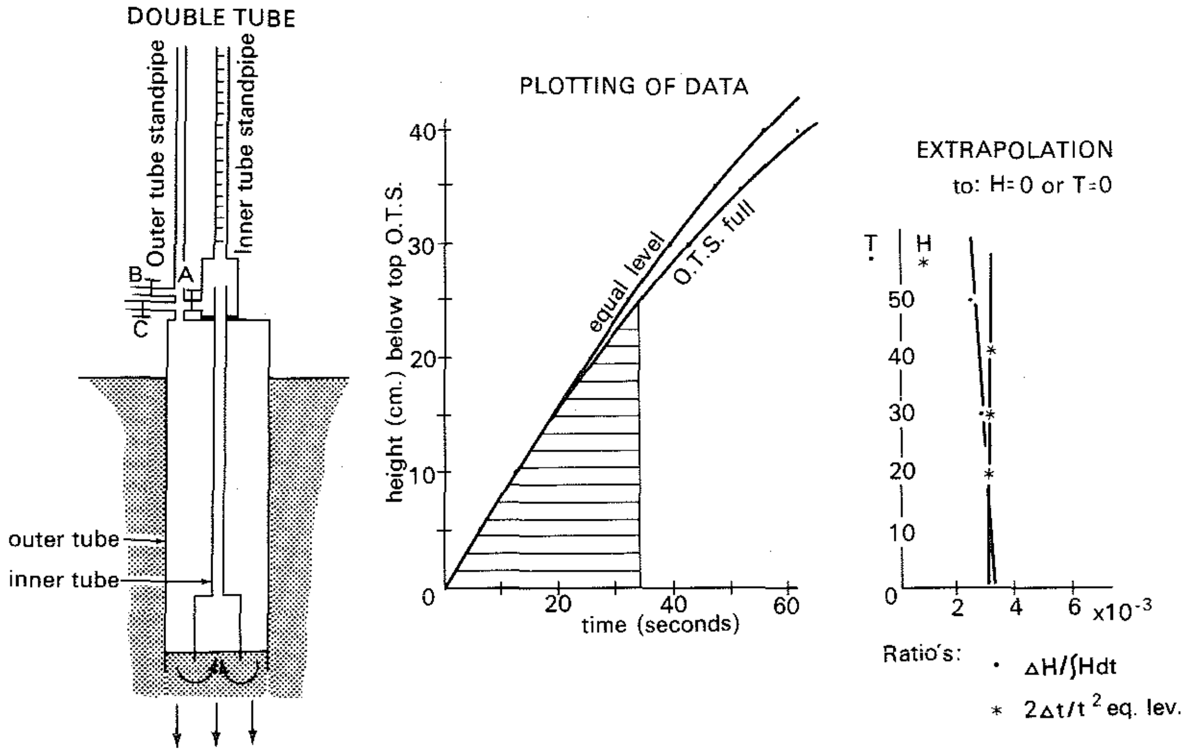


Fig. 3.2.3.1. The double tube method for measurement of K_{sat} in situ: cross section of the apparatus and plotting of experimental data.

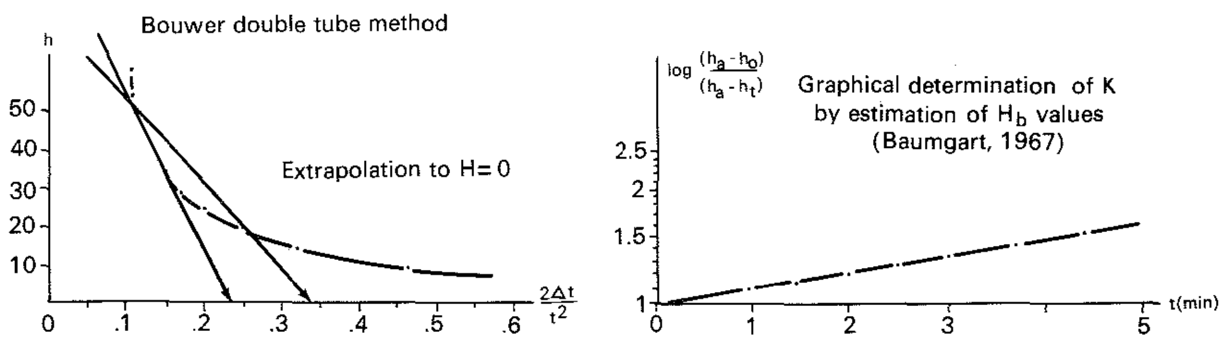


Fig. 3.2.3.2. Extrapolation procedure and graphical determination of K_{sat} using field data of the double-tube method (after Baumgart, 1967).

Table 3.2.3. Calculations of the double-tube method for determining K_{sat} in situ.

General data:
Date: Aug. 5, 1969. Soil profile: Plano silt loam, B_2 55 cm depth. Time water started: noon.
Temp. water: 20°C. Tube radii: outer tube = 12.5 cm, inner tube (R_c) = 6.2 cm, R_v = 0.6 cm · d = 2.6 cm.

Measurements:

t H	1:45 PM OTS	1:55 Eq.1	2:05 OTS	2:15 Eq.	2:25 OTS	2:35 Eq.	2:45 OTS	2:55 Eq.	3:05 OTS	3:15 Eq.	3:25 OTS	3:35 Eq.	3:45 OTS	3:55 Eq.
0														
5	3.9	4.4	4.3	4.6	4.2	4.7	4.2	5.2	5.4	5.6	6.2	6.2	6.0	6.2
10	7.7	7.9	8.8	9.0	8.9	10.0	9.2	9.8	10.4	11.0	11.8	12.2	12.4	12.0
15	12.0	11.6	13.0	13.0	13.4	14.7	13.8	15.0	16.2	16.8	18.2	18.4	19.0	18.2
20	16.6	15.5	18.2	17.7	18.6	20.0	19.0	20.4	22.0	23.0	24.8	25.6	26.2	25.0
25	20.8	20.0	23.9	23.0	24.0	26.0	24.5	26.0	28.4	28.9	32.5	32.2	33.8	31.9
30	25.8	24.2	28.8	27.6	29.8	31.6	30.0	31.8	35.2	35.2	39.8	39.4	41.8	39.2
35	31.7	28.8	34.4	33.0	35.9	37.4	37.0	37.6	42.6	42.0	48.4	47.0	50.8	47.0
40	37.0	34.2	41.2	38.6	42.6	44.2	45.0	44.4	50.0	49.4	58.0	55.0	61.0	55.1

Ratio's $\dfrac{\Delta t}{t^2 \text{ eq.lev.}}$: 0.00305 (1:55-2:15); 0.0007 (2:15-2:35); 0.00032 (2:35-2:55); 0.00014 (2:55-3:15); 0.00020 (3:15-3:35) and 0.00020 (3:35-3:55). (constant!)

Calculation of K based on:

OTS: 3:45 PM
Eq.: level: average of 3:35 and 3:55

t	ΔH	Hdt	Ratio
30	1.0	352.5	2.84×10^{-3}
40	1.8	610.0	2.95×10^{-3}
50	2.2	975.0	2.25×10^{-3}

H	2Δt	t^2 eq. lev.	Ratio
20	1.8	625	2.9×10^{-3}
30	5.0	1544	3.2×10^{-3}
40	12	3025	3.9×10^{-3}

Ratio extrapolated to t = o : 3.0×10^{-3} (Fig. 3.2.3.3.)   Ratio extrapolated to H = o; 3.0×10^{-3} (Fig. 3.2.3.3.)

The ratio $\frac{R_c}{d}$ (=2.38) was used to determine the flow factor F_f from a diagram of Bouwer (1961).

F_f = 1.1 Then:

$$K = \frac{R_v^2}{F_f \cdot R_c} \cdot \frac{\Delta H}{Hdt} = 13\text{cm/day, or } K = \frac{R_v^2}{F_f \cdot R_c} \cdot \frac{2\Delta t}{t^2 \text{ eq. lev.}} = 13\text{cm/day.}$$

H_b is the difference in cm between the top of the outer tube standpipe (OTS) and the water level at balanced flow conditions, when $Q_I = Q_H$, where Q_I is the flow leaving through the bottom of the inner tube due to intake and Q_H = flow, entering through the bottom of the inner tube due to a difference H between the water levels in inner and outer tube. Then:

$$K = \frac{2 \cdot 3R_v^2}{R_c F_f t} \cdot \log\frac{H_o - H_b}{H_t - H_b} \text{ (Bouwer, 1961)}$$

where R_v = radius of inner tube standpipe, R_c = radius of inner tube, F_f = flow factor, t = elapsed time, H = distance of water level in the inner tube below water level in the outer tube H_b = H at balanced flow. This equation can only be applied when H_b can be measured. Mostly this is not the case and then the OTS-full and equal-level measurements are made as discussed in the previous part. Baumgart (1967) suggests that this formula be used in all cases, and to estimate H_b values until the plotted values of t and log H_o-H_b/H_t-H_b are on a straight line. With some practice this can be done rather easily and quickly (see right part of Fig. 3.2.3.2., from: Baumgart, 1967). K values calculated by this procedure compared well, with those, obtained with the OTS-full equal level procedure. Application of this calculation method is recommended, because it saves time and is applicable to any type of test result.

3.2.4. Field measurement of unsaturated hydraulic conductivity by infiltration through artificial gypsum crusts*

3.2.4.1. Introduction

The solution of many problems associated with soil water flow depends upon knowledge of the hydraulic conductivity, K. As yet there appears to be no universally reliable way to obtain K from more fundamental physical measurements such as particle-size or pore-size distribution. Hence K is usually measured experimentally.

Of the numerous methods which have been proposed for this measurement (Klute, 1965a, b; Boersma, 1965a, b), the *in situ* methods must be regarded as inherently preferable as they are more directly applicable to the solution of field problems. Satisfactory procedures are now available for the *in situ* measurement of hydraulic conductivity under saturated conditions (K_{sat}), both below and above the water table (Bouwer, 1962). However, in many cases the flow regimen is such that the soil is unsaturated. In the presence of an impeding layer at the surface or in the presence of very low precipitation rates, the soil profile may never become saturated during infiltration, and the flow rate will be governed by the soil's unsaturated hydraulic conductivity which is, itself, a function of the matric suction prevalent in the soil.

*The type of gypsum used was ultracal-30, provided by the United States Gypsum Company. The authors wish to express their sincere thanks to Dr. R. B. Grossman for his helpful suggestion and to Mr. J. Needham (U.S. Gypsum Co.) for providing the gypsum sample.

Processes of infiltration into crust-capped profiles were recently studied by Hillel and Gardner (1969, 1970a). They reported that an impeding layer or crust at the top of an infiltrating profile causes a potential head loss at that point. Thus, if water head over the crust is kept small, it is possible to maintain infiltration into an unsaturated column yet retain the experimental advantages of easily measured inflow rate afforded by a flood infiltrometer. This finding formed the basis of a proposed method for measuring the unsaturated hydraulic conductivity at different suction and water-content values, which Hillel and Gardner (1970b) checked with artificially-packed laboratory columns, but not in the field.

3.2.4.2. Methods

The method described by Hillel and Gardner for measuring the hydraulic transmission properties of a profile, as a function of water content or suction, involves a series of infiltration trials through capping plates (or crusts) of different hydraulic resistances. The effect of this resistance is to prevent saturation at the subcrust boundary even though the crust itself is subject to a small positive head. Though estimates of K and D (the diffusivity) can be obtained during the transient stage of infiltration, the most reliable measurements are obtained by allowing the infiltration process to proceed to a steady state, when the flux becomes equal to the conductivity. The use of a series of crusts of progressively lower resistance can give progressively higher K-values corresponding to higher water contents up to saturation. Such a series of tests can be carried out if the soil is initially fairly dry, either successively in the same location or concurrently on adjacent locations.

The surface impedance can be applied either by means of a porous plate (e.g., ceramic) or by forming a continuous layer of puddled (slaked or compacted) soil material over the soil surface. Once the crust is established, water is applied (e.g., in a ring infiltrometer) and a small, constant head is maintained over the soil surface long enough for the inflow rate to become steady. This flow rate is equal to the conductivity in a one-dimensional flow system where the suction gradient below the crust is negligibly small (i.e. the hydraulic gradient tends to unity).

Tensiometric measurements on columns of different depth showed that in order to obtain a one-dimensional vertical flow system it was necessary to create an impervious boundary around a column at least 30 cm deep. A steel cylinder was used at the top of the column to support the small head of water over the crust, to provide a rigid sealing surface for the edges of the crust and to provide a guide for positioning tensiometers below the crust. Below the cylinder an aluminum foil moisture barrier sufficed, since saturated flow would not occur. Use of the foil also made the method applicable to stony soil. Hydraulic conductivity values were calculated from infiltration rates into capped columns and soil suction gradients below the crusts, if any.

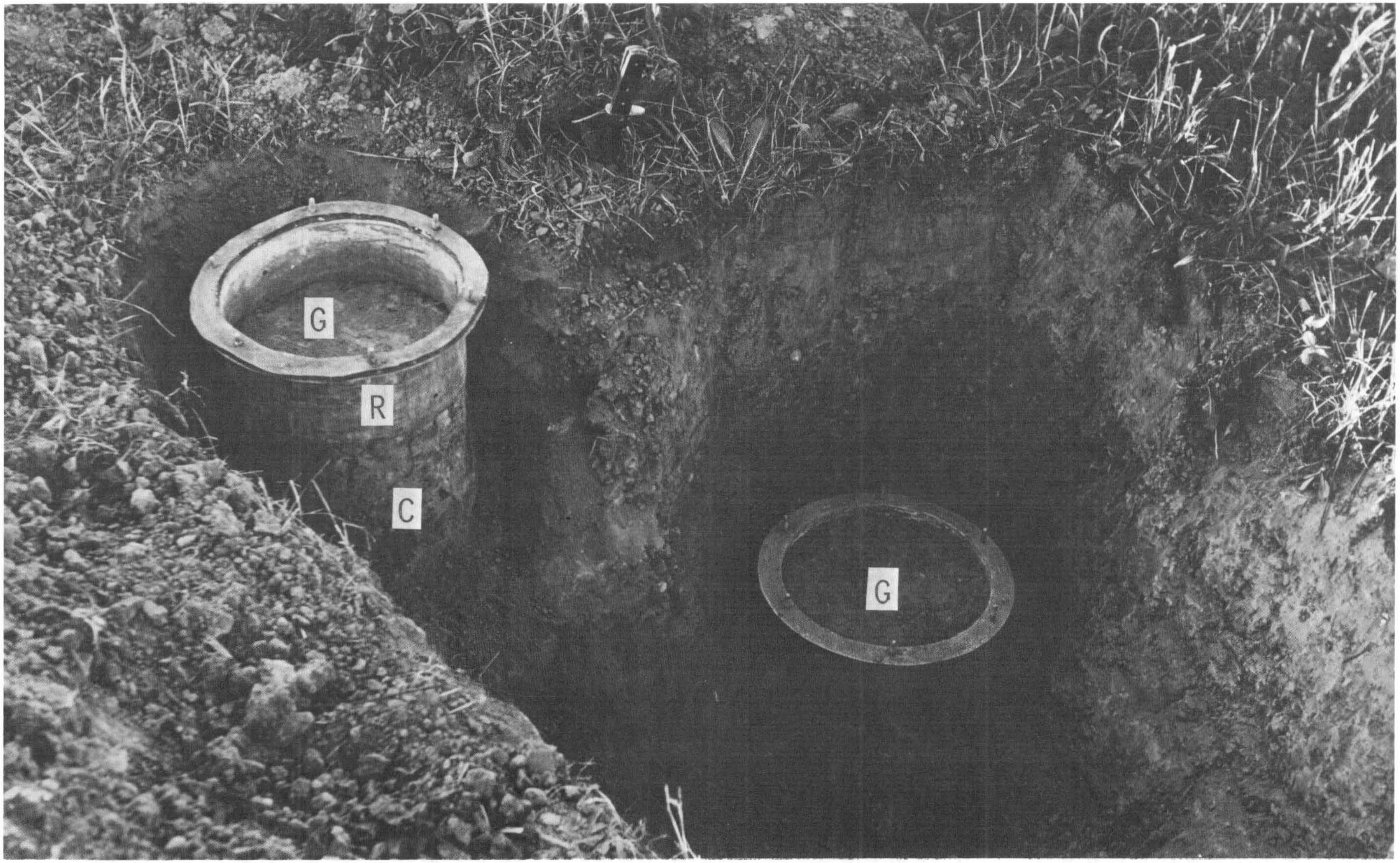


Photo 3.3. Ring infiltrometer (R) on top of a soil column (C) carved out in situ, for measurement of unsaturated hydraulic conductivity with the crust test. Successive gypsum crusts will be applied on the top surface area of the column (G).

3.2.4.3. Procedures

Tests were made at several sites in Wisconsin. The soils ranged in texture from sand to clay. At each site, a horizontal plane was prepared by using a putty knife and a carpenter's level. A cylindrical column of soil, at least 30 cm high, with a diameter of 25 cm, was carved out from the test level downward, taking care to chip or pick the soil away from the column as the desired boundary was approached, so as to prevent undue disturbance of the column itself. A ring infiltrometer, 25 cm in diameter and 10 cm high with a 2.5 cm wide brim at the top was fitted onto the column (Photo 3.3). The sides of the column were then sealed with aluminum foil and soil was packed around it. A half-inch thick acrylic plastic cover with a diameter of 12" (30 cm) and with a thin rubber gasket glued to it was bolted to the top of the infiltrometer. An intake port and bleeder valve were provided in the cover.

Thin pencil-size mercury-type tensiometers were placed just below the crust in the center of the column and 3 cm deeper, both in the center and near the periphery of the column. Carefully positioned holes in the steel infiltrometer ring and external installation guides aided in positioning the tensiometers. Stony soils present some difficulties, but successful insertion of tensiometers is usually possible after probing at several points.

In the first experiments with the crust-test procedure, various puddled soil materials were used for crusts (Bouma et al., 1971b). Additional field experience, however, showed that some of these crusts (in particular the ones with a relatively low resistance) were rather unstable and easily disturbed due to continuous swelling of the clay particles. A different procedure was developed therefore in later experiments using dry gypsum powder, thoroughly mixed with varying quantities of a medium sand. After sufficient wetting, and continuous mixing, a thick paste was obtained. Then, this material was quickly transferred to the prepared column and applied on top with a carpenter's knife as a continuous crust with constant thickness. Special care was taken to seal the crust to the wall of the cylinder to avoid boundary flow. Within about 30 minutes crusts of this type would harden, thereby providing a stable porous medium with a fixed conductivity value. Crust resistance could be varied by changing the relative quantities of gypsum and sand. Crusts composed of gypsum only had the highest resistance. For example: A subcrust tension of 52 mbar was induced in a sand column capped with a 5 mm thick gypsum crust with 3 mm water on top. This crust had a K_{sat} value of 0.007 mm/day. The microfabric of this crust consisted of very fine gypsum crystals. Some microfabrics of other crusts are pictured in Fig. 3.2.4.2. The upper picture shows relatively large pores occurring between sand grains, while fine gypsum crystals are concentrated around the grains, cementing them together. This crust was formed from a pre-wetted mixture composed of 14% gypsum and 86% sand by volume, as measured in the field using a graduated cylinder. As a crust on top of a column in sand, this mixture induced a subcrust tension of 11 mbar. K_{sat} of the crust was 8.3 cm/day. The middle picture shows a crust formed from a pre-wetted mixture with 30% gypsum by volume (70% sand). Pores are smaller and K_{sat} was 2.9 cm/day.

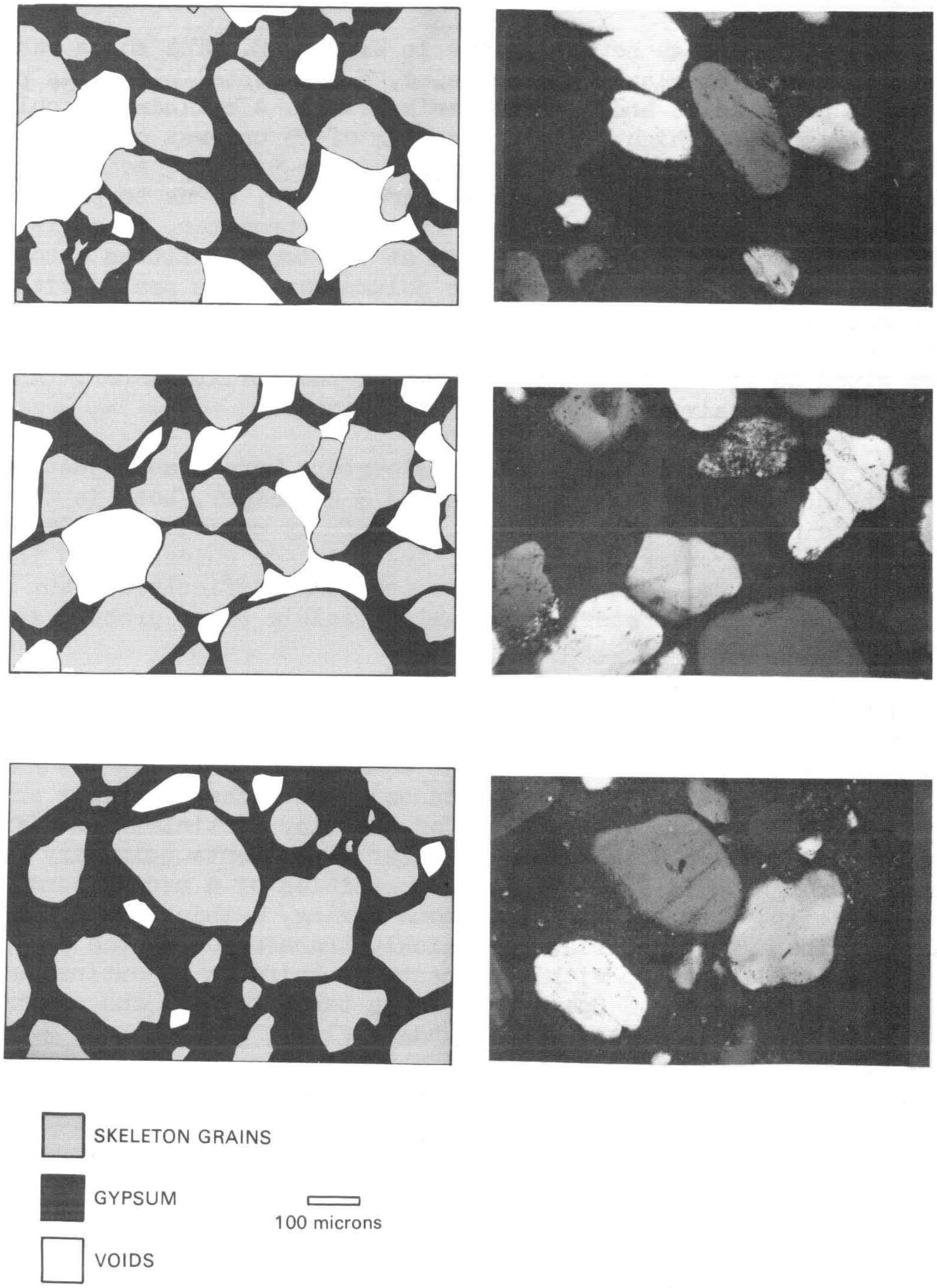


Fig.3.2.4.2. Three crust materials composed of mixtures of gypsum and sand, as seen in a thin section.

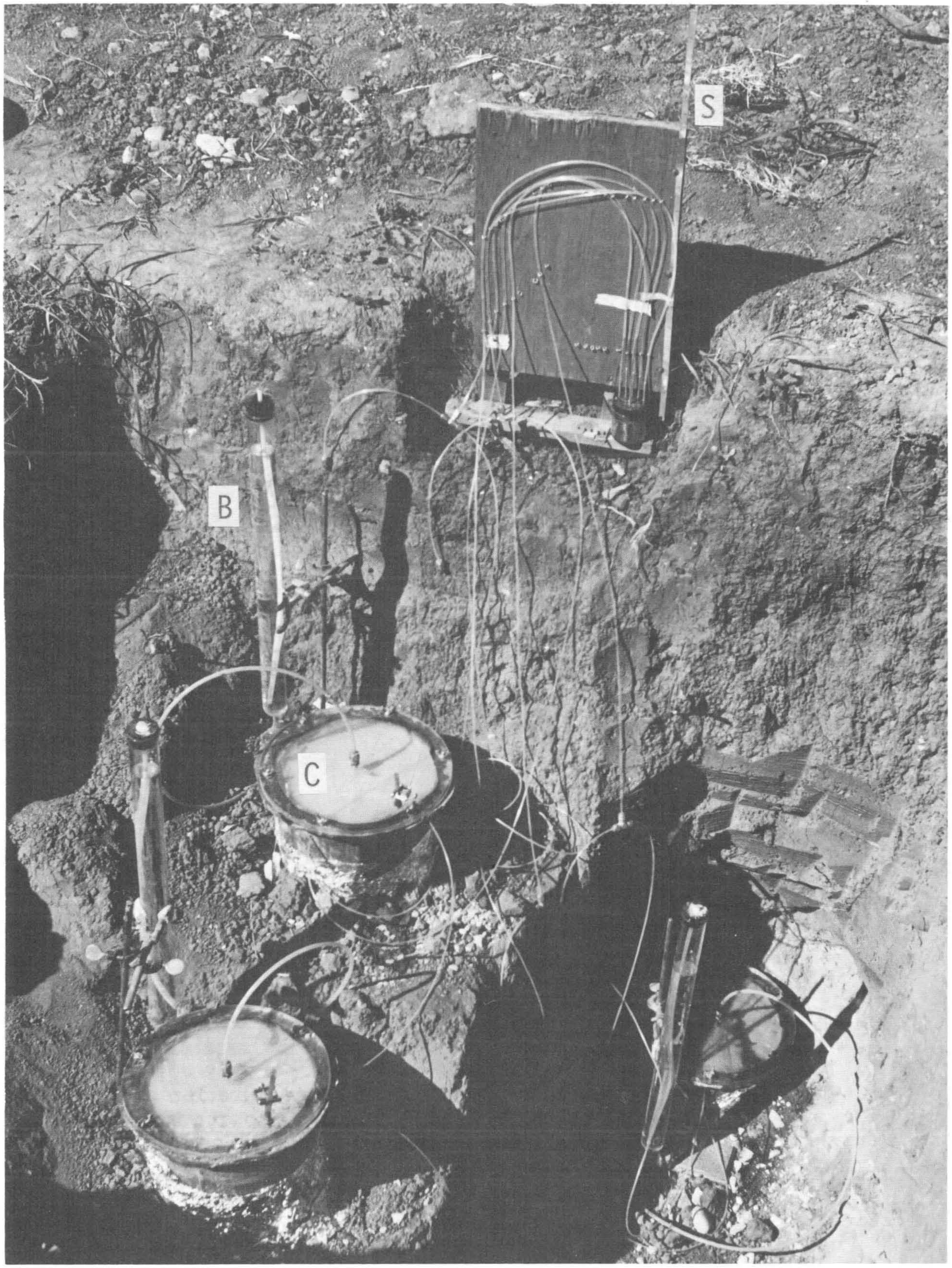


Photo 3.4. Field measurement of unsaturated hydraulic conductivity in situ with the crust test procedure. Inflow into the soil through the crust on top of the column is measured with a burette (B) discharging into the water filled space between the crust and the acrylic plastic cover (C). Soil moisture tensions derived from the mercury rise in 1/8-inch plastic tubes along calibrated scales (S) are measured in the columns.

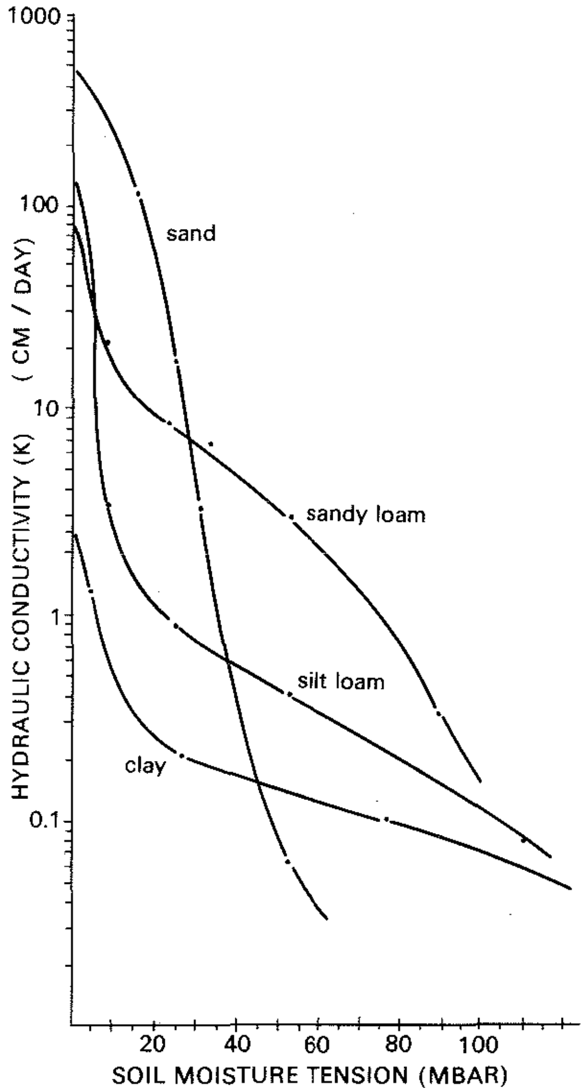


Fig. 3.2.4.1. Hydraulic conductivity (K) as a function of soil moisture tension measured <u>in situ</u> with the crust test procedure.

The induced subcrust tension in sand was 18 mbar. The third picture shows a crust formed from a dry mixture with 50% gypsum (50% sand). Virtually no larger pores are visible in the crust, indicating that pore sizes between the fine grained gypsum crystals are smaller than the thickness of the thin section (20 microns). K_{sat} of this crust was 0.8 mm/day and the induced tension in the subcrust sand in the column increased to 30 mbar.

Crusts of this type were applied to the same column for succeeding runs. Each infiltration run through a particular crust yielded one point of a curve of hydraulic conductivity versus soil suction (see Fig. 3.2.4.1). The small space between the crust surface and the cover of the cylinder was kept full of water. A Mariotte device, in a burette, maintained a constant pressure of about 3 mm water over the crust (Photo 3.4). The infiltration rate into the soil, corresponding to the rate of movement of the water level in the burette, was recorded as soon as the tensiometers showed that equilibrium had been reached. This infiltration rate, when constant for a period of at least 4 hours, was taken to be the unsaturated K-value at the subcrust suction, when the suction gradient was zero. In some cases a suction gradient remained at steady state conditions. Hydraulic conductivity was then calculated according to: $K = v/i$, where v = infiltration rate and i = hydraulic gradient below the crust (in such a case $\neq 1$).

3.2.4.4. Results

Figure 3.2.4.1. gives the hydraulic conductivity versus suction curves for some horizons of four soils. These curves could be extended farther into the dry range, but this would take more time and requires that the soil be initially quite dry. The hydraulic conductivity values for saturated soil, measured with the double tube apparatus corresponded well with infiltration rates into these columns before crusts were added. One column was of glacial till, containing many stones that made use of the Bouwer tubes impossible.

The data indicate that hydraulic conductivity decreases sharply with increasing soil moisture tension. This is most evident in soil materials with coarse pores (B3, Plainfield sand) and less so in fine porous clays (B3, Hibbing), in which saturated conductivity is low. These results are important for the study of liquid waste disposal in soils. Measurement of soil moisture tensions around seepage beds of operating systems (Section 5) indicated the occurrence of considerable soil moisture tensions. Movement of liquid, therefore, is governed by processes of unsaturated flow. A quantitative analysis of the flow system can only be given when relevant K values, as measured with this new test, are available.

3.2.5. Other soil physical methods

3.2.5.1. Soil physical characteristics determined from saran coated clods or from soil samples in cylinders

The method to determine soil physical characteristics from large clods obtained from pedal swelling soil materials and using saran resin as a coating material, was introduced by Brasher et al., 1966. Clods should have a volume of at least 100 cm^3, but preferably more than that. They should represent the soil strucutre from the sampled horizon. In general about 20 elementary units of structure should be represented in any clod sample. A medium sized blocky structure, with ped volume of 1 cm^3 should be represented by a clod volume of at least 20 cm^3. This guide does not work in coarse prismatic structures, since individual peds may have volumes of 150 cm^3 or more. It should be clearly stated when values are determined for such single peds. The method consists of the following steps:

1. A weighed air-dry clod is coated with saran; and slowly saturated with water through one flattened side of the clod where the coating has been temporarily removed.

2. After saturation, the open side of the clod is coated again with saran and weight and volume of the clod are determined.

3. The coating on the flattened side is removed again, and the clod is placed in a pressure apparatus to determine water contents and soil volume at different pressures. After equilibrium has been reached at a given pressure, the clod is coated again at the flattened side, and weight and volume are determined. It is essential not to loose any soil from the clod during this procedure, since this would lead to erroneous results. After determining moisture contents and volumes of clods for a range of pressures (usually 0.03b, 0.1b, 0.3b, 1b, and 15b), the clod is dried at 105 C. Then all values are available to calculate bulk densities, porosities at different suctions, and the moisture retention curve. Non-swelling soil materaals, such as sands, can be sampled directly in cylinders of known volumes.

Example of clod method calculation: Clod from C-horizon of Mexico silt loam, calculations for 1 bar suction only.

Basic data: Air dry weight of clod: 55.30 gr. Coated with saran: 57.90 gr. Weight of coats: 2.60 gr. = 1.73 cc (Spec. dens. saran = 1.50). At 1 bar equilibrium: 57.10 gr. Volume of clod (+ plastic): 30.50 cc (difference between weight of beaker with water and total weight when clod is suspended in the beaker). After drying clod + plastic at 105°C for one day: weight = 47.40 gr. Volume = 27.9 cc.

Calculation 1:

Determine bulk density (bulk density = gr/cm^3 of natural soil). Since B.D. of soil is required, the plastic has to be excluded. Volume of soil at 1 b = 30.50 - 1.73 = 28.77 cc. The weight of 57.10 gr. is composed of water, plastic and soil. After drying at 105°C, weight = 47.40 gr. (= soil + plastic). From a separate experiment it was learned that the saran plastic looses 25% of its weight when heated for 24 hrs. at 105°C. Soil weight only, therefore, is 47.40 - (0.75 x 2.60) = 45.45 gr. This is an important value, from which dry bulk densities at different moisture contents are derived. B.D. at 1 bar is:

$$\frac{45.45}{28.77} = 1.58.$$

Calculation 2:

Determine percentage of moisture (in % of dry weight and volume) at 1 bar. Stovedry soil weight was 45.45 gr. We need to know now the weight of the moisture only at 1 bar. Soil + plastic + water = 57.10 gr. Soil + water = 57.10 - 2.60 = 54.50 gr. Moisture % of dry weight =

$$\left(\frac{54.50 - 45.45}{45.45}\right) \times 100\% = 19.9\%.$$

Moisture % by volume = % of dry weight x B.D. = 19.9 x 1.58 = 31.4%.

Calculation 3:

Determine porosity (= vol. % of soil occupied by the non-solid soil phase). Calc. 2 showed that 31.4% of the soil volume is occupied by water at 1 bar suction. What about the remaining 68.6%? For this we need to know one additional soil characteristic: the particle density (= gr/cm^3 of the solid soil phase only). This can be determined by a separate procedure, using pyknometers (see appendix at the end of this section and Blake, 1965). Presuming we have a particle density of 2.60, the 45.45 gr of soil represents 17.45 cc. Total volume of clod was 28.77. Pores form 28.77 - 17.45 = 11.29 cc which is (11.29/28.77) x 100% = 39.2% of soil volume (this means that 7.8% of the pores in the soil are filled with air). In formula:

$$\text{Porosity} = \left(1.0 - \frac{\text{Bulk density}}{\text{Particle density}}\right) \times 100\%.$$

Calculation 4:

Determine coefficient of linear extensibility (COLE) as:

$$\sqrt[3]{(V_m/V_d)} - 1$$

where V_m = volume of moist whole soil fabric and V_d = volume of dry whole soil fabric (Grossman, et al., 1968). Here: COLE = (28.77/26.60) - 1 = 0.081.

Moisture retention characteristics for non-swelling soil materials, such as sands, were determined from samples obtained in the field with the double cylinder hammer driven core sampler (Blake, 1965, p. 376) in small cylindrical rings (2 cm high, with a diameter of 7.5 cm). These rings were placed in the pressure apparatus, and later calculations, which are basically the same as the ones for saran coated clods, were relatively simple since the bulk density was constant at different moisture contents and since there was no plastic coating involved. Bulk densities of these materials were determined separately (after using the same sampling device) from larger cores with a diameter and height of 7.5 cm.

Appendix:

Summary of pyknometer test to determine particle density of soil (see Methods of Soil Analysis).

Pyknometer (dry, empty) = W_1 gr. Pyknometer + about 5 gr. stove soil = W_2 gr. Pyknometer filled with de-aired water = W_3 gr. Pyknometer with water + soil = W_4.

$$\text{Particle density} = \frac{W_2 - W_1}{W_3 + W_2 - W_1 - W_4} \quad \text{gr/cm}^3$$

The principle on which the method is based is the same as that for the clod tests: a body suspended in water will be subjected to an upward force that is equal to the weight of the volume of the displaced liquid.

3.2.5.2. Calculation of hydraulic conductivities from moisture retention data (method of Green and Corey).

A detailed description of this method, based on a review and revision of earlier work, is given by Green and Corey (1971). Larger soil pores are progressively emptied with increasing soil moisture tension and since flow rates are strongly correlated with pore sizes (Chapter 2), a relationship between flow rates and moisture tension can be derived in principle for different soil materials using moisture retention characteristics. In addition, a pore interaction model is necessary to express the dominant hydraulic effect of small pores on the rate of flow in a complex heterogeneous pore system. The equation used by Green and Corey (1971) is as follows:

$$K(\theta)_i = (K_s/K_{sc}) \cdot (30\delta^2/\rho g_\eta) \cdot (e^p/n^2) \cdot \sum_{j=1}^{m} \left[(2j+1-2i)h_j^{-2}\right]$$

$$i = 1,2, \ldots m$$

where: $K(\theta)$, is the calculated conductivity for a specified water content (given in cm/day); θ is water content (cm^3/cm^3); i = last water content class on the wet end: i = 1 = pore class corresponding with θ_{sat}. i = m = pore class with lowest water content for which K is calculated; K_s/K_{sc} = matching factor (= measured/calculated K); δ = surface tension of water (dynes/cm); ρ = density of water (g/cm^3); g = gravitational constant (cm/sec^2); η = viscosity of water (g/cm sec) e = porosity (cm^3/cm^3); p = parameter. Here p = 2, n = total number of pore classes between $\theta = 0$ and θ_{sat}; h_j = pressure of a given class of waterfilled pores (cm water).

The need for use of the matching factor (K_s/K_{sc}) implies that the method does not directly yield a curve at the correct level of conductivities for each moisture content or tension, but that the slope of the calculated K-curve is assumed to be correct. This method has been used for many of the soil materials investigated in this project. A few comparisons between curves determined with the crust test and calculated curves showed reasonable agreement. However, no systematic attempt was made in this report to compare calculated and measured curves.

3.2.5.3. Measurement of soil moisture tensions in situ with tensiometers

General principles of tensiometry have been discussed by Richards (1965). In our studies we used pencil sized tensiometer-cups with an air-entry value of 800 mbar, with 1/8" flexible, transparent plastic tubing. A three-way type tensiometer was used for measuring moisture tensions below seepage beds (upper part of Fig. 3.2.5.3). The distilled, de-aerated water in tensiometercup and tubing was applied and flushed as needed by injecting the water with a syringe into a small 1/16" plastic tube which was placed inside the larger one, between the open end of the tube (to be capped later) and the tensiometer cup. Any air in the porous cup was then flushed from the system with the water through the end submerged in mercury and through the area between the two tubes at the point of injection. A closed water-filled system, with the porous cup in contact with the surrounding soil and the open end of the tube in mercury, was then formed by capping the end of the tube where the water was injected. Readings of soil moisture tensions were made, using a scale calibrated in mbars. A simpler tensiometer could be used in the columns for the crust test procedure (see Section 3.2.4). Only the larger size tubing was used here (lower part of Fig. 3.2.5.3) and water was applied with a syringe to the tube, the open end of which was submerged in mercury. A closed system was formed by capping the tube at the point of injection.

3.3. Chemical methods

When and where possible, water samples were collected from observation wells installed by Olcott. The depth and construction of the observation wells determined whether the samples were obtained by pumping or bailing. Sampling was accomplished at each site within a several hour period to give an "instantaneous" picture of the ground water as affected by the

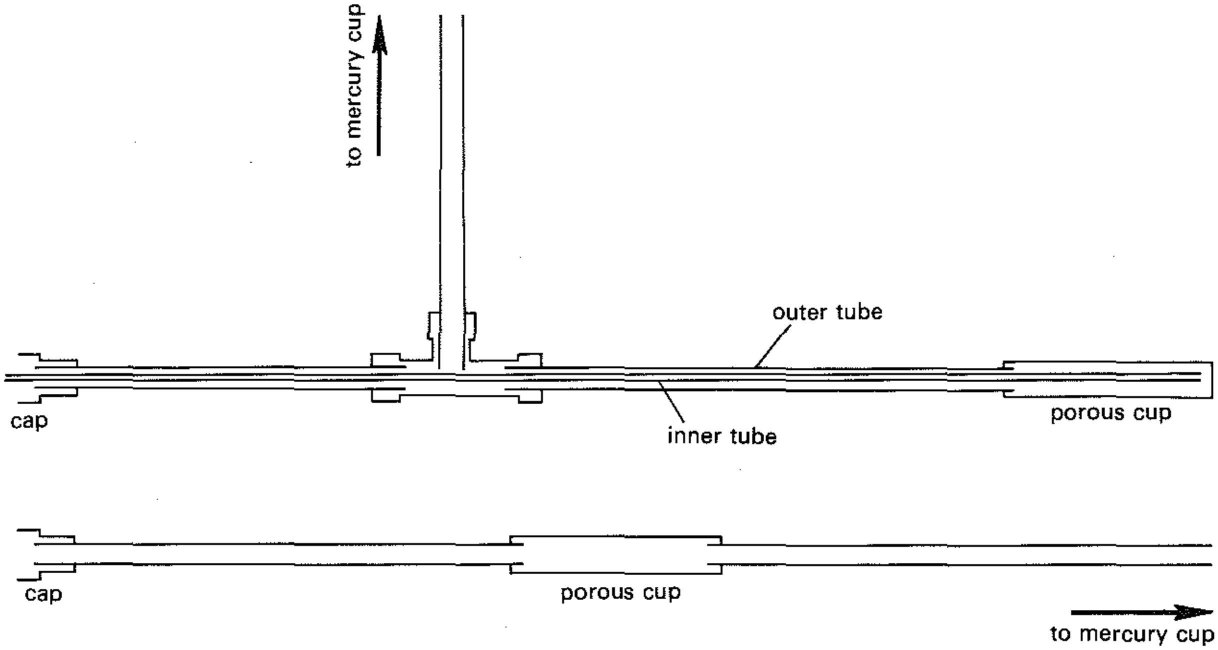


Fig. 3.2.5.3. Two types of tensiometers used to measure soil moisture tension around operating seepage beds and in soil columns for the crust test procedure.

effluent. Water samples were then treated with phenol mecuric acetate, a bacteriological inhibiter, and stored under refrigeration with chemical determinations made according to the 1 to 7 day time limits specified in Standard Methods (1971).

Soil samples were obtained by excavating a deep pit next to the drainfield system. Soils under the bed were then sampled at a specified interval, refrigerated, and frozen upon return to the lab until analysis was performed on them.

In all cases, chemical procedures were chosen on the basis of their simplicity, precision, accuracy, specificity, and their adaptability for determinations of soil and water samples, both heavily polluted and relatively pure.

Total soil N was determined utilizing the Olson Modified Semimicro-Kjeldahl Procedure as outlined by Bremner (1965). This method, to include nitrate and nitrite, is basically a wet oxidation procedure which can be employed on a wet soil sample so as to avoid N loss while drying. The resulting NH_4^+ -N formed was determined by steam distillation after neutralization with NaOH. The same procedure is directly applicable for total N determinations on water samples.

The NH_4^+ -N and NO_3^- -N in wet soil samples were determined via direct distillation as described by Bremner (1965). Again, the method is directly applicable for similar determinations on water samples. This procedure involves the use of MgO to convert NH_4 to NH_3, followed by the addition of Devarda's Alloy to reduce NO_3^- to NH_3. The liberated NH_3-N in each case was collected separately in 3% Boric Acid solution which was then back-titrated with standardized H_2SO_4.

Sample size, depending on N content, was usually 2.2g wet soil or 50 ml water.

Total Phosphorus was determined on 2.00 g oven dried (100°C) soil samples and unfiltered water samples from 1 to 100 ml size, depending on P content.

Complete digestion of the organic P containing compounds and condensed P was achieved with a 30 ml mixture of concentrated HNO_3, $HClO_4$, and H_2SO_4 in a 20:8:2 v/v ratio. The solution was then neutralized and the P colorimetrically determined by the Ascorbic Acid Method described in Standard Methods (1971).

Dissolved inorganic Phosphorus, (Dip), was determined directly on glass fiber filtered water samples, again using the ascorbic acid procedure.

Soil samples were extracted with 15 ml of Bray Solution (0.025N HCl, 0.03N NH_4F), then filtered and suitable aliquots taken for color development. All samples were analyzed in duplicate, or triplicate when there was more than 10% disagreement between duplicates. Standards and blanks were analyzed with each sample set to check precision. Whenever possible, known interferences with the procedures were experimentally determined with the necessary steps taken to eliminate these interferences as prescribed by Standard Methods (1971).

3.4. Bacteriological methods

The general purpose of the bacteriological investigation was to monitor the number of coliform and enterococcus organisms in septic wastes, in soil samples taken at various points in drainage fields and in test wells located around a number of such systems. A total bacterial count (TBC) was also obtained in order to evaluate the interaction of the general soil microflora and the sewage microflora in the area. The enterococcus count was assumed to be equivalent to the fecal streptococci (FS) as *Streptococcus faecalis*. These counts, together with the coliform counts (TC = total coliform and FC = fecal coliform), gave an indication of bacterial movement and density in the field system. Movement of any of these pollution bacteria to the surface of the soil was considered *a priori* evidence of unsafe conditions, *i.e.* failure of the system.

3.4.1. Sampling methods

Soil samples were obtained by first exposing the undisturbed region of soil to be sampled with a sterile spatula. A 1.8 x 15 cm sterile test tube was then gently pushed into the soil at the desired sampling point. In this way a 10 to 20 gram sample was easily obtained. All samples were cooled in an iced container and transported to the laboratory for analysis. This precaution was taken because of the known delicacy of fecal streptococci and fecal coliforms in competition with soil and water flora. Analyses were done as soon as possible, within 24 hours.

Test well samples and other liquid samples were taken by a number of methods depending upon the construction of the well being sampled. Three-quarter inch conduit wells of 14 to 16 foot depth and $1\frac{1}{4}$ inch iron pipe wells of 35-70 foot depth would be flushed by bailing, then bailed for a sample. Shallow conduit wells, 1 to 3 feet deep, would be sampled by pipetting with sterilized glass tubing. The $1\frac{1}{4}$ inch pipe wells which had sufficient recharge and were less than 30 feet deep would be flushed with a pitcher pump or with a vacuum pump, powered by a gasoline-driven electric generator. Samples would be taken of the influent to these wells obtained after flushing. Septic tanks and dry wells would be sampled by bailing.

Because the quality of the well samples was sometimes questionable in terms of bacterial contamination from the surface, in analyzing the data from these wells emphasis was placed on results showing no fecal indicator organisms detectable or on the FC/FS ratio whenever such organisms were found.

3.4.2. Plating methods

Bacterial counts were recorded as the average count from triplicate poured plates. For well samples at the periphery of the system no dilution was required, a 1 ml sample being plated. For other samples serial decimal dilutions were made as needed in 0.05% peptone diluent. The poured plates were preferred over spread plates because a larger amount of sample could be handled (1 ml for the poured vs. 0.1 ml for the spread). However, the poured plate method did require recognition of colonies of indicator organisms grown either on the surface or embedded in the agar. After a little practice this presented no problem.

Total bacterial counts were determined on Difco Plate Count Agar incubated at 30°C for 3-4 days. The composition of PCA (Standard Methods) is:

Tryptone	5 gr
Yeast extract	2.5
Dextrose	1
Agar	15
Distilled water	1000 ml

This medium supports growth of a variety of sewage and soil bacteria. Typical actinomycetes of the soil flora are recognizable by their sporulating aerial hyphae, and their relative numbers are indicative of the population gradient to a typical soil flora with increasing distance from the drainage tile.

The TC and FC populations were enumerated by counting typical colonies on Levine's Eosin Methylene Blue Agar. The composition of EMB (Standard Methods, 1971) is:

Peptone	10	gr
Lactose	10	
K_2HPO_4	2	
Agar	15	
Eosin Y	0.4	
Methylene blue	0.065	
Distilled water	1000	ml

Plates were incubated at 37°C for 48 hours. From the majority of platings isolates were taken and placed in lactose broth with Durham tube inserts to detect the production of acid and gas, confirming the isolates to be coliform organisms. IMViC patterns were also confirmatory. The isolates which were not confirmed proved to be recognizable colony types and in later work were disregarded in counting plates.

Fecal coliform counts (FC) were based on colonies with green metallic sheen on EMB. The total coliform counts (TC) were derived from the FC colonies plus all nucleated and non-nucleated, mucoid, pink colonies on EMB.

Fecal streptococcus counts (FS) were taken from platings on m-Enterococcus agar of the following composition: (Standard Methods, 1971)

Tryptone	20	gr
Yeast extract	5	
Dextrose	2	
K HPO	4	
Na azide	0.4	
Agar	15	
2,3,5-triphenyl tetrazolium Cl	0.1	
Distilled water	1000	ml

After incubation at 37°C for 48-72 hours all read and red-centered colonies (reducing tetrazolium) were recorded as FS.

Initially in analyzing the soil samples 10 gr of soil plus 90 ml of sterile 0.05% peptone dilution water were mixed with a Waring Blender for 1 minute, after which serial dilutions were made over the range expected. With this method the absence of an indicator organism in the least dilution plated was recorded as X, in the tables in Chapter 5, indicating < 10 organisms/gr based upon 3 plates inoculated from the 1:10 dilution.

After a time it was discovered that shear forces on the impeller of the Blender brought about by sand grains and small stones were severely damaging to the apparatus. The method of dilution was then changed: a 5 gr sample was added to a 25 ml peptone dilution blank in a $2\frac{1}{2}$ x 20 cm test tube. To shear and disperse the bacteria from the soil particles, a Vortex mixer was used for 1-2 minutes, which is known to be satisfactory from experience of soil bacteriologists. In this method the initial dilution is 1:6. Absence of a given organism was indicated by ** in the tables, Chapter 5, implying < 6 organisms/gr based upon 3 plates inoculated with the least dilution.

Similarly, in plating liquid samples when no organisms of the kind being considered were detectable in the least dilution, i.e. 1 ml directly plated, the results were expressed as * in the tables; expressed another way, this means < 1 organism/ml based on 3 plates inoculated with 1 ml each of the original sample.

Bacterial counts from soil samples were expressed per gram of moist soil because for the underground soil samples there was little variation in moisture. Considering the 10 to 20% moisture content observed, there was little advantage in expressing the numbers of organisms on a per gram of dry soil basis. Also because the microorganisms in the soil are associated with the adsorbed and interstitial water it was more meaningful to enumerate them in terms of moist soil. The counts are expressed in the tables of Chapter 5 on a per ml or per gram basis instead of the USPHS convention for water samples of 10 ml or 100 ml, in order to keep the numbers in the order of magnitude of soil counts, which some of them actually are. If the bacterial counts for soil (or septic waste, for that matter) were expressed on a per 10 or per 100 gr basis unwidely high numbers would result.

3.4.3. The FC/FS ratio

The FC/FS ratios are presented in Chapter 5 for a number of systems investigated because of the interest in the relative survival of these two indicator organisms in the small systems under study. If the ratios are relatively stable, a wide versus narrow ratio may be useful as an indicator of the source of pollution bacteria involved. Geldreich (1966) found FC/FS ratios of < 0.7 to indicate the feces of farm animals, dogs, cats, rodents, etc. whereas FC/FS ratios of > 4 were indicative of human feces and domestic waste waters. Smith and Twedt (1971) accepted this difference in ratios and used it in study of surface waters, rivers and streams. The values proposed by Geldreich have also been used in analyzing the movement of such indicator fecal organisms in the presence of minor numbers of them in natural soil and water. It was felt that this expression of data might also be helpful in consideration of the small systems here under study.

3.4.4. The so-called total bacterial counts (TBC)

Question could be raised as to the validity of the total bacterial counts (TBC) on PCA agar with an incubation time of only 3-4 days. It is probable that this time is insufficient for the slow growing organisms in the soil microflora. It also fails with respect to the autotrophic bacteria, which are an admittedly important part of the soil microflora. However, a rich medium, such as PCA, will support the great majority of bacteria originating in the septic tank effluent as well as the general fast-growing heterotrophs of the soil with which we are most concerned. We are not interested in the actual numbers of soil bacteria in the outer ranges of the drainage field but rather in the transition from the sewage (fecal) type flora near the drain tiles to the "normal" soil microflora at a distance; i.e. in the zone of interaction and finally displacement of the fecal forms by the soil forms such as actinomycetes and molds, indicative of typical soil microflora. PCA plating also reveals pigmentation of many types of bacteria and it was soon found that it did so here, as in plating of water flora. This was very helpful in judging how far out of the drainage tile and into the water gradient within the soil the sewage flora was moving. By the time actinomycetes and molds appeared on the plates, the pigmented forms were virtually gone, and this finding was useful in establishing the transition zones from sewage to soil types. Exceptions existed (as at the Pickerel Lake system) in which the pigmented forms were found with the actinomycetes in the moist soil below the tile lines. This, however, was the only system where effluent was not ponded in the seepage bed due to irregular, low loading (see Chapter 5.2.3.2.).

4. GENESIS AND CHARACTERISTICS OF SOIL PEDONS SELECTED FOR STUDY

The soil pattern shown on the state map in the back of the report reflects the combined influences of parent materials, climate, organisms (both plants and animals), and landforms, acting over a period of thousands of years. Recognizable are traces of the U- shaped disposition of bedrock formations (Dunn to Sauk and Marinette Counties), principal glacial end moraine zones (in Langlade, Taylor and Barron Counties), and the dissected Driftless Area (soil region A, approximately).

Regions C and H are major sand regions where meltwaters from wasting glaciers, and accompanying strong winds, left coarse materials and at the same time removed fines from the landscapes. Parts of region C have deep dark topsoils formed under prairie vegetation (Cp).

The sandy loams of region D are in the Cambrian sandstone belt, which is hilly to level.

Reddish brown clays (Region I) of the Lake Superior and Lake Michigan border lands were deposited in vast glacial lakes and were reworked over large areas by later glacial advances. Pink loams of region E are colored by a small proportion of red clay mixed into sandy glacial drift. All of these reddish and pinkish materials received limestone debris, that added to the fertility of soils that formed in them.

Region G is a hilly, somewhat stony glacial moraine landscape with many small flat areas of outwash with loamy coverings. Soil region F differs by having a two- to three-foot thick silty deposit over the glacial drift. The soils of both regions are acid because little or no limestone was mixed into the materials by glaciers and meltwaters from them.

Regions A and B are, respectively, in the Driftless Area of the southwest and the drifted area of the southeast. Two to several feet of silty material cover most of both areas, the thickest deposits being near the Mississippi River, which is considered to have been the major source of the fine loess materials.

Region J represents wetlands throughout the other nine regions. This includes alluvial soils and the more extensive peat and muck bogs that occupy more than ten percent of the area of Wisconsin.

The ample rainfall of about 31 inches (775 mm) per year, and the high level of the watertable in many lowlands have created wet soil conditions over at least one third of the state. These areas, together with tight silty and clay soils, steep lands and soils shallow to bedrock create problems for the conventional type of subsurface liquid waste disposal in about 60 percent of the land of the state.

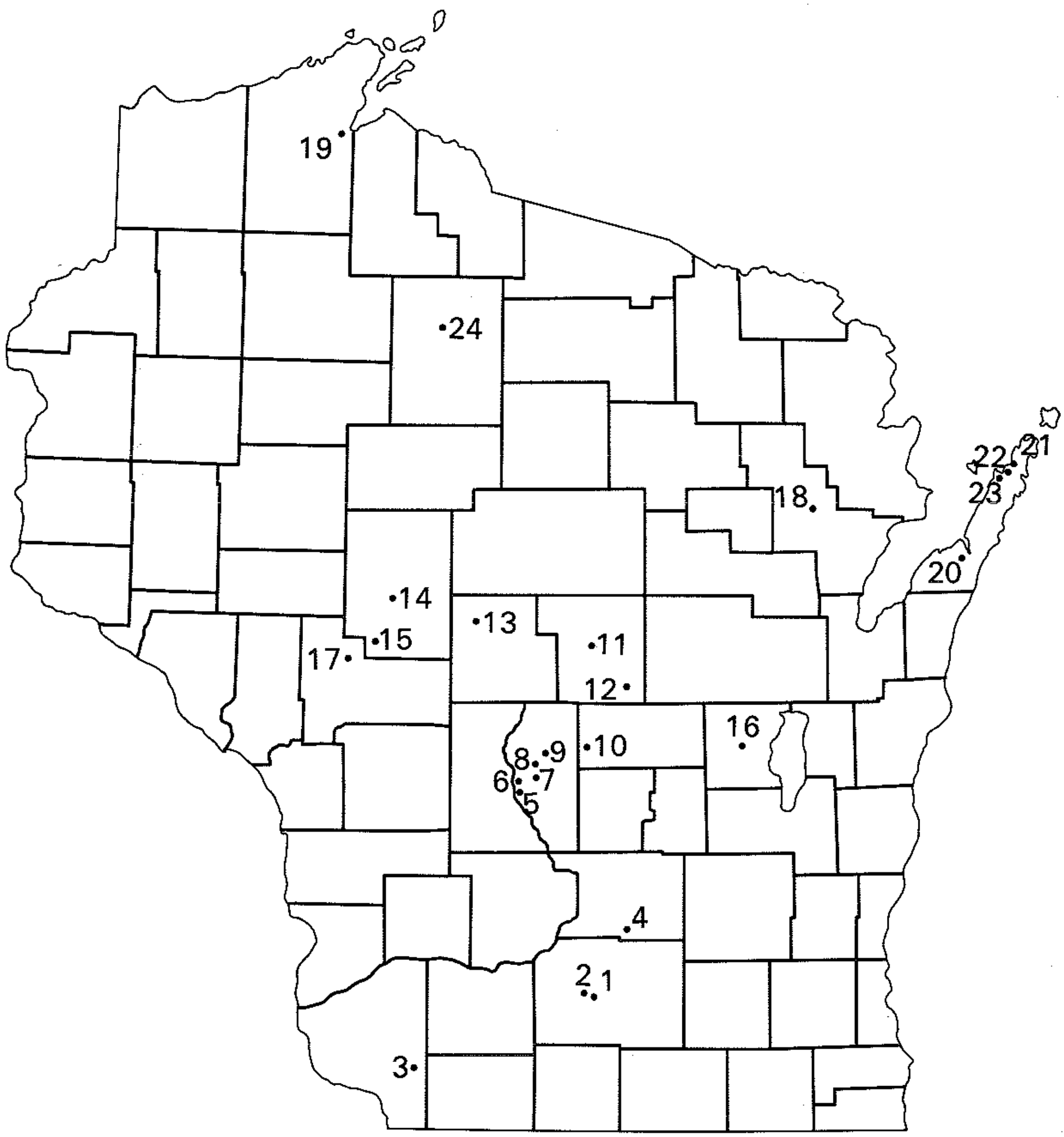


Fig. 4.1. Index map showing location of study sites.

Table 4.1: LEGEND FOR FIGURE 4.1

Site Number	Soil type and parent material	Soil classification at higher categories	Location	Soil Association: On the leaflet state map (Plate I)	Soil Association: On the 1:710000 map (Hole *et al*, 1968)
1	St. Charles - Batavia silt loam; loess over dolomitic sandy loam glacial till	Mollic Hapludalf, fine silty, mixed, mesic (Gray-Brown Podzolic-Brunizem intergrade, well drained)	Charmany Farm, U. W. Agric. Exper. Sta. NE 1/4, NW 1/4, Sec. 30. T7N, R9E, Dane County	B	B25
2	Plano silt loam deep loess over dolomitic glacial outwash	Typic Argiudoll, fine-silty, mixed, mesic (Brunizem, well drained)	Mandt Farm, U. W. Agric. Exper. Sta. NE 1/4, NW 1/4 Sec. 30, T7N, R9E, Dane County	Bp	B22
3	Tama silt loam; deep loess over residuum over fissured limestone	Typic Argiudoll, fine-silty, mixed, mesic (Brunizem, well drained)	NW 1/4, SE 1/4 Sec.1, T2N, R1W, Grant County	Ap	A1
4	Saybrook silt loam; loess over dolomitic loam glacial till	Typic Argiudoll, fine-silty, mixed, mesic (Brunizem, well drained)	Arlington Farm, U. W. Agric. Exper. Station NE 1/4, NW 1/4 Sec. 31 T10N, R10E, Columbia Co..	Bp	B22
5	Plainfield loamy sand; deep glacial outwash	Typic Udipsamment, sandy, mixed, mesic (Regosol, Excessively drained)	SW 1/4, SW 1/4 Sec. 8, T16N, R5E, Adams County	C	C18

TABLE 4.1 (continued)

Site Number	Soil type and parent material	Soil classification at higher categories	Location	Soil Association: On the leaflet state map (Plate I)	Soil Association: On the 1:710000 map, (Hole *et al*, 1968)
6	Plainfield loamy sand; deep glacial outwash	Typic Udipsamment, sandy, mixed mesic (Regosol, excessively drained)	NW 1/4, SW 1/4, Sec 29, T17N, R5E, Adams County	C	C18
7	Plainfield loamy sand; deep glacial outwash	Typic Udipsamment, sandy, mixed, mesic (Regosol, excessively drained)	NW 1/4, SE 1/4, Sec. 24, T17N, R5E, Adams County	C	C13
8	Plainfield loamy sand; deep glacial outwash	Typic Udipsamment, sandy, mixed, mesic (Regosol, excessively drained)	NW 1/4, SE 1/4, Sec. 31, T18N, R6E, Adams County	C	C10
9	Plainfield loamy sand; deep giagial outwash	Typic Udipsamment, sandy, mixed, mesic (Rogosol, excessively drained)	SE 1/4, SW 1/4, Sec. 28, T18N, R6E, Adams County	C	C10
10	Plainfield loamy sand; deep glacial outwash	Typic Udipsamment, sandy, mixed mesic (Regosol, excessively drained)	Hancock Farm, U. W. Agric. Exper. Station, NW 1/4, NW 1/4, Sec. 15, T19N, R8E, Waushara County	C	C15
11	Plainfield loamy sand; deep glacial outwash	Typic Udipsamment, sandy, mixed mesic (Regosol, excessively drained)	SE 1/4, SE 1/4, Sec. 15, T23N, R8E, Portage County	C	C15

TABLE 4.1 (continued)

Site Number	Soil type and parent material	Soil classifications at higher categories	Location	Soil Association: On the leaflet state map (Plate I)	Soil Association: On the 1:710000 map, (Hole et al, 1968)
12	Plainfield loamy sand; deep glacial outwash	Typic Udipsamment, sandy, mixed, mesic (Regosol, excessively drained)	Pickerel Lake; SE 1/4, SW 1/4, Sec. 5, T21N, R 10E, Portage County	C	C15
13	Withee silt loam; shallow loess over compact, acid loam glacial till	Aquic Glossoboralf, fine-loamy mixed frigid (Gray-Brown Podzolic, somewhat poorly drained)	Marshfield farm, U. W. Agric. Exper. Station SW 1/4, SW 1/4, Sec 15, T25N, R3E, Wood County	F	F21
14	Humbird sandy loam Acid shaly sandstone	Typic Haplorthod, coarse-loamy mixed, frigid (Podzol, moderately well drained)	NE 1/4, NW 1/4, Sec. 10, T23N, R3W, Clark County	D	D12
15	Arland loam; Loamy till over sandstone	Typic Hapludalf, fine-loamy, mixed, frigid (Gray-Brown Podzolic, well drained)	SW 1/4, NE 1/4, Sec. 5, T25N, R2W, Clark County	F	F11
16	Oshkosh silty clay loam; deep, calcareous glacio-lacustrine clays	Typic Eutrochrept, very fine, mixed, mesic, calcareous (Gray-Brown Podzolic, moderately well drained)	SW 1/4, SE 1/4, Sec. 3, T18N, R14E, Winnebago County	I	I5
17	Sparta loamy sand; deep glacial outwash	Entic Hapludoll, sandy, mixed, mesic (Brunizem, excessively drained	NW 1/4, NE 1/4, Sec. 3, T22N, R4W, Jackson County	D	D4

TABLE 4.1 (continued)

Site Number	Soil type and parent material	Soil classifications at higher categories	Location	Soil Association: On the leaf-let state map (Plate I)	Soil Association: On the 1:710000 map (Hole *et al.*, 1968)
18	Tustin fine sandy loam; outwash over calcareous clayey glacial drift	Arenic Hapludalf, fine, mixed, mesic (Gray-Brown Podzolic, well drained).	Kelley Lake; NE$\frac{1}{2}$, NW$\frac{1}{4}$, Sec. 5, T29N R19E, Oconto County	E	E2
19	Hibbing silty clay loam and loam; deep dolomitic glaciolacustrine clays	Typic Eutroboralf, very fine, mixed mesic (Gray-Wooded soil, moderately well drained)	NW$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 11 T47N, R5W, Bayfield County	I	I18
20	Summerville loam; thin glacial till over fissured limestone	Lithic Hapludoll, loamy, mixed frigid (Brown forest soil)	SW$\frac{1}{4}$, NE$\frac{1}{4}$, Sec. 1 T27N, R25E, Door County	E	E4
21	Summerville loam; thin glacial till over fissured limestone	Lithic Hapludoll, loamy, mixed, frigid (Brown forest soil)	NW$\frac{1}{4}$, SW$\frac{1}{4}$, Sec. 4, T31N, R28E, Door County	E	E6
22	Summerville loam; thin glacial till over fissured limestone	Lithic Hapludoll, loamy, mixed frigid (Brown forest soil)	NW$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 8, T31N, R28E, Door County	E	E6

TABLE 4.1 (continued)

Site Number	Soil type and parent material	Soil classifications at higher categories	Location	Soil Association: On the leaflet state map (Plate I)	Soil Association: On the 1:710000 map, Hole et al., 1968)
23	Summerville loam; thin glacial till over fissured limestone	Lithic Hapludoll, loamy, mixed, frigid (Brown forest soil)	$SE\frac{1}{4}$, $NE\frac{1}{4}$, Sec. 24, T31N, R27E, Door County	E	E6
24	Vilas loamy sand; deep, acid glacial drift	Entic Haplorthod, sandy, mixed, frigid (Podzol, excessively drained)	Dardis Lake; $SE\frac{1}{2}$, $NE\frac{1}{4}$, Sec. 34, T38N, R1E, Price County	G	G

Table 4.2: Acreages of soils represented in this study.

Site Number	Soil Name	Estimated acreage in Wisconsin: of the soils named	Estimated acreage in Wisconsin: of these soils and associated similar soils
		(acres)	(acres)
1	St. Charles-Batavia silt loam	100,000	250,000
2	Plano silt loam	100,000	500,000
3	Tama silt loam	150,000	500,000
4	Saybrook silt loam	50,000	150,000
5-12	Plainfield loamy sand	400,000	1,000,000
13,15	Withee silt loam	200,000	800,000
14	Humbird sandy loam	30,000	150,000
16	Oshkosh silty clay loam	50,000	150,000
17	Sparta loamy sand	200,000	400,000
18	Tustin fine sandy loam	20,000	200,000
19	Hibbing silty clay loam and loam	100,000	600,000
20-23	Summerville loam	50,000	100,000
24	Vilas loamy sand	700,000	1,500,000

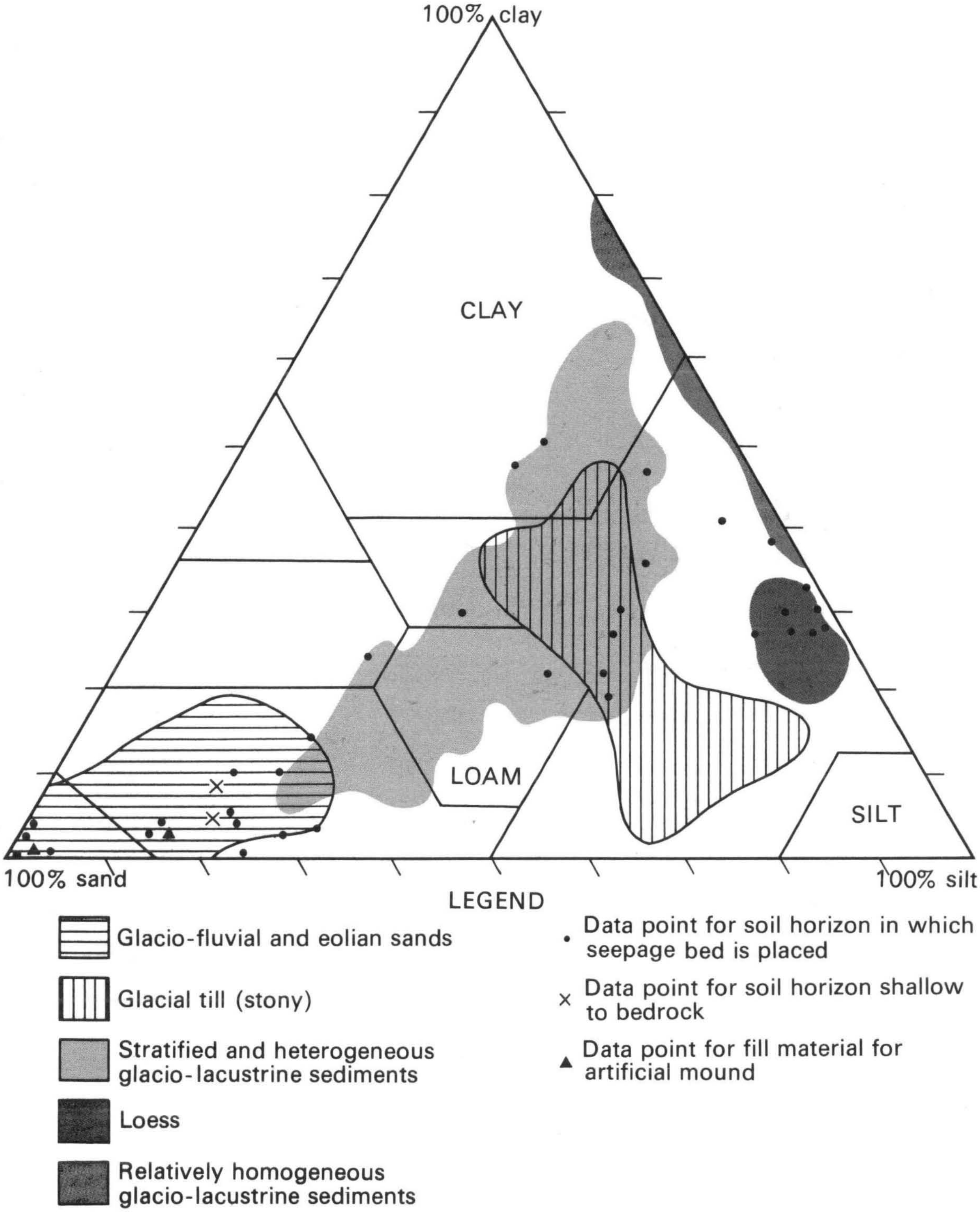


Fig. 4.2. Soil texture diagram showing data points for horizons studied.

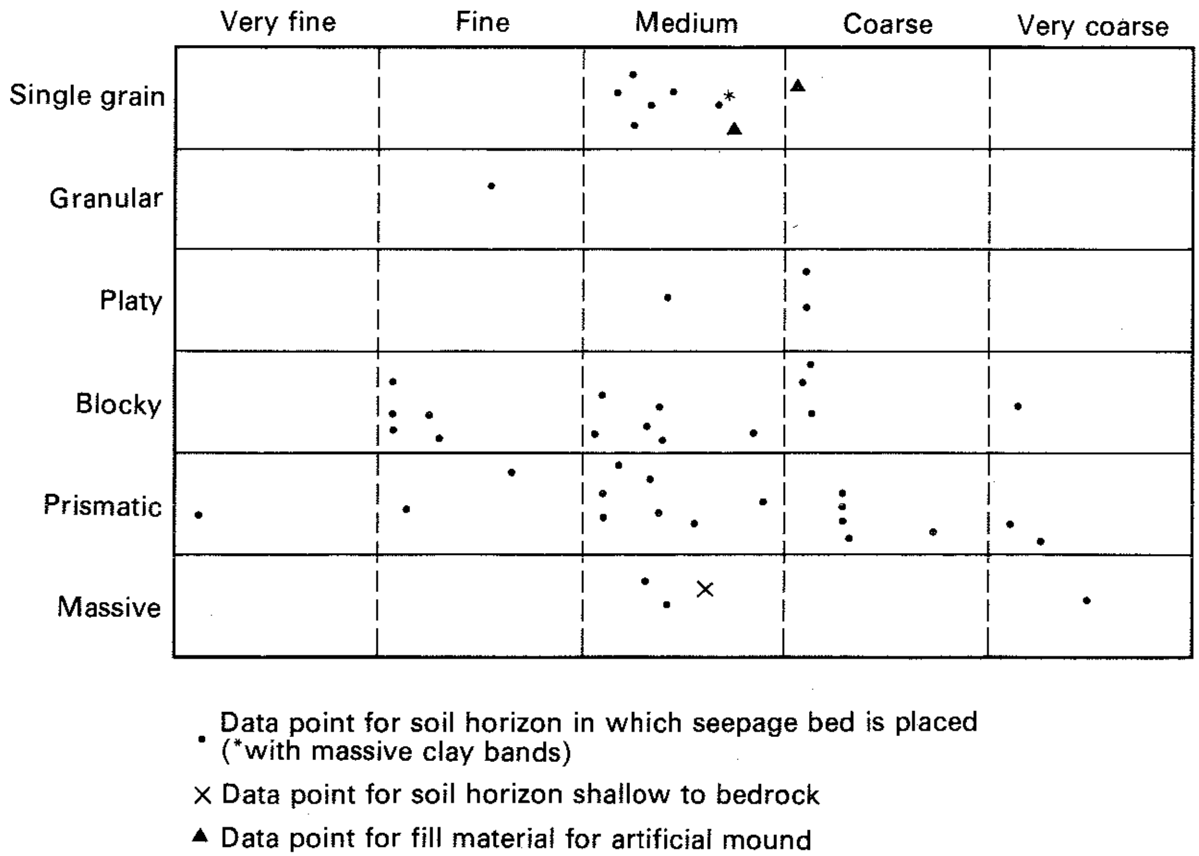


Fig. 4.3. Soil structure diagram showing data points for soil horizons studied.

Of the ten major soil regions, eight are represented by the pedons selected for study in this project (see Fig. 4.1 and Tables 4.1 and 4.2). Although site 24 is in region G, the soil, Vilas loamy sand, is more typical of region H, and in that sense the latter region is represented. Soils of region J are not included in the study because they are subject to a high stationary water table and to flooding by streams, which makes them unfit for installation of septic soil absorption fields.

The soil horizons in which the seepage beds occur range in texture from clays to sands (Fig. 4.2) (Lee, et al., 1962) and in soil structure (Fig. 4.3) from apedal (massive and single grain) to pedal (granular, platy, blocky and prismatic). These four types of peds are shown diagrammatically in Fig. 4.4, where, except for sandy soils, A1 horizons are depicted as granular, A2 horizons as platy, upper B2 horizons as blocky and lower B horizons as prismatic. In the same figure mounds (to be discussed in Chapter 8) are indicated as possible superstructures on the six soils that are most troublesome with regard to subsurface liquid waste disposal, namely the tight soils with a low hydraulic conductivity (Hibbing, Oshkosh, Withee and Tustin) and the shallow soils over fissured limestone (Summerville) and sandstone (Arland). Data points in Figs. 4.2. and 4.3. include some for mound fill materials used in Door and Ashland County, showing that they are as sandy as C horizons of Plainfield and Sparta soils.

In this study, stratification of soil materials below seepage beds was only encountered in the Humbird sandy loam (at site 14), in the C horizon of which clay bands interrupt the sand substratum. More study is needed to determine the influence of such lamination in subsoil materials on movement of liquid wastes under and near land-disposal systems. However, the array of soil materials selected for the current field study appears to be quite representative of major soils of the state (Figs. 4.2. and 4.3.). Even so, special attention was paid to sandy soils because of problems of disposal of septic tank effluent in them at recreational facilities near lakes and streams, remote from municipal sewer systems.

For thousands of years our soils have served as disposal systems for wastes from upland forests and prairies. The accumulations of black humus (particularly evident in surface soils at sites 2, 3, 4, 17) and reddish brown organic matter (in subsoils at sites 14, 24) represent decomposing plant debris from grasslands and forestlands, respectively. If these natural vegetable and animal wastes had not been taken care of by normal processes, vast blankets of wood and prairie hay would have smothered the land long ago. When, in the present context, people put human wastes in soils, care must be taken not to overload the soils. Design and management must be such that the natural processes of waste disposal are permitted to work, as they have through the ages, to gradually and safely return organic materials and nutrients to soil, air and water.

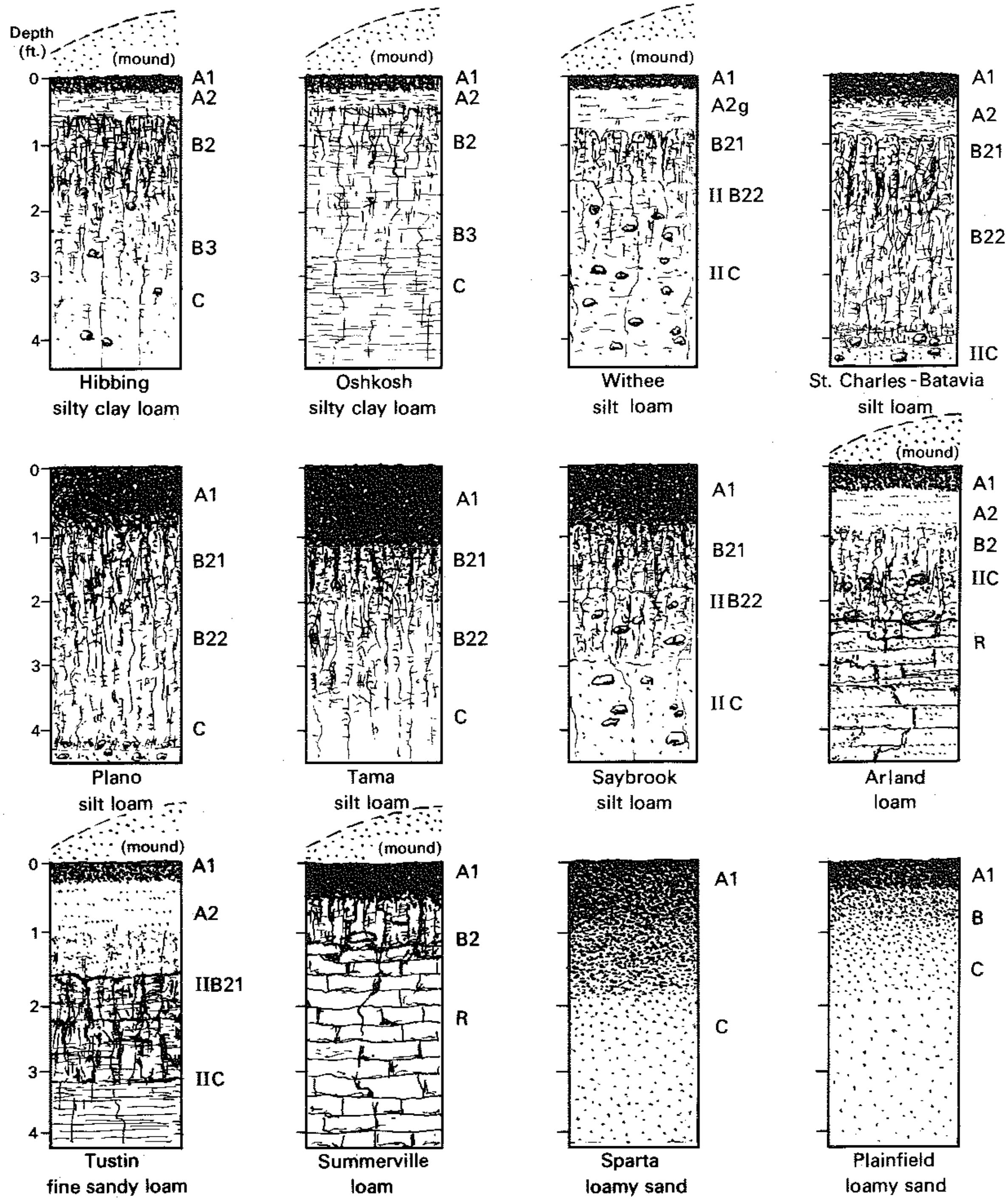


Fig. 4.4. Sketches of profiles of the soils observed at study sites.

5. RESULTS OF FIELD AND LABORATORY STUDIES

5.1. Introduction

Results of monitoring fourteen operating seepage beds will be discussed in this chapter. Ten of these beds were in soil materials with a sand texture (Chapters 5.2.1, 5.2.2 (dry wells), 5.2.3.1, 5.2.3.2, and 5.2.7). The five systems discussed in Chapter 5.2.1 were most thoroughly investigated by not only applying soil-physical, bacteriological and chemical methods to the soil surrounding the bed, but also by analysing liquids from well points installed around the system to study movement and pollution of the ground water. Such emphasis on the study of sands as a porous medium for liquid waste disposal is justified by considering the increasing number of recreational facilities in sandy soils near lakes and streams being constructed at this time, most of which have to rely on septic tank liquid waste disposal. Study of sandy materials is also important because of their potential use as fill materials in experimental mound systems to be constructed in soils that are unsuitable for a conventional subsurface seepage bed (see Chapter 8). The four remaining systems discussed in this chapter were in moderately permeable loamy soil materials (Chapter 5.2.4) and slowly permeable clayey soil materials (Chapter 5.2.3.3, 5.2.5 and 5.2.6). One basic decision was made in this study regarding the total number of sites to be studied and the desirable degree of detail in observations at each site. Rather than concentrate on a few sites in great detail, which would involve sacrificing the possibility to obtain a more comprehensive picture, it was decided to work at more sites instead, using moderately detailed procedures of monitoring. In addition, the sampling program was not rigidly similar at each site but was varied as needed, to obtain the maximum relevant information at an optimal cost of manpower and other resources. Continuing studies are in progress at this time in which specific aspects of problems encountered during this field work are being studied both in the laboratory and in the field.

5.2. Results of monitoring operating subsurface soil disposal systems

5.2.1. Adams County study area

5.2.1.1. Introduction

Five subsurface seepage beds, used for the disposal of septic tank effluent, were investigated with soil-physical, hydrogeological, bacteriological and chemical methods. In the first phase of the project soil moisture tensions were measured around the seepage bed of system 1 and bacteriological samples were taken of soil and effluent in September 1970 and in May 1971. The sampling program was considerably expanded in the Summer of 1971 with the construction of well points around this and four additional systems in the area. The five study sites are located in the vicinity of Adams-Friendship in Adams County, Wisconsin (see Fig. 5.1, which is derived from the U.S. Geological Survey topographical map, Adams Quadrangle). Monitoring results are reported and discussed for each of these systems in the following chapters.

The purpose of these investigations was to obtain a relatively complete picture of processes of liquid movement and transformations occurring during disposal of septic tank effluent in sands.

Study sites were selected to represent a range of characteristics, such as: (1) distance of the seepage bed to the ground water, (2) age of the system, and (3) hydrogeologic setting.

Observation wells were installed in the immediate vicinity of each drain field, ranging in number from 6 to 17 per site. The depth and construction of observation wells at each site along with the elevation of each well curb (top) above an assumed site datum are shown in Table 1 in the Appendix. Locations of the observation wells at each site are shown on the potentiometric map for each separate system. Steel electric conduit, 3/4 inch diameter, was used for casing the wells at sites 1 and 2 and were driven by hand. Black iron pipe, $1\frac{1}{4}$ inch diameter, with $1\frac{1}{4}$ x 12 inch drive points were used at sites 3, 4 and 5. The pipe was installed with a power auger. Elevations of well curbs above an assumed datum were surveyed by a Zeiss self-leveling level and were resurveyed at sites 1 and 2 for each set of water measurements. The depth of the water table below well curb measurements are shown for each site in Table 2 in the Appendix.

Potentiometric maps were constructed from measurements of the ground-water level at each site to establish the direction of ground-water movement. Physical measurements of soil moisture tensions were made in the soil adjacent to the seepage beds to physically define the infiltration process (Photo 5.1). For procedures, see Chapter 3.2.5. In addition, hydraulic conductivity values were measured <u>in situ</u> (Chapters 3.2.3. and 3.2.4.) and moisture retention characteristics were determined in the laboratory using undisturbed field samples (Chapter 3.2.5.). Liquid samples were taken from the effluent and from wellpoints in three different periods to be analyzed for chemical and bacterial pollutants. Liquid samples were obtained with a small bailer after first bailing the stagnant water from each observation well. (For analytical procedures, see Chapters 3.3 and 3.4).

5.2.1.2. Geologic and hydrologic setting of the area

The 5 study sites lie in an area covered by eolian, outwash, and glacial lake deposits (Alden, 1918) consisting of interlayered clay, silt and sand. The topography is quite flat with a westward slope of less than 10 feet per mile except for isolated sandstone bedrock mounds that rise abruptly 250 feet or more above the general land surface (Fig. 5.1). The thickness of unconsolidated glacial lake deposits ranges from zero at the sandstone mounds up to about 150 feet in and to the west of Adams-Friendship.

The area lies adjacent to the Castle Rock Flowage on the Wisconsin River and is drained by Little Roche a Cri, Carter, Klein, Duck, and several unnamed creeks that empty into the flowage and the Wisconsin River (Fig. 5.1). The flowage is regulated within a range of 7 feet of stage which effects ground-water levels at sites 1 and 2.

Ground-water movement in the area is generally westward toward the flowage and, locally, toward streams. At the southeastern part of the flowage, in the vicinity of Site 1, water is moving eastward out of the flowage at least part of the time into the ground water reservoir due to the hydraulic head imposed by the reservoir. However a drainage canal paralelling the flowage (Fig. 5.1) captures much of this water as well as westward moving ground water from east of the canal.

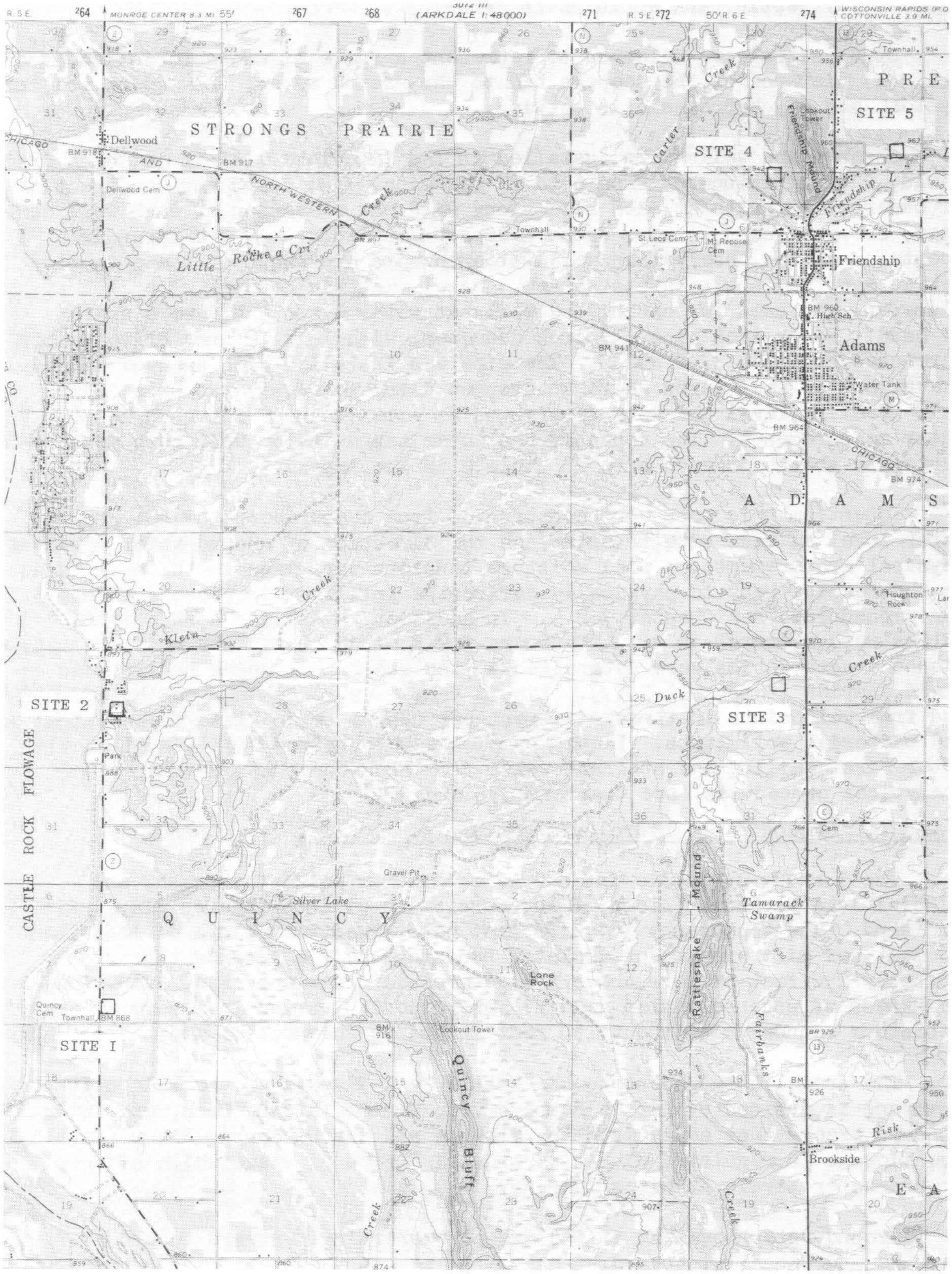


Fig. 5.1. Location of the five study sites in Adams County.

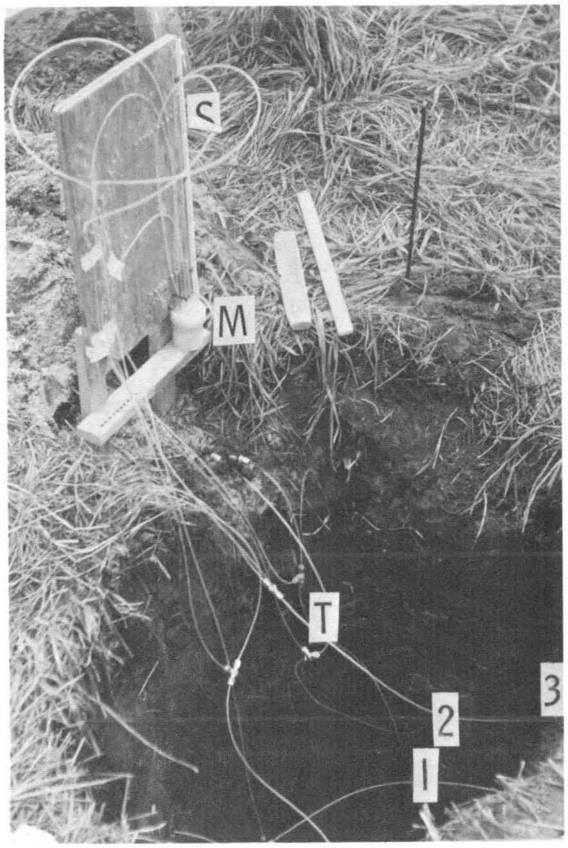


Photo 5.1. Apparatus for field measurement of soil moisture tensions. The 1/8-inch plastic tubes (T) are filled with water and connect pencil-sized tensiometers (inserted into the soil at points 1, 2 and 3) to mercury cup M. Moisture tension in the soil is determined by reading the equilibrium level of the mercury column in the tube along the calibrated scale, S.

5.2.1.3. System 1

The site is located about one half mile west of the drainage canal paralleling the Castle Rock Flowage (Fig. 5.1) which is the principal discharge point for ground water in this area. The terrain as well as the water table is very flat.

This system is twelve years old and has functioned satisfactorily over the years. A top view of the system and two cross sections of the seepage bed are in Fig. 5.2. The locations of the three seepage beds are very evident on the soil surface due to abundant grass growth on top of them (Photo 5.2). The tiles are set in gravel-filled trenches approximately $2\frac{1}{2}$ feet deep. A distribution box selectively directs effluent to the three drain tiles based on amount of flow, as the opening of each tile enters the box at different elevations. The pipe leading into the southern leg of the system (Fig. 5.2) is one inch higher than the northern one. However, the level of liquid in the distribution box was sufficiently high to enter all pipes at the time of the study, thereby establishing one liquid level in the three beds (Photo 5.3.). The system usually serves 3 adults and the measured loading rate was 130 gallons per day (based on figures for flow through the housewell measured in a one-month period in January 1972).

Photo 5.2. Absorption field in Plainfield loamy sand (system 1). The location of the seepage beds, which were partly filled with effluent, is clearly marked by lush growth of grasses (G). An excavation (E) was made next to the middle bed for purposes of sampling and measurement of soil moisture tensions (see diagram, of system, Figure 5.2).

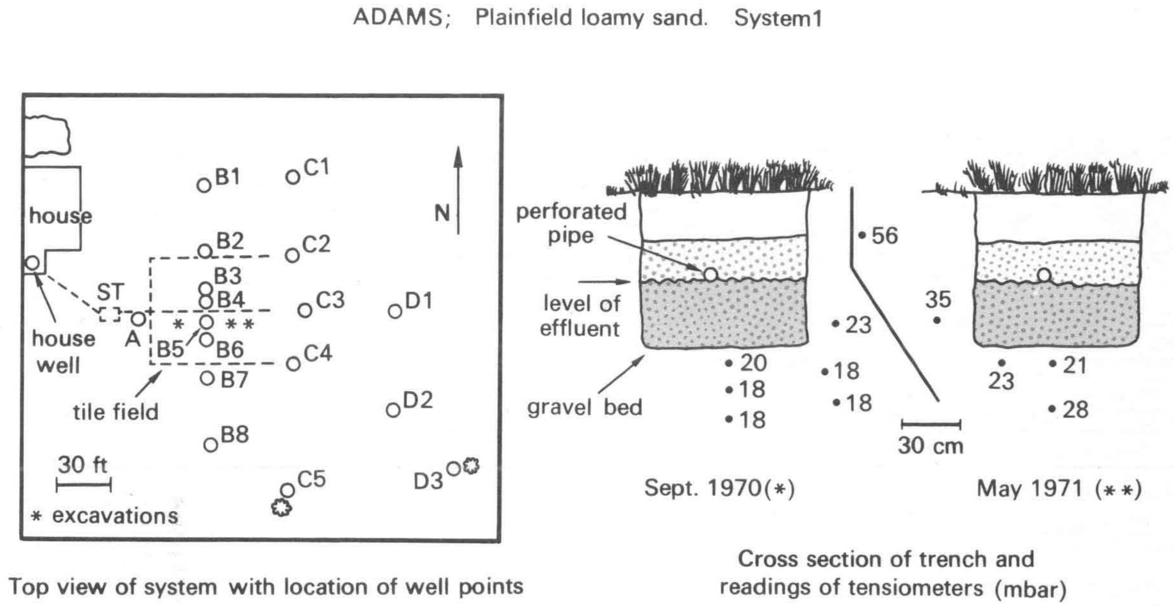


Fig. 5.2. Top view of system 1 with locations of sampling wells and two cross sections of the seepage bed with locations and readings of tensiometers (Adams).

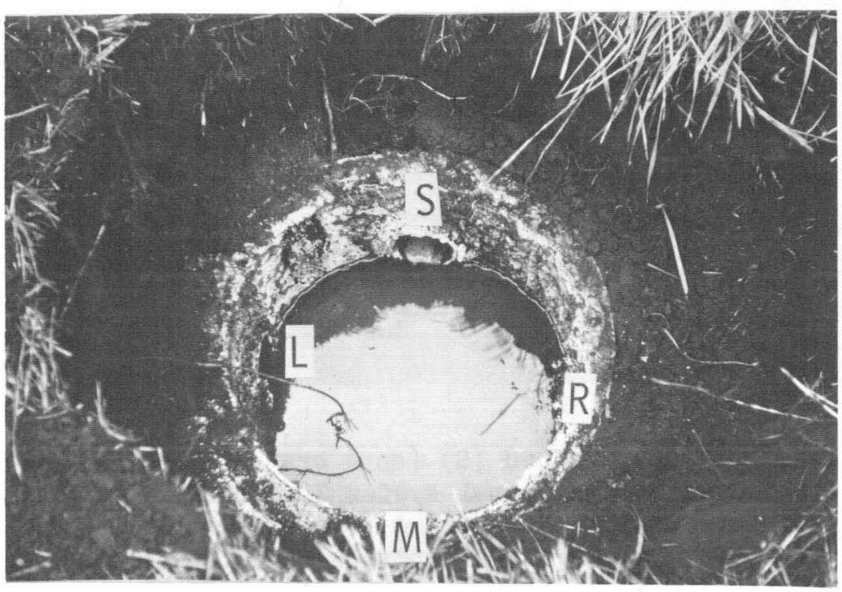


Photo 5.3. View of distribution box with lid removed, showing inlet from septic tank (S). Three pipes, of which L is clearly visible, lead to the three legs of the seepage field. These pipes leave the box at different levels: pipe (L) is one inch higher than M, which is one inch higher than R.

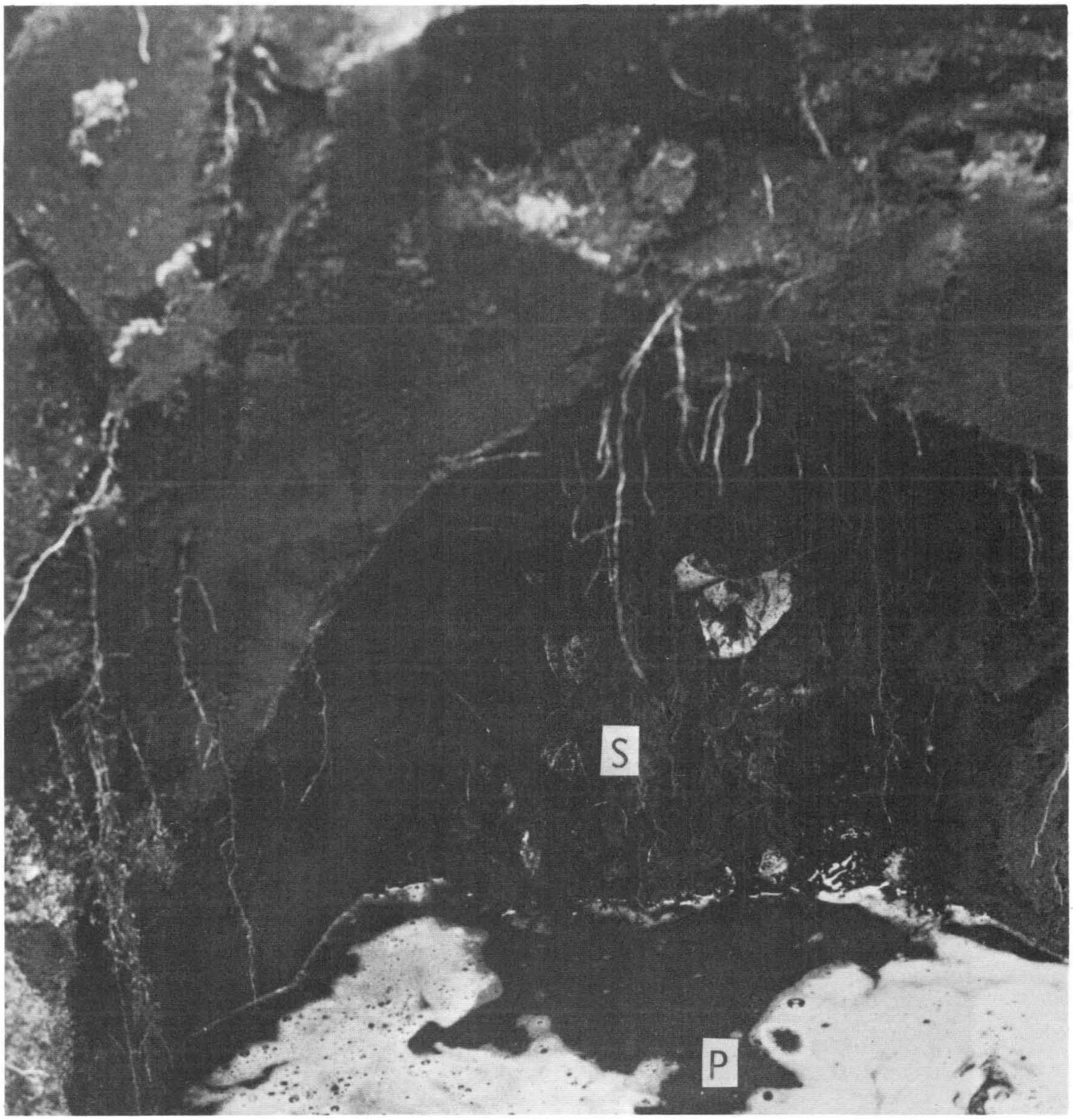


Photo 5.4. Excavated seepage bed (S) (note gravel and abundant root development) of disposal system 1 (Adams County). The sand surrounding the seepage bed had a high K_{sat} of 500 cm/day. However, effluent was ponded in the bed due to crusting which induced a tension of 23 mbar in the surrounding unsaturated soil. The crust was punctured at one time and effluent flowed from the bed into the adjacent pit (P) where it seeped away in minutes through the very permeable uncrusted sand.

The soil in the area was classified as a Plainfield loamy sand (Typic Udipsamment) with the following soil horizons: Ap:0-26 cm: Very dark grayish brown loamy sand, apedal coherent structure resulting from inter-granular bonds in the soil matrix (agglomeroplasmic basic fabric). B2:26-70 cm: Strong brown sand, structure as Ap. B3:70-85 cm: Strong brown sand, single grain. C:85 cm+. Brownish yellow sand, single grain. Particle size distribution and some other physical data are in Table 5.1. Hydraulic conductivity values for the C horizon and moisture retention data for all horizons are in Fig. 5.3. Three percolation tests were made that averaged 2 min/inch. Moisture tensions of 20 to 23 mbar were measured in the soil adjacent to the central seepage bed in September 1970 and May 1971 (Fig. 5.2). Effluent was ponded in the bed at the same time, indicating the presence of a crust at the interface of the soil and the bed that reduced the infiltration rate into the soil. The crusted zone on the sidewall of the bed was punctured at one time and ponded effluent flowed from the bed into the adjacent pit where it seeped away in minutes through the very permeable uncrusted sand (Photo 5.4). With K_{sat} = 500 cm/day and K_{23mbar} = 15 cm/day, the reduction can be estimated to be 33 fold (assuming hydraulic gradients of 1 cm/cm, which are close to the real measured gradients, that can be derived from Fig. 5.2). The number of excavations had to be limited, unfortunately, to these two pits due to the disturbing effect of digging in the lawn. However, hydrological data indicate that the rate of infiltration of effluent into the soil is not evenly divided over the entire seepage bed area. This aspect can not be verified at this time, due to the lack of additional moisture tension measurements at other locations. The crusting phenomenon, however, is well documented because only crusting can explain the occurrence of ponded effluent in the seepage bed in this very permeable soil. The soil environment is well-aerated at a moisture tension of 23 mbar. Only 13% of soil volume is occupied by liquid, which occurs in the finer soil pores only, and 24% is occupied by air (Fig. 5.3). Relatively slow movement of effluent through fine soil pores has been effective in removing fecal indicators from the effluent after only a few cm of soil percolation as is shown by the results of bacterial analyses of soil samples as reported in Table 5.2. The liquid in some well points contained fecal indicators.

However, fecal coliform (FC) to Fecal streptococcus (FS) ratios did not indicate contamination of the test wells by percolating effluent, except for a sample from well B4 that had a FC/FS ratio of 1.8 which may have indicated possible contamination as the ratio was between the 0.7 and 4.0 values discussed earlier in Chapter 3.4. (Table 5.2).

Ground water at the site is moving under a gradient of less than 3 feet per mile. Soil auger borings to a depth of 9 feet at the site showed underlying material to consist largely of medium to fine-grained quartz sand with some very fine and very coarse sand.

The potentiometric map of the water table, Fig. 5.4, was constructed from water level measurements made on November 11, 1971 (Table 1, Appendix) and shows direction of ground-water movement and effects of seepage on the water table. Ground-water movement is down gradient and essentially perpendicular to the contour lines. Thus, areal movement of ground water is southwestward under a very low gradient (Note the contour interval of the map is only .05 feet). Superimposed on the flat water table is a low

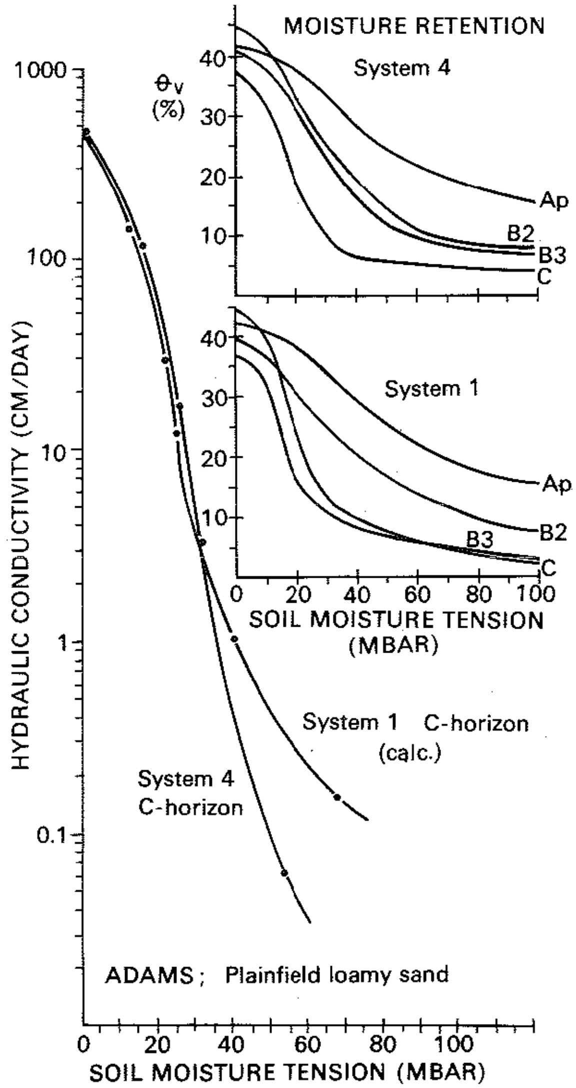


Fig. 5.3. Hydraulic conductivity and moisture retention data for horizons in a Plainfield loamy sand at the locations of systems 1 and 4 (Adams).

Table 5.1. Particle size distribution, bulk densities and particle densities of horizons in a Plainfield loamy sand (System 1, Adams Co.).

Horizon	C	FS	MS	CS	VFS	FS	MS	CS	VCS	Texture	Bulk density (gr/cm^3)	Particle density (gr/cm^3)
Ap	1.00	2.00	4.00	5.00	5.82	3.20	23.74	49.67	5.88	loamy sand	1.51	2.57
B2	----	2.00	1.00	3.00	9.45	6.48	32.53	41.12	4.21	sand	1.44	2.59
B3	----	----	----	1.00	1.72	3.42	22.72	63.76	6.55	sand	1.56	2.59
C	----	----	----	----	0.03	0.50	13.60	84.15	1.99	coarse sand	1.56	2.45

Table 5.2 Bacterial Analyses, System 1, Adams County

(bacterial counts per gram of soil or per ml in liquid samples)

Sample and Date (See Fig. 5.2)	Enterococci	Fecal coliform	Total coliform	Total bacteria	FC/FS	pH
Sept. 18, 1970				($x10^5$)		
A, 6cm below trench	X	X	300	50		
B, 28cm below trench	X	X	100	2,200		
C, 6cm from side of trench	X	X	10-100	10		
D, 36cm from side of trench	X	X	10-100	17		
Control	X	X	10-100	5		
Distribution(1) box effluent	X	31,000	46,000	270		
May 26, 1971				($x10^0$)		
Crust material at base of trench	X	X	$40x10^4$	$40x10^6$		
5cm below base crust	X	X	6,400	$73.5x10^5$		
40cm below base crust	X	X	40	$12x10^4$		
150cm below base crust	X	X	X	68,500		
2m below trench(1) (ground water)	*	*	10-100	38,000		
Side wall crust	X	X	26,000	$15x10^7$		
5cm from side wall (horizontally)	X	X	12,600	$18.9x10^6$		
30cm from side wall (horizontally)	X	X	10-100	$7.3x10^5$		
Household well	*	*	*	32		
May 26, 1971						
Trench effluent (1)	1	2,200	16,600	$29.5x10^4$	2,000	

Table 5.2 (continued)

Sample and date (See Fig. 5.2)	Enterococci	Fecal coliform	Total coliform	Total bacteria	FC/FS	pH
Nov. 17, 1971						
(test wells) (1)				(x10^2)		
A1	*	*	2.7	555		6.4
B1	194	20.0	70.0	192	0.1	6.4
B2	0.7	*	21.0	320		6.6
B3	*	*	4.3	224		6.5
B4	1.7	3.3	57.0	288	1.8	6.6
B5	*	*	4.0	328		6.6
B6	3.7	*	6.3	469		7.1
B7	3.3	*	23.3	692		6.1
B8 (2)	491	7,250	7,250	2,430	14.8	6.3
C1	13.0	6.7	16.7	309	0.5	6.3
C2	52.7	*	23.3	140		6.3
C3	256	*	6.7	180		6.5

Table 5.2 (continued)

Sample and date (See Fig. 5.2)	Enterococci	Fecal coliform	Total coliform	Total bacteria	FC/FS ratio	pH
Nov. 17, 1971 (test wells)(1)				($x10^2$)		
C4	1.3	*	*	160		6.4
C5	*	*	*	49		6.4
D1	0.3	*	32	192		6.6
D2	0.3	*	*	122		6.5
D3	1.3	*	7.3	140		6.5
House well	*	*	*	0.7		6.7

(1) Liquid samples

(2) A large amount of decaying organic material was found in the well.

X = organisms not detected, < 10/gram in average of triplicate plating

* = organisms not detected, < 1/ml in average of triplicate plating

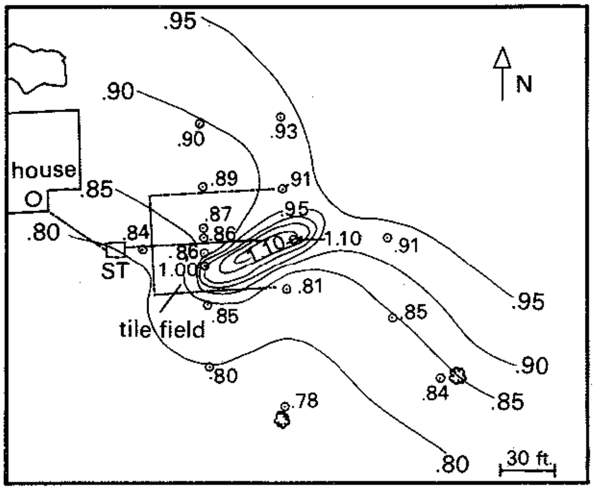


Fig. 5.4. Potentiometric map of ground-water levels around system 1 (Adams).

mound (.20-.25 foot high) created by recharge from the drain field. The position of the mound indicates recharge is occuring only from the middle tile of the drain field and largely from the end of the tile. The recharge mound is elongate in the direction of ground-water movement.

An attempt to estimate the ratio of mixing of effluent and ground water under the drain field was made at this site as it is one of the least complicated, hydrologically. The ratio is important to determine the dilution by ground water of pollutants introduced into the aquifer by septic systems.

Hydraulic conductivity measurements yielded a K_{sat} of 500 cm/day (Fig. 5.3). Measurements were made by the double tube method which is largely a determination of vertical conductivity. Horizontal hydraulic conductivity in layered sediments is generally greater than vertical conductivity. According to Weeks and Stangland (1971, p. 25) ratios range from 1:1 to 1:7 vertical to horizontal hydraulic conductivity in sands of the central sand plain of Wisconsin. A ratio of 1:5 vertical to horizontal conductivity was assumed for sands at site 1. Converting the 500 cm/day to Meinzer units and multipling by 5, gives a horizontal hydraulic conductivity of 600 gallons per day (gpd) per square foot.

It was assumed that all mixing of effluent and ground water occurs within the top 10 feet of the aquifer and, from the piezometric map, (Fig. 5.4) across a 100 foot width immediately under the drain field. Thus, the transmissivity of the aquifer strip is 6000 gpd/ft (hydraulic conductivity x aquifer thickness). Darcy's Law states that the amount of water (Q) moving through a saturated porous media equals the product of the transmissivity (T), gradient on the water table (I), and the length of a contour line across which the water is moving (L), or Q=TIL. From the piezometric map, the average gradient was calculated to be .0015 feet/foot. Then Q=6000 gpd/ft x .0015 feet/foot x 100 ft. or 900 gpd is moving through the 10x100 feet strip of aquifer beneath the drain field.

Table 5.3. Results of chemical analyses of ground water sampled in wellpoints around system 1 (Hw - housewell).

Location of wellpoint	NH_4^+-N			NO_3^--N			Total-N			Dip			Total-P			Cl^-	pH
	24 Aug	8 Oct	17 Nov	24 Aug	8 Oct	17 Nov	24 Aug	8 Oct	17 Nov	24 Aug	8 Oct	17 Nov	24 Aug	8 Oct	17 Nov	24 Aug	17 Nov
HW	--	--	.21	--	--	4.2	--	--	4.8	--	--	<.02	--	--	.02	--	6.7
A1	0.9	1.1	0.4	0.4	2.2	2.7	5.6	7.3	3.6	.18	<.02	<.02	1.12	.21	.06	4	6.4
B1	1.9	5.7	2.2	0.3	9.1	0.4	6.0	17.7	3.9	.13	.07	.05	.58	.50	.18	5	6.4
B2	.3	1.1	0.4	1.3	0.8	1.1	5.3	6.2	2.0	.30	.10	.23	.48	.30	.34	6	6.6
B3	1.8	1.0	0.3	1.1	0.9	1.2	6.2	4.3	2.0	1.23	.25	.21	1.80	.31	.62	10	6.5
B4	6.7	12.9	0.1	16.1	1.2	1.7	34.4	17.6	2.9	.09	.16	.15	.48	.28	.72	29	6.6
B5	1.6	4.1	0.7	16.2	12.4	1.0	38.6	18.4	3.1	.05	.02	.03	.74	.94	.44	25	6.6
B6	4.0	2.5	1.2	9.1	1.5	1.1	15.6	11.6	3.9	.05	.03	.02	.32	.23	.28	23	7.1
B7	5.7	8.1	2.1	0.3	3.5	20.5	9.1	16.8	24.9	.23	.03	<.02	.80	.24	.48	22	6.1
B8	13.7	1.5	1.4	0.2	2.7	0.3	31.4	13.8	7.6	.45	.16	.04	1.26	.44	.84	50	6.3
C1	0.3	0.9	0.4	0.3	0.7	0.7	3.2	3.6	1.6	.03	<.02	<.02	1.06	.14	.16	5	6.3
C2	13.6	8.4	20.5	0.3	0.6	0.1	20.2	13.0	22.0	1.90	.20	.04	2.80	.36	.42	28	6.3
C3	5.6	5.9	1.5	0.2	0.7	0.4	12.2	8.4	3.1	1.00	.05	.06	1.98	.21	.92	24	6.5
C4	0.9	0.9	0.3	0.2	0.9	0.4	4.7	6.9	0.8	.04	.02	<.02	.58	.17	.28	6	6.4
C5	0.2	0.5	0.5	0.9	0.6	0.4	2.6	2.7	1.2	.02	<.02	<.02	.56	.22	.16	3	6.4
D1	0.6	1.0	0.3	0.5	0.7	0.3	12.1	3.5	1.5	.04	.02	<.02	.36	.49	.06	5	6.6
D2	1.0	0.4	0.3	0.3	0.5	0.6	1.5	6.2	1.1	<.02	<.02	<.02	.30	.36	.04	4	6.5
D3	0.2	0.4	0.3	0.3	0.3	0.4	0.4	6.7	1.1	<.02	.02	.03	.50	.17	.08	2	6.5

Loading was 130 gallons/day for three adults. Thus, the estimated ratio of mixing of effluent and ground water immediately under the drainfield is 130/900 or 1:7. Dilution will increase rapidly down-gradient when the effluent disperses over a larger area of the aquifer.

The analysis of waters obtained from observation wells in this system at a depth of about two feet below the ground-water level, reveals several trends. The first of these is the occurrence of high nitrogen and phosphorus contents below the system (for example: well points C2, B6, B7) as compared with control samples outside the flow system and thus not influenced by the seepage bed (for example: well points C1, D1, C5) (Table 5.3). The extent of diffusion of N and P downwards into the ground water was not determined as no deep wells were installed. However, water from the relatively deep house well at this site contained relatively high total-N concentrations that were greater than 4 mg/L, as tested in July and November. Lateral ground water flow from the system is difficult to describe because of the probable heterogeneous flow patterns throughout the layered soil in the C horizon. However, relatively low Cl contents, as measured in August in well points A1, B1, B2, C1, C4 and C5 could indicate a general southwesterly flow direction which would correspond with hydrogeological trends (Fig. 5.4). More well points are needed in the area southwest of the field to further document these trends. Effluent from the bed was not analyzed here, but data from other sites showed that N in the effluent occurred exclusively as NH_4-N and organic-N. The data from the well points of this system indicate that nitrification of NH_4-N to NO_3-N occurred in the shallow, approximately three feet deep, unsaturated soil between the seepage bed and the ground water (see well points B5 and B7 in some, but not all sampling periods). But nitrification appeared to be incomplete as several well points had still relatively high NH_4 contents (for example: C2). A decrease in N and P concentrations was found as a general trend in most well points from August to November. This may have been caused by a decrease in the loading rate in this period as the number of occupants in the house decreased from three to six. Concentrations in some well points were quite variable in different sampling periods (for example: B4, B5, B7) and continued monitoring should be made to determine the cause.

5.2.1.4. System 2

This system is eight years old. A top view and a cross section of the seepage bed are in Fig. 5.5. The system has a single 60 feet long perforated pipe laid in a gravel filled trench about 2 feet deep. The system regularly serves three adults and handles a measured daily load of 150 gallons (average for January 1972).

The site is located adjacent to an inlet of the Castle Rock flowage (Fig. 5.1, see also Photo 5.5). Ground water under the site is moving northward toward the inlet under a very low gradient of 6×10^{-5} feet/foot or about .3 feet/mile. Auger holes to a depth of 5 feet at the site indicated a predominantly medium to fine grained sand with some peat. The area reportedly has been filled several feet and covered a small wetland adjacent to the inlet. The heterogeneous soil fill was about two feet deep and had a loamy sand texture. Below this fill buried, and saturated, A and C horizons were found of the original "soil". The Ab horizon (0-20 cm) was a black sand with a dense soil fabric (bulk density: 1.8 gr/cm3). The horizon had 1% clay, 7% silt and 92% sand (8% very fine and fine, 13% medium, 68% coarse and 3.4% very coarse). The Cb horizon was a dark greenish gray sand with a single grain structure and a similar texture as the Ab.

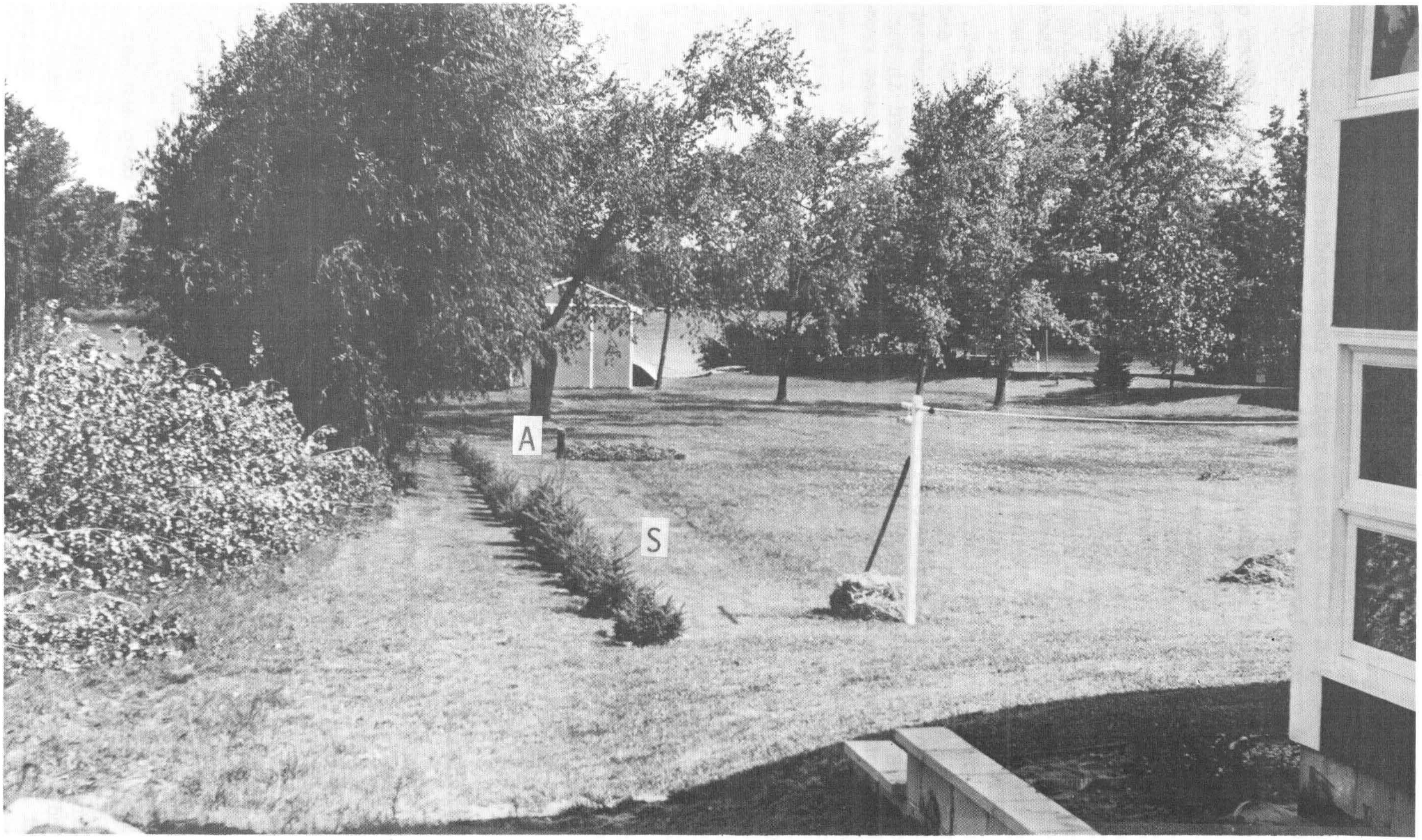
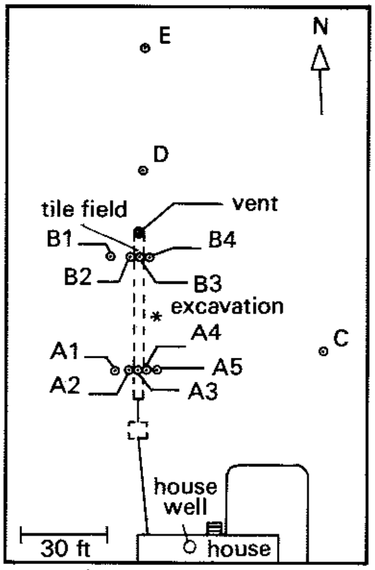
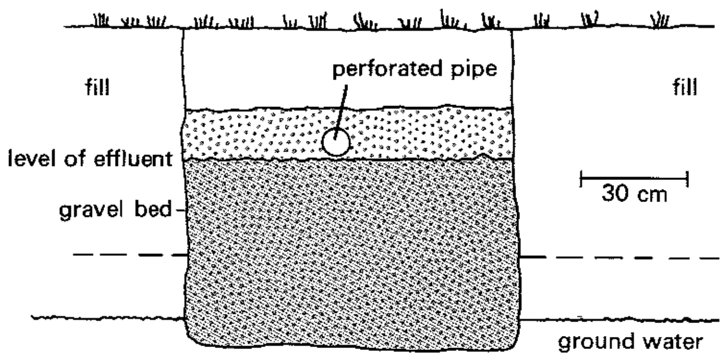


Photo 5.5. Subsurface soil disposal system 2 (Adams County). The subsurface seepage bed (S) with an airvent (A) was close to the ground-water level, which is indicated by the level of the lake in the background. This system functioned poorly.



Top view of system
with locations of well points



Cross section of trench

Fig. 5.5. Top view of system 2 with locations of sampling wells and a cross-section of the seepage bed (Adams).

The ground-water level at the drain field in July through November was $1\frac{1}{2}$ to $2\frac{1}{2}$ feet deep depending on topography. The water table was at or slightly above the bottom of the gravel-filled trench during this period. Because of its proximity to the Castle Rock lowage, ground-water levels are directly influenced by changes in stage of the flowage. A rise in level of the flowage may cause ground water to inundate the trench and possibly reverse the gradient on the water table. Conversely, a substantial drop in stage will greatly increase the gradient of the water table and effect movement of effluent out of the drain field. At the time of the measurements the stage of the flowage was near maximum. Continued monitoring of the site is needed to document these changes.

The potentiometric map of the water table at site 2, measured on November 11, 1971 (Fig. 5.6), shows only a very slight general mounding along the trench with a small mound at the north end of the trench indicated by well B2. Wells A3 and B3 are set in the gravel filled trench and show that the trench is filled with effluent approximately to the level of the discharge pipe. Ground-water movement and thus the flow path of effluent is perpendicular to the contours shown (Fig. 5.6) and is northward to the inlet where it is discharged.

The processes of disposal of effluent occurring in this system are essentially different from those in soils where the seepage bed is located well above the ground water and where movement occurs through unsaturated soil.

Table 5.4 Bacterial Analyses, System 2, Adams County

Sampled Aug. 24, 1971 and Nov. 17, 1971

(bacterial counts per ml)

Sample (See Fig. 5.5)	Enterococci 8/24	Enterococci 11/17	Fecal coliform 8/24	Fecal coliform 11/17	Total coliform 8/24	Total coliform 11/17	Total bacteria 8/24 ($x10^3$)	Total bacteria 11/17 ($x10^2$)	FC/FS 8/24	FC/FS 11/17	pH 11/17
A_1	33.7	1.0	7.0	*	660	*	67	30	0.2		6.4
A_2	328	68.0	*	*	5,410	3.7	900	112			6.6
A_3	990	1,220	1,300	1,070	27,000	53,000	23,000	700	1.3	0.9	6.9
A_4	33.7	1.0	*	0.3	267	2.3	900	290		0.3	6.9
A_5	5.0	*	*	*	2,600	2.0	140	>10,000			6.5
B_1	33.7	5.3	*	*	287	2.0	1,130	64			6.6
B_2	1.0	249	23.0	0.3-3.0	6,300	3-33	7,000	1,560	23.0	<0.02	-
B_3	697	205	300	200	37,300	1,200	18,700	6,900	0.4	1.0	7.4
B_4	*	*	31.0	*	410	0.3	42	124			6.7
C	1.3	*	*	*	767	*	41	108			6.3
D	0.7	43.0	*	50	163	1,320	27	256		1.2	6.4
E	58.0	*	110	*	1,480	3.0	417	220	1.9		6.6
F	913	13.7	*	*	7,240	1.0	223	256			5.8
H		0.7		*		1.7		7			6.8

* = organisms not detected, < 1/ml in average of triplicate platings

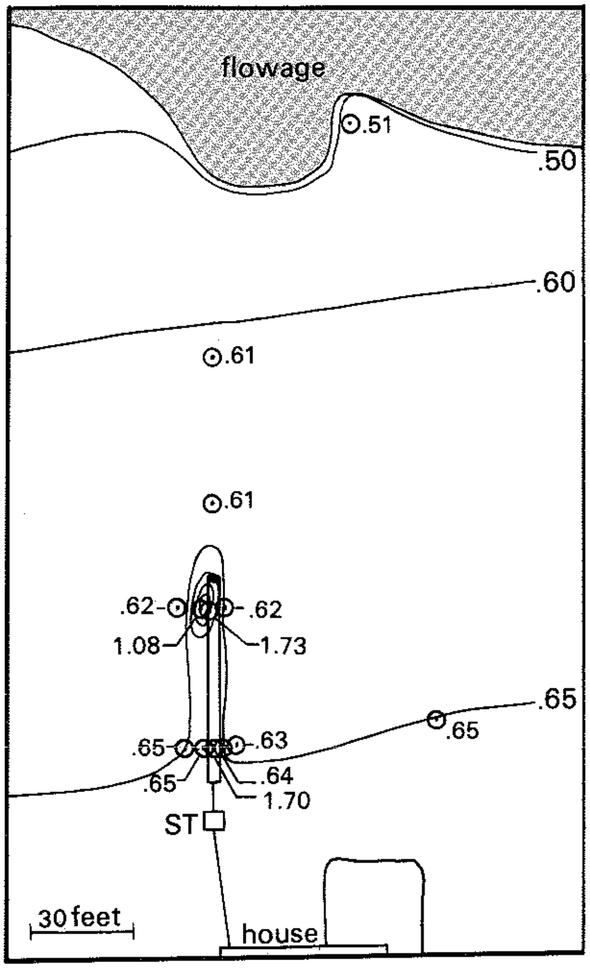


Fig. 5.6. Potentiometric map of ground-water levels around system 2 (Adams).

Effluent is flushed from this system by the ground water and the bacterial analyses of liquid from the surrounding wellpoints (Table 5.4) indicate that the lack of unsaturated flow in this flow system strongly decreases its effectiveness as a purifying filter. The movement of fecal organisms into test wells adjacent to the adsorption trench occurred as indicated by FC/FS ratios. The ratios of FC/FS obtained for trench effluent were, 0.4, 0.9, 1.0 and 1.3. In adjacent wells FC/FS values of 0.2, 0.3 and 23.0 were found. This seems to imply that the absence of crusting permitted greater lateral movement of fecal organisms than in similar soils where crusting was found. Two other wells located in the direction of ground water flow also had FC/FS ratios within the range of 0.7 to 4.0, indicating possible human contamination.

Interpretation of the Nitrogen and Phosphorus concentrations in the ground waters of this site, sampled at two feet below the ground-water level, is considerably more complicated than at site 1 (Table 5.5). The system is subject to more interferences, due to its location both in the shallow water table and heterogeneous fill material. For example, leaching of surface applied nutrients, grass clippings and lawn fertilizers are potential interferences in such a shallow water table.

Table 5.5. Results of chemical analyses of ground water sampled in well points around system 2. (Hw = housewell).

Location of wellpoint	NH_4^+-N 24 Aug	NH_4^+-N 8 Oct	NH_4^+-N 17 Nov	NO_3^--N 24 Aug	NO_3^--N 8 Oct	NO_3^--N 17 Nov	Total-N 24 Aug	Total-N 8 Oct	Total-N 17 Nov	Dip 24 Aug	Dip 8 Oct	Dip 17 Nov	Total-P 24 Aug	Total-P 8 Oct	Total-P 17 Nov	Cl^- 24 Aug	pH 17 Nov
Hw	--	0.3	0.6	--	0.3	0.3	--	4.2	3.6	--	.13	.10	--	.33	.14	--	--
A1	4.5	6.9	8.0	0.4	0.4	0.7	11.1	14.1	10.2	.66	.03	.05	1.62	.30	.34	10	6.4
A2	32.4	57.2	60.1	0.4	0.5	0.6	49.2	61.8	67.0	1.05	.22	1.20	3.36	.66	1.70	65	6.6
A3	74.5	67.8	74.2	0.4	0.2	0.1	105.0	93.1	81.8	4.40	.57	9.50	8.00	1.08	15.5	70	6.9
A4	39.8	32.3	43.7	0.5	0.4	0.6	46.2	42.6	47.5	1.08	.07	0.10	7.20	.28	.35	50	6.9
A5	2.7	8.6	1.3	0.4	0.8	0.1	12.6	9.1	2.2	.20	.08	.07	1.48	.26	.20	45	6.5
B1	5.8	8.6	2.3	0.4	0.7	0.6	12.1	14.9	4.6	.12	.08	<.02	.76	.30	.14	50	6.6
B2	8.5	--	--	0.4	--	--	14.1	--	--	.40	--	--	1.64	--	--	50	--
B3	--	--	--	--	--	--	62.0	--	--	4.00	--	--	11.20	--	--	60	7.4
B4	15.3	--	10.4	0.4	--	0.2	20.5	--	12.4	3.28	--	.05	6.84	--	.14	60	6.7
C1	0.3	1.9	0.3	1.1	0.8	0.2	4.0	5.9	1.2	.06	<.02	.04	.32	.22	.08	4	6.3
D1	1.9	1.8	0.1	0.2	0.4	0.3	6.1	5.0	2.3	.08	.05	<.02	3.80	.29	.13	5	6.4
E1	5.3	5.5	1.5	0.3	0.5	0.1	11.7	11.2	4.9	3.20	.32	.02	7.60	.52	.30	7	6.6
F1	0.2	2.3	0.2	0.2	0.6	0.4	3.0	4.0	2.2	.04	.09	.07	1.56	.26	.20	6	5.8
H1	--	0.4	0.2	--	0.4	0.3	--	2.0	1.1	--	<.02	<.02	--	.14	.04	--	6.8

From the data presented in Table 5.5 and the corresponding potentiometric map, Fig. 5.6, it is obvious that the seepage bed acts as a point source discharge for effluents high in N (90% NH_4-N) and P concentrations. Absence of nitrification processes in the flow system is indicated by very low NO_3 contents throughout. Nutrients have not been found in significant concentrations in wells D, E, and F between the bed and the flowage as would be expected from the hydrogeologic data. The possibility of NH_4^+-N adsorption and fixation on negatively charged clay and organic subsoil fractions could account for the low concentrations found in these wells.

5.2.1.5. System 3

This system was 5 months old at the time of the first investigation (July 1971). A top view of the system is shown in Fig. 5.7. The system has a single drain, about 42 feet long, set in a gravel-filled trench which is about 3½ feet deep. The system serves 2 adults and an infant and has a measured loading rate of 95 gallons per day (average for January, 1972).

The site is located adjacent to a broad wetland drained by Duck Creek (Fig. 5.1) which is the discharge point for ground water in the immediate area. The land surface slopes northward dropping about 6 to 8 feet in the 160 feet between the house and the edge of the marsh. Examination of samples from auger holes showed a uniform medium and coarse grained sand with some very coarse and very fine sand to a depth of 15 feet. The water table is at a depth of about 10 feet near the drain field. Separate soil analyses were not made at this site and physical characteristics of the soil around the bed are assumed to be similar to those around System 1.

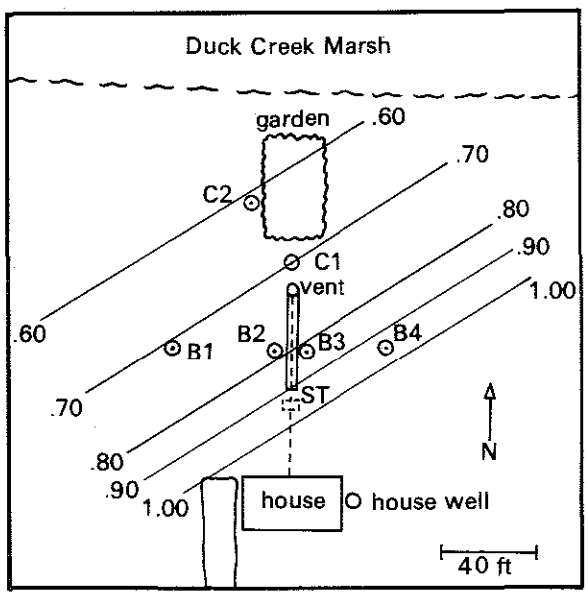


Fig. 5.7. Potentiometric map of ground-water levels around system 3, with locations of sampling wells (Adsms)

Table 5.6. Results of chemical analyses of ground water sampled in well points around system 3 (Hw = housewell, * = < 0.02 ppm).

Location of wellpoint	24 Aug	8 Oct	17 Nov	24 Aug	8 Oct	17 Nov	24 Aug	8 Oct	17 Nov	24 Aug	8 Oct	17 Nov	24 Aug	8 Oct	17 Nov	24 Aug	17 Nov
	NH_4^+-N			NO_3-N			Total-N			Dip			Total-P			Cl'	pH
Hw	--	0.4	0.8	--	0.9	0.7	--	2.5	2.5	--	*	*	--	.22	.12	--	8.2
B1	0.3	0.5	0.4	0.4	0.3	0.9	2.9	2.1	2.0	*	*	*	.10	.12	.06	7	7.2
B2	0.4	0.4	0.1	0.3	0.4	0.4	3.5	2.1	1.1	*	*	*	1.24	.14	.05	4	6.8
B3	0.1	0.3	0.2	0.2	0.4	0.3	3.2	4.0	1.5	.03	*	*	1.86	.12	.03	3	7.1
B4	0.2	0.3	0.1	0.2	0.3	0.3	3.4	2.2	1.2	.02	*	*	2.54	.24	.04	2	7.5
C1	0.4	0.3	0.1	0.3	0.3	0.1	3.6	2.5	1.2	.04	*	*	4.52	.08	.04	6	8.0
C2	0.3	0.3	0.1	0.3	0.3	0.2	1.4	2.2	1.1	.08	.02	*	2.80	.36	.02	5	6.6

Table 5.7 Bacterial Analyses, System 3, Adams County
Sampled Aug. 5, 1971, Aug. 26, 1971 and Nov. 17, 1971
(bacterial counts per ml)

Sample	Enterococci			Fecal coliform			Total coliform			Total bacteria			pH
(See Fig. 5.7)	8/5	8/26	11/17	8/5	8/26	11/17	8/5	8/26	11/17	8/5	8/26	11/17	11/17
A1 (house well)			*			*			*			276	8.2
B1		*	*		*	*		0.3	*		830	115	7.2
B2	*	*	*	*	*	*	810	197.0	*	73,000	423,000	981	6.8
B3		*	*		*	*		0.7	*		2,870	810	7.1
B4		*	*		*	*		*	*		13,000	172	7.5
C1	*	*	*	*	*	*	130	1.0	*	340,000	2,330	240	8.0
C2	*	*	*	*	*	*	*	*	*	2,000	2,870	66	6.6

* = organisms not detected, < 1/ml in average of triplicate platings

from auger holes showed a uniform medium and coarse grained sand with some very coarse and very fine sand to a depth of 15 feet. The water table is at a depth of about 10 feet near the drain field. Separate soil analyses were not made at this site and physical characteristics of the soil around the bed are assumed to be similar to those around system 1.

The potentiometric map of the water table (Fig. 5.7) was constructed from November 11, 1971 water level measurements. Ground water was moving northwestward under an average gradient of about 4×10^{-3} feet/foot or about 21 feet/mile and discharged to the Duck Creek marsh. There is no discernable mounding of the water table under the drain field. Excavation of this drain field showed the trench to be dry because crusting at the soil-gravel interface has not had sufficient time to develop due to the low volume use of the system. Thus, the trench provides only an intermittant rather than a constant source of recharge to the water table. The steeper gradient, and greater depth to the water table as compared with Sites 1 and 2, also probably contributes to lack of mounding at Site 3.

Because of its short period of use and lack of crusting this site should be monitored to document changes that occur both in the drain field trench and in the underlying ground water as the system ages.

The newness of this seepage bed is also indicated by the results of the chemical (Table 5.6) and bacterial (Table 5.7) analyses made from liquid samples from the well points at a depth of seven feet below the ground-water level.

Test wells at this site were free of FC and FS.

Analyses of the ground water at this site revealed no discernable difference in the N and P concentrations in wells placed in and out of the area potentially influenced by ground water flow. The latest sampling (Nov. 17, 1971) indicates the Total-N concentration to be no greater than 2.5 mg/L in any well tested, with NH_4-N and NO_3-N levels at less than 0.02 mg/L. The absence of higher contents of these nutrients may be due to processes of immobilization and adsorption in the eight feet of soil below this relatively new soil absorption system. However, lack of diffusion deep into the ground-water body to the level of the well points may be another reason.

Continued monitoring of this system will provide an insight as to the time lag between the introduction of effluent to the seepage bed and the appearance of excess N and P in the ground-water table. Well points will be raised to a level of two feet below the level of the water table as in the other sites.

5.2.1.6. System 4

This large system is four years old and has been functioning satisfactorily. It serves a ski lodge and has extremely heavy use during the winter months, particularly during weekends. A top view of the system and a section of the seepage bed are in Fig. 5.8. Four, 90 foot, drain tiles are set in a 95 x 30 foot gravel bed that is approximately 3 feet deep. The loading rate of this system could not be measured directly because it required a large and expensive high-capacity water meter that was not available. The loading rate, which is highly variable not only seasonally but also within any given week, was estimated to be periodically as high as several thousands of gallons per day.

This site is located north of Adams-Friendship on the west flank of the Friendship Mound (Fig. 5.1). The land surface slopes gently away from the site to the north, west and south. Ground-water movement generally follows the slope of the land surface from the sandstone mound, which acts as a recharge area, past the drain field site to Roche a Cri and Carter Creeks where it is discharged. Depth to the water table at the site is about 50 feet.

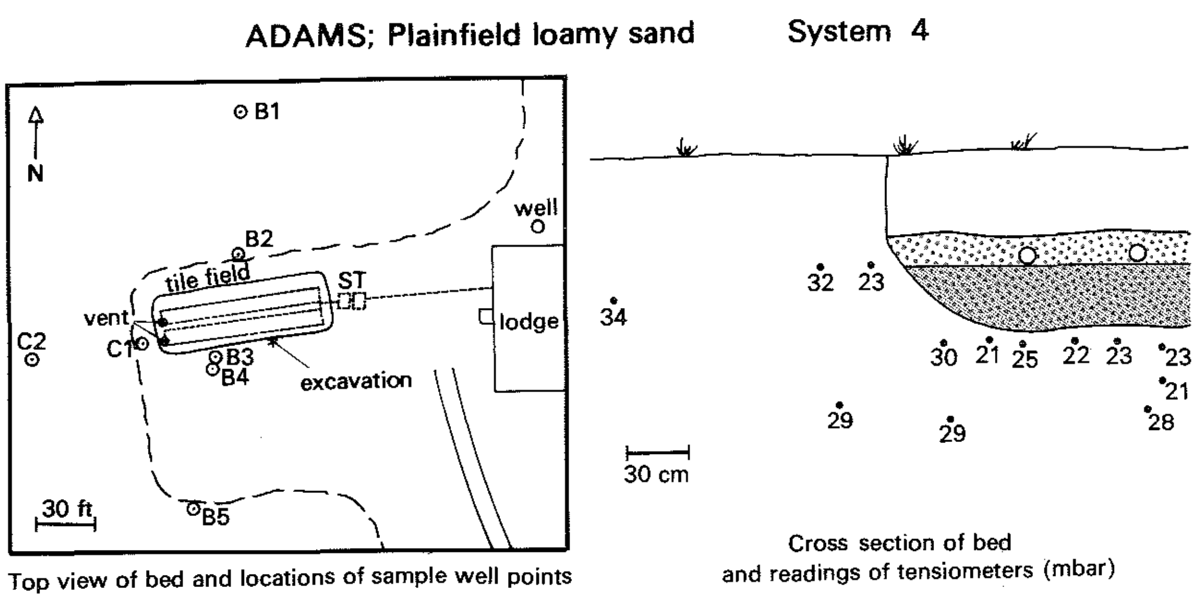


Fig. 5.8. Top view of system 4, with locations of sampling wells and a section of the seepage bed with locations and readings of tensiometers (Adams).

Table 5.8. Particle size distribution, bulk densities and particle densities of horizons in a Plainfield loamy sand (System 4, Adams Co.).

Horizon	C	FS	MS	CS	VFS	FS	MS	CS	VCS	Texture	Bulk density (gr/cm3)	Particle density (gr/cm3)
B21	1.00	2.00	3.00	1.00	2.60	6.90	15.69	65.89	1.70	coarse sand	1.54	2.71
B22	3.00	----	2.00	----	1.72	2.98	6.25	82.08	2.70	coarse sand	1.49	2.67
B3	----	----	1.00	----	1.19	2.17	10.24	82.27	3.04	coarse sand	1.61	2.72
C	----	----	----	1.00	0.11	0.63	6.68	86.02	6.20	coarse sand	1.67	2.63

The soil profile in the area was classified as a Plainfield loamy sand (Typic Udipsamment) with the following horizons: A1:0-6 cm: Brownish black loamy sand with many recognizable plant remains, fine subangular blocky. A2:6-9 cm: Brownish black loamy sand. B21:9-51 cm: Brown sand, medium subangular blocky. B22:51-60 cm: Brown sand, single grain. B3:60-75 cm: Yellowish brown sand, single grain, and C:75cm+: Bright yellowish brown sand, single grain. Particle size distribution and some other physical data are in Table 5.8. Hydraulic conductivity values for the C horizon, as measured with the crust method in situ, and moisture retention data for all horizons are in Fig. 5.3 (Chapter 5.2.3). Three percolation tests at the site in the C horizon averaged 2 min/inch. Moisture tensions of 21-25 mbar were measured in the soil adjacent to the bottom of the seepage bed, whereas tensions in the natural soil at similar depths were 34 mbar (Fig. 5.8). Crusting of the interface between the gravel bed and the underlying soil, is indicated by the occurrence of ponded effluent in the entire seepage bed. The measured tensions were remarkably similar to those measured around the bed in System 1, indicating that the "crust" had a similar hydraulic resistance despite differences in loading patterns of the two systems. With K_{sat} = 500 cm/day and $K_{23\ mbar}$ = 15 cm/day, the reduction in infiltration rate into the soil due to crusting can be estimated to be 33 fold. The soil below the bed is well aerated due to the unsaturated condition. At 23 mbar the C horizon contains 15% liquid by volume and 22% of air (see Fig. 5.3). Results of bacterial analyses of soil around the seepage bed show that fecal indicators are removed within a few cm of percolation, and analyses of well waters also prove to be free of fecal indicators (Table 5.9). This implies that this system was functioning quite well from the viewpoint of bacterial purification.

The hydrology of the area is quite complex because of the sandstone mound and because of interbedded silt and clay layers in the alluvial aquifer. The sample log for the ski lodge well, located about 100 feet west of the drain field, is shown in Fig. 5.9. The clay layer from 30-55 feet is persistant under the drain field and acts as a partial barrier to the downward movement of water. The clay layer appears to dip westward at about the same angle as the land surface. The well at the old ski lodge (Fig. 5.8), located east of the drain field and closer to the sandstone mound, is reported to be 35 feet deep and was flowing 3 to 4 feet above land surface during field investigations. The well apparently taps a small artesian flow system confined by clay layers that dip quite steeply westward off the sandstone mound.

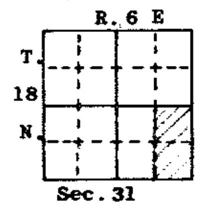
The potentiometric map of the water table (Fig. 5.10) was constructed from November 11, 1971 water level measurements. It shows the regional water table at about 50 ft depth and a shallower mound of water perched on the clay layer under the drain field. This shallow perched water body is defined by shallow wells B2, B3, and C1 (Fig. 5.8) and apparently results from effluent from the drain field that is retarded by the clay layer in its downward movement. The slight westward "bulge" of the contours on the regional water table at the drain field indicate that recharge is occurring from the perched water through the clay layer.

Fig. 5.11 gives a cross section of the seepage bed and underlying soil layers and graphically demonstrates the chemical transformations in the leached effluent. The perched water table on top of the clay layer permits

UNIVERSITY OF WISCONSIN GEOLOGICAL & NATURAL HISTORY SURVEY — **Log No. All-Ad-55**

1815 University Avenue, Madison, Wisconsin 53706 — Sample Nos. All Retained

Well name	Sky Line Ski Area Well #2 Preston Township	County:	Adams
		Completed...	1/12/70
Owner....	Sky Line Ski Area,, Inc.	Field check.	
Address..	Route 2 Friendship, Wisconsin 53934	Altitude....	
		Use.........	Lodge
Driller..	Ace Well Drilling Co.	Static w.l..	20'
Engineer.		Spec. cap...	2



Quad. Adams 15'

Drill Hole						Casing & Liner Pipe or Curbing							
Dia.	from	to	Dia.	from	to	Dia.	Wgt.& Kind	from	to	Dia.	Wgt.& Kind	from	to
12" 6"	0' 40'	40' 108'				12"	New black steel P.E. 49.56 lbs. per ft.	0'	40'	6"	T.&C. New bl steel 19.45 lbs. per ft.	+13"	104'
										6"	5 ft. screen	104'	108'

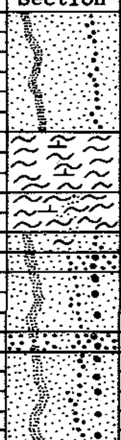
Grout: Kind	from	to
Cement and water	0'	40'

Samples from 0' to 108' Rec'd: 1/27/70 Studied by: M. Roshardt Issued: March, 1970

Formations: Alluvium

Remarks: Well tested for 12 hours at 60 gpm with 30 feet of drawdown.

LOG OF WELL:



	Depths	Rock Type	Color	Grain Size Mode	Grain Size Range	Miscellaneous Characteristics
ALLUVIUM	0-5	Sand	Gry or pnk	M	Fn/C	Quartz, feldspar, chert.
	5-10	"	"	"	"	Same
	10-15	"	"	"	"	"
	15-20	"	"	"	"	"
	20-25	"	"	"	"	"
	25-30	"	"	"	"	"
	30-35	Clay	Red brown	Clay	--	Calcareous. Trace sand.
	35-40	"	"	"	--	Same
	40-45	"	"	"	--	"
	45-50	"	"	"	--	Calcareous. Little sand.
	50-55	"	"	"	--	Same
	55-60	Sand	Bn gray	M	Fn/C	Little clay.
	60-65	"	Gry or pnk	M & C	Fn/VC	Mixed-mostly quartz. Trace granules.
	65-70	"	"	M	"	Same
	70-75	"	"	"	"	"
	75-80	"	"	"	"	"
	80-85	"	"	C	"	"
	85-90	"	"	M	"	"
	90-95	"	"	"	"	"
	95-100	"	"	"	"	"
	100-105	"	"	"	"	"
108'	105-108	"	"	"	"	"

END OF LOG

Page 1 of 1

Fig.5.9. Sample log for the well point near system 4 (Adams)

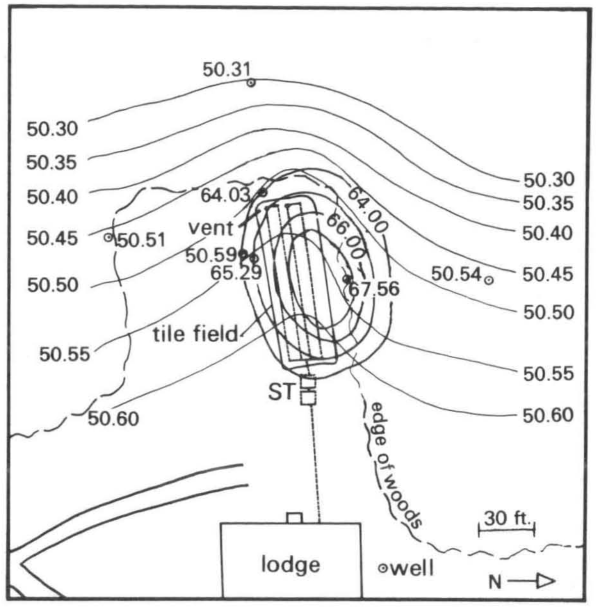


Fig. 5.10. Potentiometric map of ground-water levels around system 4 (Adams).

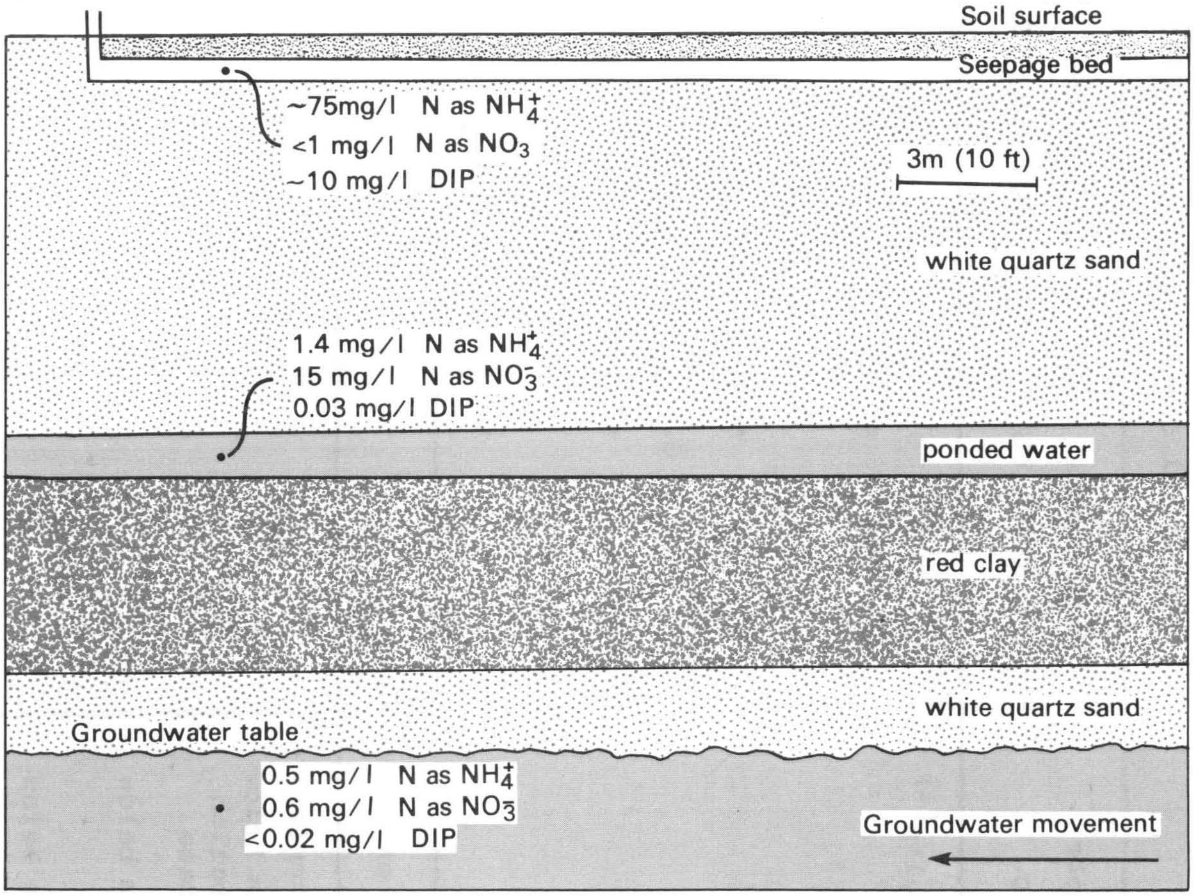


Fig. 5.11. Schematic cross section of the seepage bed and underlying soil layers in system 4, and chemical characteristics of liquid in successive stages of percolation.

Table 5.9 Bacterial Analyses, System 4, Adams County

Sampled July 22, 1971, Aug. 24, 1971, and Nov. 17, 1971

(bacterial counts per gram of soil or per ml in liquid samples)

Sample	Enterococci			Fecal coliform			Total coliform			Total bacteria			pH
(See Fig. 5.8)	7/22	8/24	11/17	7/22	8/24	11/17	7/22	8/24	11/17	7/22	8/24	11/17	11/17
Test wells(1)													
B1		*	*		*	*		3.3	*		6,300	>1,000	6.6
B2		0.7			*			3.0			20,300		
B3		7.0	*		*	*		12.0	6.3		697,000	>1,000	7.3
B4		*	0.3		*	*		2.3	*		7,700	4,000	7.4
B5		*	*		*	*		1.3	*		9,300	>1,000	7.6
C1		*			*			*			3,600		
C2			*			*			0.3			1,350	7.1
Trench effluent(1)	1,170			10,300			45,000			98.6×10^6			
Soil samples(2)										$(\times 10^4)$			
a, 30cm below distribution field base	X			X			30			333			
b, 60cm below field	X			X			X			29.8			
c, 90cm below field	X			X			X			20.3			
d, 120cm below field	X			X			X			2,500			

Table 5.9 (continued)

Sample	Enterococci			Fecal coliform			Total coliform			Total bacteria			pH
	7/22	8/24	11/17	7/22	8/24	11/17	7/22	8/24	11/17	7/22	8/24	11/17	11/17
										($x10^4$)			
e, 150cm below field	X			X			X			44.6			
f, control 10m from system 75cm below field base	X			X			X			5.0			
g, control 10m from system 120cm below field base	X			X			X			2.3			

(1) Liquid sample

(2) Actinomycetes and molds found in all soil samples

* = organisms not detected, <1/ml in average of triplicate platings

X = organisms not detected, <10/gram

Table 5.10. Results of chemical analyses of ground water sampled in well points around system 4. (E = effluent in gravel bed).

Location of wellpoint	24 Aug	8 Oct	17 Nov	24 Aug	8 Oct	17 Nov	24 Aug	8 Oct	17 Nov	24 Aug	8 Oct	17 Nov	24 Aug	8 Oct	17 Nov	24 Aug	17 Nov
	NH_4^+-N			NO_3^--N			Total-N			Dip			Total-P			Cl^-	pH
B1	0.6	0.3	0.1	0.9	0.4	0.2	3.2	2.2	1.1	<.02	<.02	<.02	.64	.20	.08	6	6.6
B2	1.5	0.7	--	8.1	9.5	--	23.3	11.6	--	.03	.02	--	.24	.24	--	10	--
B3	2.5	1.4	0.7	17.3	17.7	13.8	41.1	27.1	14.9	.02	.04	.06	.52	.20	.23	13	7.3
B4	0.6	0.6	0.1	2.4	0.8	0.3	4.8	3.5	1.2	<.02	<.02	<.02	.32	.20	.54	12	7.4
B5	1.8	1.5	1.5	0.4	1.5	0.7	4.0	5.4	2.7	<.02	<.02	<.02	.34	.08	.10	10	7.6
C1	--	1.5	--	--	15.1	--	6.8	25.6	--	.07	.03	--	.54	.24	--	13	--
C2	--	0.7	0.7	--	0.4	1.9	--	3.7	2.9	--	<.02	<.02	--	.22	.05	--	7.1
E	75.1	--	--	0.1	--	--	80.6	--	--	10.3	--	--	12.6	--	--	--	

sampling of soil-leached liquid, only diluted by percolating rainwater, since the natural ground water occurs below this clay layer. The analyses of this perched liquid (Table 5.10) indicate that the unsaturated flow of the effluent through 30 ft. of fine to coarse sands allows ample time and favorable soil climatic conditions for the nitrification of NH_4-N to NO_3-N, as evidenced by the decrease in NH_4-N (from 75 mg/L to 1.5 mg/L) and corresponding increase of NO_3-N (from 0.1 mg/L to 15 mg/L) in the leached liquid.

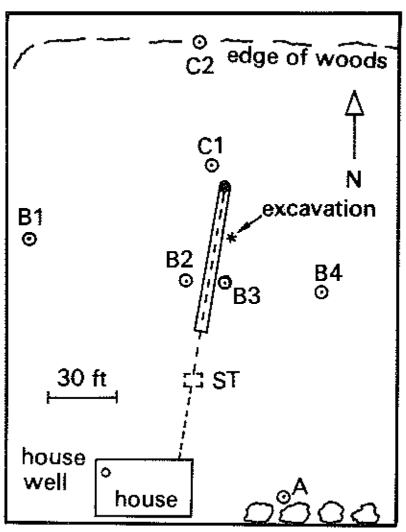
The decrease in Dip concentrations from the seepage bed to the perched water indicates absorption of P by the soil.

The still lower concentrations of N and P in the deeper water table may be due to the low permeability of the clay layer and to the relatively high flow rates of the ground water as indicated in the hydrogeologic study.

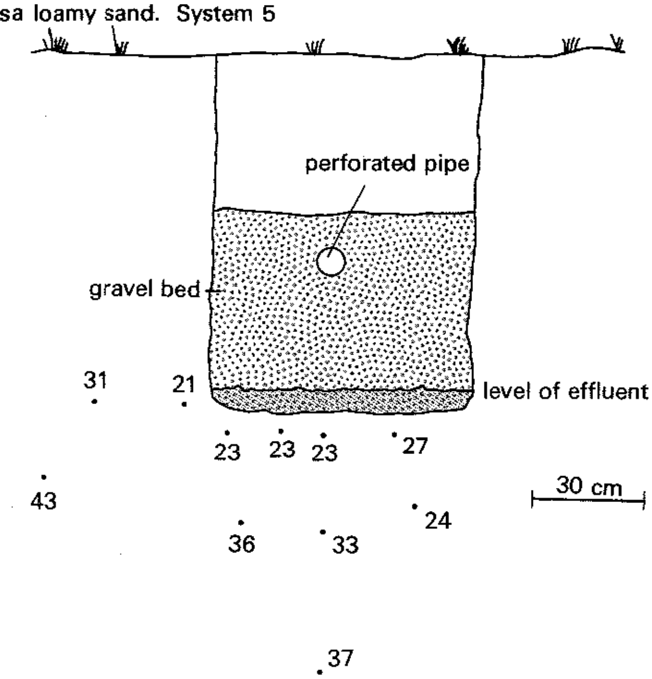
5.2.1.7. System 5

The site is located north and east of Adams-Friendship and slightly less than $\frac{1}{4}$ mile north of Friendship Lake on Roche a Cri Creek (Fig. 5.1). The lake is the discharge point for ground water moving southwestward at the site under a low gradient of approximately 1.3×10^{-3} feet/foot or about 7 feet/mile. Water table depth at the site ranges from 17 to 23 feet below land surface depending on topography. The house and the seepage bed are located on a low northwest trending ridge which appears to be a large dune deposit. Medium grained sand with some very fine and coarse grained sand ranges from about 3 to 10 feet in thickness and overlies a 10 foot, flat-lying bed of clay. Medium to coarse grained sand underlies the clay

ADAMS; Nekoosa loamy sand. System 5



Top view of system with location of well points



Cross section of trench and readings of tensiometers (mbar)

Fig. 5.12. Top view of system 5 with locations of sampling wells and a cross section of the seepage bed with locations of tensiometers (Adams).

Table 5.11. Particle size distribution, bulk densities and particles densities of horizons in a Nekoosa loamy sand (System 5, Adams Co.)

Horizon	C	FS	MS	CS	VFS	FS	MO	CS	VCS	Texture	Bulk density (gr/cm3)	Particle density (gr/cm3)
Ap	-----	-----	-----	1.00	1.67	1.73	6.10	84.07	5.20	coarse sand	1.77	2.68
B21	-----	3.00	2.00	1.00	1.95	1.94	10.77	73.32	6.53	coarse sand	1.73	2.68
B22	2.00	1.00	-----	1.00	1.37	2.85	18.05	70.58	3.88	coarse sand	1.62	2.44
B3	-----	-----	-----	-----	0.69	1.32	6.47	86.05	6.16	coarse sand	1.72	2.64
C	4.00	1.00	1.00	-----	0.69	2.07	11.28	76.82	5.44	sand	1.72	2.47
IIC	27.00	16.00	22.00	16.00	5.73	2.72	3.08	5.98	1.72	silty clay loam	1.29	2.39

bed. The land surface at the drain field slopes gently north and east.

This system was 7 years old. A top view of the system, that consists of a 60 foot long perforated pipe laid in a 3 foot deep gravel filled trench, and a cross-section of the seepage bed is shown in Fig. 5.12. This system serves 2 adults and 4 small children. The average daily flow through the system was estimated to be 250 gallons. Some seepage of effluent had occurred recently from the far end of the seepage bed where a clay layer is found within one foot of the bottom of the seepage trench. The saturated conductivity of this layer was only 5 cm/day as measured in large undisturbed soil cores. The excavation for studying moisture conditions around the trench was made at a location, indicated in Fig. 5.12, where 4 feet of sand were present on top of this clay layer.

The soil profile at the point of excavation was classified as a Nekoosa loamy sand, silty substratum variant (Alfic Udipsamment). The occurrence of the clay layer within the solum changed the classification of the soil, as compared with the other soils in the area, because of its effect on the hydrology of the overlying sand. The following horizons were distinguished in this pedon: Ap:0-30 cm: Dark brown loamy sand, fine subangular blocky. B21:30-56 cm: Brown loamy sand, fine subangular blocky. B22:56-76 cm: Yellowish brown sand, single grain. B3:76-113 cm: Bright brown sand with common distinct brown mottles, single grain. C:113-133 cm: Yellowish brown sand with common distinct brown mottles. IIC 133 cm+: Reddish brown silty clay loam, medium subangular blocky. Particle size distribution and some other physical characteristics are in Table 5.11. Hydraulic conductivity values of the sand surrounding the seepage bed were not determined but they were assumed to be comparable to the values for Systems 1 and 4 in the area, because of similar particle size distribution. Moisture retention characteristics were determined for the major horizons of the pedon (Fig. 5.13). The different physical behavior of the clayey IIC horizon is strikingly evident when compared with the overlying sandy horizons. The clay is fine porous and only a small amount of liquid (4% of total soil volume) is extracted from the IIC between saturation and 100 mbar tension. The comparable figure for the coarse sandy B3 horizon (that surrounds the seepage bed) is 30% (Fig. 5.13). Moisture tensions of 23 mbar were measured in the soil below the seepage bed (Fig. 5.12). Discussions on the effect of such moisture tensions as reported for Systems 1 and 4 apply also to this system. The well-aerated unsaturated soil forms an excellent environment for the process of nitrification. N in the effluent occurs mainly in the form of NH_4-N (Table 5.13), which is nitrified to NO_3-N in the soil below the seepage bed. Fig. 5.15 shows the relative proportions of NH_4-N and NO_3-N in the soil below the bed, sampled at small increments.

Bacterial purification was very good, which confirms results obtained from analyses at Systems 1 and 4 (Table 5.12). However, effluent surfaced at the lower end of the bed due to the occurrence of a clay layer close to the soil surface. This liquid contained 14 FS/ml, 26.7 FC/ml and 3,670 TC/ml. This is unacceptable from a public health standpoint. Construction of a second seepage bed in sand closer to the house would solve this problem.

Table 5.12 Bacterial Analyses, System 5, Adams County

Sampled July 22, 1971, Aug. 26, 1971 and Nov. 17, 1971

(bacterial counts per gram of soil or per ml in liquid samples)

Sample (See Fig. 5.12)	Enterococci 7/22	Enterococci 8/26	Enterococci 11/17	Fecal coliform 7/22	Fecal coliform 8/26	Fecal coliform 11/17	Total coliform 7/22	Total coliform 8/26	Total coliform 11/17	Total bacteria 7/22	Total bacteria 8/26	Total bacteria 11/17
Test wells (1)												
A1		*	*		*	0.3		1.7	0.3		1,400	1,300
B1		0.3	*		*	*		100	*		5,070	1,500
B2	*	*	*	*	*	-	2.0	1.0	*	3,330	63,000	130
B3		*	*		*	*		1.3	1.0		600	270
B4		*	*		*	*		3.3	*		400	370
C1	*	0.3	*	*	*	*	*	3.0	*	500	2,370	200
C2		*	*		*	*		*	*		38,700	6,900
House well (1)	*	*	*	*	*	*	*	*	*	300	127	20
Trench liquid (1)	130		41.3	$4x10^4$		6,400	$22x10^4$		23,500	$113x10^5$		$4x10^6$
Surfaced trench liquid (1)			14.0			26.7			3,620			$18x10^4$
Crust material												
1 cm below trench	X			X(3)			40,000			$27x10^6$		
2 cm " "	X			X(3)			27,000			$33x10^5$		

Table 5.12 (continued)

Sample (See Fig. 5.12)	Enterococci			Fecal coliform			Total coliform			Total bacteria		
	7/22	8/26	11/17	7/22	8/26	11/17	7/22	8/26	11/17	7/22	8/26	11/17
Crust material (3)												
3 cm below trench	X			X			226			$24x10^4$		
4 cm " "	X			X			X			$22x10^4$		
7 cm " "	X			X			X			$14x10^4$		
Adsorption field soil (2)												
15 cm below trench	X			X			X			$50x10^4$		
30 cm " "	X			X			X			$5x10^4$		
60 cm " "	X			X			X			$4x10^4$		
90 cm " "	X			X			X			$2x10^4$		
Control 1	X			X			X			$20x10^4$		
Control 2	X			X			X			$19x10^4$		

* = organisms not detected, < 1/ml in average of triplicate plating

X = organisms not detected, < 10/gr in average of triplicate plating

(1) liquid samples

(2) Actinomycetes and molds present. These organisms were present in all soil samples, with the greatest populations in samples 30 and 60 cm below the trench.

(3) Possibly some fecal coliform were present, however, a large number of Pseudomonas and other species may have masked the FC reaction on EMB.

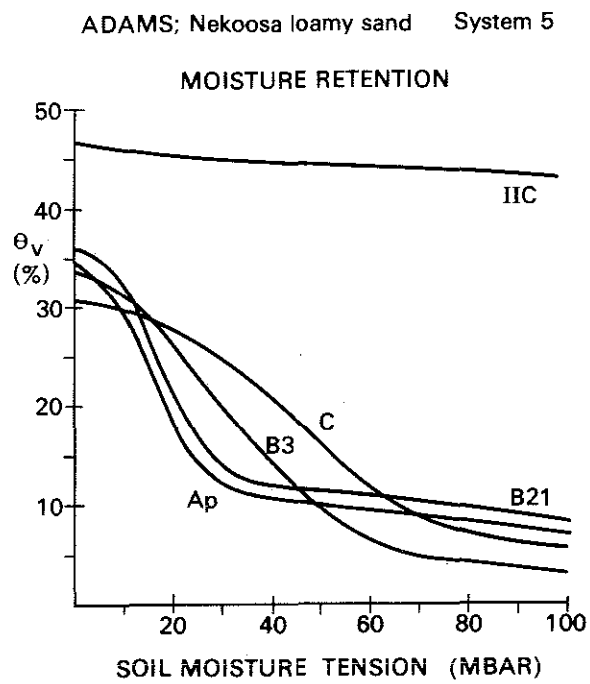


Fig. 5.13. Moisture retention characteristics for the horizons of a Nekoosa loamy sand (system 5, Adams).

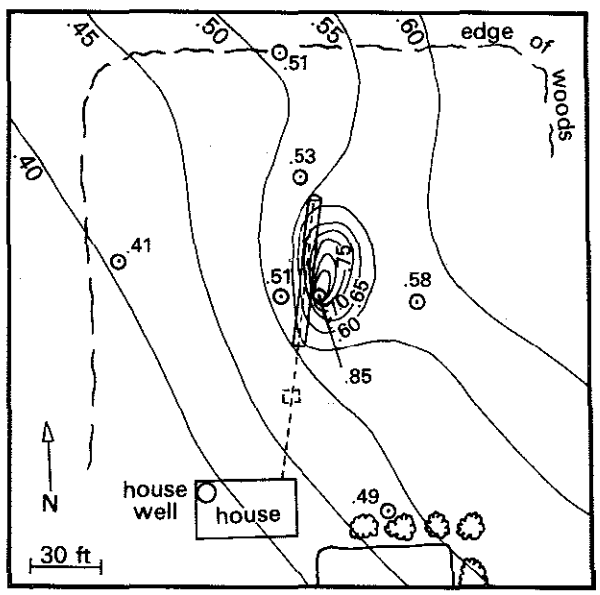


Fig. 5.14. Potentiometric map of ground-water levels around system 5 (Adams).

The potentiometric map of the water table, Fig. 5.14, was constructed from water-level measurements made on November 11, 1971. Water is moving under a low gradient perpendicular to the contour lines toward the southwest. Superimposed on this gently sloping water table is a low mound caused by recharge of effluent from the drain field as indicated by wells B3, B2, and C1. The clay layer, through which the effluent must move to reach the water table, does not appear to seriously retard the downward moving effluent and water is not perched on top of this layer. Note that the house well is directly down gradient from the drain field at a distance of about 70 feet.

Excessive leaching of N from the seepage bed into the ground water table is well documented by the high concentration of total -N (60 to 70% of which is NO_3-N) in all wells surrounding the seepage bed. These well points were located four feet below the ground-water level.

Nitrification processes in the unsaturated soil below the seepage bed are indicated by both the soil and water data. Analyses of soils taken at known increments below the seepage bed demonstrate the transformation of NH_4-N to NO_3-N (Fig. 5.15). Effluent analyses showed 57 mg/l NH_4-N and 0.1 mg/L NO_3-N in the seepage bed, whereas ground water immediately below averaged 4 mg/L NH_4-N and 30 mg/L NO_3-N (well points B2 and B3) (Table 5.13).

The relatively low levels of P in the ground water appear due to P adsorption in the soil below the seepage bed. The data indicate significant elimination of P from the effluent as it is leached through the clay layer (Fig. 5.15).

The house well, 70 feet directly down gradient, produces water apparently influenced by the septic tank system, as indicated by the relatively high N levels.

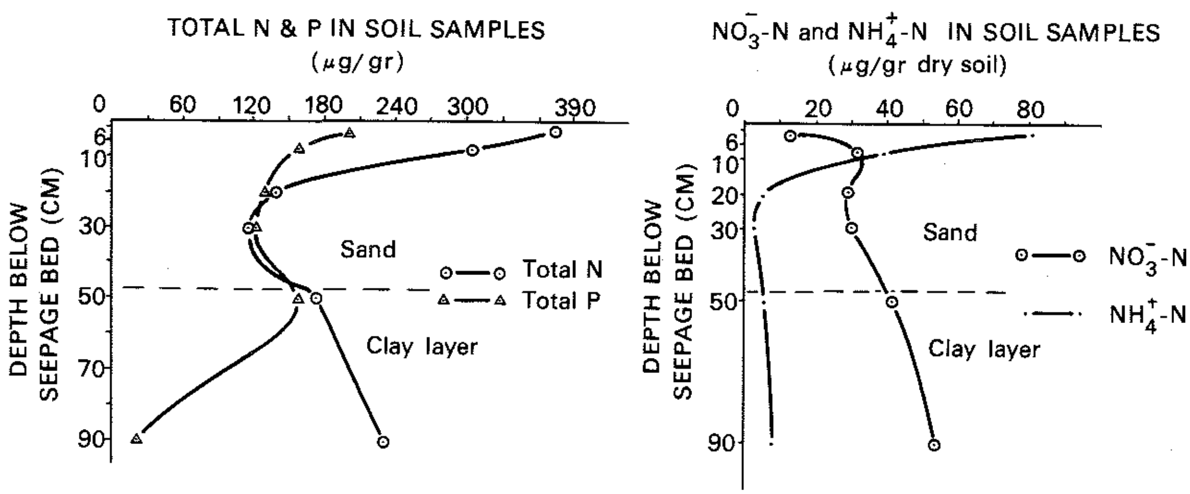


Fig. 5.15. Concentrations of nitrogen and phosphorus compounds in unsaturated soil below a crusted seepage bed (system 5, Adams).

Table 5.13. Results of chemical analyses of ground water sampled in well points around system 5 (E = effluent in gravel bed, * = < 0.02 ppm).

Location of wellpoint	NH_4^+-N			NO_3^--N			Total-N			Dip			Total-P			Cl-
	24 Aug	8 Oct	17 Nov	24 Aug	8 Oct	17 Nov	24 Aug	8 Oct	17 Nov	24 Aug	8 Oct	17 Nov	24 Aug	8 Oct	17 Nov	24 Aug
Hw	--	0.3	0.1	--	2.3	2.2	--	3.7	3.6	--	*	*	--	.07	.06	--
A1	0.5	2.2	0.6	0.7	0.8	3.5	2.2	4.9	4.8	*	*	*	.14	.08	.06	13
B1	4.4	1.0	0.7	0.5	5.7	6.9	10.5	7.6	10.7	*	*	*	.10	.10	.07	8
B2	13.0	3.8	2.2	11.8	36.4	31.0	79.6	53.3	46.7	*	*	*	.20	.44	.07	46
B3	5.8	0.5	0.1	17.1	38.1	39.3	39.7	51.4	55.4	*	.04	.04	.90	.10	.28	22
B4	5.0	2.7	1.8	0.6	10.2	12.0	11.6	17.3	19.0	*	*	*	.16	.08	.12	21
C1	13.7	5.1	1.6	9.6	37.1	33.0	65.8	54.2	43.1	*	*	*	.12	.08	.06	39
C2	0.3	0.6	0.1	0.5	0.7	0.4	2.9	2.8	1.4	*	*	*	.20	.08	.03	6
E	--	51.1	57.2	--	0.1	0.1	--	56.4	67.4	--	8.7	24.0	--	10.9	28.6	--

5.2.1.8. Summary and discussion of chemical analyses in the context of general system performance

Results of monitoring chemical transformations in percolating effluents from five subsurface soil disposal systems in sandy soils, as reported in the previous chapters, can be summarized as follows:

1. High N (80 mg/L) and P (10 mg/L) contents were found in the septic tank effluent ponded in the seepage beds. About 85% of total N was in the form of NH_4-N and about 70% of total P was in the form of dissolved inorganic P.

2. Unsaturated soil was found below crusted seepage beds, where such beds were at least three feet above the water table. Tensions in the soil adjacent to the beds varied only slightly between 20 and 25 millibars in the systems studied, which corresponded with an average air volume in the soils of 25%. The resulting oxidative conditions induced nitrification of NH_4-N to NO_3-N, as documented by analyses of soil sampled below one of the seepage beds (see also Chapter 5.2.7 where similar analyses are reported).

3. Without oxidative conditions, nitrates were not formed in the soil around the seepage bed (see System 2). Relatively high NH_4 contents were observed in some well points around System 1, where the crusted bottom of the seepage bed was only three feet above the ground-water level.

4. Nitrates formed by nitrification moved downward with the percolating liquid into the ground water. Relatively undiluted liquid, that was ponded on top of a clay layer after 30 feet of percolation through sand below the seepage bed in System 4, had 15 mg/L NO_3. Ground water below System 5 had nitrate contents averaging 30 mg/L after 12 ft. of percolation.

5. Absorption of P by the soil was most effective in clayey layers in the flow system (see System 5). However, low values were also found in the ground water where only sand was present in the flow system. This study only reports the analytical results of P-analyses, which will be used later to define more specific studies that are needed to understand P absorption and transformations during soil percolation.

6. The general directions of ground-water flow were in agreement with trends observed in the concentrations of chemicals at the different well point sites around the systems.

Many more well points would be needed per site to obtain an accurate picture of the lateral movement of chemicals. In addition, many well points at different depths would be needed to obtain a picture of the depth of vertical mixing of nutrients in the surface layers of the ground water. Even then, however, a quantitative analysis of the flow system would be very difficult to make because of the heterogeneity of the layered porous medium through which the flow occurs.

The essential question to be answered at this point is how the performance of these systems is to be judged. In general, a subsurface soil disposal system is supposed to function well when the effluent that is discharged into the bed is: 1) absorbed by the soil, and 2) purified by the soil by the time it reaches the ground water. Purification is mainly defined at this time in terms of removal of fecal indicators, but other factors such as chemical quality should be considered as well. Considering these points the following judgments can be made:

1. Four of the five systems absorbed the applied liquid well. System 5 is excepted because the far end of the seepage bed was located on top of a clay layer of low permeability causing surface discharge. Three systems had a crusted seepage bed (Systems 1 and 4 and the part of the bed close to the house in System 5). One system was new and uncrusted (System 3) and one (System 2) was flushed by the ground water.

2. Three of the five systems were very effective in removing fecal indicators from the percolating liquid. System 2 was not effective at all due to the location in the ground water. System 5 had surface seepage due to the clay layer. However, the part of the bed close to the house was very effective in this system.

3. Four of the five systems, though relatively effective in removing P, were not very effective in removing N. Systems 4 and 5 had relatively high contents of nitrates in ponded water and in ground water below the systems. System 3 was too new to show high nitrates, but the same problem will most probably occur here later after continued use. System 2 had relatively high contents of only NH_4 in the groundwater adjacent to the system due to the absence of nitrification. The ground water below System 1 had relatively high total N contents with both NH_4-N and NO_3-N, due to only partial nitrification.

System failure has traditionally been defined in terms of insufficient absorption of effluent, resulting in highly visible and objectionable surface discharge. However, criteria for purification, as discussed earlier, have to be considered as well. This means that the performance of the five systems in Adams County will mainly have to be judged not on the basis of removal of fecal indicators, which was excellent, nor on the basis of their ability to absorb effluent, which was also very good, but on the basis of their capacity to remove excess nutrients from the effluent. This leads to a general question regarding the definition of "acceptable levels" of nutrients in ground water, considering flow velocities and depths of mixing in the ground-water body. This is a complex problem that cannot be answered in the context of this report. However, the data presented here and to be presented in some of the following chapters show that an average septic tank disposal system for a family of four, producing an estimated 300 gallons of effluent per day, will introduce an estimated 0.20 lbs. of N and 0.025 lbs. of P per day into the soil. This is 73 lbs. of N and 9 lbs. of P on a yearly basis. Whatever the judgment has to be regarding the level of pollution, there is no doubt that septic tank absorption beds in sandy soils introduce nitrates into the ground water if the depth of unsaturated soil below crusted seepage beds is more than three feet. Plans are therefore being considered at this time to construct an experimental system that will reduce the nitrate content of the percolating liquid by inducing processes of denitrification somewhere in the flow system, possibly by means of a flow barrier. Work of Bouwer (1970) and Erickson <u>et al</u>. (1971) has demonstrated that as much as 80% of the nitrogen or more can be removed from the effluent if processes of denitrification occur. In addition, more specific work has to be done to study removal of P during soil percolation of septic tank effluent.

5.2.1.9. System 6 (U.W. Hancock Experimental Station)

The discussion of this system is included in this chapter because the soil at this location is comparable to those studied in Adams County as reported in the previous chapters. Physical characteristics of the C horizon surrounding the seepage bed correspond with those of System 1 in Chapter 5.2.1.3. This large subsurface seepage bed, built in 1969, was studied in July 1970 by physical and bacteriological methods only. A top view of the absorption field and a cross section of one of the seepage beds is shown in Fig. 5.16. A large pit (Pit A) was dug next to the seepage bed, the bottom of which was at 6 feet below the soil surface (Fig. 5.16) to permit flow of liquid from the septic tank into the bed by gravity. This great depth offered many technical problems, because the sand walls of the pit caved in several times, even when braced. The soil below and at the sides of the seepage bed had a relatively dry appearance as observed in Pit A. After excavation it was found that the gravel in the bed was still clean and that effluent had not yet moved far into the trench. We may conclude that more than half of the length of this bed, and presumably of the other bed, which was not investigated, had not received any effluent during the first year of operation of the system. Two additional pits (B and C in Fig. 5.16) were dug closer to the septic tank. The bed contained effluent at both locations. Tensions measured around the bed at Pit B were 8 mbar and 25 mbar at 5 cm and 35 cm below the bed respectively.

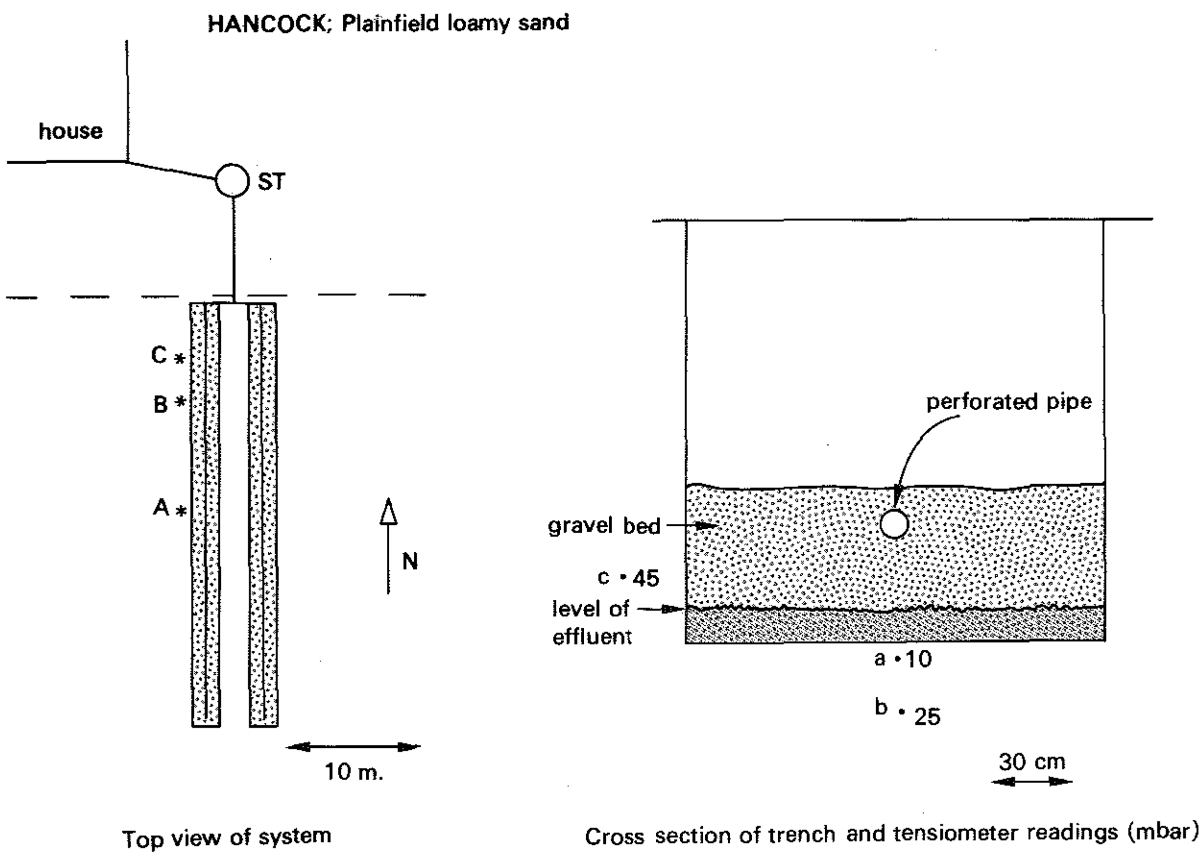


Fig. 5.16. Top view and cross section of the seepage bed with locations and readings of tensiometers (Hancock).

Table 5.14 Bacterial Analyses, System 6, Hancock, Aug. 15, 1970
(bacterial counts per gram of soil or per ml in liquid samples)

Sample (See Fig. 5.16)	Enterococci	Fecal coliform	Total coliform	Total bacteria
Excavation B				
5 cm below trench	***	***	$>10^4$	236×10^6
b, 30 cm below trench	***	***	17×10^4	24×10^6
Excavation C				
directly above(2) plastic trench cover	***	***	***	35×10^4
10 cm above(2) plastic trench cover	***	***	***	2×10^6
at side wall(2) of trench	***	***	***	6×10^5
c, 10 cm from side wall(2)	***	***	***	12×10^5
directly below trench	180	~100	13×10^4	184×10^6
a, 10 cm below trench	30	***	4×10^4	55×10^6
Control(2)				
1 ml from system 140 cm depth	***	***	***	8×10^4
Trench effluent(1)	1,240	1,000-10,000	11×10^4	92×10^6
Septic tank samples(1) (9/18/70)				
30 cm	420	18×10^3	57×10^3	75×10^6
60 cm	390	13×10^3	48×10^3	90×10^6
90 cm	100	15×10^3	46×10^3	24×10^6

*** = organisms not detected, <100/gram

(1) liquid samples

(2) many actinomycetes and molds present

This indicates weak crust formation at the bottom of the seepage bed under the advancing front of effluent. A tension of 8 mbar corresponds to a flow velocity (gradient 1 cm/cm) of around 200 cm/day. This very high infiltration rate explains why effluent did not reach beyond point B in the bed. Continued ponding will lead to increased crust development and resistance, whereupon the liquid front will move farther along the bed. Measurements of tensions could not be made in Pit C to demonstrate the increased tensions after prolonged ponding at that point, but measurements in older subsurface beds in similar sands showed subcrust tensions of 23 mbars, indicating increased crust resistance (see previous chapters). Samples for microbial analyses were taken in Pits C and B of soil below the seepage bed and liquid in the septic tank was sampled at three depths. Results are in Table 5.14.

Fecal indicator organisms were not found in the soil adjacent to the bed in Pit B. Directly below the seepage bed, FC and FS were detected in Pit C. Fecal streptococci ("Enterococci" in Table 5.14) were also found here 10 cm below the trench.

Evidence of a greater percolation rate at B over that at C due to lower crusting was implied by the density of total bacteria. At C, total bacterial counts dropped from 184×10^6/g to 55×10^6/g in 10 cm from the base of the trench. Total bacterial counts at B were 236×10^6 g at 5 cm and 24×10^6 g at 30 cm below the trench. Control samples of the natural soil contained 8×10^4/g total bacteria.

The vertical movement of FC and FS was deeper at point C than at point B, which was near the wetting front in the bed. This can possibly be explained by the greater density of fecal organisms in the soil area adjacent to the bed at point C, that had been crusted for a longer time than at point B.

Fecal coliform and FS were not found above the absorption trench. The soil in this region was very moist due to stagnation of percolating water on top of the seepage bed.

5.2.2. Stevens Point study area

This study area had an unusual number of "dry wells" or "seepage pits" for soil disposal of septic tank effluent. One such system was excavated and studied in detail in May, 1971. Homeowners of six other systems were asked about their experience with their operation. Samples of effluent and well water were taken for analysis (Chapter 5.2.2.2.). The study is important because seepage pits (dry wells) are still found in many areas of the state, although seepage beds have been installed ever more frequently in recent years.

5.2.2.1. System 1

A cross-section of a representative seepage pit (Fig. 5.17) shows that it consists of a chamber walled up with concrete blocks that are spaced to permit liquid to be in contact with the surrounding soil. The bottom of the pit is the excavated soil surface. Crushed rock (diameter 1-2 inches) fills the outer space between the concrete blocks and vertical sides of the excavation. The inside diameter of the seepage pit is 10 feet and the bottom is 11 feet below the soil surface. Samples of the effluent were taken and depth measurements were made through the air vent at the top after removal of the cap.

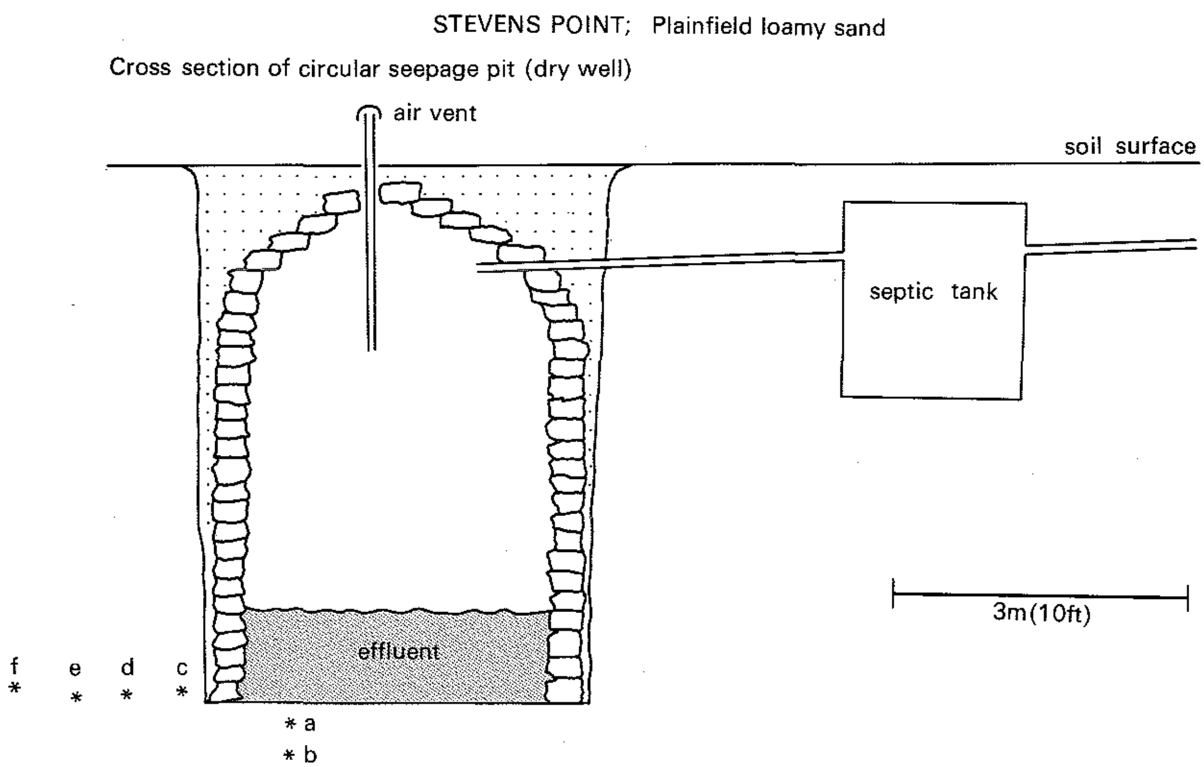


Fig. 5.17. Cross-section of a seepage pit with locations of sampling points (Stevens Point).

Seepage pits require relatively small surface areas for installation since their vertical walls form the major infiltrative surfaces. Seepage beds, in contrast, need much larger areas since their infiltrative surfaces are defined in terms of absorptive bottom areas. Construction of seepage pits has some economic advantages in forested areas, in that fewer trees have to be removed from the site and economy of space is a distinct advantage on small lots. Special provisions in the State Code H 62.20 regarding seepage pits (Board of Health, 1969) limit their construction to soils with percolation rates faster than 30 min/inch. Percolation tests are to be made in each vertical stratum penetrated below the inlet pipe. Soil strata in which the percolation rates are slower than 30 min/inch are not included in computing the absorption area. The average of the results is used to determine the required minimum absorption area, according to tables provided by the Code.

Table 5.15. Textural analysis and some other physical characteristics of a Plainfield loamy sand (Stevens Point).

Horizon	C	FS	MS	CS	VFS	FS	MS	CS	VCS	Texture	Bulk density (gr/cm3)	Particle density (g/cm3)	Porosity (%)
Ap	9.0	2.0	---	4.0	1.65	15.54	57.86	9.49	0.56	loamy sand	1.79	2.44	26.7
B2	7.0	---	---	4.0	2.20	14.75	63.06	8.49	1.12	loamy sand	1.69	2.53	33.2
B3	4.0	---	---	2.0	1.51	14.11	69.72	7.55	1.11	sand	1.66	2.67	37.8
C	2.0	---	---	2.0	0.95	5.34	87.34	2.56	0.11	sand	1.67	2.48	32.7

The soil at the study site was classified as a Plainfield loamy sand with the following horizons: Ap:0-16 cm; Very dark brown loamy sand, fine subangular blocky; B2:16-32 cm; Dark yellowish brown sand, single grain; B3:32-63 cm; Dark yellowish brown sand, single grain; C:63 cm+; Yellowish brown sand, single grain. The textural composition of the horizons is reported in Table 5.15. Hydraulic conductivity values, measured in situ with the double tube and crust tests, and moisture retention characteristics of the horizons are presented in Fig. 5.18.

Effluent was found to be ponded in all seepage pits examined in the area. However, this did not result in system failure. All homeowners indicated that their experience with their disposal systems was favorable. We may therefore assume that effluent was always absorbed by the soil in sufficient quantities to avoid overflow at the soil surface or backing up into basements. The statement does not, of course, relate to the question of ground-water pollution. Depth of liquid in the seepage pits varied from two to three feet, leaving several feet of unwetted sidewall area in the pit above the liquid level. The saturated hydraulic conductivity of the C horizon (that surrounds the greater part of the interior of the drywell) and its percolation rate (2 min/inch) are high. Liquid could not be present in the seepage pit if these high values would apply to the flow system. If they did, the term "dry well" would be literally true. For example: with K_{sat} at 400 cm/day, a layer of liquid of 60 cm would seep away in about four hours. Presence of liquid in the seepage pit, therefore, demonstrates that seepage is at a much lower rate. This is a result of crusting (see Chapter 2). A daily loading rate of 300 gallons represents a layer of liquid in the seepage pit (which has a bottom area of 6 m^2) 13 cm thick. An equivalent seepage rate, considered as a steady rate of 13 cm/day, corresponds with a soil moisture tension of 28 mbar in this soil (see Fig. 5.18). An equilibrium between liquid entering and flowing from the pit would exist if the effluent flowed through the bottom area at this rate (13 cm/day) but the real physical flow system is more complicated because liquid will also move horizontally into the sidewalls.

Moisture tensions could not be measured with tensiometers in the soil around the liquid-filled part of the seepage pit due to the technical difficulties of attempting a very deep excavation adjacent to the pit. But samples were taken of the soil around the lower part of the pit (see Fig. 5.17) and moisture contents were determined in the laboratory. Soil sampled 20 cm below the bottom of the pit had a moisture content of 15% by volume. This would correspond to a soil moisture tension of approximately 25 mbar. Samples taken at the sides of the pit averaged 11% by volume, corresponding with a tension of around 35 mbar (see moisture retention curve in Fig. 5.18). It should be noted that such indirect measurements of soil moisture tensions tend to be inaccurate because of the experimental errors involved. The soil samples may loose some moisture during sampling, transportation and weighing. The moisture content determination (% by weight) is converted into percent by volume by using the bulk density of the horizon. This value is determined in a separate experiment and has a variability of its own. This moisture content is then translated into moisture tension, disregarding hysteresis phenomena and using a moisture retention curve obtained by desorption of a separate soil sample in another experiment. However, the occurrence of

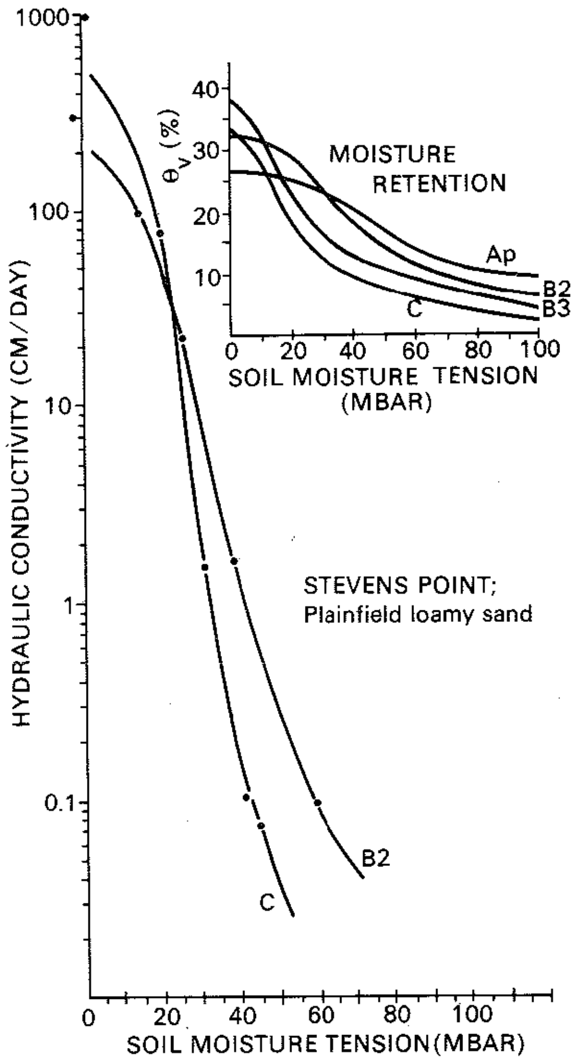


Fig. 5.18. **Hydraulic conductivity and moisture retention data for horizons in a Plainfield loamy sand (Stevens Point).**

crusting and resulting unsaturated condition of soil around the effluent-filled seepage pit is well documented and corresponds completely with phenomena observed in and around subsurface seepage beds. Bacterial analyses (Table 5.16) show that fecal indicators were removed from the infiltrating effluent by the soil within 30 cm of the side and bottom surfaces of the seepage pit (see also Chapter 7.3.4).

Although seepage pits have the advantage of requiring a relatively small area in a lot, they have the disadvantage of placement closer to the water table. For example, the ground water was at 16 feet below the soil surface at the study site, and the bottom of the seepage pit stood at 11 feet. This left only 5 feet of sand to serve as a filter. With a seepage bed at a depth of 4 feet on the contrary, 12 feet of sand would be available. The ground-water level may fluctuate considerably in these soils in different

Table 5.16 Bacterial Analyses, System 1, Stevens Point, May 7, 1971
Location of Site Corresponds to System H in Table 5.17
(bacterial counts per gram of soil)

Sample (See Fig. 5.17)	Enterococci	Fecal coliform	Total coliform	Total bacteria
a	X	200	4,550	$20x10^5$
b	X	X	5,500	$4x10^5$
c	10	40	350	$210x10^5$
d	X	X	1,800	>1,000
e	X	X	X	< 100
f	X	X	X	1,000
Control 1	X	X	X	$4x10^5$
Control 2	X	X	X	$< 10^5$

X = organisms not detected, < 10/gram in average of triplicate platings

Table 5.17 Bacterial and Chemical Analyses, House Well-Dry Well Survey
Stevens Point, May 7, 1971
(bacterial counts per ml, N and P levels as mg/l)

System	Enterococci	Fecal coliform	Total coliform	Total bacteria	NH_4^+-N	$(NO_2^- + NO_3^-)$-N	Total-N	DIP	Total-P
A, well	*	*	*	< 100					
dry well	28.5	< 100	4,000	10^3-10^5					
B, well	*	*	*	130	0.15	1.25	1.82	<0.02	0.03
dry well	5,370	900	32,500	10^4-10^5	82.12	0.49	99.61	39.50	89.60
C, well	*	*	*	<100	0.13	0.25	0.74	<0.02	0.04
dry well	47.5	<100	<1,000	<10^5	84.95	0.46	93.45	10.65	23.00
D, well	*	*	*	600	0.15	1.08	2.00	< 0.02	0.06
dry well	412	<100	14,000	31.5×10^5	61.29	0.37	76.63	9.60	22.20
E, well	*	*	*	672	1.12	0.65	3.86	< 0.02	0.08
dry well	240	200	18,000	1×10^5	100.66	0.69	124.00	20.25	45.40
F, well	*	*	*	< 100	0.15	2.31	4.05	< 0.02	0.64
dry well	650	10,000	40,000	14.5×10^5	33.26	0.49	51.50	7.35	16.60
G, well	*	*	*	13	0.26	1.42	2.28	< 0.02	0.05
dry well	10,000	<100	2,000	4×10^5	53.28	0.37	65.05	21.85	47.60
(1) H, well	*	*	*	<100	0.18	0.31	1.11	< 0.02	0.13
dry well	3	1,000	31,500	6×10^5	34.80	0.68	44.11	17.10	36.80

(1) This is System 1 Table 5.16

* = organisms not detected, < 1/ml in average of triplicate platings.

seasons. Under these conditions seepage pits are much more vulnerable to flooding than are seepage beds. Flooding of any seepage bed or pit is very unfavorable because it stops oxidative and filtrative processes characteristic of unsaturated soil (see Chapter 5.2.1.4).

Conclusion: Seepage pits (also called dry wells), as studied here, can be effective in absorbing septic tank effluent. Such systems are, however, only suitable in coarse textured soils with permanently deep watertables. These restrictions severely limit their use potential. There is the possibility of chemical pollution of ground water in this as in other types of soil absorption systems in sands (Chapter 5.2.1).

5.2.2.2. Results of a survey of dry-well systems

Ponded effluents in eight soil disposal systems of the dry-well type, as discussed in Chapter 5.2.2.1, were sampled in the Stevens Point study area, to obtain figures on variability of septic-tank effluent composition. In addition, samples were taken of the house wells to document ground water pollution, if any. The depth of the ground water at these sites was around 15 feet below the soil surface, whereas water from the house well was pumped from depths over 50 feet. The well samples, therefore, do not give a picture of ground-water quality in the upper part of the aquifer. Data of this type was obtained and discussed in the Adams County study (Chapter 5.2.1). Results of bacterial and chemical analyses are summarized in Table 5.17. The data indicate a great variation in the number of indicator organisms found in the different dry wells. But enterococci and fecal coliforms occurred in large numbers in all effluents. None of the well samples had any fecal indicators, which shows that soil percolation, followed here by movement in the ground water, has been effective in removing these organisms. Chemical analyses of effluents also varied considerably (NH_4-N from 33 to 101 mg/L; Total N from 44 to 124 mg/L). Contents of nitrate were very low (0.4 to 0.7 mg/L) due to the anaerobic environment in the septic tank and in the ponded effluent in the dry well. However, the well aerated soil below the dry well, which absorbs and conducts the effluent, induces nitrification which explains why nitrate concentrations even at a depth of approximately 35 feet below the level of the ground water, are in some cases higher than those in the effluent. Also contents of Organic N (which is Total-N minus NH_4-N and NO_3-N) are relatively high. This trend was observed at other sites as well. Total P figures varied from 17 mg/l to 90 mg/l, while dissolved inorganic P (Dip) varied from 7 to 39 mg/l, which represents about 40% of total P. P contents in the well waters were all very low.

5.2.3. Lakeshore study area

Movement of nutrients from subsurface soil disposal fields into nearby lakes and streams is one of the subjects of study in the Inland Lake Renewal and Demonstration Project, of the University of Wisconsin and the Wis. Dept. of Natural Resources. In this project several soil disposal systems were located in different areas of the state and the current study includes periodic chemical monitoring of well points placed around these systems. Three of these systems were used by our research group to study crust development in seepage beds and bacterial purification during soil percolation. Samples were taken from the well points at these three sites for chemical analysis. However, the results of these tests will not be reported here at this time. The following three chapters will deal only with physical, and bacteriological aspects of soil disposal of septic tank effluent in these three soils. The authors express their appreciation to Dr. Steve H. Born and Mr. James A. Peterson for their cooperation in establishing this opportunity to study these systems.

5.2.3.1. System 1. Dardis Lake (Price County)

This soil disposal system was studied in July 1971 to establish physical flow conditions around the seepage bed. The system was one year old, and ground water at the site was at 24 feet depth. A second sampling trip was made in September 1971 to obtain samples for bacteriological analyses. A topview of the system and a cross section of the seepage bed are in Fig. 5.19.

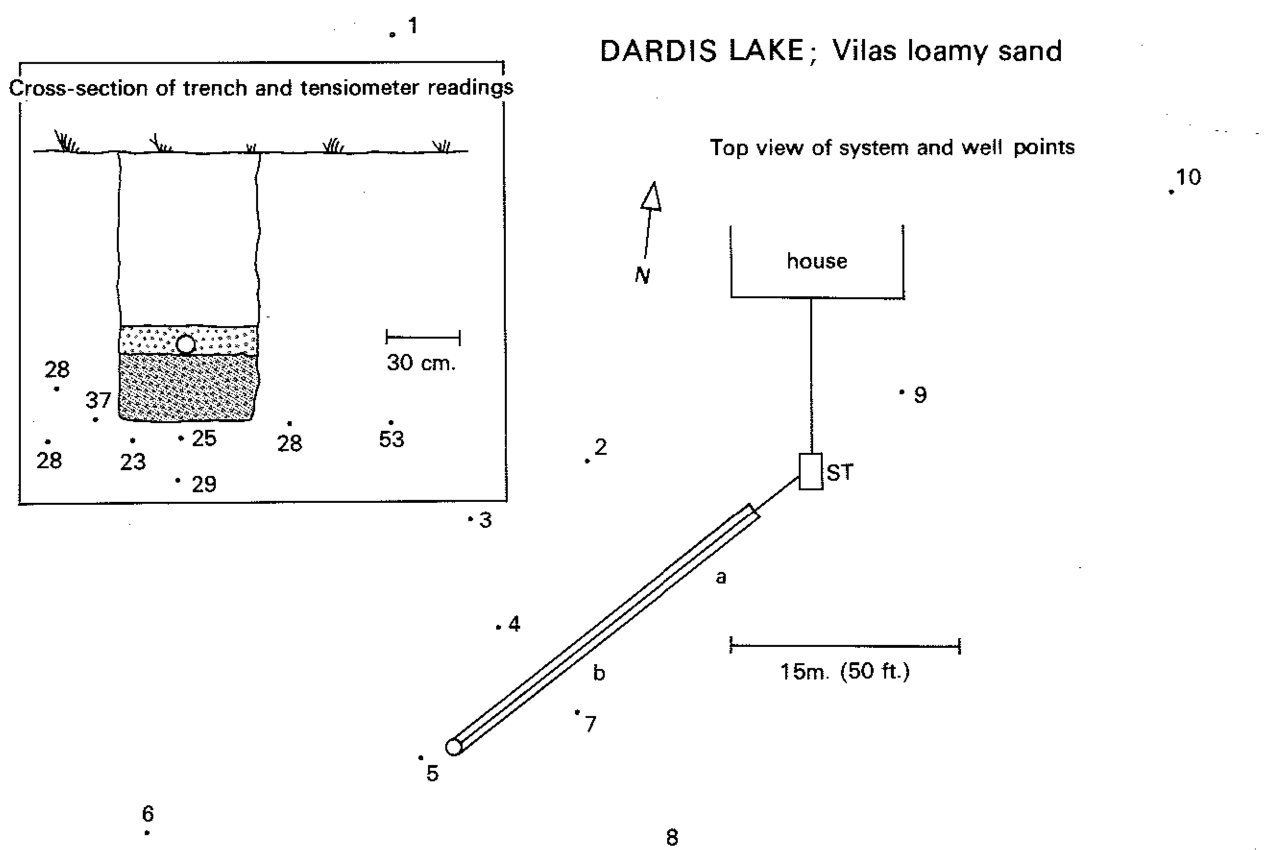


Fig. 5.19. Top view and cross section of the seepage bed with locations of well points and tensiometers (Dardis Lake).

Table 5.18 Textural analysis and some other physical characteristics of a Vilas loamy sand pedon near Dardis lake.

	C	FS	MS	CS	VFS	FS	MS	CS	VCS	Texture	Bulk density	K(sat) (cm/day)	Percolation rate
A1	10.00	3.00	5.00	11.00	7.64	3.89	4.47	42.55	11.78	coarse sandy loam	1.17		
A3	7.00	5.00	5.00	8.00	9.28	7.18	12.62	39.29	8.47	coarse sandy loam	1.47	130	
B21	3.00	1.00	2.00	8.00	7.03	4.34	9.65	55.14	10.07	coarse sandy loam	1.50	770	
B22	3.00	1.00	1.00	9.00	13.87	7.94	9.21	34.69	20.42	coarse loamy sand	1.59		
B31	1.00	1.00	-----	1.00	3.46	4.42	5.94	52.92	30.71	coarse sand	1.60	24	
B32	2.00	1.00	5.00	18.00	30.30	18.73	12.26	8.92	4.79	loamy fine sand	1.65		
C	-----	----	-----	1.00	0.78	1.21	6.35	70.65	20.21	coarse sand	1.49	600	10 Sec/inch

The soil at the site of the disposal field was classified as a Vilas loamy sand (Mollic Haplorthod), and the following horizons were distinguished: A1:0-8 cm: Very dark grayish brown loamy sand, fine subangular blocky. A3:8-20 cm: Dark yellowish brown loamy fine sand, fine subangular blocky. Bir:20-72 cm: Brown loamy sand, medium subangular blocky. B31:72-80 cm: Yellowish red coarse sand. B32:80-90 cm: Yellowish brown very fine sand. C:90 cm+: Dark yellowish brown coarse sand, single grain. The C-horizon was stratified. Textural analyses of the major horizons and some other physical characteristics are in Table 5.18. Moisture retention data and a calculated hydraulic conductivity curve for the C horizon of this pedon are in Fig. 5.20.

The measurements in July were made in an excavation at point a) adjacent to the trench (see Fig. 5.19). The bed was partly filled with effluent and tensions in the surrounding soil, induced by crusting, were 25 mbar below the bed and somewhat higher between 28 and 37 mbar at the sides of the bed. This creates a soil environment containing 10% liquid by volume and 30% gases

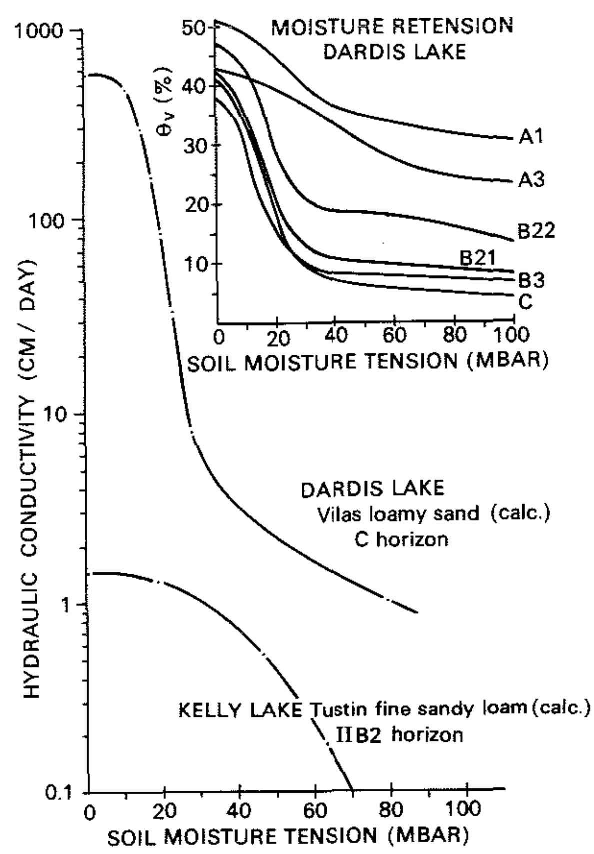


Fig. 5.20. Hydraulic conductivity and moisture retention data of horizons in a Vilas loamy sand (Dardis Lake).

Table 5.19 Bacterial Analyses, Dardis Lake, Sept. 8, 1971
(bacterial counts per gram of soil or per ml in liquid samples)

Sample (See Fig. 5.19)	Enterococci	Fecal coliform	Total coliform	Total bacteria	pH
Test wells(1)					
1	*	*	0.9	4,800	-
2	*	0.3	12.8	7,200	6.4
3	*	*	4.0	21,100	6.6
4	*	*	1.7	22,800	6.3
5	*	-	-	8,200	6.5
6	*	1.1	3.8	793	6.4
7	*	*	0.7	12,500	6.3
8	*	*	1.3	810	6.5
9	*	3.5	3.5	3,100	6.6
10	*	*	*	500	6.5
House well	*	*	*	2,470	8.1
Soil samples (Fig. 5.19 Location B)					
a, crust material	13	1,700	12,000	104×10^6	7.1
b, immediately below crust	X	-	760	46×10^6	6.9
c, 50 cm below crust	X	X	X	75×10^3	6.3
d, 80 cm " "	X	X	X	85×10^4	7.1
e, 110 cm " "	X	X	40	249×10^4	7.1
f, 140 cm " "	X	X	13	92×10^4	6.8
g, 170 cm " "	X	X	40	131×10^4	6.9
control	X	X	X	72×10^2	6.9

* = organisms not detected or <1/ml in average of triplicate platings
X = organisms not detected or <10/gram in average of triplicate platings
(1) liquid samples

(see moisture retention curve in Fig. 5.20). The uncrusted soil had a very high K_{sat} value (600 cm/day), and a high percolation rate (10 sec/inch). At a tension of 25 mbar flow rates will be reduced by a factor 40 to 10 cm/day, (in a one-dimensional flow system with a hydraulic gradient of 1 cm/cm). With a total absorptive area of 20 m^2, a flow rate of 10 cm/day would roughly represent a volume of 500 gallons per day. Observations made in July revealed that the bed was not filled with effluent at point b alongside the trench. However, when monitored in September, liquid was ponded in the trench at this point and bacteriological samples of the soil below the bed were taken at this location. Results of these analyses (Table 5.19) indicated that high FS, FC and TC were present in samples from the crust. Soil samples taken at depths exceeding 50 cm below the bed did not contain FC or FS. Three of the ten test well samples contained low numbers of FC. This observation is not in agreement with figures discussed earlier that showed removal of fecal indicators within 50 cm of percolation after passage through the crust. Experience in other sandy soils has also shown that crusted beds effectively remove fecal indicators (Chapter 5.2.1.). However, movement of these organisms can be much faster under hydraulic conditions approaching saturation. Observations indicate that the crusted bottom area of the bed had increased in area between July and September. Effluent moving into the trench will either seep away slowly through crusted soil or will flow over the crusted area to as yet uncrusted soil, which offers an initially high infiltration rate. This mechanism may explain penetration of fecal indicators to considerable depths in sandy soils below new seepage beds in which a crust is developing.

Conclusions: Crusting of the infiltrative surface in a subsurface seepage bed in the C horizon of a Vilas loamy sand strongly reduced the infiltration rate into the soil. Removal of fecal indicators occurred within 50 cm of the soil below the crusted bed. Data indicate, however, that movement to greater depths may have occurred near the advancing wetting front in this relatively new system.

5.2.3.2. System 2 Pickerel Lake (Portage County)

This system was studied in July and September 1971 to establish physical flow conditions around the seepage bed. The system was five years old and ground water was at 60 feet depth below the surface. A top view of the system is presented in Fig. 5.21. The soil around the bed was classified as a Plainfield loamy sand. The reader is referred to Chapter 5.2.1.3 for textural and soil-physical data. Loading of this system was irregular. Effluent was not found in the seepage bed when excavated in July and September. However, the soil below the gravel bed at locations a) and b) (Fig. 5.21) was very moist and a thin layer of wet, dark organic materials, usually associated with crusts at the bed-soil interface, was found at the bottom of the seepage bed.

If loading of a system is temporarily interrupted, ponded effluent in a crusted bed will continue to slowly infiltrate until the supply of effluent

Table 5.20 Bacterial Analyses, Pickerel Lake, Sept. 8, 1971
(bacterial counts per gram of soil or per ml in liquid samples)

Sample (See Fig. 5.21)	Enterococci	Fecal coliform	Total coliform	Total bacteria	pH
Test wells(1)					
1	*	*	*	273	7.1
2	*	*	*	6,750	7.4
3	3.0	*	*	22,600	6.8
4	*	*	*	68	6.8
Soil samples				(x 10^4)	
a, wet sand immediately below trench	X	430	3,800	1,370	6.4
b, 30 cm below trench	X	X	X	73	6.5
c, 60 cm below trench	X	130	430	57	6.5
d, 90 cm below trench	X	X	X	51	6.8
Control	X	X	87	11	6.0

* = organisms not detected, <1/ml in average of triplicate platings

X = organisms not detected, <10/gram in average of triplicate platings

(1) liquid samples

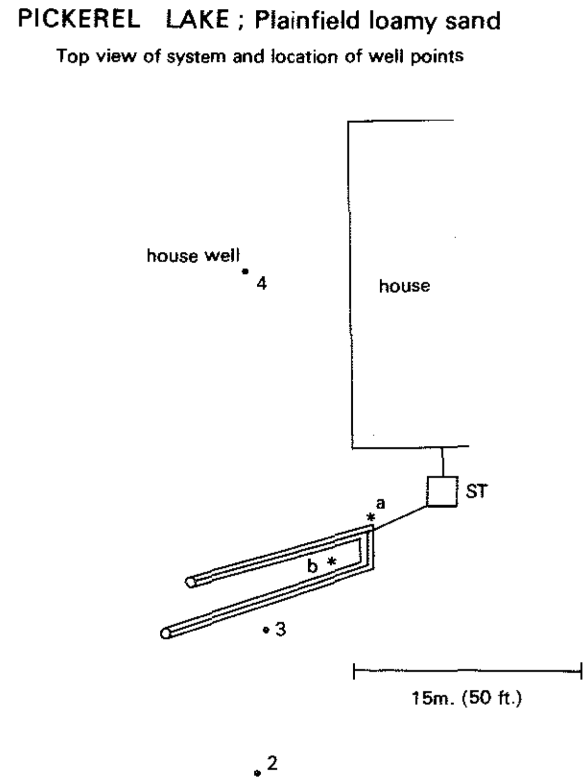


Fig. 5.21. Top view of the seepage bed with locations of wellpoints (Pickerel).

is exhausted. Then, oxidation of the crust material may occur upon exposure to the air in the seepage bed. This point appeared to have been reached in this system. Bacterial analyses of soil sampled below the bed and of liquid from the four well points, including the house well, are in Table 5.20. Soil sampled at the base of the trench was very moist and contained high FC, TC and total bacterial counts. These organisms may have originated from the septic tank and their growth may have been stimulated by the increased moisture and nutrient content in the soil adjacent to the bed. Water sampled from well number 3, which had a lateral distance of only 3 m from the seepage bed, had high total bacterial counts and some enterococci, but FC and TC were not found. Total bacterial counts decreased with distance from the system.

<u>Conclusion</u>: This seepage bed in sand did not contain effluent at the time of the investigation, but showed trends of bacteriological purification that corresponded with crusted ponded systems.

Photo 5.6. Malfunctioning subsurface soil disposal system (Kelly Lake). Effluent surfaced as it was not sufficiently absorbed by the very slowly permeable glacial drift in this Tustin sandy loam. Sand (S) was dumped on top of the absorption field area in a vain attempt to stop leakage.

5.2.3.3. Kelly Lake (Oconto County).

A top view of this soil absorption system and a cross section of the seepage bed are in Fig. 5.22. At the time of investigation in June 1971 the seepage bed was filled with effluent which flowed onto the soil surface and downslope toward the lake. Sand had been dumped on top of the soil surface in an attempt to stop this flow (Photo 5.6) but seepage persisted. The sampling program included: (1) study of the soil type in the area, (2) measurement of hydraulic conductivity of the major horizons of the soil and (3) measurement of soil moisture tensions in the soil around the gravel bed.

The soil in this area was classified as a Tustin fine sandy loam (Arenic Hapludalf) with the following horizons: A1:0-14 cm; Very dark grayish brown fine sandy loam, fine subangular blocky. A2:14-31 cm; Yellowish brown sandy loam, fine subangular blocky, A3:31-46 cm; Brown sandy loam, fine subangular blocky, faint strong brown mottles, IIB2t:46-76 cm; Reddish brown clay loam, coarse platy and medium subangular blocky, argillans. IIB3:76-120 cm; Brown sandy loam, coarse platy and fine subangular blocky. IIIC:120 cm+; Yellowish brown fine sand, single grain.

Results of textural analyses and other physical measurements are in Table 5. 21 The surface horizons of the pedon are shown to be relatively permeable (K_{sat} = 104 cm/day) but the subsurface horizons around the seepage bed had a low K_{sat} of 1 cm/day, decreasing strongly upon desaturation (see Fig. 5.20). The percolation rate was lower than 60 min/inch. The dense structure of the B horizons is also evident from the moisture retention characteristics (Fig. 5.23). Tensiometric measurements in the soil immediately adjacent to the bed showed a tension of 0 mbar. The K_{sat} of the B horizon is too low to absorb the effluent. The absorptive area of the bed is appr. 54 m^2 (bottom + sidewalls). Assuming hydraulic gradients of 1 cm/cm, infiltration through uncrusted soil would be 500L (125 gallons) per day, which is much lower than the estimated loading rate of 540 gallons per day.

KELLY LAKE; Tustin fine sandy loam (IIB2 silty clay loam)

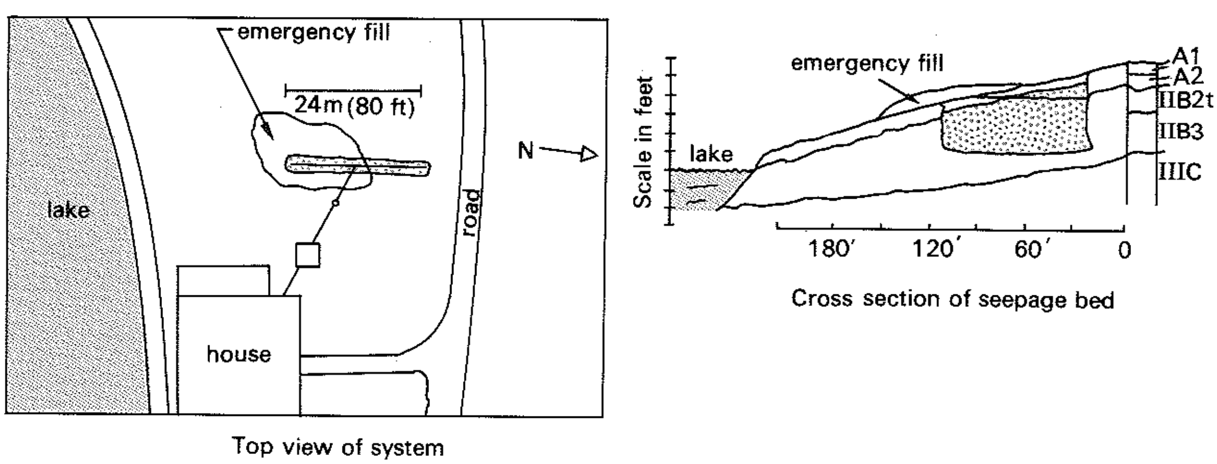


Fig. 5.22. Top view and cross-section of the seepage bed (Kelly Lake).

Table 5.21 Particle size distribution and some physical characteristics of a Tustin fine sandy loam.

Horizon	clay	fine silt	med. silt	coarse silt	very fine sand	fine sand	med. sand	coarse sand	very coarse sand	texture	Bulk Density	Porosity	K_{sat} (cm/day)	Perc rate
											(g/cm^3)	(%)		
A1	11.00	5.00	18.00	10.00	11.53	6.05	8.53	24.89	5.03	Sandy loam	1.28	45.2		
A2	5.00	7.00	16.00	14.00	14.26	6.73	13.18	20.18	3.65	Sandy loam	1.40	50.6	104 cm/day	
A3	13.00	14.00	8.00	4.00	14.17	7.85	13.06	21.77	4.22	Sandy loam	1.60	58.2		
IIB2	26.00	6.00	12.00	9.00	10.34	6.04	9.85	17.24	3.56	Sandy clay loam	1.62	36.0	1 cm/day	240, 120, 240 min/in.
IIB3	6.00	6.00	14.00	10.00	13.51	8.22	11.06	25.37	5.83	Sandy loam	1.71	54.7		
IIIC	5.00	2.00	13.00	12.00	14.71	7.45	13.38	26.85	5.59	Coarse sandy loam	1.51	48.1		

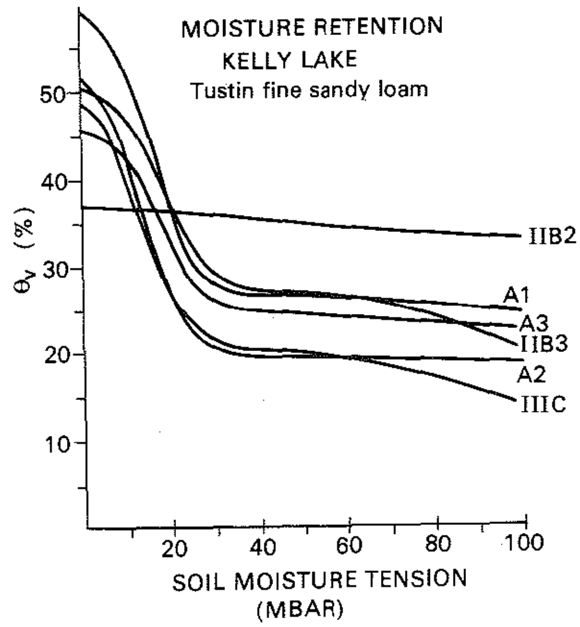


Fig. 5.23. Moisture retention data for horizons in a Tustin sandy loam (Kelly Lake).

Conclusion: The subsurface B horizons in the Tustin fine sandy loam have a low hydraulic conductivity, which explains low infiltration rates from the seepage bed and, as a consequence, system failure.

5.2.4. Arlington study area

5.2.4.1. System 1

The septic tank disposal system at the Poultry Farm of the Arlington Exp. Farms, University of Wisconsin was studied in the summer of 1970. The system was loaded at a rate of 80 gallons per day. The system had worked satisfactorily for eleven years. A large pit was dug next to one of the two seepage trenches and a tunnel extended under the trench (see Fig. 5.24). Tensiometers were installed on July 20 at several distances below and at the sides of the trench. Stoniness of the till was not such as to prevent installation of the tensiometers, although several attempts were necessary at most points before success was attained. Soil moisture tension measurements began as soon as equilibrium had been reached on July 21. The topsoil fill was removed from above the far end of the seepage trench and the depth of effluent in the bed was found to be 20 cm.

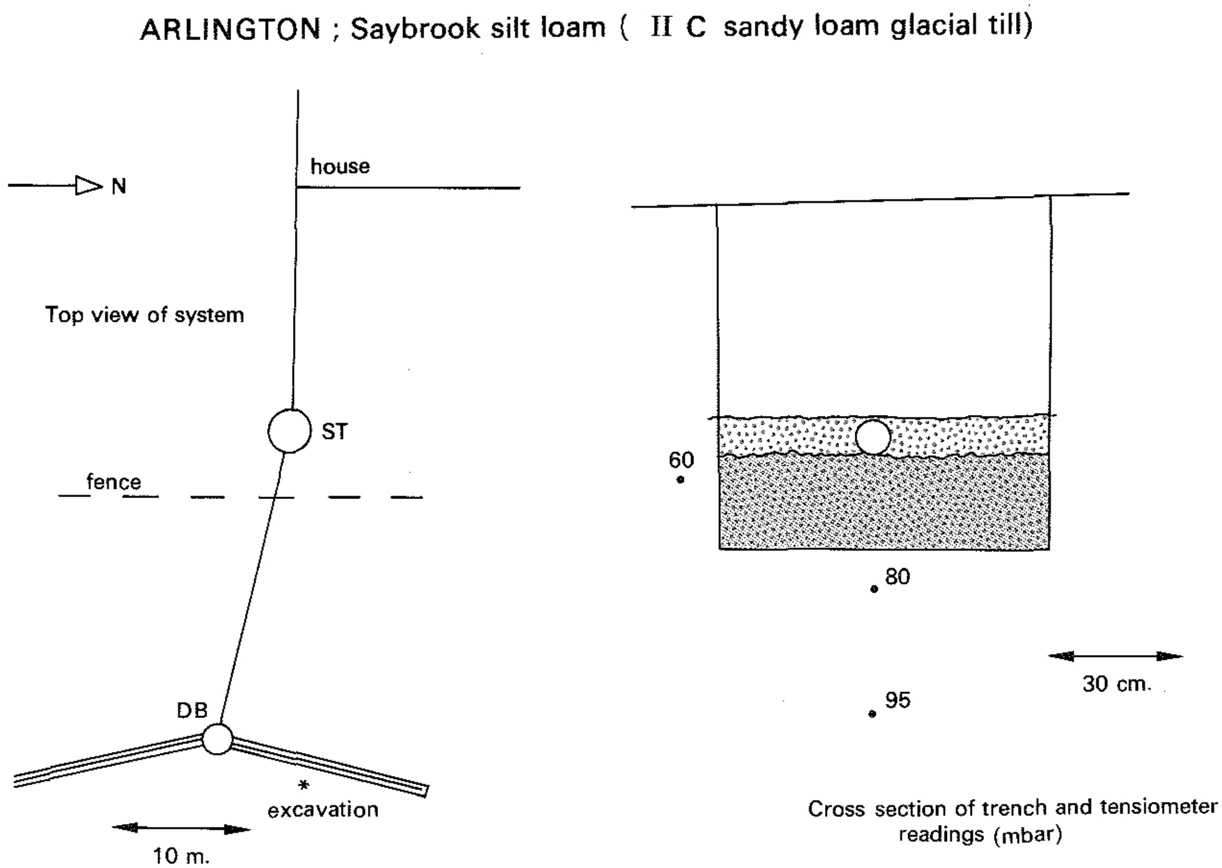


Fig. 5.24. Top view and cross-section of the seepage bed with locations and readings of tensiometers (Arlington)

The soil in the area around the seepage bed was classified as a Saybrook silt loam (Typic Argiudoll), with the following horizons (for a more detailed profile description see Bouma and Hole, 1971). Ap:0-20 cm: Very dark brown silt loam, medium subangular blocky. B21t:20-55 cm: Dark brown silt loam. IIB22t:55-85 cm: Brown to dark brown sandy loam with pebbles, coarse subangular blocky. IIC:85 cm+: Dark yellowish brown sandy loam with pebbles and boulders, single grain (intertextic S-matrix, see Fig. 6.6 in Chapter 6.2.3). A textural analysis of these horizons is in Table 5.22.

Moisture retention and hydraulic conductivity data for the horizons are in Fig. 5.25. Six state percolation tests were made in the glacial till, which averaged 6 min/inch. Soil moisture tensions, as measured around the trenches during the experiments, are in Fig. 5.24.. Results of microbial analyses of samples taken at the locations of the tensiometers are in Table 5.23. Soil moisture tensions were high around the seepage bed, although the level of the effluent stood at two-thirds the height of the bed of crushed rock. Below the trench tensions were 80 mbar and 90 mbar. At the sides, the tension was somewhat lower at 60 mb. The presence of such high tensions, and free liquid in the trench, indicates the presence

Table 5. 22 Particle size distribution for a Saybrook silt loam.

	Clay	C.S.	M.S.	F.S.	V.F.S.	C.Si.	M.Si.	F.Si.	VCS	Texture
Ap	20.5	1.5	3.5	4.5	2.5	23.5	34.0	9.5	0.5	silt loam
B21t	18.0	1.5	5.0	9.0	4.0	19.5	32.5	10.0	0.5	silt loam
IIB22t	9.5	5.0	14.5	33.5	13.5	8.5	11.0	3.0	1.5	sandy loam
IIC	5.0	4.0	25.5	24.7	20.1	13.0	6.0	2.0	1.3	sandy loam

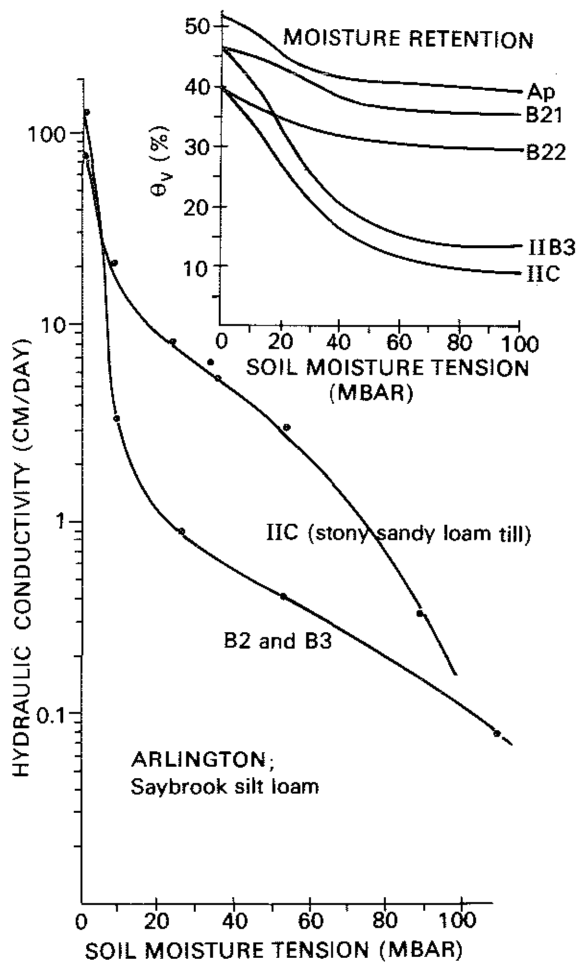


Fig. 5.25. Hydraulic conductivity and moisture retention data of horizons in a Saybrook silt loam (Arlington).

Table 5.23 Bacterial Analyses, Arlington

July 21, 1970 and Aug. 5, 1970

(bacterial counts per gram of soil)

Sample (See Fig. 5.24)	Fecal coliform July	Fecal coliform Aug.	Total coliform July	Total coliform Aug.	Total bacteria July	Total bacteria Aug.
10 cm below trench	***	***	***	***	$3x10^4$	$67x10^4$
25 cm " "	***	***	***	***	$9x10^3$	$31x10^5$
40 cm " "	***	***	***	***	$9x10^3$	$5x10^4$
10 cm from side of trench	***	***	-	1,300	$1x10^5$	$10x10^6$
30 cm from side of trench	***		$17x10^3$		$3x10^5$	
Control soil sample	***	***	***	***	$36x10^4$	$14x10^4$
Distribution box liquid (No./ml)		$4x10^3$		$16x10^3$		$123x10^5$

*** = organisms not detected, <100/gram

Enterococci were not detected in any sample except the distribution box liquid. It contained 260 enterococci/ml in Aug.

Note: Preliminary data. Methods followed were not the same as those developed later; therefore results are not considered as significant as those of later work.

of a crust at the interface between trench and soil, that strongly reduced the infiltration rate into the underlying soil. The reduction here was estimated to be approximately 200 fold (K_{sat}/K_{80} mb). Crusting is very effective in increasing the filtrative capacity of the soil due to the slow movement of liquid in the finer soil pores in unsaturated soil. Counts of fecal indicators were therefore very low in the soil around the bed (see Table 5.23).

The amount of effluent flowing from the crusted bed into the surrounding soil can be estimated by considering K values, hydraulic gradients and wetted areas. K at 80 mb was 5 mm/day. Flow through the bottom area of the beds is estimated as 51 gallons/day (surface area = 24 m^2; hydraulic gradient = 1.5 cm/cm). Liquid also leaves the trench through the sidewalls. Flow can be estimated as 42 gallons/day (K at 60 mb = 15 mm/day, total wet sidewall area = 12.3 m^2, and the hydraulic gradient is 1 cm/cm). Total flow is then estimated as 93 gallons/day, which is within 15% of the measured loading rate of 80 gallons/day (measured during only a one-week period in July). The calculated amounts of flow are estimates based on separated vertical and horizontal flow patterns. In the real two-dimensional flow system, flow lines will be curved, and the solution of the flow equation will be much more complicated. However, this approximation is sufficiently accurate for our purpose here. This system would fail with a normal, much higher, loading rate of around 300 gallons per day. The K_{sat} value of 80 cm/day and the percolation rate of 6 min/inch indicate that the soil is potentially very permeable, if uncrusted. This absorption system was used for experiments to determine the effect of intermittent application of effluent on soil absorption. Results are reported in Chapter 8.2.

Conclusion: This subsurface soil disposal system with an absorptive bottom area of 27 m^2 (300 square feet) built in a soil material with a percolation rate of 6 min/inch and a K_{sat} value of 80 cm/day, could only absorb 90 gallons of effluent per day due to crusting of the interface of the seepage bed and the soil. This would be insufficient if the system were loaded at a regular rate of 300 gallons per day.

5.2.4.2. Measurement of soil temperatures in winter by D. J. van Rooijen

Temperature diodes were installed at depths of 30, 60 and 90 cm in natural soil as well as above, next to and below the seepage bed discussed in the previous chapter. Temperature readings were recorded at regular intervals.

Temperatures at 30 cm depth in the natural soil stayed relatively constant for the entire period of observation. The temperatures at depths of 60 cm and 90 cm were only slightly different but were significantly higher than at a depth of 30 cm. The temperature in the subsoil decreased gradually during the period of study from 6.5°C to 4.8°C.

The maximum temperature above the gravel bed was 2.8°C and the minimum was 0.9°C. Temperatures next to the gravel bed at 60 cm below the soil surface were lower than at the same depth in the natural soil. Temperatures below the gravel bed were close to those in the natural soil at the same depth.

Table 5.24. Soil temperatures in winter (1971-1972) in a Saybrook silt loam and around an operating seepage bed in the IIC horizon of this soil.

	Soil Temperatures (°C)				
Date:	17 Dec	31 Dec	21 Jan	26 Feb	25 Mar
Natural soil:					
30 cm (B2)	3.4	3.4	3.0	3.0	3.0
60 cm (IIB2)	6.8	6.8	6.0	5.2	4.5
90 cm (IIC)	6.5	6.5	5.6	5.2	4.8
Seepage bed:					
Above (40 cm)	2.8	1.9	1.4	0.9	0.9
Adjacent (60 cm)	5.2	2.8	3.3	2.3	1.9
Below (90 cm)	6.8	6.0	6.0	5.7	5.7

Snow depth was 22 inches after Dec. 15, 1970 and did not decrease appreciably during the following months. An additional 12 inches of snow fell on March 19, 6 days before the last measurements were made. Air temperatures at the time of observation in December were -8°C. In January and February temperatures of -20°C were reached.

<u>Conclusion</u>: Temperature measurements in the horizons of a Saybrook silt loam and around a subsurface seepage bed in this soil, made during the winter months of 1971-1972, showed that the soil did not freeze, due to a 20-inch snowcover, even though air temperatures were as low as -20°F (-28°C). Soil temperatures in the soil above the seepage bed were lower than those measured in the natural soil at the same depth.

5.2.5. Ashland study area

5.2.5.1. System 1

This seepage bed was constructed in the Spring of 1970 and was investigated in August 1970. A top view and cross section of the bed are shown in Fig. 5.26. The system never worked well as indicated by continuous seepage of effluent from the downslope end of the bed at the location of the airvent (Photo 5.7).

The soil type in the area was a Hibbing silty clay loam (Typic Eutroboralf) with the following soil horizons (for more details, see Bouma and Hole, 1971a). Ap:0-10 cm, Reddish brown silty clay loam, fine subangular blocky; A2:10-18 cm, Reddish brown silty clay loam, medium subangular blocky, skeletans on ped faces; B1:18-24 cm, Dark yellowish brown clay loam, medium prismatic breaking into medium prismatic and medium angular blocky; B2t:24-65 cm, Red clay, very coarse prismatic and medium angular blocky; $CaCO_3$ glaebules in lower part of horizon; B3:65-120 cm, Red clay, prisms as B2. Pockets of weak red clay, very rich in $CaCO_3$, C:120-180 cm, Red clay, prisms as B2.

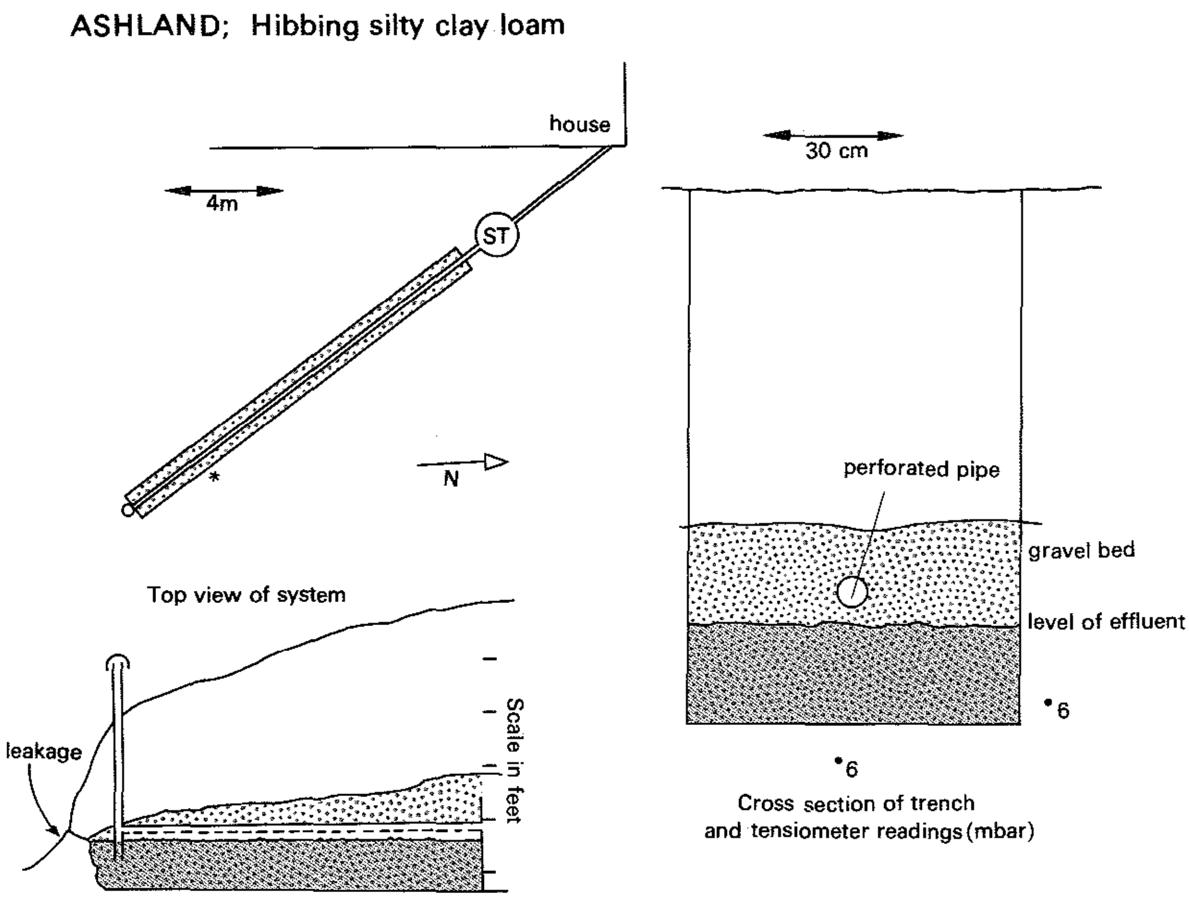


Fig. 5.26. Top view and cross-section of the seepage bed with locations and readings of tensiometers (Ashland).

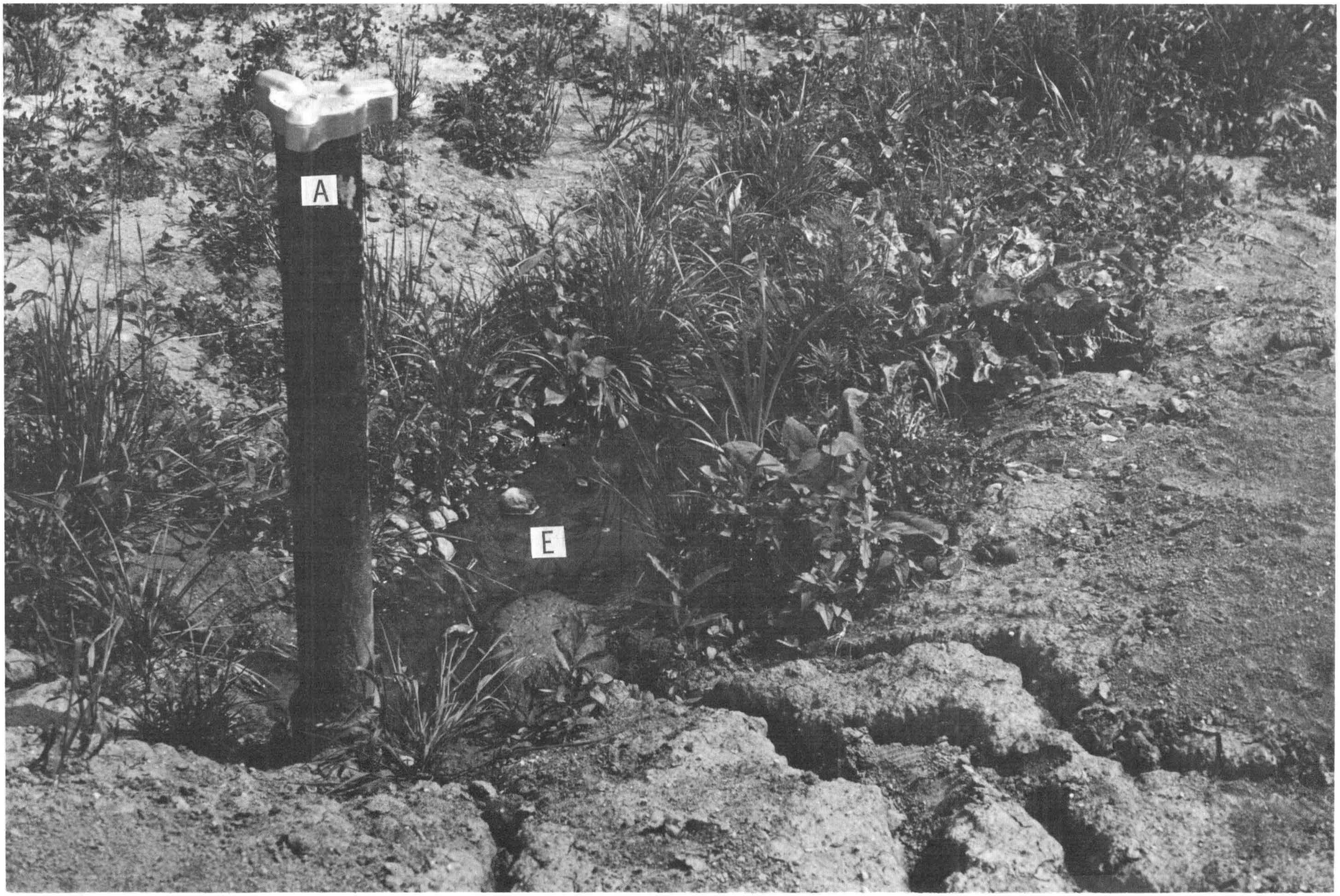


Photo 5.7. Air vent (A) at the lower part of the soil absorption system in Hibbing silty clay loam. Raw effluent (E) is flowing from the system because low conductivity of the soil does not permit it to absorb the liquid (see top view of the system in Fig. 5.26).

The B3 horizon, in which the seepage bed was built, had the following particle size distribution:

VCS	C.S.	M.S.	F.S.	V.F.S.	C.Si.	M.Si.	F.Si.	Clay
0.2	1.4	4.6	5.8	13.0	4.0	12.0	12.5	46.5

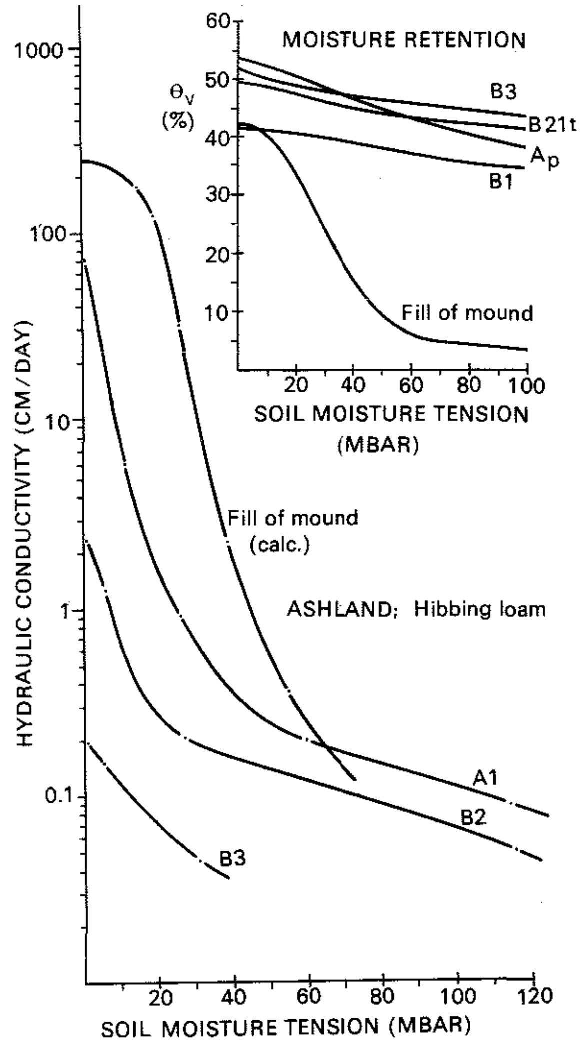


Fig. 5.27. Hydraulic conductivity and moisture retention data of horizons in a Hibbing loam (Ashland).

The K-curve (Fig. 5.27) was measured later <u>in situ</u> in a Hibbing loam nearby, that had B horizons identical to those of the Hibbing silty clay loam described above. The curve for the B3 horizon of the Hibbing loam (Fig. 5.27) shows a very low conductivity (K_{sat} = 2 mm/day). The percolation test, performed in triplicate at the B3 level, yielded an average 1400 min/inch, much below the

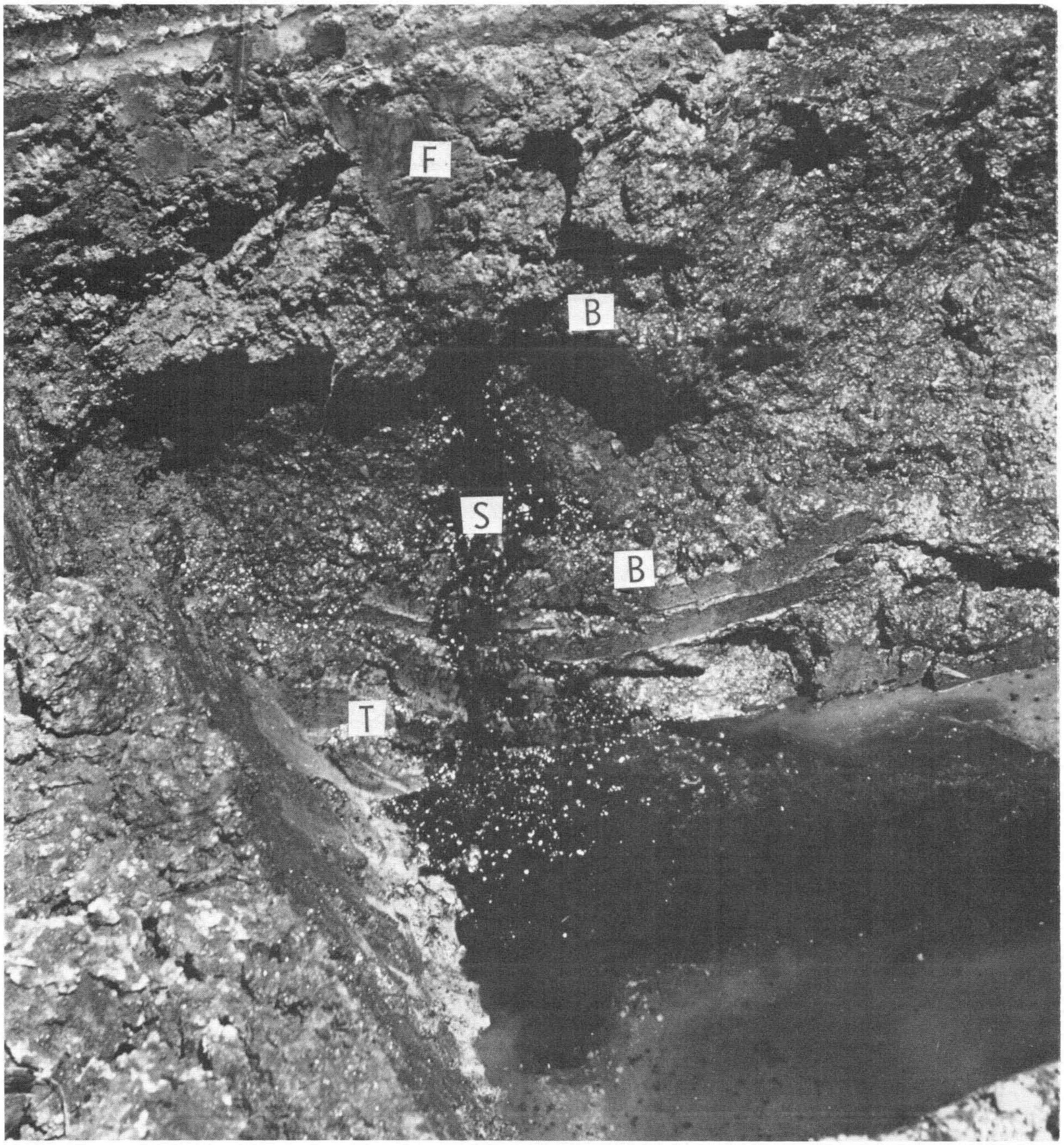


Photo 5.8. Black sewage sludge (S) flowing from a tile line down the side of an exploratory trench across the seepage bed (B-B) at 120-160 cm depth at the Marshfield Experiment Station. Field tests showed the underlying compact reddish till (T) to be impermeable. Fill (F) above the bed had a bluish "reduced" color and had been enriched in nitrates and organic matter by upwelling effluent.

minimum allowable 60 min/inch. Tensiometric measurements in situ of moisture tensions around the trench (which was partly filled with effluent at the time, see diagram in Fig. 5.26) indicated that tensions of 6 mbar occurred close to the trench. Lack of saturation points to the occurrence of weak crusting on trench surfaces. The bottom area of the bed was 11.25 m^2, the sidewall area in contact with effluent was 6.3 m^2. With K at 6 mb at 1 mm/day, infiltration into the soil can be estimated to have been only 17 liters (4 gallons) per day, assuming hydraulic gradients of 1 cm/cm. This rate is much too slow to make possible the operation of a modest sized subsurface seepage bed at normal loading rates. An area of 600 m^2 (6540 square feet) would be needed to dispose of 300 gallons per day at an infiltration rate of 2 mm/day. This very large and therefore impractical size would still be too small after crusting, which causes a decrease of an already very low infiltration rate. The surface horizons of the pedons have higher conductivities (Fig. 5.27) and this favorable property is used in the design of experimental "mound systems" for these soils, which will be discussed in Chapter 8.3.

Conclusion: The subsurface horizons of the Hibbing silty clay loam and the Hibbing loam have a very low hydraulic conductivity, which explains very low infiltration rates from the seepage beds and, as a result, system failure.

5.2.6. Marshfield study area.

5.2.6.1. System 1

This seepage bed, observed in 1970, was constructed in 1951, at a depth of four to five feet below the soil surface to made possible gravity flow of liquid waste from the farm building into the septic tank and from there into the seepage bed. The system never worked well as indicated by seepage of effluent into the road-ditch. The soil type in the area of construction was a Withee silt loam (Aquic Glossoboralf) with the following soil horizons (for more details see Bouma and Hole, 1971a): Ap:0-18 cm: Very dark grayish brown silt loam, fine plates, common dark reddish brown planar ferrans; A2g:18-27 cm: Brown silt loam, medium prisms breaking into fine plates, common yellowish red planar and channel ferrans; B1:27-37 cm: Pale brown silt loam, medium prisms breaking into fine plates; IIB21tg:27-50 cm: Dark brown loam with few pebbles, medium prisms breaking into medium plates, skeletans on prismatic ped faces; IIB22g:50-63 cm: Dark brown loam, coarse prisms breaking into medium plates, brown mottles and skeletans on ped faces; IIB3g:63-120 cm: Dark reddish brown clay loam, very coarse prisms breaking into coarse plates, light gray mottles along root channels; IIC:120-180 cm: Reddish brown sandy clay loam with olive gray mottles, very coarse prismatic. Particle size distributions of the horizons are in Table 5.25.

The K-curve (Fig. 5.28) shows that the natural soil is very slowly permeable at the level of the seepage bed (K_{sat} = 2 mm/day). This was confirmed by the very low measured percolation rate (1400 min/inch). The seepage bed area was approximately 84 m^2. At a rate of 2 mm/day (which would represent the vertical infiltration rate in the IIB3 horizon without

Table 5.25. Particle size distribution of horizons in a Withee silt loam.

	VCS	C.S.	M.S.	F.S.	V.F.S.	C.Si.	M.Si.	F.Si.	Clay
Ap	Tr	1.4	4.9	5.7	14.9	21.0	24.0	9.0	19.5
A2g	Tr	1.1	2.8	2.5	14.1	17.5	27.5	8.5	21.0
B1	0.6	1.6	5.0	4.7	14.6	22.0	28.0	10.5	13.0
IIB21tg	Tr	0.5	7.8	9.5	9.7	13.5	18.5	7.0	22.5
IIB22tg	Tr	1.4	7.2	7.2	16.7	17.0	19.0	8.0	23.5
IIB3g	Tr	1.7	8.5	9.0	12.3	16.0	8.5	8.5	29.5
IIC	0.2	2.3	14.2	13.5	20.5	11.0	5.0	6.0	19.5

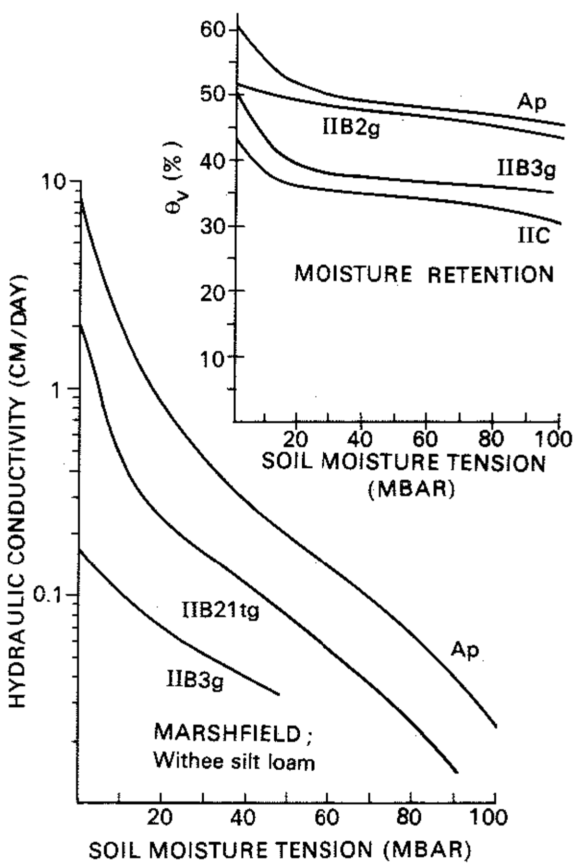


Fig. 5.28. Hydraulic conductivity and moisture retention data of horizons in a Withee silt loam (Marshfield).

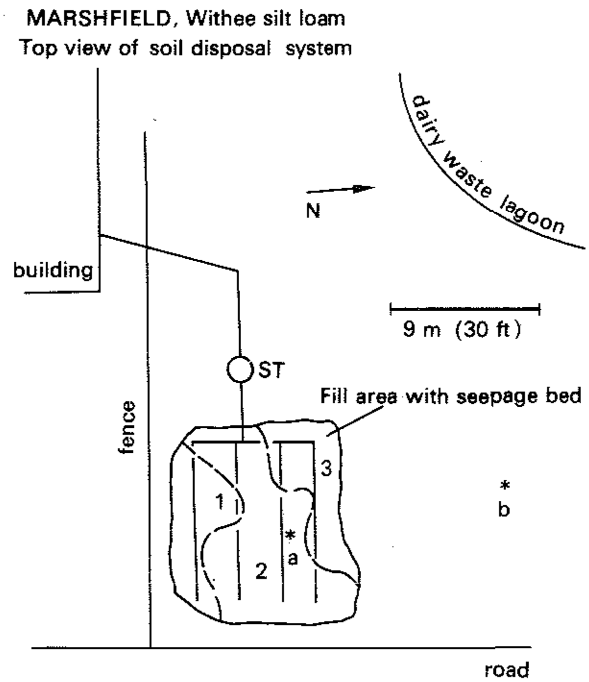


Fig. 5.29. Top view of the seepage bed area showing different degrees of reduction in the soil fill (Marshfield). (See text).

any crusting of the infiltrative surface) a total volume of only 168 Liters (40 gallons) can be absorbed per day, which is insufficient because loading rates will usually be much higher. In addition, crusting and resulting unsaturated flow is likely to occur and then rates are much lower yet (see Fig. 5.28). Soil morphology around the seepage bed strongly suggested that effluent did indeed not move downwards in appreciable amounts. The natural soil immediately below and at the sides of the seepage bed was brown (10YR 4/6) or dark brown (7.5YR 4/4), whereas the soil-fill on top of the bed was dark greenish gray (10Y 4/1), gray (7.5Y 5/1) and olive black (7.5Y 4/1), indicating effects of processes of reduction. Depth of reduction varied over the seepage bed area. In area 1 (Fig. 5.29) such reduced colors were found only between 80 and 120 cm below the soil surface; in area 2 between 40 and 120 cm and in area 3 from the surface downwards to 120 cm. The increase in thickness of the zone of reduction corresponded with the general slope of the area, which was to the north. Anaerobic conditions in the bed were evident during the excavation of the system when large quantities of black sludge, rich in sulfides, flowed from exposed pipes in the bed (Photo 5.8). The fill material on top of the seepage bed (sampled in unit 2 as indicated in Fig. 5.29) was enriched with nutrients (notably K and NO_3) from upwelling effluent as compared with an adjacent natural pedon (sampled at point b in Fig. 5.29). The organic matter content and the pH of the fill material (which was composed of soil material of the upper horizons of a Withee silt loam) were also higher than in the natural pedon (Table 5.26).

Table 5.26. Chemical characteristics of fill material on top of the seepage bed and of an adjacent natural Withee silt loam pedon (sampling sites shown in Fig. 5.29).

	Withee silt loam						Fill					
Depth	pH	OM %	P	K	Na	NO_3	pH	OM %	P	K	Na	NO_3
			--------ppm--------						--------ppm--------			
30 cm	4.3	0.3	66	600	24	25	6.2	1.6	45	1050	18	10
60 cm	4.2	0.2	43	177	25	--	5.6	0.7	28	202	13	12
90 cm	4.1	0.1	35	135	25	--	6.2	0.5	39	162	10	47
120 cm	4.3	0.1	53	152	27	--	6.6	0.3	37	320	16	35
160 cm*							6.2	0.2	59	205	10	--

*Till beneath gravelbed.

Conclusion: The subsurface horizons of the Withee silt loam have a very low conductivity which explains very low infiltration from seepage beds and the resulting failure of septic systems. Movement of effluent occurred from the bed upwards into the soil fill in the studied system.

5.2.7. Black River Falls study area

5.2.7.1. System 1

This new, very large, dual-bed, subsurface soil disposal field was designed and built for an Institute with an average daily production of 5,600 gallons of effluent. The system was studied in October 1971 after only six weeks of operation. Fig. 5.30 shows a top view of this system and also of the old seepage bed that had failed in 1970, after only four years of use. An excavation in the old gravel bed revealed that the clay-tile lines had been plugged with fine cloth fibres originating from the laundry room. This resulted in overflow of large volumes of raw effluent into a nearby stream. The new system (provided with filters to avoid similar difficulties) consisted of two beds, each of which was sufficiently large to absorb the current volume of effluent. Liquid wastes first pass through two septic tanks, each with a capacity of 5700 gallons, and through a distribution box. Movement is by gravity-flow. The soil in the area was

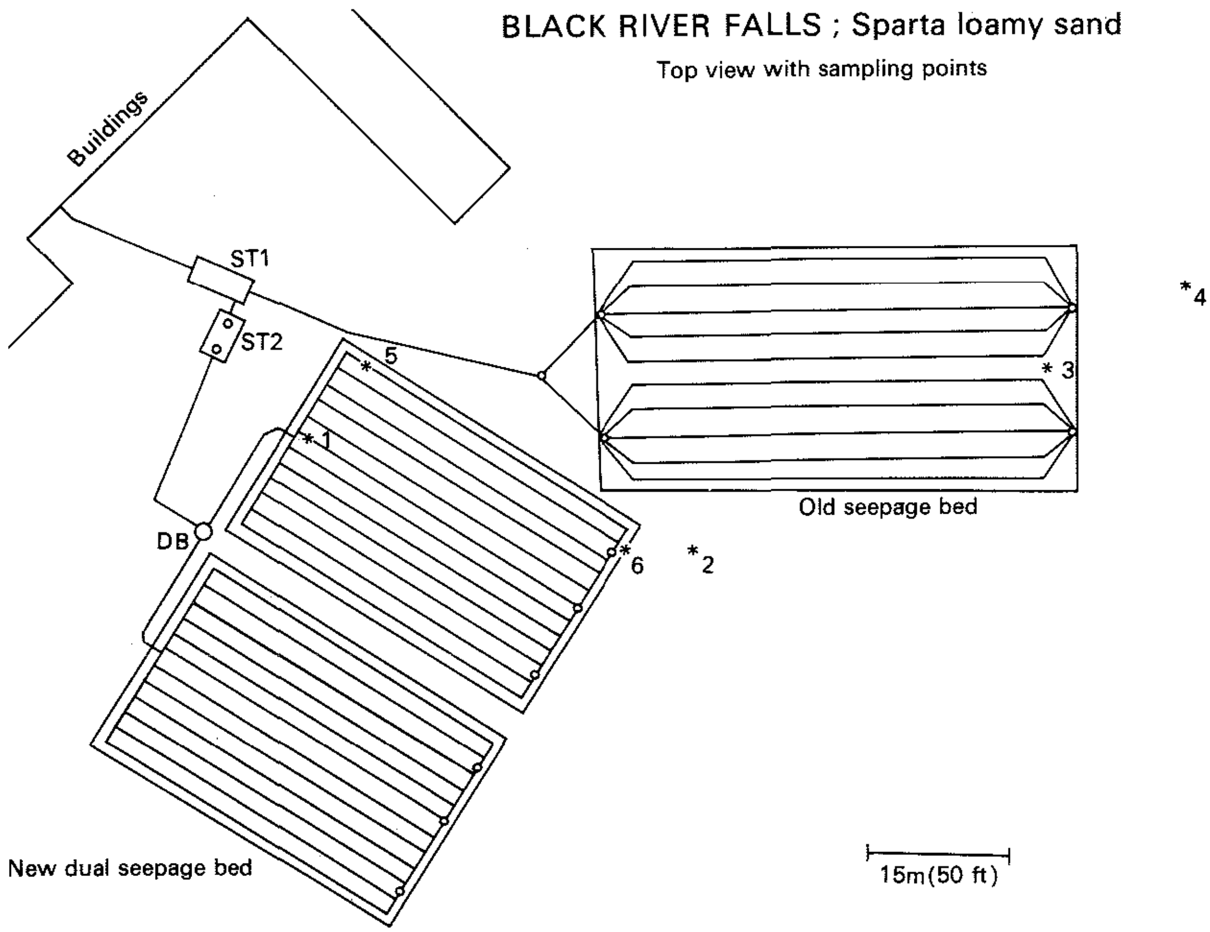


Fig. 5.30. Top view of the seepage bed with sampling points (Black River Falls).

classified as a Sparta loamy sand. Attention was confined to the C-horizon sand that surrounds the seepage bed. This sand consists of 4% clay, and 96% sand (9% coarse, 83% medium, 3% fine and 1% very fine). Hydraulic conductivity and moisture retention characteristics are reported in Fig. 5.31.

The principle of the dual-bed system is to shift the flow of effluent from one bed to the other at regular time intervals. The bed not receiving effluent is allowed to drain. Inhibiting crusts developed at the infiltrating surfaces during the previous loading period will then be oxidized, thereby restoring the infiltrative capacity of the soil for the next loading cycle. Construction of a dual-bed system is necessary if crusting can be expected to be so severe during a prolonged period of continuous loading, that the system will fail. If, however, the development of crust resistance is not a continuous function of time but, rather, approaches some equilibrium value, a second bed may not be needed. In such a case, this equilibrium value, which corresponds to a certain infiltration rate, could be used to design a bed large enough to handle all effluent on a permanent basis. The study of operating subsurface beds in sands reported in Chapter 5 indicated a striking uniformity of moisture conditions around beds from site to site. Tensions were close to 25 mbar, even in a system that was twelve years old (Chapter 5.2.1.3). This seems to indicate that crust resistance does in fact, reach a condition of equilibrium.

The bottom area of each seepage bed at the Black River Falls site is 900 m^2. The critical downward flow rate, to be calculated from the average measured loading rate of 5600 gallons per day, is 2.5 cm (one inch) per day. This flow rate corresponds with a soil moisture tension of 55 mbar (Fig. 5.31) which is a much lower tension than tensions measured around operating beds in other sands similar to the one discussed here. It is, therefore, probable that a single bed of the present size would be sufficiently large to handle the effluent permanently. Future monitoring will test the validity of this preliminary conclusion.

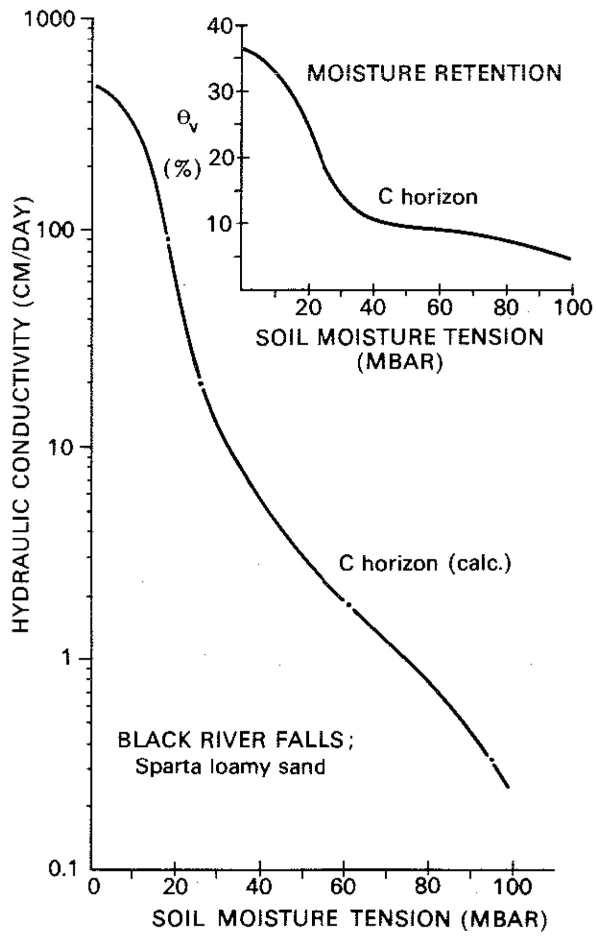


Fig. 5.31. **Hydraulic conductivity and moisture retention data for the C-horizon of a Sparta loamy sand (Black River Falls).**

Six excavations were made around the bed for sampling purposes (Fig. 5.30). Lateral excavations into the seepage bed at points 5 and 6 showed that the gravel in the bed was clean and dry. This means that effluent had not yet reached these points. A deep excavation was made at point 1 near the inlet close to the side and below the seepage bed. Effluent was ponded in the bed at that point while the underlying soil was unsaturated. Moisture tensions could not be measured directly, but soil samples were taken below the bed and the tension was estimated from moisture contents to be around 30 mbar, as derived from the moisture retention curve (Fig. 5.31). At the time of study, therefore, this system provided a good illustration of progressive crusting, to be further discussed in Chapter 6.2. In this process the soil close to the inlet receives much effluent through perforations of the pipe and a crust develops as a result of local overloading. The crusted area in the bed expands as liquid moves farther into the bed (see also the system in Chapter 5.2.1.9).

The soil below the partly filled seepage bed was considerably warmer (23°C) than the natural soil nearby at the same depth (18°C), due to the warmth of the infiltrating effluent.

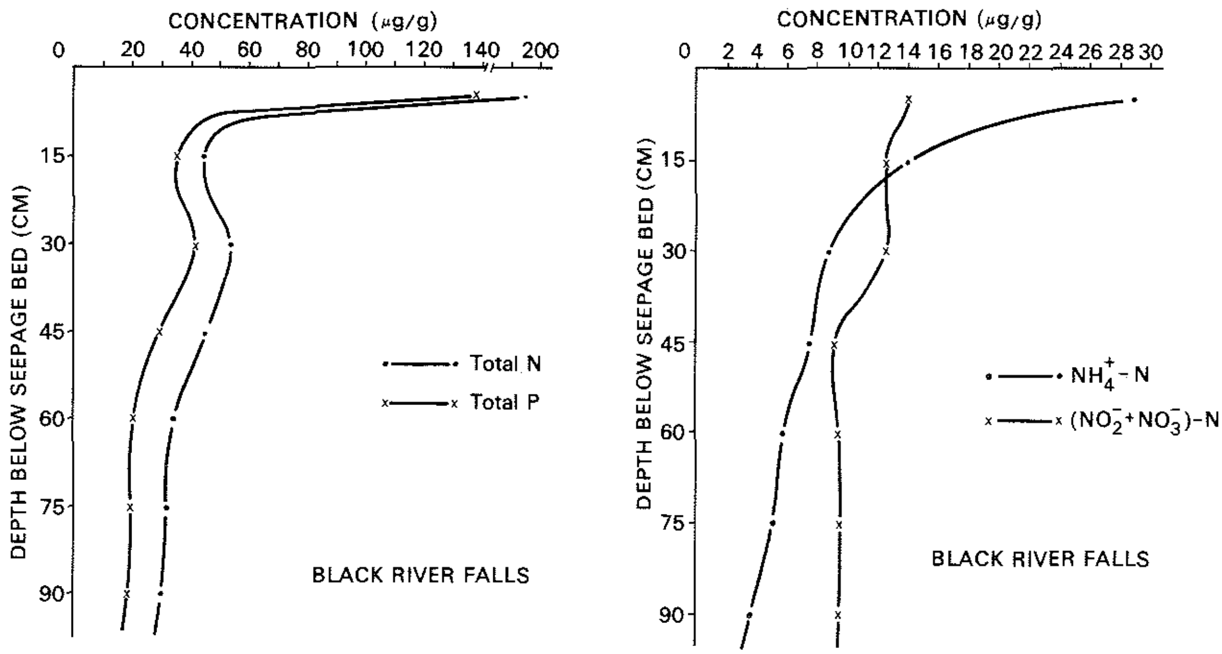


Fig. 5.32. Concentrations of nitrogen and phosphorous compounds in unsaturated soil below a crusted seepage bed (Black River Falls).

Table 5.27 Results of chemical analyses of effluents and water from observation wells around the seepage bed in Black River Falls. (ST = septic tank; DB = distribution box)

Date	Sample or well number	NH_4^+-N	NO_3^--N	Total-N	DIP	Total-P
October 1972	Housewell	0.3	0.8	1.8	<.02	.43
	ST #1	26.5	0.1	27.8	12.6	13.3
	ST #2	24.2	0.6	28.9	13.2	13.3
	DB	21.9	0.4	27.4	13.8	14.0
	Well No. 1	0.7	5.0	12.0	.23	1.29
	Well No. 2	0.6	0.5	2.8	.07	.49
	Well No. 3	0.7	0.2	3.2	.26	1.24
	Well No. 4	0.5	2.0	4.6	.80	1.16

Table 5.28 Bacterial Analyses, Black River Falls, Oct. 21, 1971
(bacterial counts per gram of soil or per ml in liquid samples)

Sample (See Fig. 5.30)	Enterococci	Fecal coliform	Total coliform	Total bacteria	pH
Septic tank #1(1)	500	3,000	34,000	206×10^7	6.8
Septic tank #2(1)	230	4,000	48,000	22×10^5	6.9
Distribution box(1)	300	7,000	27,000	39×10^5	7.2
Soil samples (Fig. 5.30 Point 1)				($\times 10^2$)	
a, 1 cm below bed	50	2	60	8,500	6.9
b, 3 cm " "	12	4	14	11,000	6.5
c, 5 cm " "	**	**	**	1,000	6.7
d, 7 cm " "	**	**	2	20,000	6.9
e, 15 cm " "	4	**	34	600	6.3
f, 30 cm " "	**	**	**	5,100	6.5
g, 45 cm " "	**	**	**	5,100	6.2
h, control	**	**	**	5	5.3
Untreated well water(1)	*	*	*	89	-
Treated well water(1)	*	*	*	39	-
Test wells				($\times 10^3$)	
1	*	*	1,100	940	6.6
2	*	*	30	51	6.7
3	*	*	*	38	6.6
4	*	*	60	16,300	6.7

* = organisms not detected or $<$1/ml in average of triplicate platings

** = organisms not detected or $<$6/gram in average of triplicate platings

(1) liquid samples

Note: Soil below distribution field was at 23°C.
The soil at the point of the control sample was 18°C.

Soil samples taken at 15 cm intervals below the bed were analysed for total N, total P, NH_4 and NO_3. The ground water was at 16 feet below the soil surface at the location of the seepage bed. Samples of the ground water were taken at points 1, 2, 3 and 4. Sample wells extended only one foot into the ground water. Results of chemical analyses are in Table 5.27. Bacterial analyses of soil and well samples are reported in Table 5.28. Fecal indicator organisms were not detected in any of the test wells below the absorption field. These indicators (FC and FS) were also absent in soil samples obtained at depths exceeding 1 foot below the seepage field. The effluents in the septic tanks and in the distribution box had a relatively high NH_4 content (22 ppm) whereas the NO_3 content was low (0.4 ppm) due to the anaerobic environment (Table 5.27). Contents of NH_4 were relatively low when compared with effluents sampled from individual homes at other locations. The ground water below the inlet in the bed at point 1, on the contrary, had a relatively high nitrate content (5 ppm). The content of organic N (6 ppm) was similar to that in the distribution box. Oxidation of ammonia to nitrate and a gradual decrease of total N with increasing depth of soil percolation is graphically illustrated in Fig. 5.32. The composition of gases in the soil pores below the bed is unknown but approximately 24% of total soil volume is occupied by gases at 30 mbar tension (see moisture retention curve in Fig. 5.31) creating a potentially oxidative environment in this coarse porous well aerated soil. The phosphate contents in the ground water are relatively high as compared to other studied sites. It should be noted that the analyses of effluents in the septic tanks and in the distribution box may be influenced by the time of sampling, which was in the morning hours when the laundry was operating. Wastes entering the system at a later time during the day may have somewhat different chemical characteristics. This aspect remains to be investigated.

Conclusion: The bottom of this large seepage bed was partially crusted near the point of inlet after six weeks of use. Nitrification and a very strong reduction in the amount of fecal indicators was observed in the effluent during the downward percolation through unsaturated soil below the crusted seepage bed. Calculations indicate that effluent might be absorbed continuously without failure in a system consisting of a single large bed.

6. EVALUATION OF PHYSICAL MEASUREMENTS

6.1. Evaluation of the Wisconsin State Percolation Test Procedure

6.1.1. Introduction

Suitability of a site for the construction of a septic tank disposal system is determined on the basis of slope of the area, level of the water table, depth to bedrock, if any, and a mandatory percolation test (State Board of Health, 1969), (see Chapter 3.1). The percolation rate is expressed in the number of minutes required for the water to fall one inch. This value can be translated into the more universal physical units of cm per day by dividing 3600 by the number of minutes per inch. Estimates of required dimensions of a future system are based on the percolation rate, if less than 60 minutes per inch, and predicted loading rates of the system. These estimates can be reliable only if 1) the test procedure itself gives representative and reproducible results for each location, and 2) if such results apply to the real physical conditions in and around an operating disposal system. These two aspects will be considered separately in the following sections.

6.1.2. Variability of test results; comparison with other methods

The methodology of the mandatory percolation test (State Board of Health, 1969, Section 3.1) has been studied by many authors (see review by McGauhey and Krone, 1967). Correlations of percolation tests with soil properties have been reported by Derr et al., (1969), based on results of several thousands of observations in Pennsylvania. At any given site, 3 to 6 tests were made. The coefficient of variability for replicate tests on one site varied from zero to 253%, with an average of 73%. Variation between sites was slightly higher than variation within a site. The percolation rate was positively correlated with the clay content of the subsoil and the drainage class. The authors concluded that the very high variability of results makes the test quite unreliable. Mokma (1966) demonstrated considerable seasonal variations in test results.

Results of the present study are reported below with respect to:

1. Range of variability of test results.

2. The seasonal variation of percolation test results.

3. A comparison of results obtained by the official test procedure (which allows a falling water level) with results obtained by a procedure in which a constant water level is maintained in the test hole.

4. A comparison of the percolation test results with K-values determined by the Bouwer double tube procedure.

Investigations were made in seven soil horizons, as indicated in Table 6.1. Variation of test results is expressed as the coefficient of

Table 6.1 * Results of percolation tests of seven soil horizons.

	No. of holes	Perc. rate first day 2hr	4hr	6hr	Perc. rate sec. day 2hr	4hr	6hr	Perc. rate third day 2hr	4hr	6hr	CV, second day (%)	CV, 1969-70 (%)
St. Charles-Batavia silt loam (Charmany farm).												
1. Horizon: B21t (60 cm depth) Initial moisture 1969: 0.6b; 1970: 0.1b (est.)												
SPT July 1969	6	---	---	---	---	22	---	---		---	36 }	41
SPT April 1970	3	15	14	20	14	22	24	---	---	---	40 }	
CLPT April 1970	3	15	15	---	10	10	10	9	9	---	35	
Individual test holes April 1970-SPT												
No. 7		14	11	16	12	18	24				30 }	
No. 8		16	8	17	15	15	27				40 } 40	
No. 9		16	22	27	15	32	22				53 }	
April 1970-CLPT											0	
Bouwer K: 57 cm/day (63 min./inch) 4 meas.												25
2. Horizon: B31 (120 cm depth) Initial moisture tension 1969: 0.3b; 1970: 0.5b (est.)												
SPT July 1969	6					45					100 }	90
SPT April 1970	3	38	54	57	44	87	89				100 }	
CLPT April 1970	3	80	80	80	76	76	76				90	
Individual test holes April 1970-SPT												
No. 10		14	12	20	11	13	19				30 }	
No. 11		20	30	30	40	128	90				73 } 50	
No. 12		80	120	120	80	120	200				48 }	
April 1970-CLPT											0	
Bouwer K: 22 cm/day (160 min./inch) 4 meas.												25

*All percolation rates are given in min./inch, unless otherwise stated.

Table 6.1 (continued).

	No. of holes	Perc. rate first day 2hr	4hr	6hr	Perc. rate sec. day 2hr	4hr	6hr	Perc. rate third day 2hr	4hr	6hr	CV, second day (%)	CV, 1969-70 (%)
Plano silt loam (Mandt farm).												
3. Horizon: B21t (50 cm depth) Initial moisture tension: 1969: 0.1b; 1970: 0.03b (est.)												
SPT July 1969	6	---	---	---	---	28	---	---	---	---	35	45
SPT May 1970	3	7	9	---	10	11	11	---	---	---	15	
CLPT May 1970	3	3	3	---	6	6	5	3	---	---	10	
Individual test holes												
May 1970-SPT												
No. 7		7	8	---	7	11	11				22	
No. 8		7	11	---	16	12	12				20 } 23	
No. 9		7	8	---	6	9	10				26	
-CLPT												
No. 2		2	---	---	6	8	5	3	---	---	25	
No. 5		4	---	---	6	6	6	6	9	9	0 } 16	
No. 6		2	9	---	6	4	4	4	4	---	22	
Bouwer K: 28 cm/day (120 min./inch)												25
4. Horizon: B31 (20 cm depth) Initial moisture tension 1969: 0.1b; 1970: 0.1b (est.)												
SPT July 1969	6					33					20	40
SPT May 1970	3	8	6	---	15	16	13	---	---	---	48	
CLPT May 1970	3	5	---	---	12	10	10	19	8	---	25	
Individual test holes												
May 1970-SPT												
No. 10		7	8	---	23	21	18				12	
No. 11		10	5	---	13	19	12				17 } 17	
No. 12		6	7	---	8	9	10				11	
-CLPT												
No. 1		10	---	---	25	19	19	40	15	---	16	
No. 3		2	---	---	6	5	---	10	5	---	15 } 15	
No. 4		4	---	---	6	5	---	6	5	---	15	
Bouwer K: 11 cm/day (330 min./inch)												25

Table 6.1 (continued).

	No. of holes	Perc. rate first day 2hr	4hr	6hr	Perc. rate sec. day 2hr	4hr	6hr	8hr	CV, second day (%)	CV, 1969-70 (%)
Tama silt loam (Platteville) virgin site.										
5. Horizon: B2t (20 cm depth) Initial moisture tension 1969: 0.3b; 1970: 0.1b (est.)										
SPT Oct. 1969	2	---	---	---	---	6	---	---	10	
SPT May 1970	3	---	---	---	9	12	16	42	70	82
CLPT May 1970	3	5	8	6	6	6	6	---	30	
Individual test holes										
May 1970-SPT										
No. 8				15	14	30	80	90		
No. 10				7	11	10	23	54	} 70	
No. 11				6	10	9	23	62		
-CLPT										
No. 1		6	10	5	6	6	6	---	0	
No. 6		6	9	9	8	8	8	---	0 } 5	
No. 4		4	4	4	5	4	4	---	16	
Bouwer K: 95 cm/day (38 min./inch) 3 meas.										30
Tama silt loam (Platteville) cultivated site.										
6. Horizon: B31 (80 cm depth) Initial moisture tension 1969: 5b,; 1970: 1b (est.)										
SPT Oct. 1969	2	---	---	---	---	38	---	---	40	45
SPT May 1970	3	---	---	---	14	21	42	17	25	
CLPT May 1970	3	1	3	5	8	8	8	---	12	
Individual test holes										
May 1970-SPT										
No. 9		---	---	---	11	24	13	16	44	
No. 7		---	---	---	20	15	96	16	100 } 60	
No. 12		---	---	---	10	24	16	19	40	
-CLPT										
No. 2		1	1	4	8	8	9	---	8	
No. 5		2	6	7	9	9	9	---	0 } 3	
No. 6		1	2	4	7	7	7	---	0	
Bouwer K: 27 cm/day (130 min./inch)										30

Table 6.1 (continued).

	No. of holes	Perc. rate second day 2hr	4hr	CV, second day (%)	CV(of both# sites), 1970 (%)
Stony sandy loam till (Arlington Experimental farm).					
7. At 90 cm depth in a Saybrook silt loam. Initial moisture tension: 0.lb.					
SPT July 70 (Poultry)	3	4	4	35	60
SPT July 70 (Dairy)	3	3	3	60	
PLTC July 70 (Poultry)	1	4	3		20*
PLTC July 70 (Dairy)	1	5	4		
Individual test holes					
SPT Poultry					
	No. 1	5	5		
	No. 2	6	6	0	
	No. 3	1	1		
SPT Dairy					
	No. 1	1	1		
	No. 2	3	3	0	
	No. 3	5	5		
PLTC Poultry		4	3	20 } 17	
PLTC Dairy		5	4	15	

Bouwer K: No measurement possible because of stones. From crust test procedure:

$$K_{sat} = 80 \text{ cm/day } (45 \text{ min./inch})$$

*Amount of replicates is too low here.
#Poultry Farm and Dairy Center, Arlington Farms, Wisconsin Agr. Exp. Sta.

variability, that gives the standard deviation S of test results as a percentage of the average:

$$S = \left(\sqrt{\frac{\Sigma(x-\bar{x})^2}{n-1}}\right)$$

At each site the individual test holes were made within an area of 25 m^2 (≈225 sq. ft.). The distance between holes was always more than 1.2 m (4 feet). Data derived from the field tests are presented in Table 6.1 for 7 pedons. SPT data for the 1969 field season (Bouma et al., 1970) were calculated from the rate of fall of the water level after 3½ to 4 hours on the second day, as directed in the test procedure. The State Percolation test data of the 1970 field season (abbreviated as SPT data) include the rates as measured after 2, 4, 6 or 8 hours of wetting on the second day. The value observed after 3½ to 4 hours on that day is taken as the official percolation rate. Infiltration rates were also recorded during the "soaking period" of the previous ("the first") day.

The coefficient of variability (CV) was calculated for replicate SPT measurements at every location for each field season separately and for all values combined. The Constant Level Percolation Test (Abbreviated as CLPT) was done in 1970 only. CV values for this test, therefore, only apply to the spring season of 1970.

CV values were also calculated for each individual hole used for a SPT or CLPT determination, expressing the variability of readings on the second day after 2, 4, and 8 hours. This CV value, calculated only for 1970 data, made possible an evaluation of the significance of the required arbitrary four hour period of measurement during the second day. Hydraulic conductivities (K) measured in triplicate with the double tube apparatus in both summer and fall of 1969 and in the spring of 1970 are reported here for each horizon, along with their CV values.

The seven horizons represented in Table 6.1 are referred to by number in the test, Viz. No. 2, No. 5, etc.

The following conclusions can be drawn from the assembled data:

(1) The CV values of the State Percolation Tests in the summer and fall of 1969 vary between 10% (No. 5) and 100% (No. 2). The average was 50%. When all values for each horizon are combined, the range is 40% (No. 4) to 90% (No. 2), with an average of 57%. This is a high value although still lower than the 73% reported by Derr et al. (1969). It means that an average percolation rate of, for example, 20 min/inch has to be read as being between 31 and 9 min/inch with a probability of 68%; so there is a chance of one in three that values occur even outside this range. All horizons included in our experiments were in relatively homogeneous well drained materials, except for the B3 of the St. Charles-Batavia silt loam (No. 2). This horizon was close to the interface between leached loess and glacial till, which may account for its quite variable behavior. But even when this horizon is excluded, CV is still 50%. The greater part of this high variability is due to the heterogenity of the natural soil. Some of it, however, is the result of the measurement procedure (see item 3, below).

(2) Seasonal differences in SPT results do not show any consistent pattern. Similar rates were measured in spring and late summer in No. 1; higher rates in spring in Nos. 3, 4, and 6 and lower in Nos. 2 and 5. Differences do not correspond with the initial soil moisture contents before soaking. For example, in the spring the rate was higher in No. 3, although the initial moisture content of the horizon was highest in that season. The rate in No. 2 was lower in spring, although the initial moisture content was lowest then. Except for the initial soil moisture content, many other factors may contribute to the observed differences: better cleaning the bottom of the hole with a new hole cleaner in 1970 as compared with the work done in 1969; the method of measurement of the water level; the way the hole was filled with water after each six-inch fall, etc. These results do not confirm those of Mokma (1966) who reported relatively low values in spring, due to the relatively high water content of the soil which reduced the hydraulic gradient (see point 4). Presoaking, during the first day of the test procedure, has apparently substantially reduced differences in hydraulic conditions in different seasons. The percolation rates observed during the first day of soaking, are sometimes lower than those measured on the second day (see data for Nos. 1, 3 and 4 in Table 3.6.1).

(3) The variability of the Constant-Level Percolation Tests (CLPT) is lower than that of the regular percolation test. The average CV for CLPT tests in spring 1970 was 34%, whereas SPT results in the same period had a CV of 50%. A constant water level is maintained in the CLPT at 6 inches above the gravel. Any variability in infiltration with time can therefore be attributed to changes in soil structure and hydraulic conditions around the test hole. The State Percolation Test, on the contrary, measures the rate of fall of the water level from the 6" level downward to the gravel. As the water level moves down, the area available for horizontal flow through the sidewall of the hole decreases. This may lead to a marked decrease of infiltration during each run.

Four different infiltration patterns of the SPT can be distinguished and are illustrated in Fig. 6.1. Type I shows a constant infiltration rate at all times. Type II shows a decrease of infiltration with time, due to other factors than change in water level, as indicated by the constant slope of each separate line. Types III and IV, on the contrary, show rate decreases related to the decreasing level of the water, reflected in the change in

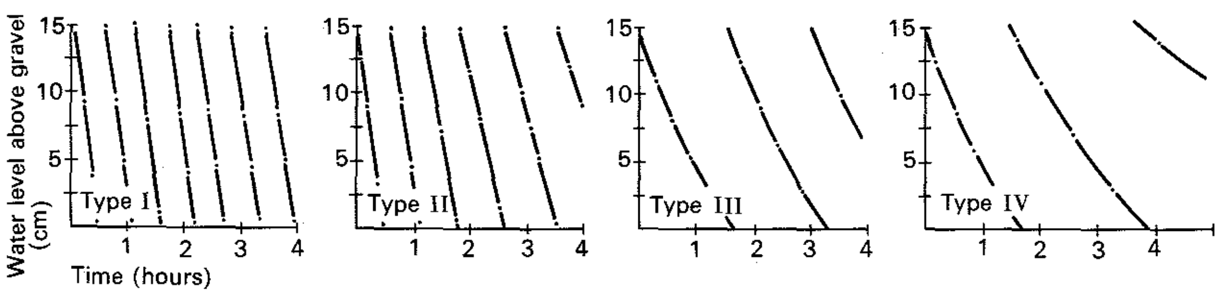


Fig. 6.1. Types of infiltration patterns of the percolation test.

the slope of each line during each separate run. Type III shows a constant pattern in each run. Type IV shows a gradual decrease as time progresses. Variation in the percolation test results of the latter two types is caused by the method of measurement as well as by soil factors.

The observed difference in CV between SPT and CLPT test results can be explained, since most SPT measurements exhibit curves of Types III and IV, indicating the influence of the water level in the hole, which is not constant in CLPT tests. To further explore the variability of SPT measurements, percolation rates (spring, 1970) for individual test holes have been calculated not only after a 4 hour period as required, but also after 2, 6 and 8 hours. Generally a decrease in the percolation rate with time is to be expected, since wetting will lead to a decrease of suction gradients in the soil and processes of swelling may reduce infiltration. However, attention should be given only to decreases caused by hydraulic and soil factors, which are relevant, not to these caused by the measurement procedure itself. In individual SPT holes the CV values varied between 70% (No. 5) and 17% (No. 4), with an average value of 44%. CV values for individual CLPT holes varied between 0 (No. 1 and 2) and 16% (No. 3) with an average of 6%. Again, the observed differences have to be attributed to the measurement procedure followed in the State Percolation Test. Maintaining a constant water level in the test hole, therefore, reduced the variability of results substantially.

(4) Hydraulic conductivity (K) values measured with the double tube method in a confined volume of soil of about 1,000 cm^3 (see Chapter 3) have a significantly lower CV (26%) than the other methods. K values are well defined soil physical constants that can be used in physical models of moisture flow. An infiltration rate such as that measured by the SPT cannot be considered as a physical constant because it is affected by variable boundary counditions in a large, undefined, volume of soil. Flow rates can be calculated if K values for both saturated and unsaturated soil, as well as the hydraulic gradients in the soil material are known. The gradients are measured in situ with tensiometers.

Investigation of operating systems (Chapter 5) has proved that the soil around septic tank seepage trenches is not saturated due to the presence of crusts of organic material on the trench surfaces. This implies that the liquid moves much more slowly into the soil than would be indicated by the saturated hydraulic conductivity. The new crust test (Chapter 3) yields the hydraulic conductivity (K) as a function of moisture content. Using such K values, flow rates can be predicted for unsaturated soil in accordance with suction gradients. This approach will be further explored in Chapter 6.2.

6.1.3. Interpretation of Percolation Test Results

The infiltration rates measured with the State Percolation Test are actually all relatively high. The limiting value of 60 min/inch (= 60 cm/day) still represents a considerable volume: In one day, 150 gallons of liquid would percolate into an area of 1 m^2 ($\approx$ 10 sq. ft). An absorption field of only 20 square feet in an uncrusted soil with K = 60 cm/day, would be sufficiently large to handle 300 gallons per day, the average effluent load for a family of four. In sandy soils an even smaller field would be adequate. A soil with a percolation rate of 2 min/inch (= 1800 cm/day) would need an absorptive area of only 700 cm^2 (that is less than one square foot) to handle 300 gallons per day! Practical experience has shown that things do not work out this way and as a consequence, the State Code (State Board of Health, 1969) requires a minimum absorption area of 50-85 square feet in soils with a percolation rate less than 3 min/inch. Some systems fail nevertheless. Percolation test results, therefore, do not predict the infiltration rates as they occur from seepage trenches. The real rates are much lower than those given by the test. This has been known for a long time (McGauhey and Krone, 1967) but the test has continually been applied since the nineteen twenties primarily because of lack of a better one, and also because of its proven usefulness in ranking different soils according to their relative capacities to transmit liquid. The great reduction in the soils infiltrative capacity by organic crusts on the walls of the trench (McGauhey and Krone, 1967) has been deemphasized. Since it has been quite obvious that real infiltration rates in disposal fields are much lower than rates measured by the SPT, empirical research and theorizing have been relied on to determine "factors" of reduction. Ludwig et al. (1949; see McGauhey and Krone, 1967) suggested the use of a "factor" of 20. That is to say, the amount of sewage effluent which may be leached away in a soil was estimated to be approximately one-twentieth of the amount of clear water that could seep through the same soil, in the absence of a crust. Kiker (1953) stated that soils in Florida would absorb 40 times as much water as effluent from settled sewage.

Percolation rates have also been empirically interpreted in terms of loading rates. Federik (1952) introduced the formula:

$$Q = 5/\sqrt{t}$$

where Q = the loading rate in gallons per day per sq. ft. in a tile field and t = percolation rate in min/per inch. Kiker (1953) introduced:

$$G = 29/t + 6.24$$

where G = Q of the previous formula.

In the original approach of Ryon, who introduced the test in 1928, percolation rates and loading rates were measured at several sites. Those values were plotted in a figure (see Fig. 6.2 after McGauhey and Krone) and a line was drawn arbitrarily separating systems where all applied liquid was absorbed by the soil from those where overflow occurred. Criteria, relating loading rate and sizing to percolation rate, as derived from this type of graph, are still being used. According to this approach the percolation rate is reduced by a factor varying from 20 to 2500, depending on the location of the system on the chart. Data reported above show that the interpretation of percolation test results is empirical and that effects of specific soil factors are intertwined with those of many factors of system management or construction, all of which together determine whether or not a system overflows. Knowledge of the hydraulic conductivity character-

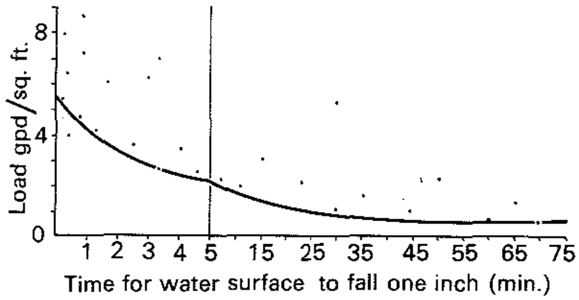


Fig. 6.2. Graphical expression of the relationship between system performance, soil percolation rate and loading rate of subsurface disposal systems. Each point represents an overflowing system (after McGauhey and Krone, 1967).

istics of soils will make it possible to consider soil factors separately (Section 6.2). Crust resistance and rate of application of effluent are not constant factors but vary as a function of the dosing regime. This points to an oversimplification in the Percolation Test. There is no single fixed permeability value, whether for saturated or unsaturated soil, that will sufficiently characterize a potentially dynamic soil-system around a seepage bed. Rather, there is a possible range of permeability values, characteristic for each soil material, that may be represented by a K-curve, which gives infiltration rates at unit hydraulic gradient in a one-dimensional flow system. Loading rates, pretreatment and the distribution of the effluent in the bed will determine at what rate, lying within this certain range, the soil absorbs the liquid at any given time.

Percolation tests or measurements of K emphasize hydraulics. The problem of liquid waste disposal, however, is very much a problem of disposal of excess nutrients (nitrogen and phosphorous) and harmful microorganisms. Therefore, an adequate study of the problem of liquid waste disposal from septic systems through soil absorption can only be made by considering all those interrelated factors together. These aspects will be further discussed in Sections 6.2 and 7.

6.2. The occurrence of unsaturated flow phenomena around seepage beds

6.2.1. Introduction

Results obtained from monitoring operating seepage beds in several soils (Section 5), indicate the occurrence of unsaturated soil materials below and at the sides of the bed, while effluent is ponded inside. This condition may result from a variety of causes. Bouwer (1959) has shown that considerable soil moisture tensions may pertain around a filled tile line due to divergence of flow lines (even without any physical barrier to flow at the interface of the tile and the soil). However, the flow system is quite different below a three or four feet wide seepage bed, where flowlines, except for the edges of the bed, will be more vertical and parallel. Then the phenomenon can be explained by assuming the presence of an impeding layer, a "crust", at the infiltrating surface, which has the effect to prevent saturation at the subcrust boundary even though the crust itself is subject to a positive hydraulic head (Hillel and Gardner, 1969, 1970a). As crust resistance increases, the degree of saturation and, as a result, the infiltration rate into the subcrust soil, decreases (see Chapter 2.4). Crusting or clogging of infiltrative surfaces in seepage beds has not been studied separately in this project, but its effects were observed. A brief literature review will be given on the process of soil crusting and soil pore clogging.

6.2.2. The process of soil pore clogging

6.2.2.1. Introduction

The experimental results reported in Section 5 and percolation test results discussed in Section 6.1 clearly demonstrate that the short term infiltration rate of clean water is not a good measure of the long term capacity of a soil to accept effluent. A distinction has to be made between infiltration at the interface between soil and liquid and the potential percolation rate of water once it has entered the porous structure of the soil (McGauhey and Krone, 1967). Hillel and Gardner (1969, 1970a, 1970b) studied the effect of impeding layers on infiltration, in quantitative terms, relating the infiltration rate into crusted soil to basic hydraulic properties of the crust and the underlying soil. The effect of an impeding layer present over the top of a soil column during infiltration is to decrease the potential head at the soil surface, thus reducing the driving force, and to decrease the soil water content (and correspondingly the hydraulic conductivity) of the infiltrating column. The crust test procedure (Section 3.2.4) is based on these principles. Processes of soil clogging at the interface of soil and seepage bed create such an impeding layer under the influence of several factors (McGauhey and Krone, 1967, p. 39-70):

1. The physical factor. The following subfactors contribute to clogging: compaction of soil by machinery at the site of construction of a seepage bed; smearing of soil surfaces by the excavation equipment; concentration of fine particles in the upper few centimeters of soil by vibration during construction; concentration of fine particles by raindrop impact.

2. The chemical factor. Ion exchange, after introduction of sodium through water softening, may lead to deflocculation of clayey soil at low salt concentrations at the soil-seepage trench interface.

3. The biological and organic factors. A black, slimey concentrate of organic matter and associated mineral colloids and growth of microorganisms on the surfaces of walls of seepage trenches constitutes the most restrictive clogging layer of the system.

6.2.2.2. Biologic clogging of infiltrative soil surfaces

A percolation rate curve for prolonged water and sewage spreading on a soil core, as determined for silt loam soil aggregates of sizes between 2 and 4 mm (bulk density 0.9), is shown in Fig. 6.3. The strong decrease in infiltration may be caused initially by slaking of the soil surface. The longer-term decrease in permeability and the increase of subcrust soil moisture tension, however, may result from microbial activity as has been demonstrated by Allison (1947). By applying sterile water to sterile soil, he showed that this decrease did not occur in the absence of organisms and that the relatively high rate achieved initially is maintained indefinitely. The infiltration rate decreased only slightly less rapidly in our experiment when distilled water was applied instead of effluent. The microbial action involved in the decline in permeability is primarily that of anaerobic organisms in accumulating organic material in the soil pores (McGauhey and Winneberger, 1964). In well drained soils, aerobic organisms are active in breaking down such compounds. This process is stopped by saturation, even with bacteria-free water, and consequent blockage of gaseous diffusion of oxygen (Thomas, et al., 1968) into and within the soil system. Dissolved oxygen carried down by water is inadequate in amount to maintain the aerobic environment necessary for decomposition of organic matter. The existence of reducing conditions at the wall of the trench is indicated by a dark gray to gray zone, as much as a few cm thick, in sandy soil adjacent to a black coating on the bottom of the seepage bed.

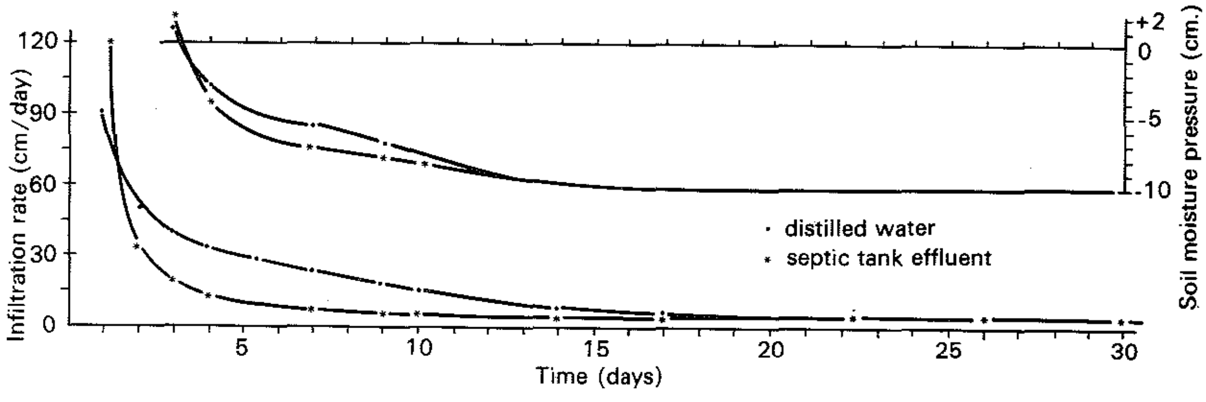


Fig. 6.3. A percolation rate curve for prolonged water and sewage spreading on soil cores.

Thomas, et al. (1966) studied biological clogging of sand in lysimeters, that were dosed at a rate of 5 gallons/day/sq. ft. A sharp decline in infiltration rate coincided with the onset of anaerobic conditions as indicated by cessation of nitrification. Sulfide accumulation resulted from the anaerobic environment and was not considered to be a primary cause of clogging. The clogging mechanism under anaerobic conditions was correlated with build-up of high contents of polysaccharides, polyuronides and organic matter in the first cm of the soil, that accounted for 85% of the total impedance over a thickness of 0-6 cm of soil. The recovery of the infiltration rate after aeration resulted from destruction of the clogging compounds that had accumulated under anaerobic conditions. Mitchel and Nevo (1965, as cited by McGauhey and Krone, 1967) also showed a positive correlation between accumulation of polysaccharides in the soil profile and reduction of its infiltrative capacity. These workers suggested the operation of a dynamic equilibrium at any level of aeration between polysaccharide-producing organisms (anaerobic), and polysaccharide-destroying organisms (aerobic).

Harris et al. (1966) demonstrated an increase of soil aggregate stability in surface soil after addition of sucrose, as a result of microbial production of organic compounds, both under aerobic and anaerobic conditions. Rates of decomposition under aerobic conditions of compounds that were produced anaerobically proceeded rapidly at temperatures over 15°C, and much slower at lower temperatures. Decomposition and synthesis of the organic compounds is accomplished not by a single type of bacteria but rather by a population of types as determined by environmental conditions.

Clogging of the bottom area of seepage beds appears to start at the point of inlet and to progress thence. All studied systems of the conventional type, while in continuous use and over six months in age, appeared to have a crust at the bottom and part of the sidewall of the seepage bed, as indicated by ponded effluent in the trench and unsaturated soil around it. The only exceptions found were a young system in Adams County (Site 3, Fig. 4.1; and Chapter 5.2.1) and an older system which had not been in use for several weeks (Pickerel Lake, at Site 12, Fig. 4.1; and Chapter 5.2.3). Relatively new systems studied near the University of Wisconsin Hancock Experimental Farm (Site 10, Fig. 4.1; and Chapter 5.2.1), near Dardis Lake (Site 24, Fig. 4.1; and Chapter 5.2.3) and near Black River Falls (Site 17, Fig. 4.1; and Chapter 5.2.7) contained ponded effluent in only the part of the seepage beds adjacent to the inlets. The remainder of the beds apparently had not yet received effluent. The following picture of progressive crusting of seepage beds emerges from the experimental evidence (see Fig. 6.4). Seepage beds are fed effluent by gravity flow. The more or less continuous trickle of effluent entering the pipe that leads into the gravel bed will periodically increase in volume when large volumes of liquid enter the septic tank during the day and will dwindle during the night. The pipe in the bed is perforated. Sometimes holes (5/8" diameter) are only at the bottom of the pipe, at spacings of about 3". The modern Orangeburg perforated pipe has two rows of 39 holes each per ten-foot segment. These two rows are found in the lower half segment of the pipe at a 45° angle with the vertical. The purpose of this is to create a flow system in which effluent moves down the whole length of the pipe before flowing out of the many holes at the side. This mechanism however, is very easily disturbed by slight variations in the slope of the pipe and from our observations we conclude that in both cases, that is with holes at the bottom and with two rows of holes at the sides, effluent is discharged from the pipe at a point close to the inlet point. The soil below the gravel-filled seepage bed at that point, then, receives a more or less continuous trickle of effluent. This leads to biogenic crusting, and consequent reduction of movement into the soil and ponding of effluent at that point. This forces some effluent to flow along the bottom of the trench until it encounters fresh uncrusted soil with a still relatively high permeability. This movement progresses until the whole bottom area is crusted, effluent is ponded in the bed, and soil below the crust is unsaturated.

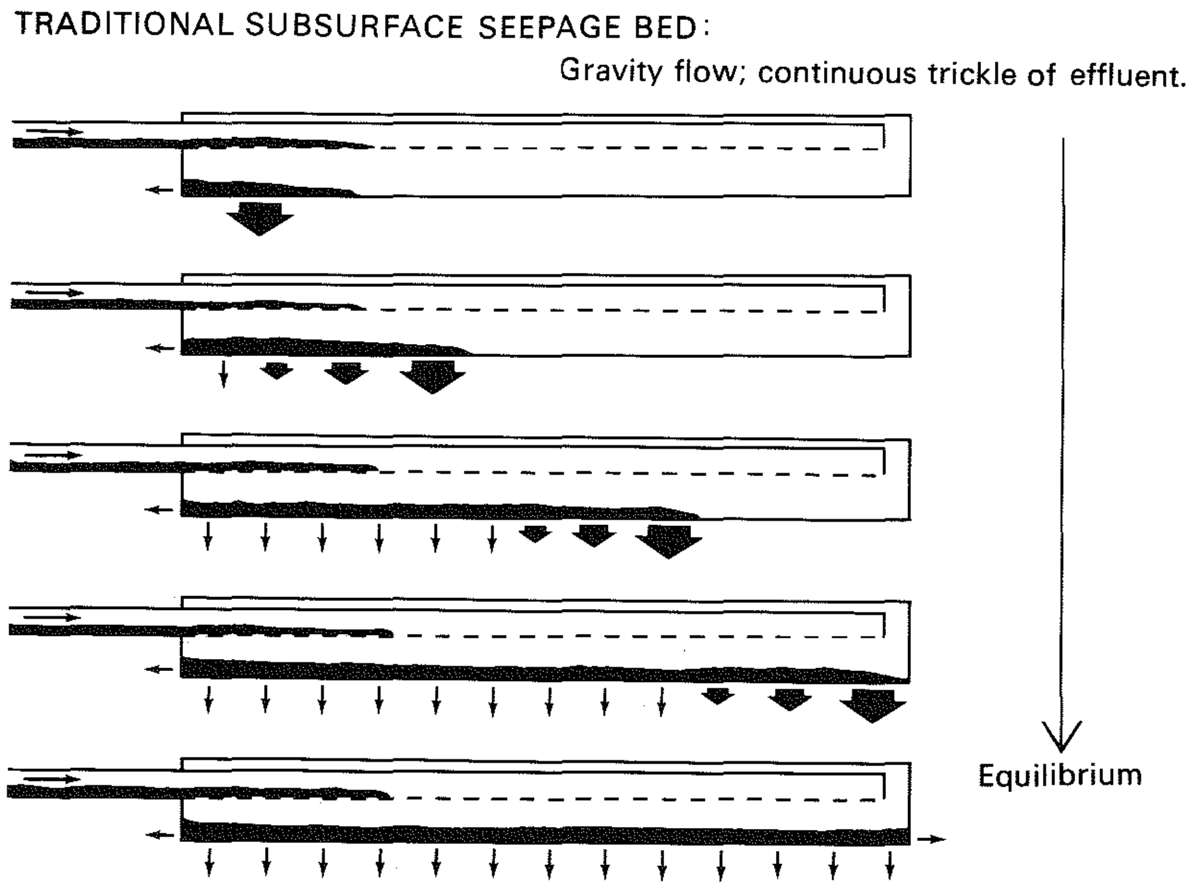


Fig. 6.4. Progressive crusting of the infiltrative surfaces of subsurface seepage beds.

6.2.3. The significance of unsaturated flow phenomena.

Flow of liquid in unsaturated soil materials proceeds at a much slower rate than in saturated soil, and flow occurs in the fine pores only (Chapter 2.4). This is potentially advantageous from a viewpoint of purification of effluent by processes of filtration and absorption, because average distances between effluent particles and the solid soil phase decrease, while the potential time of contact increases. This can be illustrated for two examples, using physical theory as discussed in Chapter 2.4. Fig. 6.5 shows a thin section of the C horizon of a Plainfield loamy sand, which has a medium sand texture. At saturation, K = 500 cm/day. Considering the water filled porosity as derived from the moisture retention curve, the flow velocity in the soil pores themselves can be estimated (Chapter 2.4). This velocity can be used to derive the time necessary for the liquid to travel one foot (30 cm), assuming a hydraulic gradient of 1 cm/cm due only to gravity. Larger pores empty at increasing tensions and K decreases correspondingly. Calculated travel times increase from 33 minutes at saturation to 13 hours at 30 mbars and 300 days at 80 mbars of soil moisture tension. The corresponding time intervals in Fig. 6.6, derived for a sandy loam till occurring as the IIC horizon in a Saybrook silt loam, are different because of the different pore size distribution. The K_{sat} value of this soil material is lower (80 cm/day) and the corresponding travel time is longer (3 hours). Due to different moisture retention characteristics and a different K curve, travel times at higher tensions are different such that they increase from 30 hours at 30 mbars to 8 days at 80 mbars tension. Similar values can be calculated for intermediate tensions. Results are graphically expressed in Fig. 6.7; including observations for a B2 horizon of a Plano silt loam and for a B2 horizon in a Hibbing loam (clay). The moisture retention curves of these horizons were presented in Fig. 2.3.2. and the K curves in Fig. 2.4.4. The lines in Fig. 6.7 illustrate the specific behavior of the different soil materials. Bacteriological studies of die-off of fecal organisms as a function of time can make this type of data useful in defining the necessary distance of soil filtration as a function of moisture content.

Very high moisture tensions below heavy crusts in seepage beds would be most favorable from a viewpoint of soil filtration. However, this would require inordinately large seepage areas to dispose of the considerable quantities of effluent usually produced. For example, at a moisture tension of 80 mbars in sand, the K value is 0.1 mm/day. An area of 12000 m^2 (almost three acres) would be needed to dispose of 300 gallons per day. This, of course, would be prohibitive in terms of cost of a subsurface gravel-filled seepage bed, and would be more analogous to spraying of effluent on the soil surface over a farm field. The limited areas available around homesites and the cost of installation of a gravel bed, therefore, present important criteria for permissible sizing of seepage beds, which is opposite to the one based on maximum filtration. Obviously some compromise between these two kinds of criteria will have to be defined for each soil material as a function of its hydraulic characteristics. In Fig. 6.8. an attempt was made to do this for the major soil materials investigated. The studied soil horizons are the same as those discussed in Fig. 6.7. The hydraulic conductivity curves of the various soil materials, as measured <u>in situ</u> in the field with the crust-test procedure, were used for each soil material to show the characteristic range of infiltration rates (at a hydraulic

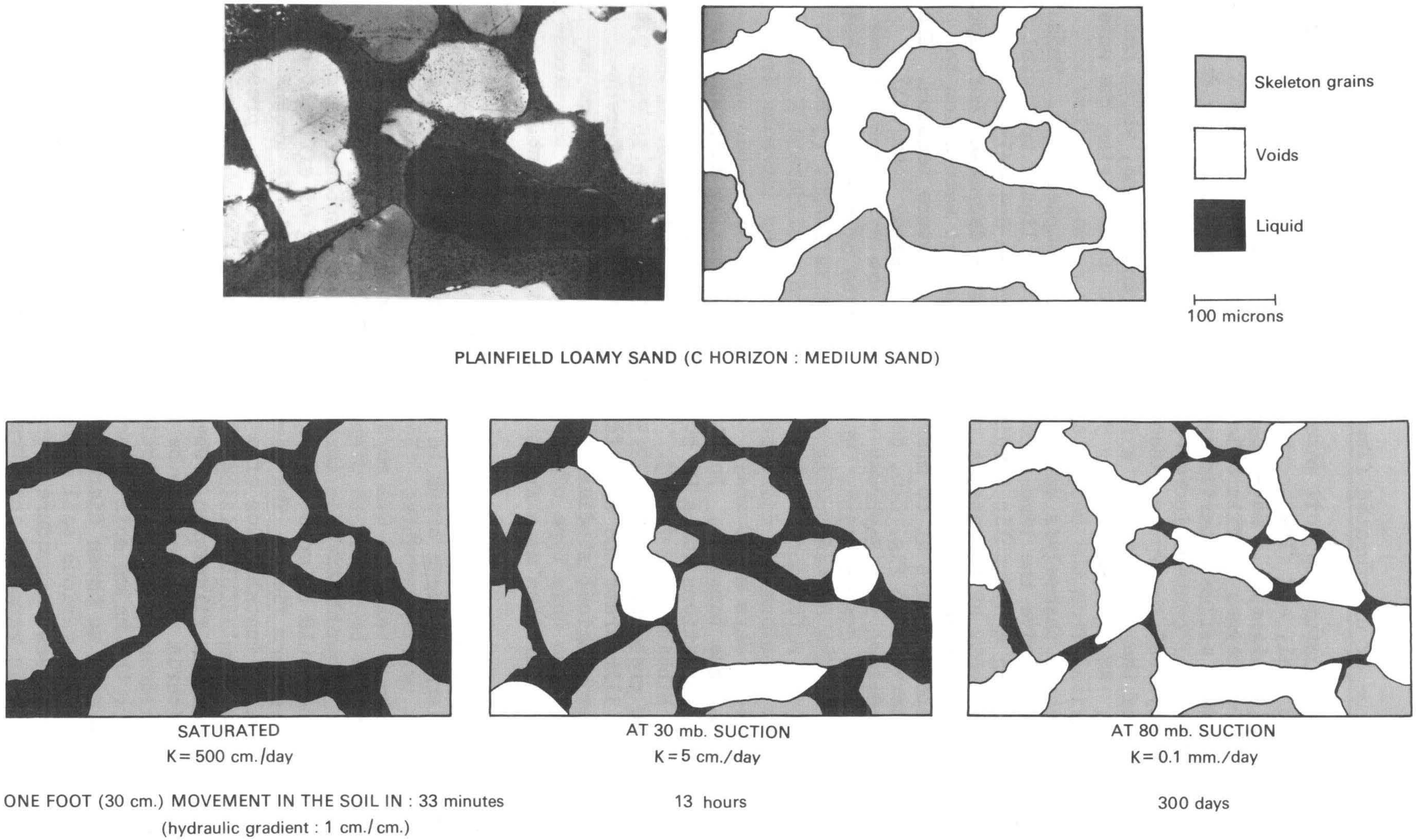
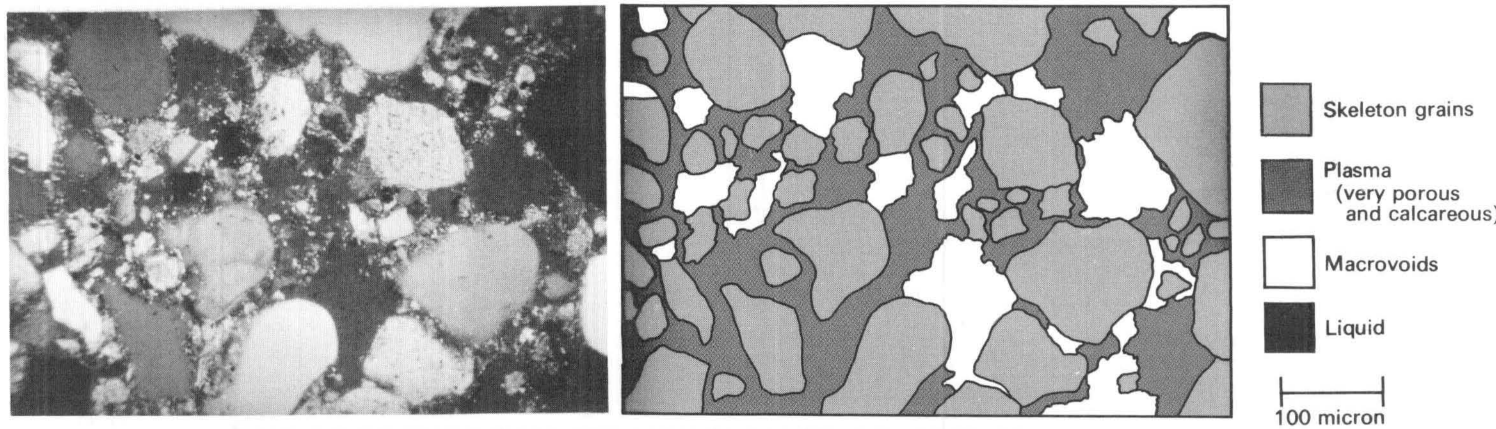
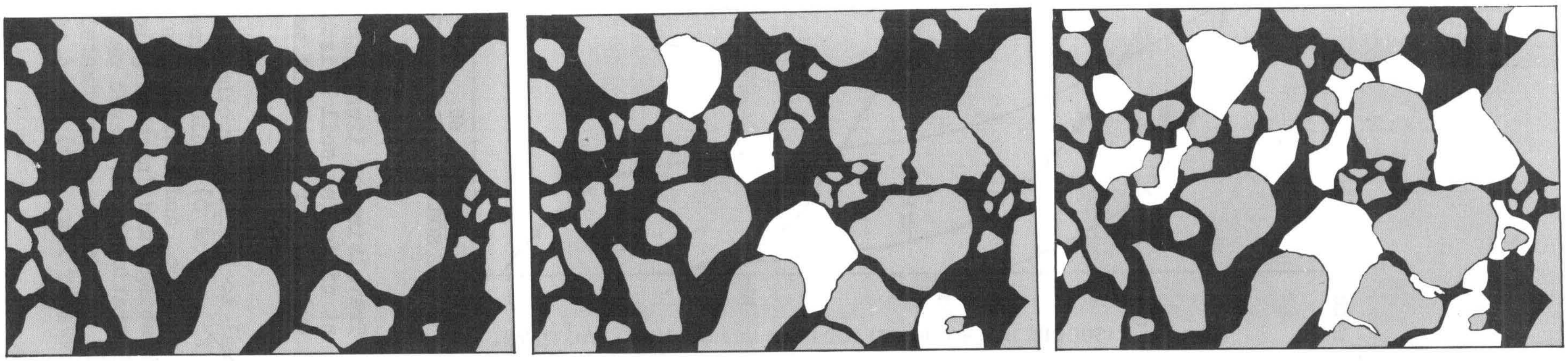


Fig. 6.5. Occurrence and movement of liquid in a saturated and unsaturated sand (C horizon of Plainfield loamy sand).



SAYBROOK SILT LOAM (IIC STONY SANDY LOAM TILL)



SATURATED
K= 80 cm./day
ONE FOOT (30 cm.) MOVEMENT IN THE SOIL IN : 3 hours
(hydraulic gradient : 1 cm / cm)

At 30 mb. SUCTION
K = 7cm/day
30 hours

At 80 mb. SUCTION
K = 7mm/day
8 days

Fig. 6.6. Occurrence and movement of liquid in a saturated and unsaturated sandy loam (IIC horizon of a Saybrook silt loam).

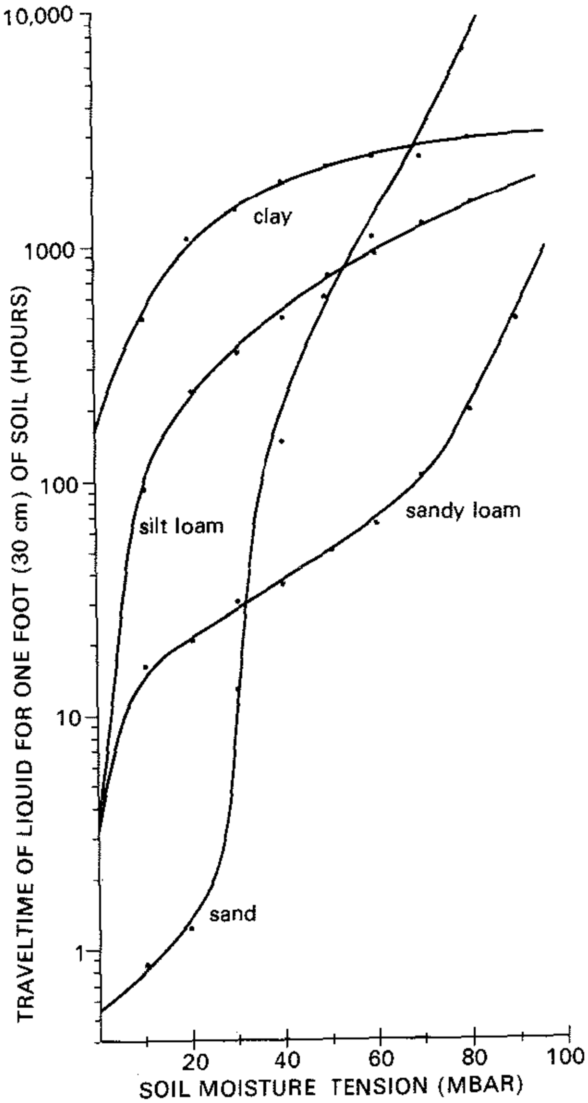


Fig. 6.7. Traveltime of liquid for one foot of soil at different soil moisture tensions, calculated for four soil materials.

gradient of 1 cm/cm equal to K) in a hypothetical one-dimensional flow system below the gravel bed. K_{sat} (P = 0) would represent the infiltration rate into an uncrusted soil surface, and K decreases in characteristic patterns with increasing soil crusting, and increasing soil moisture tension. A lower limit of allowable infiltration rate, based on practical and economical criteria was tentatively defined as approximately 2 cm/day (see lower horizontal lines in the curves of Fig. 6.8) based on a seepage bed area of 1000 sq. ft. (90 m^2) and a daily loading rate of about 300 gallons (1200 L or dm^3). An upper limit of allowable infiltration rate (the upper horizontal line in the curves of Fig. 6.8) is harder to define, as this will be a function of travel time at saturation and at very low suctions and of specific structure characteristics, such as the occurrence of worm channels or large continuous cracks. The available range in the clay soil was so small that only the lower limit was pictured in Fig. 6.8. A tension of 10 mbar was tentatively selected as the critical upper level for the silt loam as this tension is sufficiently high to keep extensive worm channels from being filled with effluent. For the sandy loam and the sand, tensions of respectively 10 and 30 mbars were tentatively selected as the upper limit. A travel time of about half a day per foot of soil corresponds with that value for these soil materials (Fig. 6.7). Shorter or longer times may be derived later from additional experiments. The travel time of half a day per foot is only given here as an example of the general approach. The creviced limestone bedrock, representative for subsoil conditions at shallow depth in Door County, presents a different situation as liquid can only move in the crevices, since movement inside the limestone itself is impossible. As a consequence a very high infiltration rate at saturation drops down to virtually zero as the crevices empty with increasing tension. In the real field situation, a thin loamy soil mantle covers the creviced bedrock. Liquid moving down through the usually unsaturated topsoil will accumulate at the surface of the bedrock until saturation is achieved, followed by flow of liquid into open crevices.

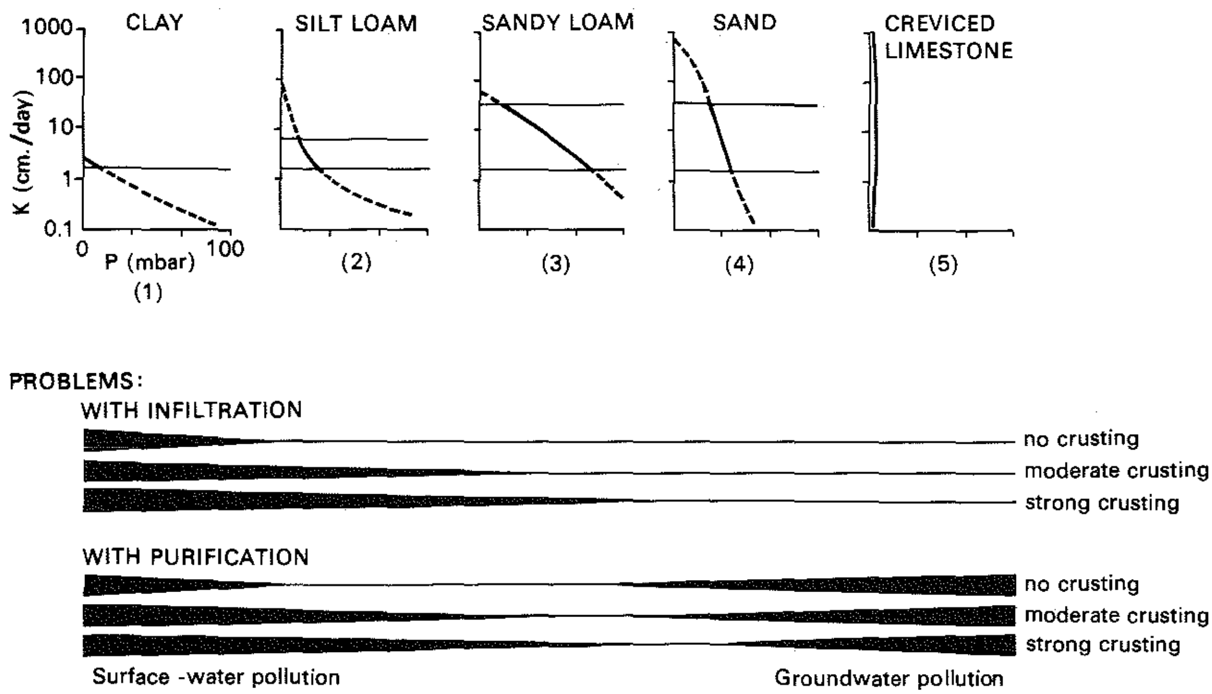


Fig. 6.8. **Potential of different soil materials for liquid waste disposal, expressed as a function of the hydraulic conductivity curve.**

The delineated sections on the K-curve graphically express soil potential for liquid waste disposal defined here as a range of acceptable infiltration rates. Management of a disposal system should be directed towards establishment of an infiltration rate in this range, either by manipulation of crust resistances, if feasable, or by means of a specific method of application of effluent to the soil.

The sandy loam soil material has, in this context, the widest potential: the suitable range of tensions is from 10 to 60 mbars. Sands (range 30-40 mbars) and silt loams (range 10-25 mbars) have a smaller potential and the subsoil clay is too low even without crusting.

Results of monitoring conventional systems as reported in Chapter 5 showed that 6 crusted systems in sand had a degree of crusting corresponding with tensions varying within a narrow range of 20 to 26 mbars which is somewhat lower than the tentative limit value of 30 mbar. Heavier crusts were not observed in sands in this study. This does not necessarily mean that such heavy crusts could not exist. However, we believe that the primary cause of failing of systems in sands, as observed when effluent backs up into the basement of a home or surfaces above the ground surface, is due to overloading of the system, or, what is equivalent, undersizing of the seepage bed. Crusting is the best thing that can happen to a seepage bed in sand, provided that the size of the bed is sufficiently large to absorb all effluent at the reduced flow level. The K curve provides a quantitative criterion for sizing, and it is suggested to use the K value at 30 mbars, which is usually around 5 cm (2 inches) per day, as a representative infiltration rate.

The two systems observed in sandy loam till (Section 5.2.4) were initially severely crusted with a subcrust tension of 80 mb, well above the lower limit of 60 mbars. Aeration of the bed and intermittent application of effluent were found to be the means of bringing the infiltration rate within the desirable range of 10-60 mbars (Section 8.2.1). The systems studied in clay or clayey till (Sections 5.2.3, 5.2.5, and 5.2.6) failed because of low K_{sat}.

A visualized summary of problems with soil disposal systems in different soils, as indicated by thick lines that relate to the type of soil pictured directly above, is presented in the lower part of Fig. 6.8. A separation is made between the two main aspects involved: 1. The infiltration; 2. The purification, considered as having both bacteriological and chemical aspects. Soils with a low K_{sat} value offer problems with infiltration, evidenced by surface leakage, as was observed at the Ashland, Marshfield and Kelly Lake sites (Sites 19, 13, and 18, Fig. 4.1). Potentially suitable but strongly crusted soil materials, like the sandy loam at Arlington (Site 4, Fig. 4.1) may offer the same problem. The thick part of the third line from the top, corresponding with heavy crusting, extends therefore farther to the right. Pollution problems are evident in terms of surface water pollution when surface leakage of effluent occurs. The lower three lines, indicating problems with purification, are therefore identical with the top three lines on the left side of the figure. Pollution may also occur, however, when the effluent moves too fast through the soil, thereby polluting the ground water. This is most evident in the case of creviced bedrock (sites in Door County) but

Table 6.2. Calculation of infiltration rates and moisture tensions below seepage beds sized according to the Code, assuming loading rates of 75 gal./person/day.

Soil type and horizon	Percolation test: Perc. rate	Percolation test: class	Seepage area needed in sq. ft. (m^2). State Code: 2 bedroom (4 persons)	Seepage area needed in sq. ft. (m^2). State Code: 3 bedroom (6 persons)	Corresponding flow, rate and moisture tension
C horizon of Plainfield loamy sand (sand)	<3	1	170(15.3)	255(23.0)	8 cm/day (25 mb)
IIC of Saybrook silt loam (sandy loam)	3-10	2	330(29.7)	495(44.5)	5 cm/day (42 mb)
B2 of Plano silt loam (silty clay loam)	10-30	3	500(45.0)	750(67.5)	3 cm/day (12 mb)
B3 of Plano silt loam (silty clay loam)	30-45	4	600(54.0)	900(81.0)	3 cm/day (10 mb)
Ap of Ontonagon clay (clay)	45-60	5	660(59.4)	990(89.1)	3 cm/day (12 mb)

also in sands where the problem of chemical ground water pollution may be quite evident.

The concept of soil filtration as a function of unsaturated flow phenomena discussed herein, does, however, not apply directly to the problem of nitrate movement to the ground water. Nitrification processes in partly saturated soil produce nitrates, which are not absorbed and may pollute the ground water (Sections 5.2.1. and 5.2.7). Figure 6.8 illustrates the fact that soil materials with a sandy loam, or loamy sand texture are potentially most suitable from a hydrological viewpoint for use as a purifying filter in liquid waste disposal.

Sizing of seepage beds according to quantitative criteria based on K curves can be compared with those of the State Code, based on percolation test results and empirical interpretations (see Section 6.1) (State Board of Health, 1969). It is useful to consider the case of two- and three-bedroom houses with all utilities, at several soil locations. By way of example we may take the required sizing according to percolation rate from the Code, and calculate the resulting infiltration rate (and corresponding soil moisture tension derived from the K-curve) at a loading rate of 75 gallons per person per day with 2 persons per bedroom (Table 6.2) and compare these values with the range of values defined earlier. It follows from Table 6.2 that sizing according to the State Code yields potential subcrust tensions well within the desired range, defined previously. It is found, therefore that sizes of seepage beds as recommended by the Code are potentially satisfactory, provided that subcrust-tensions don't gradually rise above the values in the last column of Table 6.2.

Finally, attention has to be paid to the method of application of liquid to the bed. Up to this point in this chapter, unsaturated flow phenomena have been discussed exclusively in association with crusting of infiltrative surfaces. As explained in Chapter 2.4, however, steady application of liquid at a rate which is lower than the saturated hydraulic conductivity will also result in unsaturated soil. With decreasing rate of application, assuming that the liquid is evenly divided over the infiltrating surface, the moisture tension in the soil increases. Improving the current crude gravity-flow technique of effluent application into the gravel bed (as discussed earlier) has the potential of yielding a reliable and flexible method to manipulate hydraulic conditions without emphasis on biological crusting. A pressure discharge system inside the bed, for example, working at regular time intervals at a selected known intensity could be used to create the most desirable moisture tensions, as defined and discussed in this chapter, in soil below the seepage bed.

7. BACTERIOLOGICAL PURIFICATION OF SEPTIC-TANK EFFLUENT BY SOIL PERCOLATION

7.1. Introduction

The data on which the following discussion is based are taken from the study of 19 conventional subsurface soil disposal systems. Some of the systems were sampled at different times of the year; thus they reflect in some degree the seasonal variation in biological activity and consequent problems. The bacteriological data are to be found mostly in the tables of Chapter 5.2 and will be cited here at the appropriate places in discussing the successful operation or failure of particular systems. The bacteriological aspects under consideration are those relating to 1) public health and sanitation, 2) activity of both sewage and soil bacteria in the soil absorption system, including crust formation, and 3) use of pollution indicator bacteria as evidence of water movement within or through the seepage bed. Because of interaction of sewage bacteria and soil bacteria, both responding to the gradients of moisture and nutrient as the effluent percolates through the soil, there are some complex and interesting aspects of the bacteriological activities.

7.2. Public health aspects

It must be assumed that the fecal bacteria in the septic effluent are the survivors of the intestinal flora, and that counts of total coliform (TC), fecal coliform (FC) and fecal streptococci (FS) can be used here, as in Standard water analysis, to reflect the possible presence of human pathogens, i.e. Salmonella spp., Shigella spp., etc. Detection of the actual pathogens in a sewage-soil system would be even more difficult than in a sewage-water system. The overwhelming numbers of soil bacteria, as well as their known potential for antagonism, have made it very difficult to detect either the pollution indicators or actual human pathogens in nature. Also the natural presence of fecal bacteria from wild animals and insects and from green plants for at least some of the "total coliform" flora makes the interpretation of counts difficult. A recent study of the significance of coliforms, including Escherichia coli, in the environment has been published by Geldreich (1966).

The picture is complicated by the presence of both coliforms and streptococci on green plants, especially their buds and flowers. Much research has been done to account for this and to devise tests to separate this background pollution from the human fecal pollution which concerns public health. By using counts of fecal coliform (FC), i.e. eliminating from the total coliform (TC) the lower temperature and IMViC --++ types, some clarification is possible. Combining such FC counts with fecal streptococcus (FS) counts still further differentiates the true fecal pollution. Geldreich (1966) reports the ratio of FC/FS to be different for human versus animal pollution. For the fresh feces of man the FC/FS ratio is in the range of 4.4 and for lower animals including poultry the range is 0.1 to 0.6. These ratios are sufficiently different that they may be used as partial evidence of the source of pollution in soils and waters. This approach was tried in the present study of seepage beds and data will be reported in Chapter 7.4 below.

Table 7.1 Bacterial counts and FC/FS ratios on samples taken at various parts of disposal systems, correlated with description of the septic tanks concerned

Sample and site	Enterococci (No./ml)	Fecal coliform (No./ml)	Total coliform (No./ml)	Total bacteria (No./ml)	FC/FS ratio	Crust	Est. liquid input (gpd)	Septic tank size (gal.)	Tank detention time (days)	Disposal field area ($ft.^2$)
Septic tanks										
Clark County Mound system 1	20	1000	44,000	2.24×10^{7}	50.0	?	450	750	1.67	600
Adams County System 6	420	18,000	57,000	7.50×10^{7}	42.8	+ (weak)	300	750	2.50	800*
	390	13,000	48,000	9.00×10^{7}	33.3					
	100	15,000	46,000	2.40×10^{7}	150.0					
Black River Falls (series tanks) 1	500	3,000	34,000	2.06×10^{9}	6.0	+	5600	2000	0.36@ (or 0.72 combined)	two beds 2400@* (one in use)
2	230	4,000	48,000	2.20×10^{6}	30.5		5600	2000		
Distribution boxes										
Black River Falls	300	7,000	27,000	3.90×10^{6}	23.3					
Door County Mound system 1	1330	3,000	9,300	2.33×10^{6}	2.3	-	1500	2000	1.33	2000*
Mound system 2	2610	6,000	18,300	1.83×10^{7}	1.5	-	375	750	2.00	400
Mound system 4	5760	1,160	10,400	6.71×10^{6}	0.2	-	225	750	3.34	500
Arlington	260	4,000	16,000	1.23×10^{7}	15.2	++	80	750	9.37	400

Table 7.1 (con't.)

Sample and site	Enterococci (No./ml)	Fecal coliform (No./ml)	Total coliform (No./ml)	Total bacteria (No./ml)	FC/FS ratio	Crust	Est. liquid input (gpd)	Septic tank size (gal.)	Tank detention time (days)	Disposal field area (ft.^{2})
Trench liquid										
Clark County Mound system 2	350	5,000	34,000	5.37×10^{6}	16.7	+	300	750	2.50	400
Adams County System 4	1,170	10,300	45,000	9.86×10^{7}	8.8	+		two tanks 2000@		2740
System 5 (sampled) 7/22/70	130	40,000	220,000	1.13×10^{7}	308.0	+	360	750	2.08	400
11/17/71	41.3	640	23,500	4.00×10^{6}	15.5					
11/17/71 (surfaced liquid)	14.0	26.7	3,670	1.80×10^{5}	1.9					
Dry wells										
Steven Point System B	5,370	900	32,500	10^{4}-10^{5}	0.2	?				
System E	240	200	18,000	1.00×10^{5}	0.8	?				
System F	650	10,000	40,000	1.45×10^{6}	15.5	?				
System H	3	1,000	31,500	6.00×10^{5}	333.3	+				

* effluent known to be unevenly distributed over the seepage bed area. Therefore, entire disposal field area is not in use.

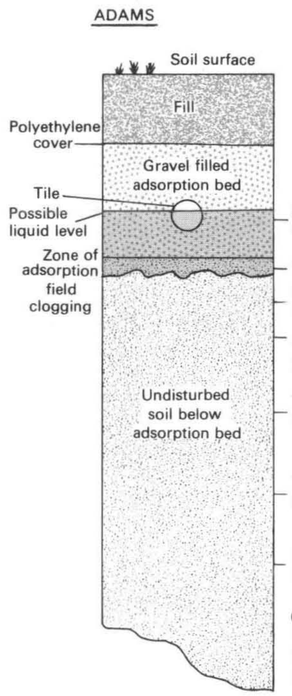
The total coliform counts (TC), which include the FC and the soil and water types such as the various IMViC patterns of the A. aerogenes group (which itself is --++) are of some value in studying the coliforms in sewage-soil systems. When TC counts are significantly higher in the system than in the adjoining natural soil, the interpretation is that they come from the sewage pollution source. However, it should be noted that the count would also include the coliforms and streptococci (enterococci) of the natural soil, and perhaps they multiply in response to moisture and nutrient of the septic percolation water. It is known that increasing moisture up to 60-80% of the water holding capacity of the soil will increase bacterial activity. However, water-logged or saturated soils cause a decrease and/or change of kind of bacterial activity. Therefore moisture addition from septic effluent should be detectable by observing changes in the microflora of the soil of the seepage bed. With increasing distance from the drainage tile there is a gradient of influence and finally the natural soil microflora. Data of this sort have been collected as total bacterial counts (TBC), and they help to interpret the water movement and influence of the sewage in the subsurface disposal.

7.3. Conventional systems analyses with bacteriological interpretation

7.3.1. Detailed study of Adams County System 5.

Detailed data on the bacterial populations for a single system (Table 5.12 for Adams County System 5) will illustrate the general picture for all. However, additional data on other systems studied may be found in Chapter 5 (Tables 5.2, 5.4, 5.7, 5.9, 5.14, 5.16, 5.19, 5.20, 5.23 and 5.28). Fig. 7.1 concerns the Adams County System 5 and it relates the counts for TC, FC, FS (= Enterococcus), and TBC to the position of the samples taken in the soil below the seepage bed. These samples were obtained by excavating and thus are moist soil samples (not test well samples which will be discussed later in 7.3.3).

The counts on the septic effluent entering the seepage field are typically high for all bacterial types counted; it should be noted also that the TC and FC counts are nearly the same and the FS counts are lower by an order of 10, as is expected for human feces. All three of these pollution bacteria are rapidly removed by soil adsorption below the trench. So also are a great many of the general bacteria of the septic effluent as shown by a drastic drop in the TBC count. So far as numbers are concerned, the population in the seepage bed is reduced within 2 feet below the trench to about the level of population in control soil. The abrupt drop in numbers occurs in the so-called crust or clogged zone which in this system is limited to less than 2 inches just below the trench. Detailed counts in the crust zone of the Adams County System 5 and of a Black River Falls system are also presented in Fig. 7.2. Efficient removal of the pollution and other bacteria in the crust is confirmed.

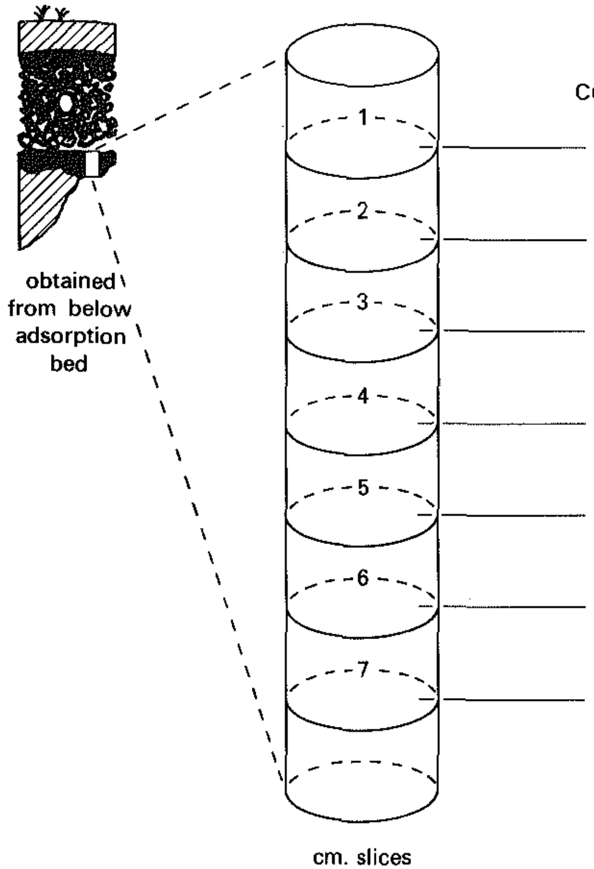


BACTERIAL COUNTS (per gram of soil)

	TOTAL COLIFORM	FECAL COLIFORM	ENTERO-COCCUS	TOTAL BACTERIA
SEPTIC TANK EFFLUENT(per ml)	22 x 10^4	40 x 10^3	130	11 x 10^6
CLOGGED ZONE	4 x 10^4 to 200	*	*	10 to 10^5
SIX INCHES BELOW BED	*	*	*	50 x 10^4
ONE FOOT BELOW BED	*	*	*	5 x 10^4
TWO FEET BELOW BED	*	*	*	4 x 10^4
THREE FEET BELOW BED	*	*	*	2 x 10^4
FOUR FEET BELOW BED	*	*	*	
CONTROL: Twelve feet from adsorption field at a depth of three feet	*	1	*	1g x 10^4

* organism not detected, <10/gram per plate (triplicate platings of each sample)

Fig. 7.1. Bacterial counts in soil samples taken below the seepage bed of Adams County system No. 5 .



Slice	BLACK RIVER FALLS: BACTERIAL COUNTS IN CLOGGED ZONE (per gram of soil) TOTAL COLIFORM	FECAL COLIFORM	ENTERO-COCCUS	TOTAL BACTERIA	ADAMS: BACTERIAL COUNTS IN CLOGGED ZONE (per gram of soil) TOTAL COLIFORM	FECAL COLIFORM	ENTERO-COCCUS	TOTAL BACTERIA
1	60	2	50	85×10^4	5×10^4	X	X	27×10^6
2					3×10^4	X	X	3×10^6
3	14	4	12	11×10^5	2×10^2	X	X	2×10^5
4					X	X	X	2×10^5
5	**	**	**	10×10^4				
6								
7	2	**	**	20×10^5	X	X	X	1×10^5

** organism not detected, < 6 /gram per plate (triplicate platings of each sample)

X organism not detected, <10/ gram per plate (triplicate platings of each sample)

Fig. 7.2. Bacterial counts in soil samples taken in the clogged zone (7 cm) of the systems in Black River Falls and Adams County (No. 5).

7.3.2. The crust zone and nature of its bacterial population

A crust or clogged zone immediately below the distribution trench is found in most seepage systems (probably in all of them eventually because such a zone develops with age and accumulation of organic aggregates). A clogged zone reduces the hydraulic conductivity and causes ponding of the effluent in the trench. A darkening, due to the presence of iron sulfide defines the zone and implies a prevailing anaerobic condition within the zone.

The bacteria within the crust are not necessarily anaerobic but can be facultative types functioning anaerobically. Such would be the case of the coliforms, streptococci and many of the TBC bacteria. The moisture tension below a heavy crust in a sand to loamy sand soil is usually 20-25 mbars. It is not possible from the data available to say whether the high bacterial population in the crust results from trapping by adsorption or from growth. Probably both processes occur, since nutrients, moisture, pH and temperature are generally favorable. One bit of evidence for growth in the region is found in the counts for soil actinomycetes. They were not found in the crust proper (because of its anaerobiosis) but large numbers were found in the subcrust region, decreasing with depth to near the numbers of actinomycetes in the soil at about 100 cm depth. This high actinomycete population is probably due to favorable moisture and nutrient in the unsaturated, therefore oxygenated, zone under the trench. Such populations of actinomycetes, as well as *Pseudomonas* and *Bacillus* species which were also found in the same region and for the same reasons, are probably important. All three of these groups of bacteria are active producers of antibiotics and thus may play an important role in the die-off of the fecal coliforms and fecal streptococci.

The bacterial populations in new systems with recent crusting are also interesting. As illustrated by the Black River Falls system (Table 5.27 and Table 7.1) the septic effluent entering the drainage system is typically high in all counts and high in the FC/FS ratio. This system had only been operated for a six-week period. The detention time of sewage in the tank was only 0.36 days compared with 2-3 days for the Adams County systems and in excess of 9 days for the Arlington system (Table 7.1). Crusting was well developed from a hydraulic point of view in the bottom area of the bed adjacent to the inlet where the samples were taken (see Chapter 5.2.7). However, a relatively low adsorption of TC, FC, and FS occurred in this recently formed crust zone (Fig. 7.2). As a result the TBC as well as the pollution types TC, FC and even FS were detected as much as 15 cm below the base of the trench (Table 5.27). Another indication of the tendency for septic effluent bacteria to be transported to greater depths in the Black River Falls system was seen in the presence of a distinctive colony type in samples from near the trench to a depth of at least 45 cm. This organism has a distinctive blue color on EMB plates and is easily recognized. While it is not a familiar pollution type, it was characteristic of this system and was never found in the control soil samples tested.

The significance of the trapping of bacteria in the crust should be noted. Although the crust is only a few centimeters or inches deep and has a very high bacterial population, it is highly efficient in adsorbing and holding both general and pollution bacteria. If the crust is poorly or unevenly developed, there is a chance for the bacteria to slip through and penetrate more deeply into the subtrench bed. Thus the crust is good in function, unless it is very heavy and causes clogging to the point of causing serious ponding.

A second point of interest at the Black River Falls site was the temperature range found in the bed. One foot below the trench the temperature was 23°C whereas in the control soil at the same depth it was 18°C on October 21, 1971. Such a thermal advantage for the seepage bed may have a great deal to do with survival and possible multiplication of both general and pollution bacteria. More studies should be done including the warm months of the year, to evaluate the effects of temperature in the system.

A third observation was made for all systems that developed crusting but the phenomenon was particularly well developed in the Dardis Lake system (Table 5.19). The TBC plates for samples taken at the crust zone and a few centimeters below it, showed both a very high count and a transitional type of flora from that of sewage to that of natural soil. For the Dardis Lake system the TBC numbers were 1.04×10^8/g of moist crusted soil, dropping to 4.6×10^7 "immediately below the crust" and to 7.5×10^4 at the 50 cm depth below the crust. More importantly, the plates for the crust samples showed a very high proportion of pigmented colonies ($> 40\%$ were yellow, orange and pink or reddish) whereas by the 50 cm depth $< 10\%$ were pigmented. Normal soil plating shows various white and cream-colored colonies with few, if any, of the pigmented types discussed above. It is interesting that the high proportion of colored bacteria should be found underground and that they appear like those in natural surface waters. The bacterial activity of this modified flora at the crust and sub-crust zones should be studied further.

7.3.3. Ground-water monitoring

One way of studying the efficiency of purification of septic effluent, as it passes from the drain tile downward and outward in the seepage bed, is to monitor the numbers of bacteria in the waters of test wells, located strategically in and near the absorption field (conventional system). The construction of wells and methods of sampling have been described in Chapter 3.4.

Waters in such wells are assumed to reflect the bacterial population of the surrounding ground water. The presence of pollution bacteria in them would evidence escaping pollution. Higher total bacterial counts (TBC) occurred in wells which were near the drain tile or in the direction of the ground water gradient away from the field. The distances exhibiting this transition are variable with the characteristics of the system and soil conditions. The Pickerel Lake system, Dardis Lake system and Adams County System 4 illustrate this trend pronouncedly (see Chapter 5.2.3., Tables 5.19 and 5.20 and Chapter 5.2.1.6, Table 5.9).

Possible explanations for the high counts in the ground waters near the drain tile include: 1) high bacterial activity (growth in the soil due to increased moisture and nutrients from the septic effluent with subsequent movement of high numbers of bacteria to the ground water, 2) growth of bacteria in the ground water due to nutrient in the percolate and 3) possibly movement of original bacteria of the septic tank flora into the ground water, especially if the crust is weak or absent. The numbers of such bacteria moving to the ground water would be inverse to the purification by soil adsorption. Thus the kind and depth of soil in the crust and of the soil below the seepage bed would determine how many such escapees there would be. Characteristics of the different systems would determine which factor was operating to account for the populations found in well waters. For example, Wells B2 and B3 at the Adams County system 4 (Table 5.9) had TBC counts 10 to 100 times those of other wells at this site. Wells B2 and B3 tapped a perched water table believed to be primarily the water of the septic tank effluent. This perched water was mounded on a clay lens 30-35 feet from the surface whereas the true ground water level was at 50 feet. Chemical analyses of the N and P in these well waters bear out their difference from the true ground water (Chapter 5.2.1.6; Table 5.10). Fecal coliforms (FC) were not detected in the Wells B2 and B3, but total coliforms were somewhat greater than in the true ground water. The coliform isolates from these wells were found to be Aerobacter aerogenes varieties I and II (IMViC patterns --++ and its variations). A few exceptions were noted, e.g. Well 4 of System 2 in Adams County and Well 6 at Dardis Lake. At the Adams County site (see Chapter 5.2.1. and Table 5.4) the general ground water table was within 2 feet of the ground surface and it fluctuated to above the base of the trench with seasonal changes. Under these conditions the coliform isolates included IMViC patterns associated with E. coli variety I (++--) and E. freundii (-+-± or ++-+). Thus actual fecal pollution types can pass from the seepage bed to ground water and thence to wells. This possibility emphasizes the importance of standards which set the minimum distance between the distribution system and the ground water. Possible fluctuation of ground-water level should also be considered, when setting the distance for a given installation.

7.3.4. Dry well studies (Stevens Point area)

The dry well disposal part of some conventional septic systems is analogous to the drain tile bed in others. In general the dry well serves to transmit the anaerobic septic effluent outward and downward to the absorbing soil and in the process provides more or less aerobic conditions. Bacterial counts for TBC, TC and FC, and FS on the liquid within the dry well have shown great variation (Table 5.17). Although the soil near only one of the wells was excavated, it appears from the data for the soil samples (see Table 5.16) that the FC and FS removal in the soil directly below the well was similar to that found in adsorption fields in sandy soil in which a moderate crust had developed. Samples taken from soil at the side of the dry well, however, showed that FC and FS had been transported outward about 30 cm. This could be explained by considering that the crust on the sides of the dry well would be weaker than on the bottom. The weak crust could result from fluctuation in depth of water in the dry well, permitting greater hydraulic conductivity of the unclogged soil and consequent rapid horizontal movement of the waste water.

7.4. FC/FS ratios and their interpretation

It was of interest to calculate FC/FS ratios for some of the systems and for different points of sampling within a system to see how the Geldreich interpretation of ratios could apply. As was said before (Chapter 7.2) high ratios of 4 or more would indicate the human type of fecal flora and would be of greater public health concern than would the low ratios of < 1, which are said to be typical of background fecal pollution by animals in nature.

Table 7.1 gives characteristics of 20 of the systems studied and groups them as to samples from: Septic tanks, Distribution boxes, Trench liquid, and Dry wells. The table also gives the physical parameters of the systems as well as the bacteriological data on samples at these four parts of the systems. The high FC/FS ratios of 30-50, rarely even higher, pertain to the raw septic effluent. Only 3 instances of low ratios were found and they apply to a Door County mound (No. 1; see Chapter 8) and 2 dry wells at Stevens Point (B and E) which are in the < 0.5 range, considered by Geldreich as typical of unpolluted or animal polluted natural waters, which, of course, they are after soil purification. The very high ratios in the septic tank samples as compared with Geldreich's figure of 4.4 for human feces could be explained if there were greater die-off of FS than of FC in the septic tanks. The detention time in the septic tank may also be a factor. While the data presented are insufficient to support a particular FC/FS ratio as prevailing in septic systems, it does appear as high or higher than reported by Geldreich. It could therefore be of some value in interpreting pollution in percolating waters where the absolute numbers are so low as to be meaningless. More work should be done on this problem.

8. SOIL DISPOSAL SYSTEMS FOR PROBLEM SOILS

8.1. Introduction

Problem soils for subsurface liquid waste disposal are soils that are very slowly permeable, permanently very highly permeable (see Fig. 6.8), with water table or bedrock within three feet of the surface, or that occur on slopes exceeding 10 to 20%, the exact slope depending on the percolation rate (State Board of Health, 1969). Very slow permeability may result from either a permanent very low saturated hydraulic conductivity (clay soils, Chapter 5.2.5; or clayey till soils, Chapters 5.2.3 and 5.2.6) or from a resistant crust on surfaces of trenches in highly permeable soil material (sandy loam till, Chapter 5.2.4). Potential for subsurface liquid waste disposal is insufficient for the first group of slowly permeable soils and alternative means of disposal have to be explored. One alternative to a conventional system in such soils is the "mound" system, to be discussed in Chapters 8.3.1.1, and 8.3.2.3. Soils of the second group do have the potential for on-site subsurface disposal, provided that important revisions are made in the traditional management procedures that lead to failure. This aspect is to be discussed in Chapter 8.2. Permanently very highly permeable soils that are shallow to creviced limestone bedrock are obviously unsuitable for the installation of a subsurface seepage bed. An alternative is again a "mound" system, with characteristics to be discussed in Chapters 8.3.1.2 and 8.3.2.4 through 8.3.2.7. Soils with high ground-water tables have only been investigated in one case, since well drained soils were the obvious first choice for this study. A mound system, built over an imperfectly drained Humbird sandy loam with periodic high ground-water table was studied in Clark County (Chapter 8.3.2.2).

8.2. Intermittent application of effluent or dual-bed systems

8.2.1. Introduction

Continuous application of effluent in a seepage bed leads to eventual clogging of the soil. Intermittent application or dosing of effluent has proved to be effective in laboratory test columns in reducing crusting. The dosing procedure permits oxidation of clogging components in the emptied column (McGauhey and Krone, 1967; Popkin and Bendixen, 1968; Thomas et al., 1966). This principle was applied to an actual septic system at site number 4. Dosing was conducted using a strongly crusted seepage bed in sandy loam glacial till that had a potentially high permeability (Chapter 5.2.4). Results are given in Chapter 8.2.2. An alternative procedure is to build two identical seepage beds, each fully sized according to the State Code. Effluent is alternately introduced into one bed and then the other, on a time schedule that prevents the development of resistant crusts in either. Oxidation of the crusts takes place while a bed sits empty of effluent. A new dual bed system has been constructed in sandy soil in Black River Falls. This is discussed briefly in Chapter 8.2.3.

8.2.2. Arlington study area

8.2.2.1. Introduction

The soil disposal system at the Poultry Farm of the University of Wisconsin Experimental Farms Arlington, has already been discussed in Section 5.2.4. In order to study effects of dosing, the access port for the north trench was closed at the distribution box, the effluent was pumped out and the trench was left empty of liquid from July 22 to August 4, 1970. During this period the other seepage trench and surrounding soil handled all the effluent of the system. The effluent was admitted to the north trench on Aug. 4. Starting on August 8, the amount of liquid introduced into the entire system was increased to an average 200 gallons per day, by running water from a faucet in the basement of the house. This part of the experiment was completed on August 14 (Fig. 8.1). A second series of experiments was started on September 18. The occupants of the house had been on holidays for a three week period from August 14 to September 4. No effluent was in the trench at the start of the second experimental period. Large amounts of water were added to the system for short periods of time on certain days (Fig. 8.1). Tensiometric reactions to these intermittent dosages were observed. From October 1 to October 7, a continuous trickle of water was maintained by means of the basement faucet to establish a total rate of 200 gallons per day. After October 7, only the regular input of 80 gallons per day entered the system. The experiment was terminated on October 15.

8.2.2.2. Results

Moisture retention, conductivity and porosity data for the glacial till have been presented in Chapter 5.2.4. Soil moisture tensions, as measured around the trenches during the experiments, are reported in Fig. 8.1.

8.2.2.3. Discussion

Soil moisture tensions were high around the seepage trench at the start of the experiment on July 21, although the level of the effluent stood at two-thirds the height of the bed of crushed rock. Below the trench, tension was 80 mb (Tensiometer No. 3) and 90 mb (Tensiometer No. 2). At the sides, the value was somewhat lower, at 60 mb. The presence of such high tensions, despite the presence of free liquid in the trench, shows the effect of a highly resistant barrier, a "crust", at the interface between trench and soil, causing the loss in potential head (Hillel and Gardner, 1970).

Soil moisture tensions increased by natural drainage, as expected, after the trench was pumped dry on July 22. Heavy rain on July 28 decreased most tensions, but at the time of reintroduction of the effluent in the system on August 4 tensions were still considerably higher than those at the start of the experiment. In the period from August 4 to 8, tensions did not change. At no time did we observe effluent standing in the trench.

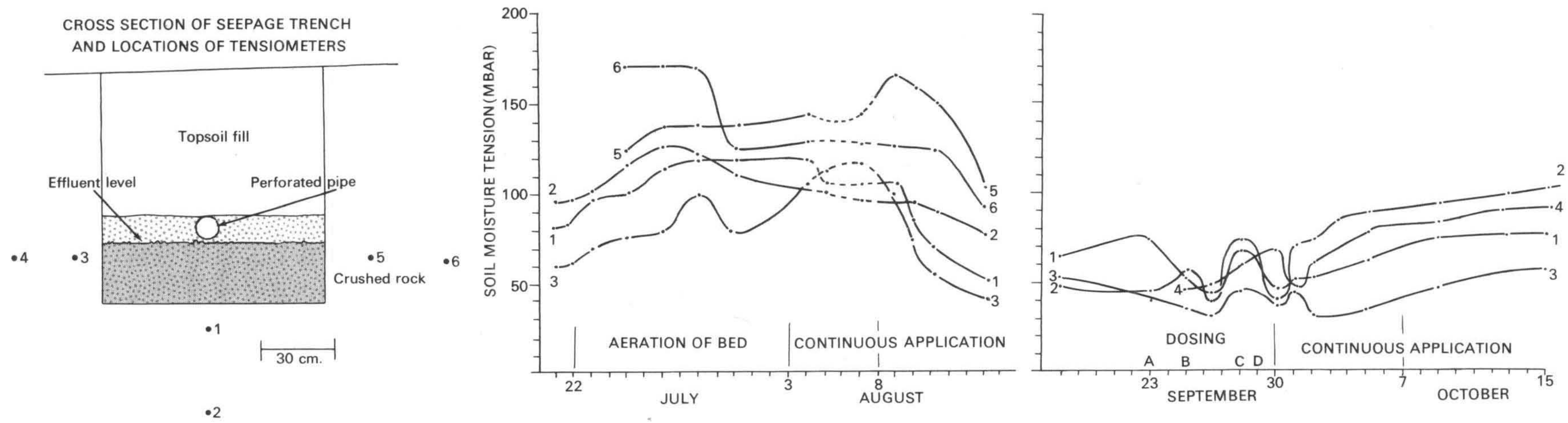


Fig. 8.1. Moisture tensions around the seepage bed during dosing experiments (Arlington).

Obviously, the amount of effluent going into the system (80 gallons/day) was being absorbed by the soil, without ponding. Moisture tensions around the trench probably fluctuated each day, following the daily dosing pattern. Since observations were made only once a day such effects were not observed. An attempt was made to reestablish ponding in the trench, by increasing the loading rate to 200 gallons per day. A permanent trickle of water into the system from a faucet in the basement of the house was sufficient to accomplish this. The much increased loading rate apparently exceeded the infiltrative capacity of the soil, and effluent filled the trench again starting August 8 and remained so until the end of the first experiment on August 14. Soil moisture tensions decreased to values of 50 mb below, and 35 mb next to the trench. This indicates a marked decrease in impedance by the crust, as compared with that under the initial condition, when the trench was nearly full of effluent and much higher tensions obtained in the surrounding soil.

Fig. 5.25. gives the relationship between hydraulic conductivity K and soil moisture tension for the sandy till. K at 80 mb was 4 mm/day, at 50 mb: 15 mm/day. For a bottom area of 0.8 x 30 = 24 m^2, this would amount to a vertical (one-dimensional) flow of 50 gallons/day at 80 mb (potential gradient = 2) and 180 gallons/day at 50 mb (potential gradient = 2). For the bottom of one trench, only 90 gallons/day. But effluent moves not only through the bottom of the bed, but also through the sidewalls due to gradients in the soil water potential alone, since strict horizontal movement is not affected by gravity. Assuming a potential horizontal gradient of unity (see values from tensiometers 5 and 6) we obtain flow values on July 21 of 19 gallons/day at 60 mb ($K = 6$ mm/day sidewall area: 0.2x 61.6 m^2 = 12.3 m^2). In August, the potential gradient was one-third lower and flow through sidewalls was estimated at 20 gallons/day at 40 mb ($K = 18$ mm/day); for one trench: 10 gallons/day. Total flow can therefore be estimated at 69 gallons/day for July 21 and 135 gallons/day for August 14. On both dates effluent stood 20 cm deep in the trenches. The first value is within a reasonable 15% of the measured loading rate of the system (= 80 gallons/day, measured during one week in July by Mr. Ripp, resident of the home). These calculated amounts of flow are estimates based on separate one-dimensional vertical and horizontal flows. In the real two-dimensional system flow lines will be curved. Real flow rates can be determined by modeling, using numerical techniques with the computer (Amerman, 1969). However, we do not expect such calculated values to be very different from these estimates. The second series of experiments was started on September 18, when both trenches were empty of liquid (the occupants of the house had been on holidays for three weeks, Aug. 14-Sept. 4). Starting on September 23, additional water was added to the system, through a basement faucet, as during the first experiment. Large amounts of liquid were added in relatively short periods of time (see Fig. 8.1). The effluent was absorbed by the soil within one or two days. Tensiometers reacted clearly to this intermittent dosing pattern. For example, after adding 180 gallons in a 40 minute period on September 25, soil tensions moved down around the trench. The trench was empty on September 27, and tensions moved up to relatively high values on September 28 as a result of drainage. Then another 120 gallons were added. The next day the trench was empty of effluent. The high amount of 350 gallons was added, and tensions reacted strongly. Two days later, however, the trench was again empty and tensions had increased again since the previous day. Starting on October 1 the method of adding water to the system was changed to a continuous trickle at the rate of 200 gallons per day. After that, the trench nearly filled with effluent and remained so to the end of the experiment (October 15).

Addition of water was stopped on October 7, when the trench started to overflow. Thereafter only the regular daily input (80 gallons) entered the system. During the period October 2 to 15, tensions around the bed gradually increased to levels remarkably similar to those measured on July 21 at the start of the experiment. Such increasing tensions around a bed that contains ponded effluent indicate an increase in hydraulic resistance of the crust. This is probably caused by increasing anaerobic conditions that induce the formation of organic products that clog soils pores (see Chapter 6.2.2). The identical hydrological situation at the start and at the end of the series of experiments may indicate a dynamic equilibrium specific for this particular system. Air diffusing through the soil to the crusted sidewalls of the bed, will permit break-down of anaerobically produced organic substances there. This process is influenced by soil texture and position of trenches. Stronger diffusion, for example in a coarse porous material and with trenches placed closer to the surface, could result in an equilibrium at a lower suction, and thus a higher infiltration rate made possible by a diminished resistance of the crust. Inflow of effluent with a lower B.O.D. (after aeration), could have the same effect (Popkin and Bendixen, 1968). More experiments in different soils are needed to investigate this aspect. In any case, soil moisture tensions measured in this study were never lower than 40mb.

Conclusion: The data show that (1) only about one week of ponding was sufficient to create soil moisture tensions similar to those present after ten years of system use. (2) Intermittent application of effluent (dosing) can result in a marked increase of overall infiltration (in this case at least twofold).

8.2.3. Black River Falls study area

The dual seepage bed, constructed in the C horizon of a Sparta loamy sand, was discussed in Chapter 5.2.7. This system had only been used for a period of six weeks prior to the time of investigation. The principle of a dual-bed system is to shift the flow of effluent from one bed to the other at regular time intervals. The bed not receiving effluent is allowed to drain. Inhibiting crusts developed at the infiltrating surfaces during the previous loading period will then be oxidized, thereby restoring the infiltrative capacity of the soil for the next loading cycle. Construction of a dual-bed system is necessary if crusting can be expected to be so severe after a prolonged period of continuous loading, that the system will fail. Calculations made in Chapter 5.2.7 indicated that a dual bed system might not be necessary in this type of soil. However, the system is included in this chapter as an example of a dual-bed system, the construction of which would, most probably, be quite appropriate in loamy soil materials where crusting was found to be quite severe (see Chapter 5.2.4).

8.3. Mound systems

8.3.1. Introduction

The principle of the mound system is simple: If the conditions in a natural soil are unfavorable for on-site subsurface liquid waste disposal, soil material from elsewhere is placed on top of the original soil and a gravel-filled seepage bed is built inside. Percolation from this bed downwards through the fill supposedly supplies the necessary filtration that the original soil was unable to provide. There are several types of soils with unfavorable characteristics, as discussed in Chapter 6.2, and design criteria for mounds vary accordingly.

In general, the mound system concept offers some attractive aspects: (1) Size and shape of the mound, and textural composition of the mound fill can be controlled, according to specifications, whereas properties of subsoils around conventional seepage beds cannot be altered; (2) A mound system utilizes the upper soil horizons which are usually more permeable and richer in organic matter than the underlying horizons, but which are not used by a conventional subsurface system; (3) Because the mound is surrounded by air immediately above and on all sides, the interior can be expected to be better aerated than the soil surrounding a conventional buried system.

Some potential disadvantages to mound systems may be noted, however: (1) The exposure of the mound may lead to freezing problems in wintertime; (2) Seepage of polluted effluent from the sides of the mound onto the surrounding soil surface or into creviced bedrock below the mound, may take place in times of excessive rain or snow melt or in case of overloading of the system from within.

Two basic soil conditions have been taken into account in designing mound systems (Fig. 8.3.1).

1. Soils with relatively permeable topsoils but with slowly permeable subsoils.

2. Soils with thin, relatively permeable topsoils, and highly permeable substrata, such as creviced bedrock.

8.3.1.1. Dimensions of mound systems in slowly permeable soils

The main function of a mound system over soils with slowly permeable subsoils (Fig. 8.3.1) is to avoid seepage of polluting effluent from the mound onto the surrounding soil surface, which would present a health hazard and could lead to contamination of surface water. The danger of pollution of ground water seems to be minimal in most cases, because the K_{sat} value of subsoils is very low. Design criteria, therefore, are to be based on lateral flow of effluent away from the system through relatively permeable topsoil, using the fill material in the mound for downward unsaturated flow.

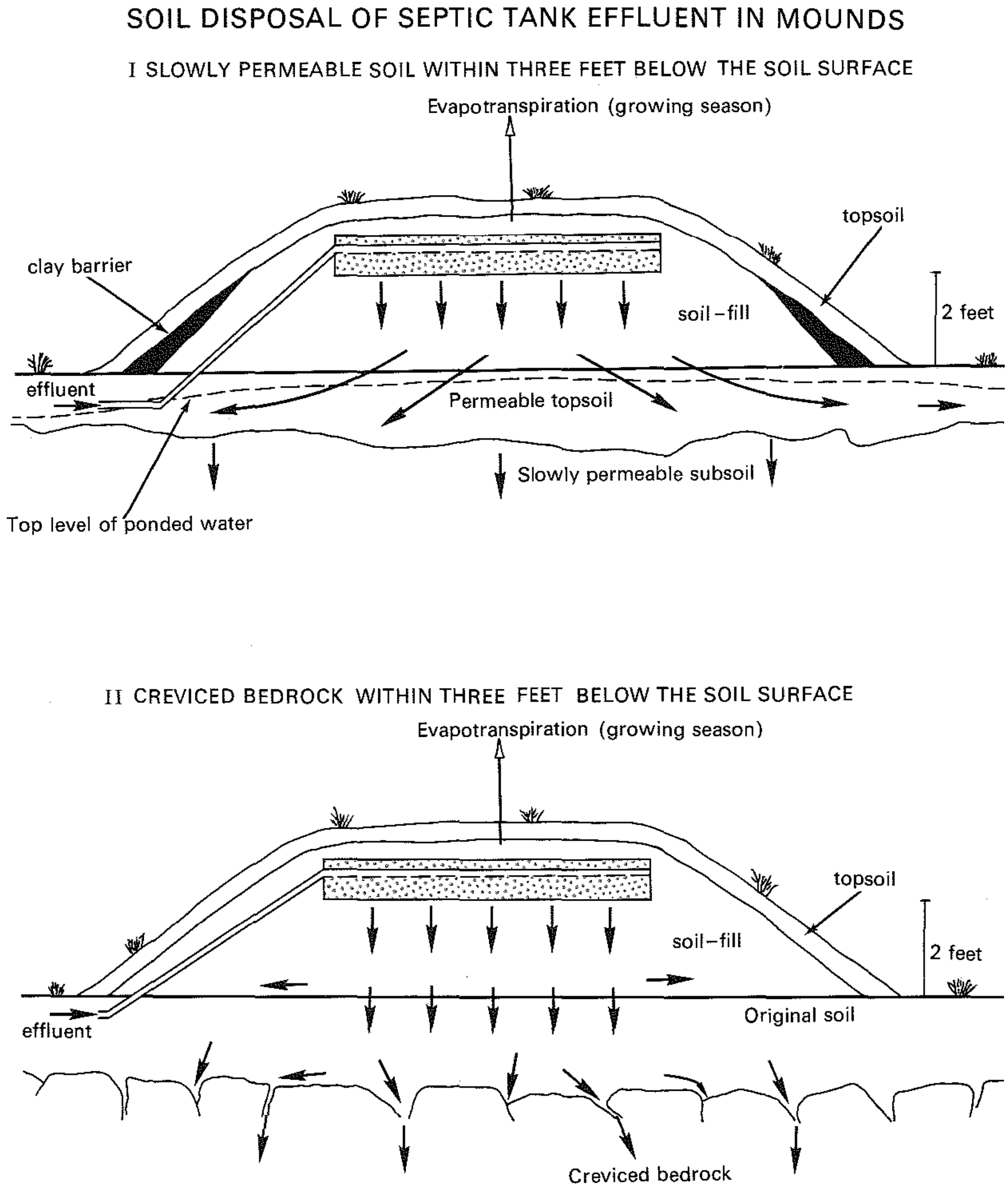


Fig. 8.3.1. General diagrams of mound systems over slowly permeable soils and over creviced bedrock.

Vegetation on top of the mound plays an important role, during the growing season, in removing liquid and nutrients by transpiration. A schematic cross section of a mound is in Fig. 8.3.1. Effluent is to be pumped into the seepage bed, and will infiltrate downwards into and through a fill of thickness F (see Fig. 8.3.2).

To keep the fill material below the bed unsaturated, stagnant water in the topsoil of the original soil body should not be permitted to rise above the original soil surface into the mound itself, as could happen if the volume of downward percolating effluent from the mound were excessive. Lateral movement of this stagnant water through the topsoil is a function of: (1) loading rate of the system, (2) dimensions of both mound and the underlying body of ground water, (3) depth to the very slowly permeable natural soil horizons, (4) hydraulic conductivity distribution throughout the mound-ground-water system, and (5) hydraulic gradients in the ground-water system.

In mound systems, where soil boundaries restrict movement of liquid to an approximately horizontal plane in the topsoil, certain approximations, like the one of Dupuit-Forchheimer (Bouwer, 1970, Childs, 1969), can be used to describe the flow of ground water in quantitative terms. Fig. 8.3.2. (derived from Bouwer, 1970) shows a seepage bed with width W in a mound on top of a soil profile with a relatively permeable topsoil and a subsoil which is considered impermeable. Due to the addition of liquid from the mound, the level of the ponded water is highest in the topsoil below the center of the seepage bed. The hydraulic properties of the aquifer can be expressed in terms of the transmissibility coefficient T_e (= hydraulic conductivity x aquifer height). Steady flow below the water table on top of the B can be described with the Dupuit-Forchheimer assumption of horizontal flow as follows:

$$I \cdot x = T_e \cdot \frac{dh}{dx} \qquad (1)$$

where I = infiltration rate for recharge area, x = horizontal distance from centerline of recharge area, T_e = effective transmissibility of aquifer, h = height of water mound above static water table on top of very slowly permeable subsoil. $I \cdot x = q$ (= horizontal flow rate per unit width across a plane perpendicular to direction of flow at distance x from the center of the flow system of infinite length). Integrating between x = 0 and x = w/2 yields:

$$h_c - h_e = \frac{I \cdot W^2}{8T_e} \qquad (2)$$

where h_c = h below center of seepage bed (x = 0), h_e = h at edge of the seepage bed (x = w/2), W = width of seepage bed.

Knowing T_e for a flow system, makes possible series of calculations, varying I, W and h_c and h_e.

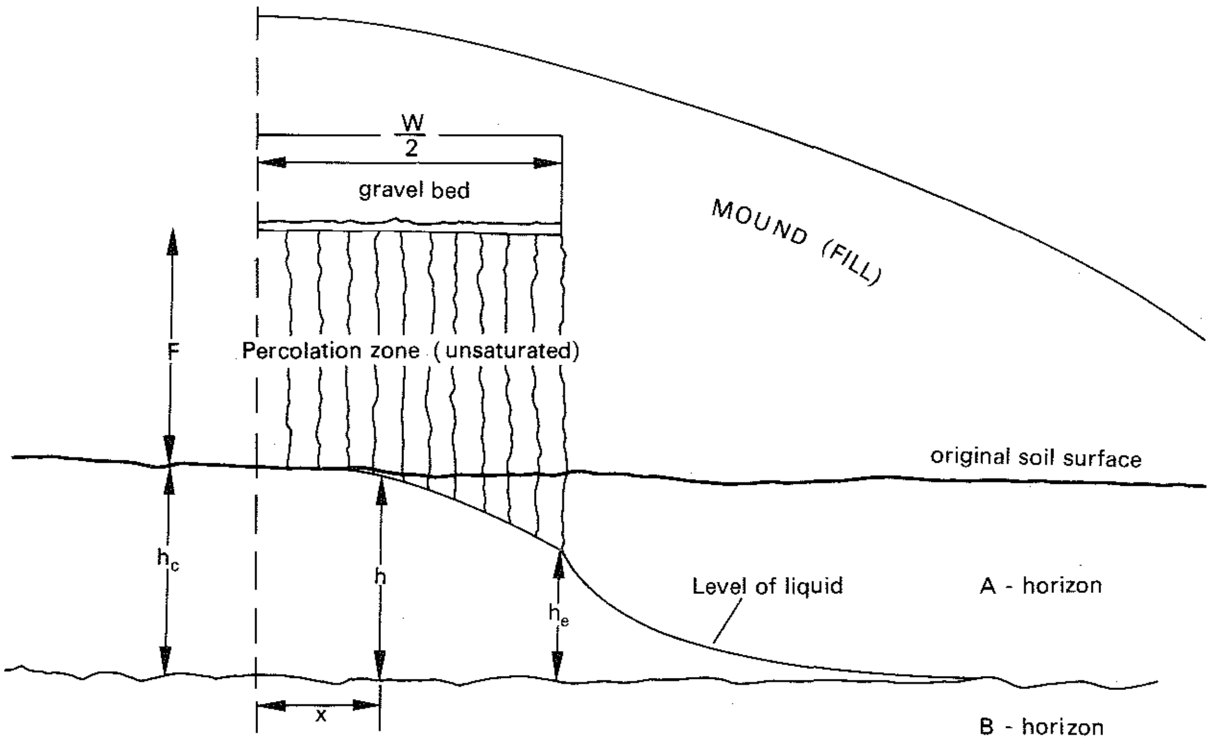


Fig. 8.3.2. Dimensions of a mound over slowly permeable soil.

The following steps are involved in the calculation of seepage bed dimensions after measuring T_e.

1. The infiltration rate from the seepage bed (I) is selected from the K-curve of the fill material; and is based on the rate corresponding to the most desirable moisture tension (Section 6.2). Construction and use of the mound system is to be directed towards achievement of this tension in the fill below the seepage bed, either by appropriate dosing of liquid or by development and management of optimal crusts.

2. A value for $h_c - h_e$ is determined, preferably by measurement in situ. A value of 5 cm was measured at one of the systems in Clark County (Bouma and Hole, 1971a).

3. W is calculated with equation (2).

4. Next, length L of the seepage bed is calculated according to:

$$L = \frac{E}{I \cdot W}$$

where E is loading rate of system (volume/day).

5. Finally, the height of the gravel bed is calculated, based on a sufficient amount of available storage for effluent. Assuming a pore volume of 30% in the gravel, height h of the gravel bed is calculated as:

$$h = \frac{E}{0.3(W\mathrm{x}L)}$$

The minimal height of the gravel bed below the perforated pipe is recommended to be 8" (20 cm); the pipe itself should be covered and protected with a few inches of gravel as well.

Some additional construction details which are based on preliminary experience, are these:

(1) At least two feet of fill is to be in place below the gravel bed and the original soil surface. A sandy loam or loamy sand is recommended as a fill material or any material with a similar pore size distribution (see Chapter 6.2). The original topsoil should never be removed or compacted during construction. Future experiments with peaty fill materials will be conducted.

(2) A barrier of clayey impermeable soil material is to be placed all around the outer edges of the mound to reduce the danger of surface leakage (see Fig. 8.3.1.). This could also prove useful in marginal periods when the whole soil area is very wet or covered with snow. Then, the interior of the mound can act as a temporary storage facility, in which the liquid level may rise above the original soil surface.

(3) The gravel bed is to be separated from the fill on top by a thin layer of hay to prevent slaking of topsoil into the bed during settling. Use of a plastic sheet is not recommended as this does not decompose with time.

(4) About two feet of fill is to be placed on top of the gravel bed to reduce the freezing hazard. As shown elsewhere (Chapter 5.2.4), a snowcover is essential to reduce the freezing hazard. Placing of snowfences on top of mounds is recommended, and trees or shrubs in the area around the mound (not on top, where roots could disrupt tile lines) will reduce the force of the wind, while helping to remove liquid from the surrounding soil at the same time during the growing season.

(5) The mound must be covered with at least 6 inches of dark topsoil to be seeded with grasses. This has a twofold purpose: 1. Evapotranspiration in spring and summer and autumn is a very important mechanism for the removal of liquid from the mound, and 2. A vegetative cover will reduce erosion. The sides of the mound can have a 1:5 slope and the top should preferably be rounded so as to induce runoff of rainwater or snowmelt.

8.3.1.2. Dimensions of mound systems in soils with highly permeable substrata

The main function of a mound system over soils with highly permeable substrata (Fig. 8.3.1) is to avoid seepage of contaminated liquid through the original topsoil into bedrock crevices, and from there into the ground-water. The role of the original topsoil, which may vary in thickness between one and three feet, is important in the flow regime. None of it should be removed nor compacted prior to construction of the mound. Most of the technical details discussed in Section 8.3.1.1 also apply to this type of mound. Lateral flow through the topsoil does, however, not play a crucial role here because of the permeable substratum. Sizing, therefore, is not accomplished by special calculations as in Section 8.3.1.1 but is determined by considering hydraulic properties of fill and topsoil.

The infiltration rate from the seepage bed is selected from the K-curve of the fill material, and is based on the rate corresponding to the most desirable moisture tension (Section 6.2). Downward flow occurs through two feet of fill material and the shallow natural topsoil, each with different hydraulic characteristics. A graphical solution method for steady-state flow through several soil layers down to the ground water was described by Bybordi (1968). We followed this procedure for several of the mound systems. The saturated zone just above the open crevices in the bedrock or the level of ponded water in soils with very slowly permeable subsurface horizons, were considered as levels of zero pressure, comparable to the ground-water level of Bybordi (1968).

The hydraulic potential ϕ can be expressed in terms of the pressure head h (cm) and height Z above the water table as: $\phi = h + Z$. Darcy's law for the one-dimensional vertical case is:

$$v = -K\frac{d\phi}{dZ} \text{ or } v = -K\left(1 + \frac{dh}{dZ}\right)$$

where: v = velocity of flow and K = hydraulic conductivity. Integration yields the moisture profile formula:

$$Z_n = -\left[\int_0^{h_1} \frac{dh}{1+\frac{v}{K_1}} + \int_{h_1}^{h_2} \frac{dh}{1+\frac{v}{K_2}}\right]$$

where K_1 and K_2 are the moisture dependant hydraulic conductivities of the successive layers, to be measured with the crust test or calculated with the method of Green and Corey. The integral limit h_1 is not initially known. Starting at zero pressure integration is continued through the bottom layer until Z assumes the value of Z_1 (which is the thickness of the bottom layer). The corresponding h is found to be h_1. This tension h_1 is continuous across the boundary and is therefore the lower limit of the second term of the integration, which is continued using the K_2 values until Z assumes the value Z_2 at a pressure of h_2. The moisture profile can be derived from the pressure profile by using moisture retention data.

Examples of this type of calculation will be given in the discussion of mound systems in Chapters 8.3.2.3, 8.3.2.5 and 8.3.2.7, assuming steady flow rates from a seepage bed into the sandfill of the mound and from there into the natural topsoil. Steady flow rates will occur only in a real system if the seepage beds have a resistant biogenic crust at the infiltrating surface with ponded effluent inside the bed (see Chapter 5). However, effluent has to be pumped intermittently into the mound and the seepage bed that is about two feet above the original soil surface. Then, crusts may not form as readily due to the intermittent aeration and the hydrological picture becomes more complicated. Though the rate of application will still be, for example, a total 8 cm/day, the liquid is, in reality, applied as four dosages of two cm each at six hour intervals. Field monitoring will show the effects of intermittent application on the hydraulic conditions in the flow systems to be studied in the next field season.

8.3.2. Results of monitoring operating mound systems

8.3.2.1. Introduction

Three experimental mound systems were built in Clark County in 1969 and early 1970, according to a local design that was based on the NODAK soil absorption system of North Dakota. These systems were monitored in the field during the field season of 1970 and data have been reported by Bouma and Hole (1971a). One of the systems was studied again in 1971, results of which are reported below in Chapter 8.3.2.2. A new experimental mound system was built in Clark County in 1971 at a location where construction of a conventional subsurface seepage bed was prevented by impervious bedrock that lay at a depth of two feet in a landscape with many rock outcrops. The dimensions and design of this mound were in accordance with criteria discussed in Chapter 8.3.1.1. This system was monitored in October, 1971 and data are reported in Chapter 8.3.2.3.

The experimental mound systems in Door County were constructed in 1969 and 1970 according to a design made by the State Board of Health in cooperation with this research group. Sampling trips for monitoring purposes were made in September and October, 1971 and results are given in Chapters 8.3.2.4 through 8.3.2.7.

Four experimental mound systems were designed in early 1971 for new houses constructed in the Ashland area, where soil conditions were unfavorable for the conventional type of subsurface disposal, because of very low soil permeability (see Chapter 5.2.5). Construction details of these mounds and monitoring results will be published at a later date.

8.3.2.2. Clark County study area: Mound 1

This mound was built in the Spring of 1970 on a somewhat poorly drained Humbird sandy loam (Typic Haplorthod) over sandstone that had very slowly permeable shale layers. The original soil had the following soil horizons (for more detail see Bouma and Hole, 1971a): A1:0-5 cm: Black, very friable sandy loam. A2:5-11 cm: Brown, sandy loam, apedal; B21hir:11-15 cm: Yellowish red, sandy loam, apedal; B31:20-28 cm: Yellowish brown sandy loam, fine subangular blocky; B32:28-38 cm: Yellowish brown sandy loam, fine subangular blocky, with mottles; IIIC2:50-100 cm: Three stratified bands of White sand, Yellowish brown sand and Olive gray clay; White, weakly cemented coarse sand is found below 100 cm. Unweathered sandstone is estimated to occur at a depth of 2 m. The particle size distribution of the horizons and results of physical measurements are presented in Table 8.3.1. The occurrence of slowly permeable clay layers leads to ponding of water in the profile, particularly in wet periods or in early spring. The ground water level varied from 50 cm below the soil surface in early June, 1970; to 150 cm in late July 1970; 20 cm in May, 1971; and about 150 cm again in October, 1971.

A top view and cross section of this mound are shown in Fig. 8.3.3.

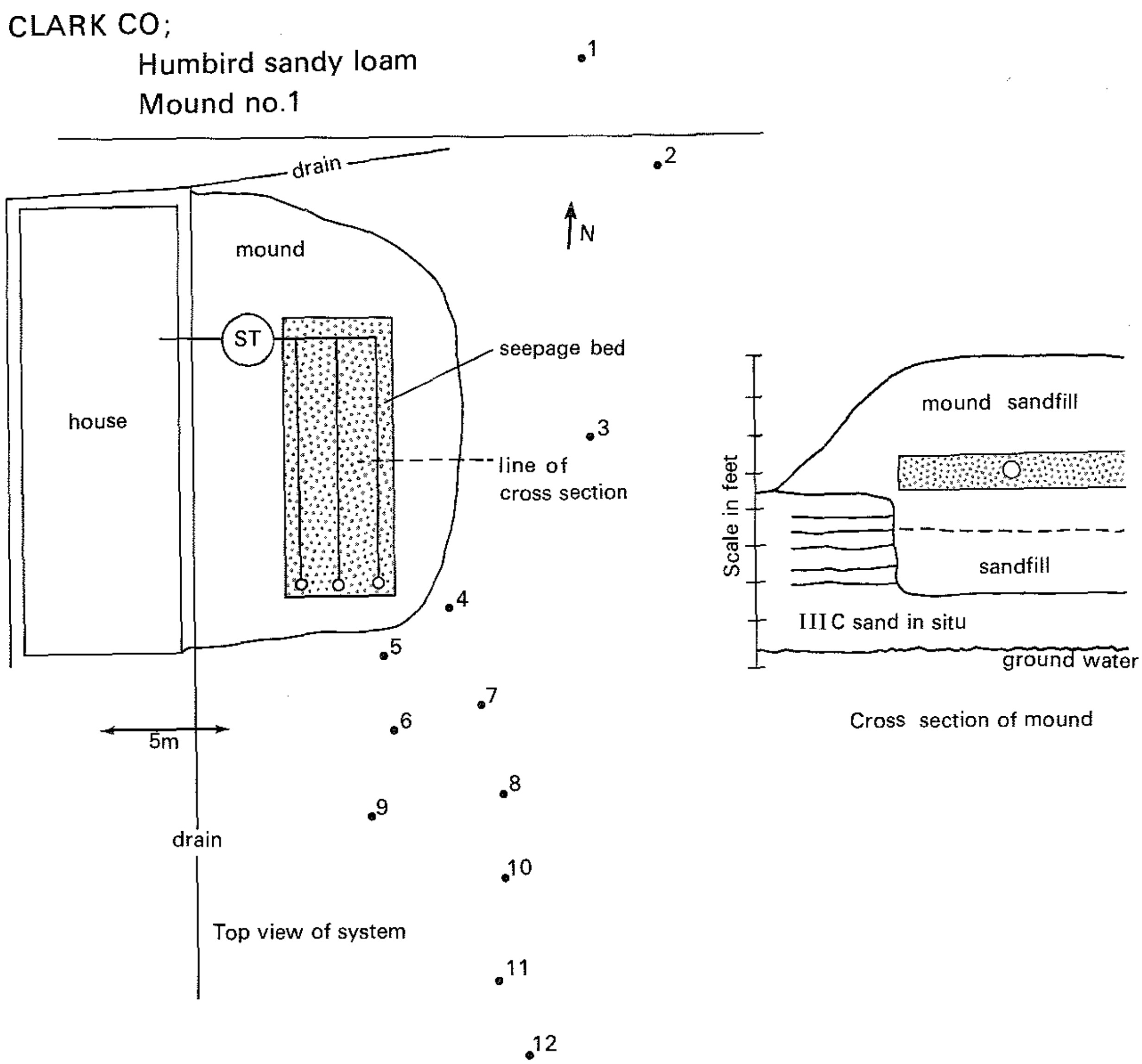


Fig. 8.3.3. Top view with sampling points and cross-section of mound 1 (Clark County).

Photo 8.1. Mound System 1 (Clark County) (summer 1970). Effluent seeped through the side of the unfinished mound at point S in early June 1970. Air vents (A) are at the ends of the three tile lines (see diagram of system, Figure 8.3.3).

At the present writing the sand mound (Photo 8.1) is still barren and undersized. The design was for a larger mound, calling for a southeastward extension, and for a silty topsoil cover to be seeded with grasses. The homeowner intends to complete the job, which is overdue, according to the time limit of the experimental permit received from the Board of Health in 1969. The performance of the incomplete system, however, is sufficiently interesting to justify discussion here. Construction of the mound was started by removing all clayey layers to a depth of about 3 feet and exposing the highly permeable white sand (see Table 8.3.1.). The hole was filled with a layer of sand, on which coarse rock was laid to form the seepage bed (Fig. 8.3.3.). Perforated pipes were laid in the bed from the septic tank into the mound at a level slightly higher than the original soil surface. The whole system was covered with about two feet of coarse loamy sand that has a low porosity, probably as a result of a wide range in particle size (see moisture retention data in Fig. 8.3.4). Samples for microbial and chemical analyses were taken at locations indicated in Fig. 8.3.3, in the septic tank and in a water well near the house. Sampling trips were made in July, 1970, and in April and October, 1971. Results of microbial analyses are in Table 8.3.2, and of chemical analyses in Table 8.3.3. In September, 1970 fecal streptococcus (FS) were observed in a number of the wells, but fecal coliforms (FC) were not detected. Because of possible surface contamination during sampling, FC/FS ratios were considered (see Chapter 3.4). A FC/FS ratio of 50.0 was measured in the septic tank liquid. FC/FS ratios for the wells in September, 1970 and November, 1971 indicated no ground water contamination due to these organisms.

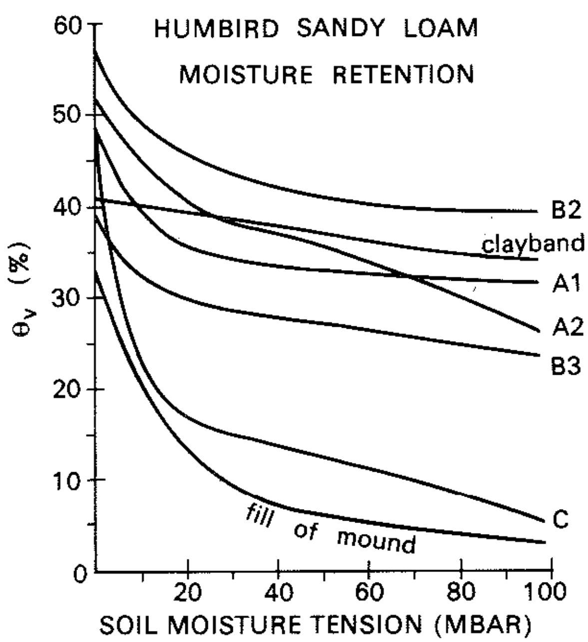


Fig. 8.3.4. Moisture retention data of horizons in a Humbird sandy loam (mound 1 Clark County).

Table 8.3.1. Particle size distribution and hydraulic characteristics of soil horizons in a Humbird sandy loam.

Horizon	V.C.S.	C.S.	M.S.	F.S.	V.F.S.	C.Si.	M.Si.	F.Si.	Clay	Hydraulic conductivity (K) (double tube)	Percolation test	
											Falling head	Constant head
A1	0.6	9.7	26.1	14.6	18.0	8.7	11.5	4.5	7.0			
A2	1.8	13.0	28.5	15.1	20.1	4.5	10.0	2.5	5.0			
B21hir	2.2	11.9	21.5	12.7	16.2	4.0	8.5	6.0	17.0	20 cm/day		
B22hir	2.0	10.4	19.2	12.0	15.0	4.5	11.5	7.5	16.0			
B3	1.8	9.6	22.2	16.7	22.0	4.5	7.5	6.0	10.5	12 cm/day		
IIIC(clay)	0.7	2.0	3.2	3.6	9.5	4.0	14.0	12.0	51.0	3 cm/day	4 min/inch (900 cm/day)	4 min/inch (900 cm/day)
IIIC(sand)	0.7	8.6	56.2	28.3	4.2	0	0	0	2.0	500 cm/day		

Table 8.3.2 Bacterial Analyses, Mound System 1, Clark County

Sampled July 27, 1970, April 16, 1971 and Oct. 21, 1971(1)

(bacterial counts per gram of soil or per ml in liquid samples)

Sample (See Fig. 8.3.3)	Enterococci			Fecal coliform			Total coliform			Total bacteria			pH
	7/27	4/16	10/21	7/27	4/16	10/21	7/27	4/16	10/21	7/27 (x10^4)	4/16 (x10^3)	10/21	10/21
1a	X	X		X	X		80	X		15	17		
1b		X			X			10			600		
2	X	X	**	X	X	**	50	150	**	22	13.5	1,000	4.9
3	39	X	**	X	X	**	300	X	**	40	22	30	6.1
4	X	10	**	X	100	**	X	10,500	**	1.6	1,450	11,000	6.4
5	X	X		X	X		X	1,550		2.3	100		
6	10-100	X	**	X	X	**	800	1,250	**	44	250	1,900	4.6
7		X			X			350			16		
8		X			X			115			5,000		
9		X			X			240			17.5		
10		X			X			X			18.5		
11		X			X			45			8		
12		X			X			900			720		
S(2)		X			X			4,000			1,000		
Septic tank	20			1,000			44,000			2,240			

(1) Samples taken on 10/21/71 were saturated soil from the upper level of the ground water table; other samples were ground water.

(2) Soil sample taken from a region of saturated sand at the base of the mound. This region was found only during the April sampling period.

** = organisms not detected, $<$ 6/gram in average of triplicate platings.

X = organisms not detected, $<$10/gram in average of triplicate platings.

Table 8.3.3. Results of chemical analyses of ground water sampled around mound system 1 (Clark Co.) (in mg/L).

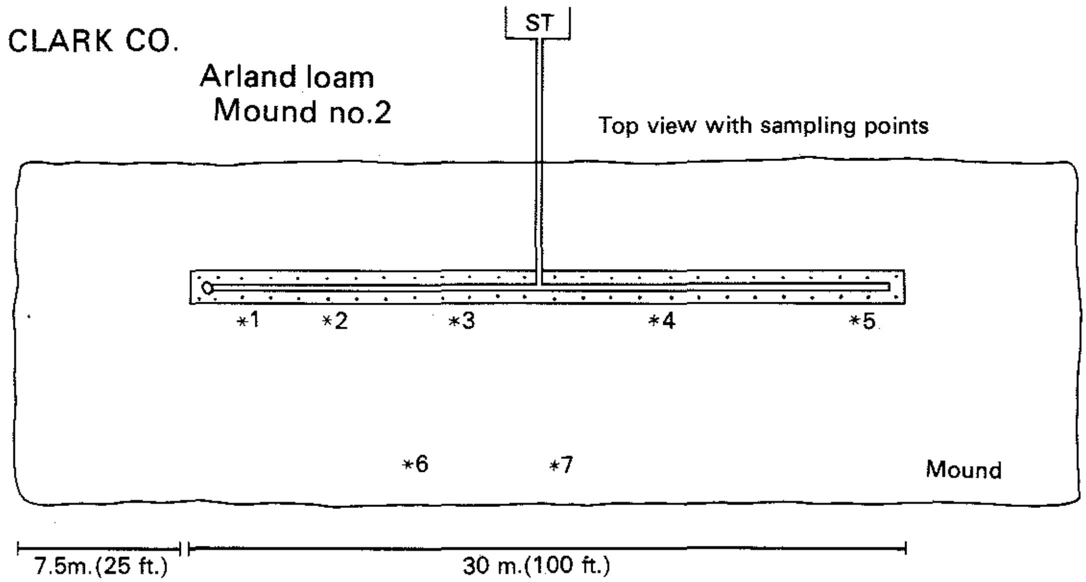
Date	Well No.	NH_4^+-N	NO_3^--N	Total-N	DIP	Total-P	pH
April 1971	1	0.4	0.4	1.5	<.02	.02	5.3
	2	0.3	0.7	1.5	.02	.06	5.3
	3	0.4	1.1	2.7	<.02	.02	5.6
	4	4.4	4.8	12.4	.37	.85	6.1
	5	1.8	0.4	4.5	.07	.31	6.3
	6	3.4	16.8	22.0	.03	.19	6.1
	7	2.4	18.7	24.0	<.02	.03	5.6
	8	0.4	2.7	3.7	.04	.11	6.3
	9	0.4	9.2	13.8	.02	.09	5.9
	10	0.3	1.6	2.0	<.02	.02	6.1
	11	0.3	3.0	6.8	<.02	.03	5.9
	12	0.3	0.4	1.5	<.02	.02	6.4
October 1971	4	14.1	8.6	27.0	.19	.92	
	7	7.3	16.9	25.3	.30	1.86	

A similar condition was found for each of the wells in April 1971, with the exception of well number 4, located about one foot from the mound periphery (see Fig. 8.3.3), in which both fecal coliform and enterococci were found. The FC/FS ratio in well 4 was 10.0, indicating human fecal contamination. Total bacterial counts in this well were correspondingly large. At this time of the year the ground-water table was very high (within 1 ft. of the surface) and the soils were wet. Ground-water contamination was not indicated at sampling points more distant from the system than well number 4. This observation points to the necessity of extending this mound system. Ground-water analyses in April and October, 1971 seem to verify these trends, because the highest levels of N and P occur in wells 4, 6 and 7, south of the mound (Table 8.3.3). Analysis of the ground water from wells number 4 through 12 indicate: (1) Nitrification of NH_4-N to NO_3-N; the extent of which is dependent on distance from the mound. The seepage bed inside the mound is close to the original soil surface and vertical unsaturated flow is insufficient to induce complete nitrification, as is found in systems where vertical unsaturated flow occurs through a distance of several feet; (2) movement of NO_3-N and its dilution by ground water; and (3) immobilization of P by sorption in the soil. Data from October, 1971 indicate less dilution of the N and P contents in the ground water when the water table is low and flow rates are minimal. The absorptive area of the seepage field is approximately 54m^2 (600 sq. ft.). At an estimated loading rate of 450 gallons/day, a minimum vertical flow rate of 3.3 cm/day is necessary to avoid overloading. This would correspond to an estimated moisture tension in the sand below the bed of around 30 mbar, well below tensions found in soil surrounding crusted seepage beds in sands up to twelve years of age (see Chapter 5.2). So it appears that after crusting of the seepage bed (which is highly probable as a result of gravity-flow loading through highly perforated pipe, as discussed in Chapter 6.2) the absorptive area will be sufficiently large to absorb the current volume of effluent.

Conclusion: This mound system offers an alternative to a conventional subsurface seepage bed that otherwise would be sure to fail because of the periodic very high ground-water table. The system needs to be extended, however, since bacterial ground-water pollution occurs near the lower part of the mound in wet periods, as a result of the very short distance between the perforated pipe and the edge of the mound.

8.3.2.3. Clark Co. study area: Mound 2

This mound was built on top of a well drained Arland silt loam underlain by sandstone bedrock at depths varying from a few inches to three feet. Many rock outcrops were found in the area. The general slope was southwards (5%). The original soil, described in an adjacent forest, had the following horizons: A1:0-15 cm: Black, friable silt loam; A2:15-20 cm: Grayish brown, friable, silt loam; B2:20-40 cm (lower boundary quite wavy): Brown loam, fine subangular blocky. The particle size distribution of the A and B horizons is given in Table 8.3.4. Moisture retention characteristics of the topsoil and the calculated hydraulic conductivity curve are in Fig. 8.3.5. This



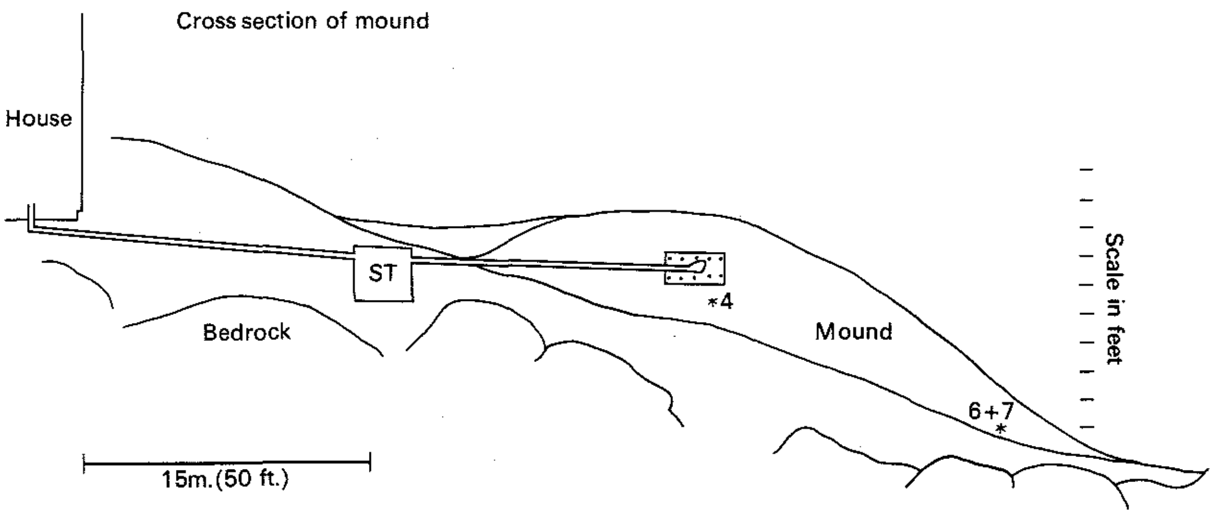


Fig. 8.3.6. Top view with sampling points and cross-section of mound 2 (Clark County).

includes the K_{sat} value measured on large undisturbed cores. A top view and cross-section of this mound are in Fig. 8.3.6. The fill for the mound was delivered to the site in November, 1970. The seepage bed was built in July, 1971 and connected with the septic tank. An on-site inspection in October revealed that the fill material was very heterogeneous. Large quantities of loamy soil materials, some with a very high content of material coarser than 2 mm, changed the character of the sand, that was supposed to have been the sole fill material. Two representative samples of this heterogeneous fill were analyzed for texture (see Table 8.3.4). The system was monitored on October, 1971, when still incomplete. The design called for a 20 cm thick covering of topsoil, to be seeded with grasses, and for a moisture barrier at the downslope part of the mound. The dimension of the seepage bed were based on criteria developed in Chapter 8.3.1.1.

The topsoil had a K_{sat} of 21 cm/day, as measured in large undisturbed cores (see Fig. 8.3.5). The heterogeneous fill material around the seepage

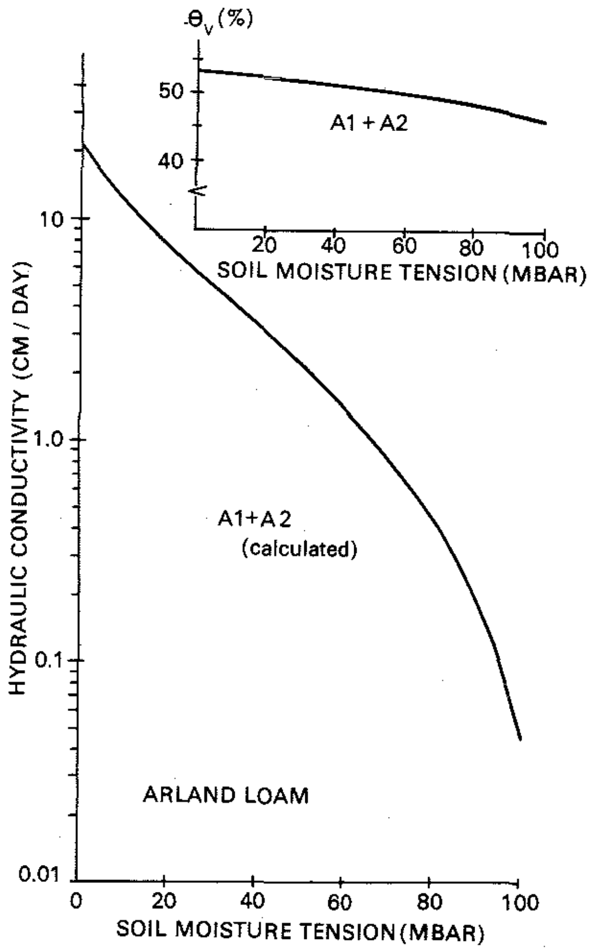


Fig. 8.3.5. **Hydraulic conductivity and moisture retention data for the topsoil in an Arland loam (mound 2, Clark County).**

Table 8.3.4. Particle size distribution of horizons in an Arland loam and of fill materials in Mound 2 (Clark County).

Horizon or material	C	FS	MS	CS	VFS	FS	MS	CS	VCS	>2mm	Texture
A1	24.0	9.0	23.0	14.0	5.6	5.7	15.6	2.6	<1	<1	loam
B2	27.0	6.0	26.0	15.0	6.2	8.2	18.5	3.0	<1	1.6	clay loam
Sandfill I	16.0	1.0	1.0	--	<1	7.7	64.9	6.9	2.0	3.0	sandy loam
Sandfill II	20.0	1.0	3.0	1.0	5.9	47.8	15.6	5.3	<1	30.4	sandy clay loam
Alg below mound	22.0	2.0	10.0	6.0	6.3	20.3	29.8	3.4	<1	<1	sandy clay loam

bed made the choice of a representative I value rather arbitrary. A relatively low value of 5 cm/day was selected, which corresponds with a tension of around 35 mbar in a medium sand. With h_c-h_e = 5 cm, and T = 800 cm /day, the required width of the seepage bed was found to be 80 cm (close to three feet), following equation (2) in Section 8.3.1.1. The length L of the bed would then be 30 m (100 ft.), assuming a loading rate of 300 gallons per day. It should be noted that the calculations in Chapter 8.3.1.1 were based on a level flow system, whereas a slope of 5% was actually found. The flow system is therefore more complicated and the calculation, as made here, can only be considered a general approximation. Monitoring of the system involved: (1) Establishment of the moisture conditions around the seepage bed at different distances from the effluent inlet. For this purpose five small pits were dug adjacent to the seepage bed, extending beneath them (see Fig. 8.3.6). (2) Determination of certain microbiological and chemical characteristics of the effluent and of percolating liquid inside the mound. To accomplish this, two small pits were dug at the lower end of the mound, down to the original soil surface (Fig. 8.3.6), and samples were taken from the liquid that seeped into these pits. Excavations around and into the seepage bed showed that effluent was ponded in the bed near the inlet (pit numbers 2, 3 and 4 in Fig. 8.3.6). Excavations in the two pits adjacent to the ends of the seepage bed (Pits 1 and 5) showed that effluent was not present at those locations. It was planned to make tensiometric measurements in the soil immediately beneath the bed, where it was filled with effluent, in order to estimate crust resistance. However, due to the very heterogeneous nature of the fill material and corresponding variable hydraulic characteristics, this could not be done. The simple observation that ponding of effluent is localized in the seepage bed, however, is in accord with the general process of progressive crusting in beds fed by gravity flow (see Chapter 6.2). Biologic crusting of sandy material or, in this case, the occurrence below the bed of very slowly permeable loamy soil bodies in the fill, leads to a strong reduction in infiltration, and forces the effluent to move farther along the trench to uncrusted soil surfaces.

The final stage, then, is one in which the whole bottom area and also part of the sidewalls of the bed are crusted. As tensions measured elsewhere below crusted subsurface beds were never lower than 25 mbar in sands (see Chapter 5.2), the assumed loading rate of 5 cm/day should be sufficiently low to avoid future overloading. The only potential problem could arise from the very slowly permeable fragments of loamy fill material, with K_{sat} values much below 5 cm/day, bordering the trench, and thus strongly decreasing the infiltrative capacity of the soil. Future monitoring will show the magnitude of these effects.

The original topsoil, now below the mound, was quite different in appearance from the natural topsoil in the forest. The color had changed from black and grayish brown to bluish gray and porosity was reduced. The topsoil below the seepage bed was very moist, close to saturation. However, free water was not ponded on top of the soil surface. Downslope, at observation pits No. 6 and 7, the topsoil and about 5 cm of the superjacent sand fill were saturated. This liquid was sampled for bacterial and chemical analyses.

The theoretical soil moisture tension distribution and corresponding contents of moisture and air can be calculated for varying infiltration rates into a fill (with known K values) on top of a saturated soil surface (see Chapter 8.3.1.1; method of Bybordi). The purpose of this calculation is to define the physical filtration process by describing the degree of saturation at different distances above the soil surface and the corresponding percolation rates of effluent. The minimum most desirable thickness of fill below the seepage bed and the soil can be derived from this type of analysis. The fill material in this mound is difficult to use as a basis for such a calculation, due to its heterogeneity. We will illustrate the method by using the hydraulic properties of the more suitable sand used as a fill in the mounds constructed in the Ashland area. The hydraulic conductivity curve and moisture retention characteristics of this sand were given in Chapter 5.2.5. Fig. 8.3.7 shows moisture tensions as a function of the distance above a saturated soil surface (where pressure is zero) and the rate of application of liquid to the sand fill material on top of that soil. An infiltration rate of 45 cm/day corresponds with a moisture tension of 25 mbar in a soil column of infinite length filled with this sand; 8 cm/day with 30 mbar and 4 cm/day with 35 mbar (Fig. 5.27 in Chapter 5.2.5). Where 60 cm (2 feet) of sand is placed between a saturated soil surface and a seepage bed, however, tensions decrease to lower values close to the soil surface (Fig. 8.3.7). A tension of 30 mbar, corresponding to a relatively low flow velocity in the soil pores and therefore a favorable long retention time in the soil, is then maintained only in the upper 20 cm of the fill, directly below the seepage bed. Tensions decrease rapidly approaching the soil surface. If only 30 cm (one foot) of fill had been placed between the bed and the soil, tensions would never become higher than about 25 mbar at the bed-fill interface, with a strong decrease in tension (and an unfavorable increase in flow-velocity) downwards.

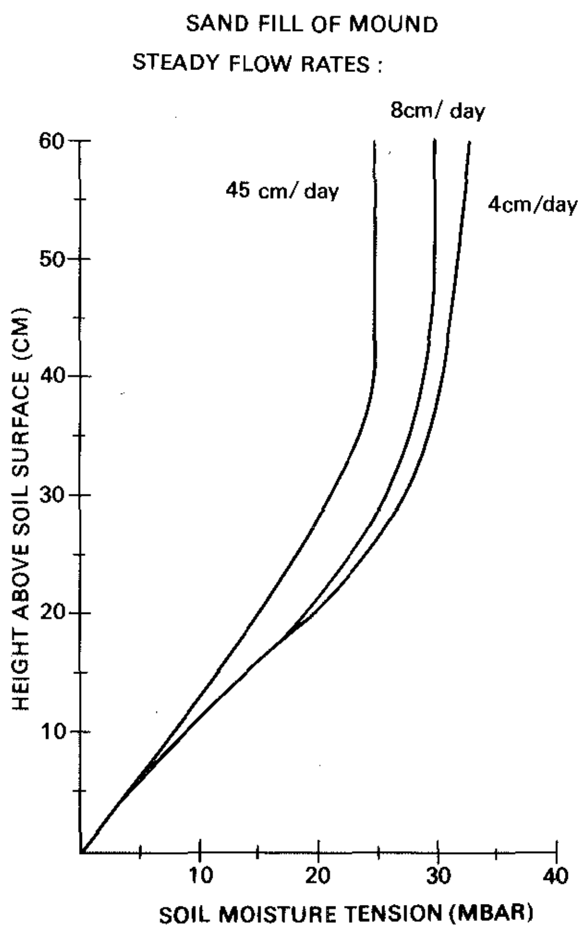


Fig. 8.3.7. Soil moisture tensions in a sandfill as a function of distance to a saturated soil surface at three infiltration rates.

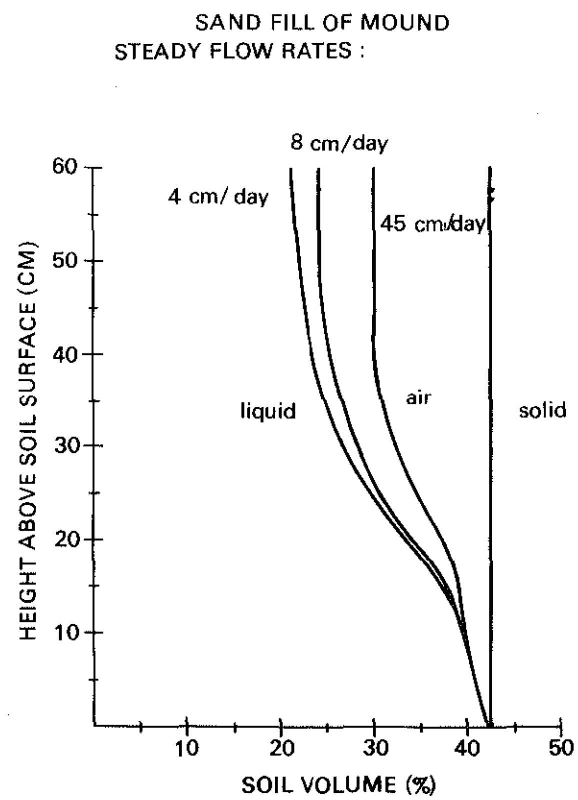


Fig. 8.3.8. Phase distributions corresponding with the flow systems in Fig. 8.3.7.

The minimum thickness of fill in a mound below a seepage bed should therefore, in this case, be at least two feet. Fig. 8.3.8 shows the corresponding phase distributions for the three flow rates as derived from moisture retention data. The lowest infiltration rate corresponds with the highest air content (approximately 20% by volume).

Table 8.3.5 Chemical and Bacterial Analyses, Mound System 2

Clark County, Oct. 21, 1971

Chemical Analyses

Sample See Fig. 8.3.6	Total N (mg/l)	Dip (mg/l)	Total P (mg/l)
Liquid in seepage bed (1)	31.5	5.8	6.1
Point 6	3.5	0.02	0.11
Point 7	4.9	0.02	0.18

Bacterial Analyses (bacterial counts per gram of soil or per ml in liquid samples)

Sample See Fig. 8.3.6	Enterococci	Fecal coliform	Total coliform	Total bacteria ($\times 10^3$)	pH
Liquid in seepage bed (1)	330	5000	34,000	5370	6.8
Point 6	**	**	**	3.7	5.9
Point 7	**	**	**	4.0	5.9

(1) liquid sample

**= organisms not detected, <6/gr in average of triplicate platings

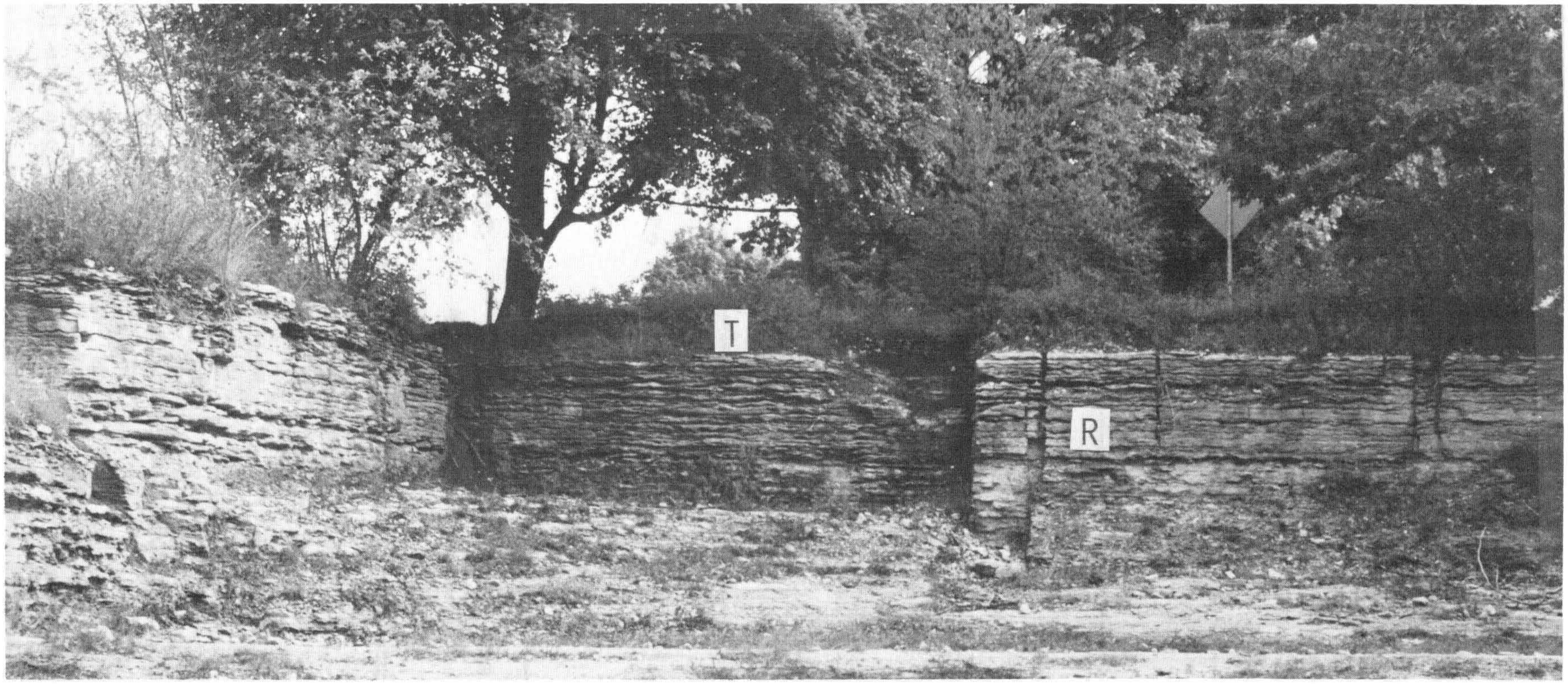


Photo 8.2. View of shallow topsoil (T) over creviced bedrock (R) in Door County. The conventional type of subsurface seepage bed cannot be constructed in such locations and the feasibility of a possible alternative, the "mound system" is explored in Chapter 8.3

Results of the chemical and bacterial analyses of this mound system are in Table 8.3.5. A comparison of data for effluent in the bed and liquid in the soil at points 6 and 7 indicates strong reductions in contents of total N and P. Bacterial analyses of samples from these points showed no fecal indicators. This means that the mound system was functioning properly from a bacteriological point of view.

Conclusion: This mound system offers an alternative to a conventional subsurface system that would not function at this location because of the presence of impermeable bedrock at a shallow depth.

8.3.2.4. Door County study area: mound 1

This mound (see Fig. 8.3.9) is used for the disposal of effluent from a motel with 20 units. At the time of the test at September 30, 1971 only two units were occupied. Therefore, the picture obtained is not representative of conditions in the peak tourist season, when all units are in use, and loading may be ten times higher. The original topsoil at this site is very shallow. Large open crevices, ten inches wide, are abundant in the forest all around the present mound, which suggests that they must also be present below the mound. The profile description, submitted to the Board of Health, mentioned a soil thickness of over 24 inches. The system was not built according to plans submitted for approval. A large distribution box was found on top of the mound and liquid flowed from there into the perforated pipes. The plan did not show this distribution box, and the positions of the divergent perforated pipes were found to be different from those indicated on the plan. The fill in the mound consisted of 1.5% clay, 2% silt and 96.5% sand (of which 1.7% was very fine, 12.5% fine, 80% medium, 5.3% coarse and 0.7% very coarse).

Two excavations were made, one (pit 1) close to the distribution box, and the other as far away from it as possible (pit 2). It was found that the sandfill was saturated on top of the original soil surface in pit 1 (moisture tension was measured to be 0), whereas the soil was only slightly moist at the corresponding position in pit 2. This points to the important phenomenon, also observed elsewhere in this study, that effluent was poorly distributed over the entire field. The perforated pipe has a total of 74 holes, in each 10 feet segment. The effluent is pumped into the pipes at a high rate (approximately 100 gallons in 2 min.). Most of the effluent must empty out of the perforated pipe into the fill within a short distance of the distribution box. This will overload the system there, whereas farther away, no effluent is received. Tensiometric measurements made in situ immediately below the gravel bed in pit 1 confirmed the occurrence of periodically high flow rates. When effluent was pumped into the bed, tensions decreased to 15 mbar, which corresponds with a high K value of 130 cm/day (Fig. 8.3.10). Tensions increased rapidly to a level of 30 mbar after pumping had stopped, indicating fast downward movement of the liquid. A corrective arrangement would be to reduce the number of holes, as was done at a site near Ashland, where the first ten-foot segment of pipe had only 2 rather than 74 holes, to produce a more even distribution of effluent into the mound. The total

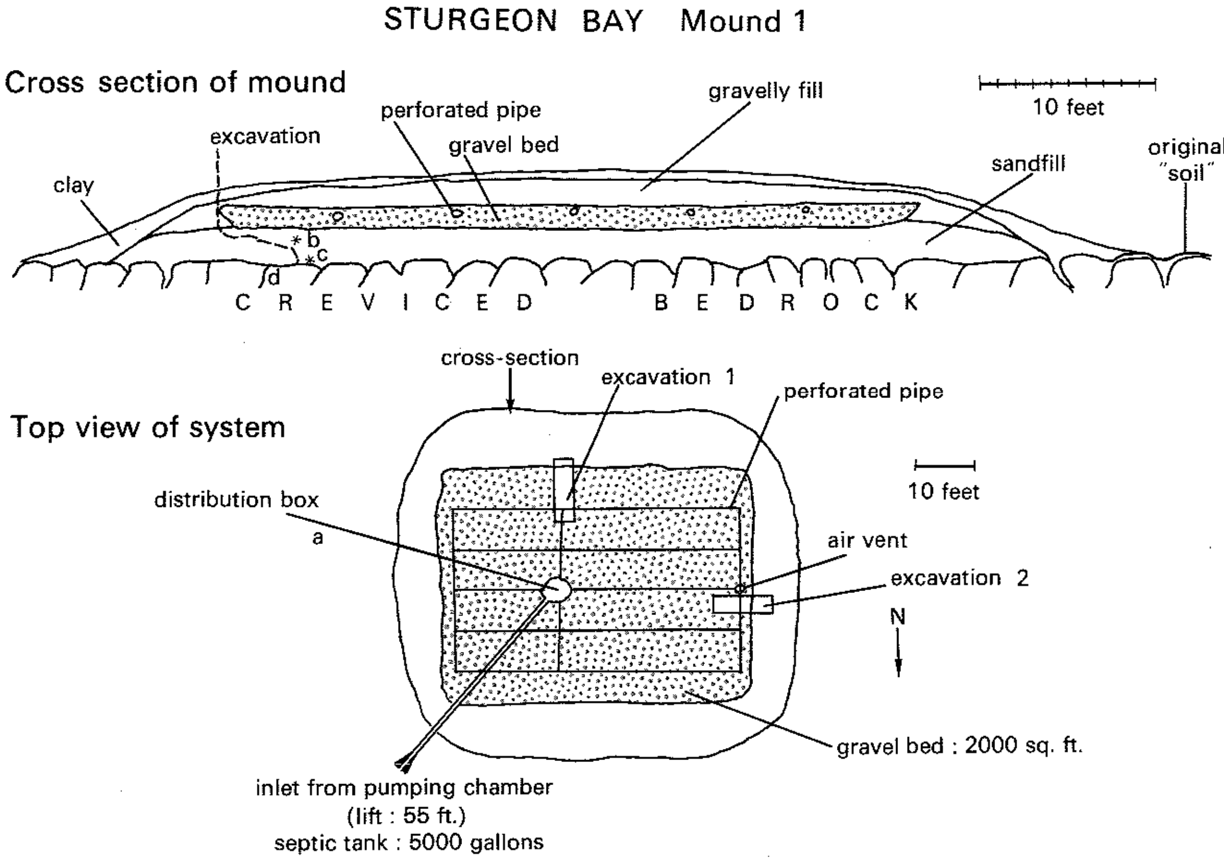


Fig. 8.3.9. Top view and cross section with sampling points of mound 1 (Door County).

absorptive area below the bed of this Door County mound is 2000 square feet (180 m^2). At an estimated daily input of 20 x 75 = 1500 gallons (6000 l), an effective permeability of 3.3 cm/day would be sufficient to dispose of the liquid, if the liquid were evenly distributed over a 24 hr. period. This would represent a moisture tension of around 27 mbar (see conductivity curve of the fill material in Fig. 8.3.10). Traditional successfully operating subsurface systems in sands in different parts of the state had tensions below crusts that never exceeded about 25 mbar (even in one 12 year old system). This calculation, then, shows that the size of the bed is satisfactory, even if the interface of the bed and the fill crusted strongly (which would be favorable from the standpoint of filtration: see Chapter 6.2.3). In the absence of crusting, it is essential to spread the effluent over the total absorptive area of the bed during each loading to stimulate the favorable hydraulic effects of crusting as closely as possible. Crusting is not likely to occur soon in this mound, because of the intermittent application of the effluent, which leads to breakdown of crust materials during the aeration periods (see Chapters 6.2.2 and 8.2.2). The natural topsoil, now below the mound, proves to be very effective as a filter, as it seems to be free of fecal coliforms and streptococcus organisms (Table 8.3.6). Note the apparent discrepancy between total coliform in the mound and those in the natural topsoil. In the mound is a sand which is normally lower in moisture, nutrients and organic materials than clayey soil. In the topsoil (an active forest soil in terms of organisms) natural soil coliforms should be present, at least in small numbers. This is confirmed by observations of the control sample.

Data from samples from the saturated sand in the mound on top of the soil surface in excavation 1 indicated that FC and FS counts were high in the duplicate samples taken (10 FC/gram and 40 FS/gram or a FC/FS ratio of 0.25). This ratio is below 0.7, suggesting contamination due to animal sources (see Chapter 3.4.3). However it is concluded that these FC and FS were of human origin here because (1) The FC/FS ratio of the effluent was only 2.3, (2) The origin of the sample was from inside the mound, not directly exposed to animals and (3) FC were not found in the natural topsoil. The fill material at excavation 2 on the other side of the mound (Fig. 8.3.8) had approximately the same moisture content at all points in vertical sequence. Neither FC nor FS were found here. This is another indication that the distribution of liquid was directed towards excavation 1, resulting in overloading there and deep penetration of fecal indicators. It can be assumed that liquid moves down open crevices in the limestone under the 3000 square feet of mound

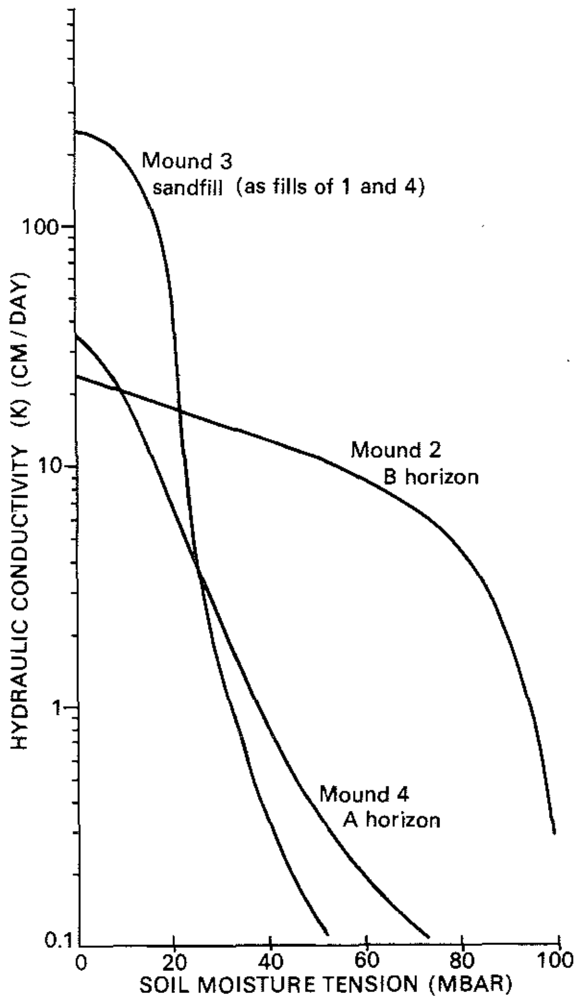


Fig. 8.3.10. Hydraulic conductivity data for some soil horizons and fill materials from mounds in Door County.

Table 8.3.6 Bacterial Analyses, Mound System 1, Door County, Oct. 1, 1971

(bacterial counts per gram of soil or per ml in liquid samples)

Sample (See Fig. 8.3.9)	Enterococci	Fecal coliform	Total coliform	Total bacteria	pH
a, [1]influent to mound	1,330	3,000	9,300	$23.3x10^5$	7.8
b, excavation 1 sand 30 cm above topsoil	X	X	90	$20x10^5$	7.9
c, excavation 1[2] saturated sand	47	10	130	$18.7x10^5$	6.9
just above topsoil	0.3	3	63	$42.3x10^5$	7.4
d, excavation 1[2]	3	X	4,000	$95.7x10^5$	7.3
topsoil below mound	X	X	12,300	$103x10^5$	7.1
b, excavation 2 sand 30 cm above topsoil	X	X	20	$32x10^5$	7.7
d, excavation 2 topsoil below mound	X	X	20,700	$201x10^5$	6.5
Control (forest topsoil)	30	X	2,000	$259x10^5$	7.4
Well water[1]	*	*	*	107	-

[1]liquid samples

[2]duplicate samples taken

* = organisms not detected, <1/ml in average of triplicate platings

X = organisms not detected, <10/gram in average of triplicate platings

Table 8.3.7. Chemical analyses of effluent, percolating liquid and well water for mound No. 1. (Door County).

	NH_4-N	(NO_2+INO_3)-N	Total N	Ortho-P	Total P	Cl
Influent of mound (distribution box)	41.66	0.74	50.84	0.76	2.60	67
Well water	<0.05	0.74	7.98	<0.03	0.62	5

BOD of effluent in pumping chamber: 121 mg/L (unfiltered), 83 mg/L (filtered).

BOD of sand filtered effluent on soil surface: 40 mg/L (unfiltered), 23 mg/L (filtered).

area. It is, therefore, no wonder that liquid surfacing from the mound was neither observed nor reported at any time. We may conclude that the effectiveness of this system in terms of the removal of indicator organisms is insufficient under the current loading regime due to local overloading. Better distribution of effluent over the entire bed at each dosing would increase the effectiveness to an acceptable level. Data were not obtained to indicate how far fecal indicator organisms and pathogens could move down the crevices or whether they could reach the ground water, which was approximately 60 feet below the base of the mound.

The chemical analyses (Table 8.3.7) show high contents of N and P in the effluent, as sampled from the distribution box. Water sampled from the house well had a high N content, mainly in the form of organic-N. BOD samples were analysed by the Sanitary Engineering Laboratory. A reduction of BOD occurred during the filtration through the sand as observed at pit 1 in the mound. However, a better distribution of effluent in the bed during loading would lead to lower flow rates through the soil and to a much stronger reduction of the BOD content.

<u>Conclusion</u>: This mound provides insufficient bacterial purification of effluent due to a very poor distribution of liquid over the entire seepage bed inside the mound during intermittent loading.

Table 8.3.8. Textural analysis of soil materials in mound No. 2. (Door County).

	C	F.S.	M.S.	C.S.	V.F.S.	F.S.	M.S.	C.S.	VCS	Texture	Fraction >2mm
Nat. A1	7.5	4.50	9.50	8.0	21.27	24.27	17.58	5.20	2.14	Fine sandy loam	1.4
Nat. B2	8.0	4.0	6.50	7.0	26.82	22.63	14.10	6.04	5.02	Fine sandy loam	17.4
Nat. B3	7.50	2.50	6.0	9.50	27.81	22.32	14.38	6.46	3.26	Fine sandy loam	27.0
Nat. C	6.0	4.0	6.50	9.0	21.36	19.63	20.30	9.13	3.50	Fine sandy loam	15.2
Fill	1.0	1.0	1.50	1.0	3.59	9.03	45.75	17.12	19.32	Sand	55.2

8.3.2.5. Door County study area: Mound 2

This mound (Fig. 8.3.11) received septic tank effluent from a family of five persons, two adults and three children. The house kitchen was provided with a garbage disposer, dishwasher and an automatic washing machine. No flow rate data was available, but it can be estimated to average 375 gallons per day. This system had been in continuous use for 14 months. No leakage was observed from the sides of the mound at any time, and there had been no problems with freezing in the winter. The system was quite satisfactory to the owner.

The natural soil depth over bedrock was about 45 cm (18"). A dark sandy loam A1 of about 8 cm (3") was found on top of a brown sandy loam B2 (Table 8.3.8). Crevices in the bedrock were filled up with B material for at least a depth of two feet. No open crevices were observed in the natural soil at the upper level of the bedrock. An excavation was made as indicated in Fig. 8.3.11. It was found that much liquid had accumulated on top of the original soil surface (point b). In the bottom of a deeper pit, excavated down to the level of the bedrock, liquid also accumulated, though very slowly. Both liquids were sampled.

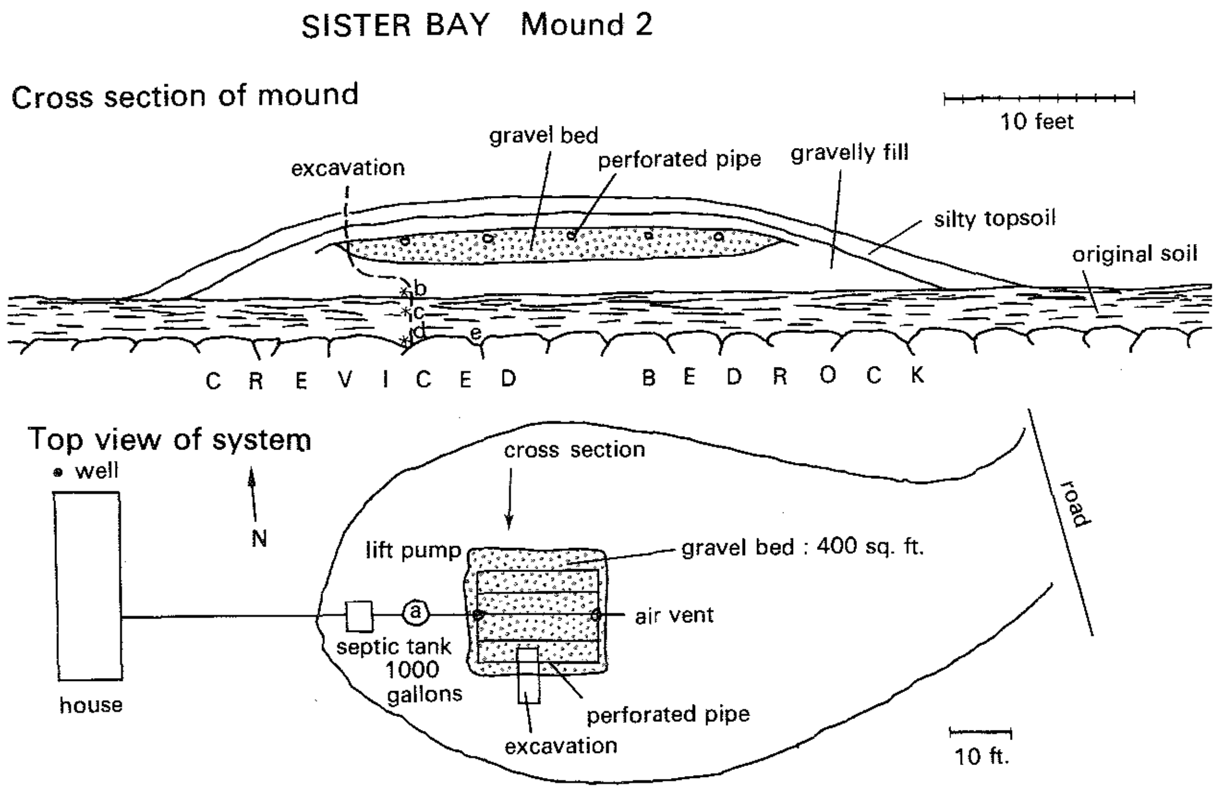


Fig. 8.3.11. Top view and cross-section with sampling points of mound 2 (Door County).

The fill in this mound was very coarse (55% of the particles were larger than 2 mm) and the hydraulic conductivity was very high (K_{sat} = 3400 cm/day, measures in a large soil core). The underlying soil had a K_{sat} of around 25 cm/day (Fig. 8.3.10). The rest of the conductivity curve was calculated by the Green and Cory method, using moisture retention data (Fig. 8.3.12). It shows a very gradual decrease of K with increasing soil moisture tension, resulting in relatively high K values at suctions higher than 30 mbars. The effluent will flow very fast through the coarse fill, leaving little opportunity for purification. The sand fill used in the other mounds is much better, as the K_{sat} value, at 260 cm/day, is much lower and the moisture retention characteristics more favorable (moisture retention curves were not prepared for the coarse fill of this mound because of the high content of gravel and stones). Potential moisture tension distributions were calculated for this system following the procedure discussed in Chapter 8.3.1.1, assuming a sandy fill material as in mound 1. Figure 8.3.13 shows the tension distribution in the fill-topsoil system at a steady downward flow of 8 cm/day, assuming

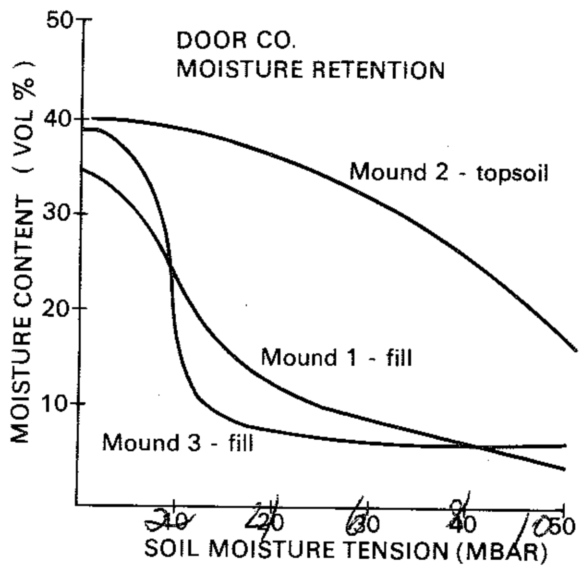


Fig. 8.3.12. Moisture retention data of soil horizons and fill materials in three mounds in Door County.

zero tension at the bedrock level. This was translated into relative volumes in Fig. 8.3.14, using moisture retention data (Fig. 8.3.12). The phase distribution pictured in Fig. 8.3.14 is very favorable, because the fill is well aerated (27% air) which may induce nitrification of the NH_4 and organic-N compounds in the effluent, whereas the underlying topsoil is poorly aerated (5% air only in the top 10 cm) which may induce denitrification, provided a sufficient energy-source is available. Erickson et al. (1971) have indicated

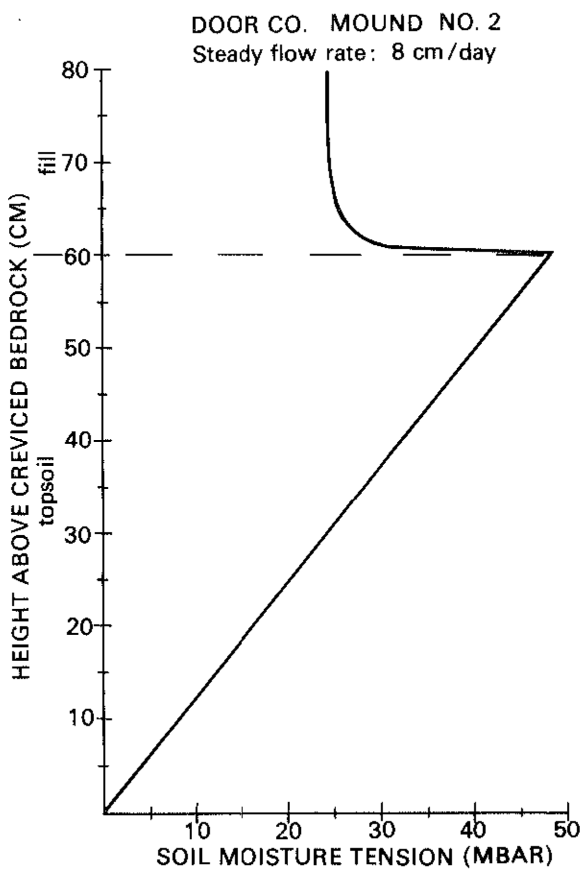


Fig. 8.3.13. Soil moisture tensions in a sand fill and in the topsoil beneath mound 2 at a steady infiltration rate of 8 cm/day.

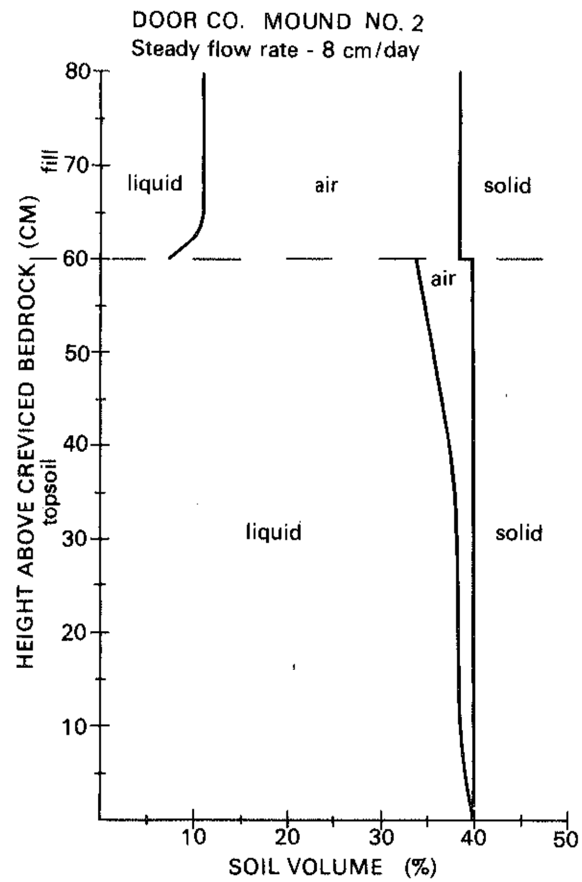


Fig. 8.3.14. Phase distribution corresponding with the flow system in Fig. 8.3.13.

Table 8.3.10 Bacterial Analyses, Mound System 2, Door County, Oct. 1, 1971

(bacterial counts per gram of soil or per ml in liquid samples)

Sample (See Fig. 8.3.11)	Enterococci	Fecal coliform	Total coliform	Total bacteria	pH
a, [1] influent to mound	2,610	6,000	18,300	183×10^5	7.9
b, [1] liquid from mound-topsoil interface	18	170	700	5×10^5	7.8
c, A horizon below mound	X	X	20,000	54×10^5	7.2
d, B horizon below mound	3.0	X	6,000	73×10^5	7.4
e, [1] liquid at B horizon-bedrock interface [2]	*	1-10	33	134×10^3	7.6
	2.5	*	80	210×10^3	7.5
Well water [1]	*	*	*	345	8.1

(1) liquid samples

(2) duplicate samples taken

* = organisms not detected, $<$1/ml in average of triplicate platings

X = organisms not detected, $<$10/gram in average of triplicate platings the feasibility of this approach. The chemical data (Table 8.3.9) show a high content of nitrates in the liquid on top of the soil surface and at the bedrock level, while the NH_4 content is low. This indicates oxidative conditions during the movement of the effluent from the distribution box into the gravel bed and through the fill. Nitrate levels of the well water of the house (2.5 ppm) are low, but there is a rather high content of total N, indicating a considerable amount of organic N. The same trend was observed in well water from the other three mounds. There is an insufficient, though

Table 8.3.9. Chemical analyses of effluent, percolating liquid and well water for mound No. 2. (Door County).

	NH_4-N	(NO_2+NO_3)-N	Total N	Ortho-P	Total P	Cl
Influent of mound (distribution box)	29.88	0.50	38.44	0.72	2.60	58
Liquid on top of original soil surface	1.12	24.92	47.62	0.64	2.36	82
Liquid on top of bedrock	1.30	24.86	49.11	0.23	1.20	75
Well water	1.36	2.54	7.69	<0.03	<0.03	2

BOD of effluent in distribution box: 125 mg/L (unfiltered); 112 mg/L (filtered).

BOD of liquid on top of the soil surface: 37 mg/L (unfiltered).

considerable, reduction in bacterial counts in the liquid while moving through the coarse fill that proved ineffective as a filter as is indicated by the still relatively high counts in the liquid on top of the original soil surface (18 FS/ml and 170 FC/ml (Table 8.3.10). Analyses of samples taken on top of the bedrock revealed the presence of some fecal indicators (2.5 FS/gr and 1-10 FC/gram). Further purification will occur when the liquid moves down through the soil-filled crevices, that, however, occupy only a fraction (about 30%) of the total horizontal area. This indicates a concentrated burden on the absorptive and filtrative capacity on the soil in those crevices. This system has therefore to be classified as only marginally effective at this time. Use of a finer textured fill (a sand or loamy sand) could have given better results.

Conclusion: This mound provides marginal bacterial purification of effluent at this time due to an ineffective gravelly fill material.

Photo 8.3. Mound system 3 in Door County. The mound (M) is characterized by gentle sideslopes and by an airvent on top (A). This system functioned quite satisfactorily.

8.3.2.6. Door County study area: Mound 3

This mound (Fig. 8.3.15 and Photo 8.3) had a temporary low loading rate estimated at 100 gallons per day at the time of the monitoring. The system had been in continuous use for 14 months. The present owner of the three bedroom house was the third occupant. No leakage had been observed from the sides of the mound at any time and there had been no problems with freezing in the winter. The gravel filled seepage bed was very close to the surface (within 20 cm; 8"). This had caused very poor growth of grasses on top of the mound, quite in contrast to the abundant growth on the sides. The plan of this mound, like that of Mound 1, differed from the actual constructed system. The bed had a different orientation from that indicated on the plan and the sequence of fill layers was apparently improvised on the spot.

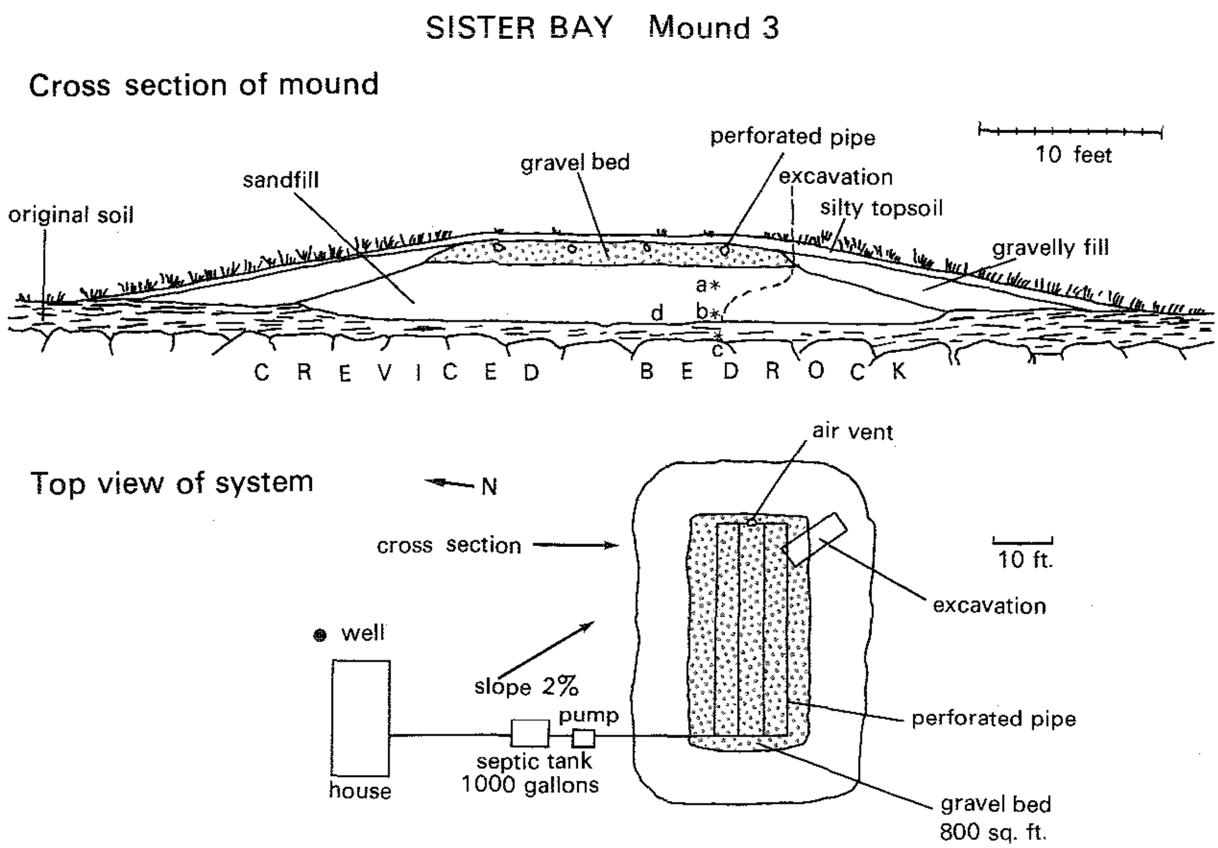


Fig. 8.3.15. Top view and cross section with sampling points of mound 3 (Door County).

Table 8.3.12 Bacterial Analyses, Mound System 3, Door County, Oct. 12, 1971

(bacterial counts per gram of soil or per ml in liquid samples)

Sample (See Fig. 8.3.15)	Enterococci	Fecal coliform	Total coliform	Total bacteria	pH
a, fill material 60 cm above soil surface	**	**	18	30.0×10^4	7.4
b, fill material immediately above soil	**	**	10	444×10^4	7.5
c,(1) soil above bedrock	**	**	1,980	40.6×10^4	7.2
	**	**	800	60.0×10^4	7.6
d, (1) fill material immediately above soil	**	**	20	27.2×10^4	6.9
	**	**	24	9.4×10^4	7.8
Control I (natural topsoil)	26	**	**	174×10^4	7.3
Control II (natural topsoil)	44	**	**	316×10^4	7.6
Well water	*	*	*	648	8.1

(1) duplicate samples taken

* = organisms not detected, <1/ml in average of triplicate platings

** = organisms not detected, <6/gram in average of triplicate platings

The natural soil depth over bedrock was about 30 cm (12"). A dark sandy loam A1 of around 20 cm (8") was found on top of a thin, brown loamy sand B2 (Table 8.3.11). Crevices in the bedrock were all filled with B2 material. An excavation was made as indicated on the diagram. It was found that natural topsoil had been removed for a depth of about 15 cm (6") before the fill was added. This was quite unfortunate as a silty topsoil, relatively rich in organic matter, is a much more effective filter than the fill material itself.

Table 8.3.11. Textural analysis of soil materials in mound No. 3. (Door County).

	C	FS	MS	CS	VFS	FS	MS	CS	VCS	Texture
Nat. A1	8.50	7.0	9.0	6.50	8.34	18.99	34.52	4.80	1.38	Sandy loam
Nat. B2	3.50	2.50	3.00	6.0	16.02	20.42	30.30	9.95	8.28	Loamy fine sand
Sand Fill	1.50	1.0	0.50	0.50	2.70	9.78	74.82	6.63	2.36	Sand
Mound Fill	3.0	4.50	6.0	5.50	7.36	17.95	25.18	22.06	8.07	Coarse sand

Sizing of the gravel bed at 500 square feet seems to be marginal, as a normal loading here for a three bedroom house could amount to 450 gallons per day, which represents a layer of liquid of about 4.5 cm per day. When applied at a constant rate during the day, this yields a tension of about 25 mbar, which is the common tension below crusts in subsurface seepage beds in sand soils. When crusted, this bed would be just large enough to handle the effluent.

Samples were taken of liquid that seeped into a little pit, dug to the bottom of the fill (points d and b). Analytical data show that this system was operating efficiently in terms of FC and FS removal (Table 8.3.12). The soil material above the bedrock, however, did contain relatively high TC (total coliforms) counts (800 to 2000/gram) which apparently originated from the septic tank effluent. Coliforms were not detected in the natural topsoil (see control samples). Stimulation of growth of natural soil coliforms, originally present in low numbers, by nutrients associated with the mound effluent could account for this high TC count.

Analyses of the well water at this location gave results comparable to those obtained at the other mounds (0.37 mg/L NH_4-N; 0.62 mg/L (NO_3 + NO_2)-N; 5.21 mg/L total N; <0.03 mg/L ortho-P and 0.1 mg/L total P · Cl was 3 mg/L).

<u>Conclusion</u>: This system can be classified as very effective.

8.3.2.7. Door County study area: Mound 4

This mound (Fig. 8.3.16) had an estimated loading rate of 225 gallons per day (2 adults and 1 child). The system had been in use for about four months, and no problems had been encountered. The natural soil depth over bedrock averaged 25 cm (10"), with a loamy sand A1 of about 15 cm (6") over a loamy sand B2. Locally soil thickness was observed to be 60 cm (24") (Table 8.3.13). Crevices in the bedrock were filled with soil. An excavation was made as indicated on the diagram, as close to the effluent inlet as possible. The sand fill in the mound was not saturated in the area below the inlet, which could indicate a better distribution of effluent through the perforated pipe than is usually found. The gravel bed had an area of 500 square feet (45 m^2). A loading of 225 gallons per day represents a layer of liquid with a thickness of 2 cm, which, when distributed evenly over a 24 hour period, would correspond with a soil moisture tension of around 32 mbar (see conductivity curve of the sand fill in Fig. 8.3.10). This figure, lower than 25 mbar, demonstrates that the sizing of the bed is quite adequate. The

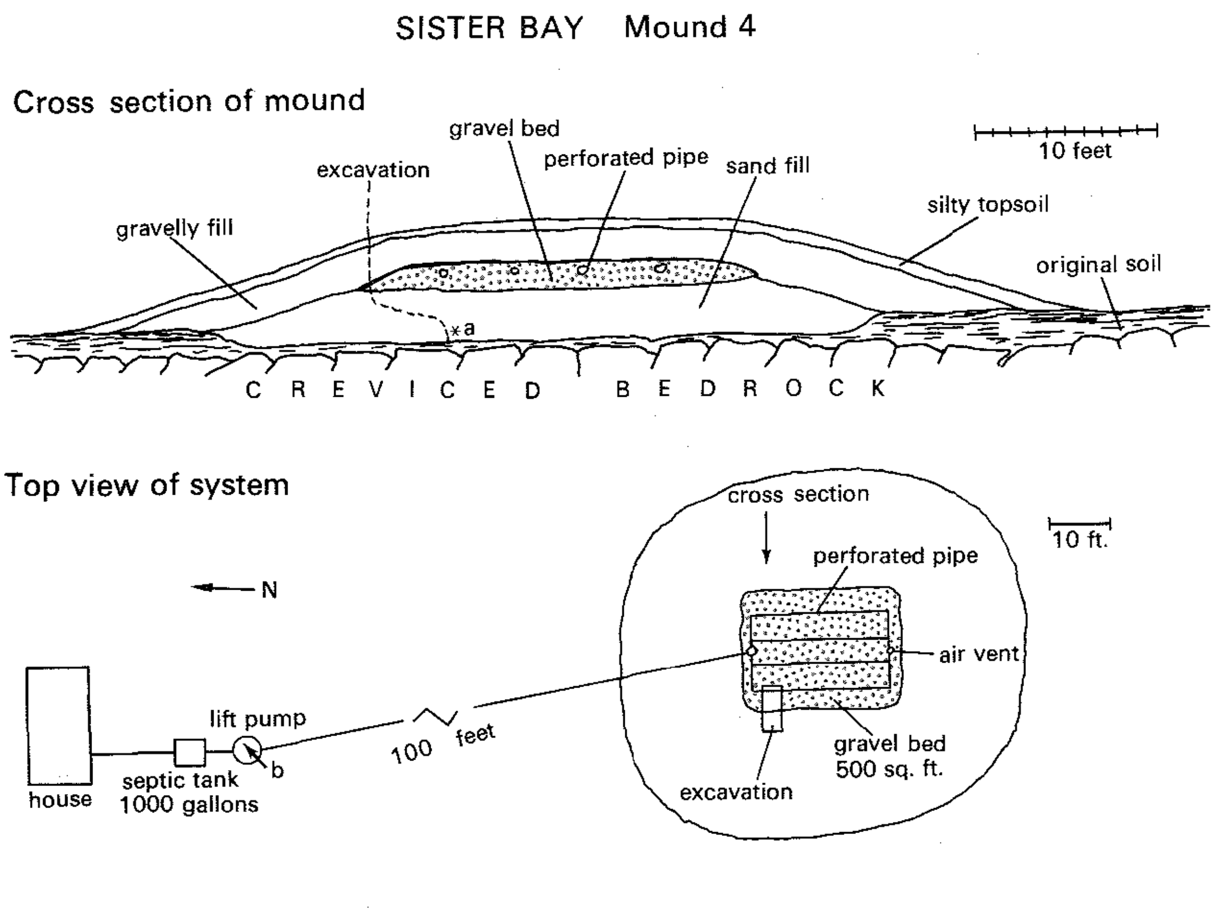


Fig. 8.3.16. Top view and cross-section with sampling points of mound 4 (Door County).

Table 8.3.13. Textural analysis of soil materials in mound No. 4. (Door County).

	C	FS	MS	CS	VFS	FS	MS	CS	VCS	Texture
Nat. A1	4.0	2.0	6.0	6.5	2.20	10.10	61.30	6.45	1.03	Loamy fine sand
Nat. B2	6.0	4.0	4.5	5.5	5.86	16.16	48.85	7.12	2.21	Loamy fine sand
Sand Fill	2.50	1.0	0	0.50	2.17	19.74	68.03	4.54	1.48	Sand
Coarse Fill	1.0	2.50	0.50	1.0	2.73	2.84	43.65	31.97	13.42	Coarse sand

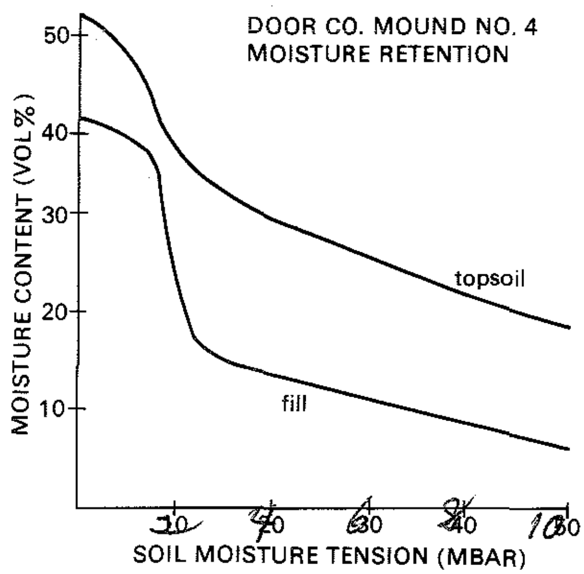


Fig. 8.3.17. Moisture retention data for soil horizons in a Summerville loamy sand (Door County, mound 4).

same conclusion would hold if figures are calculated for a loading of 300 gallons per day (2 bedrooms, 4 x 75 gallons), corresponding with 3 cm per day and a tension of around 28 mbar. Potential moisture tension distributions were also calculated for this system, assuming, again, a downwards flow rate from the seepage bed of 8 cm/day (25 mbar). The moisture characteristics of the topsoil are quite different from the topsoil under Mound 2 (see Fig. 8.3.17 and 8.3.10).

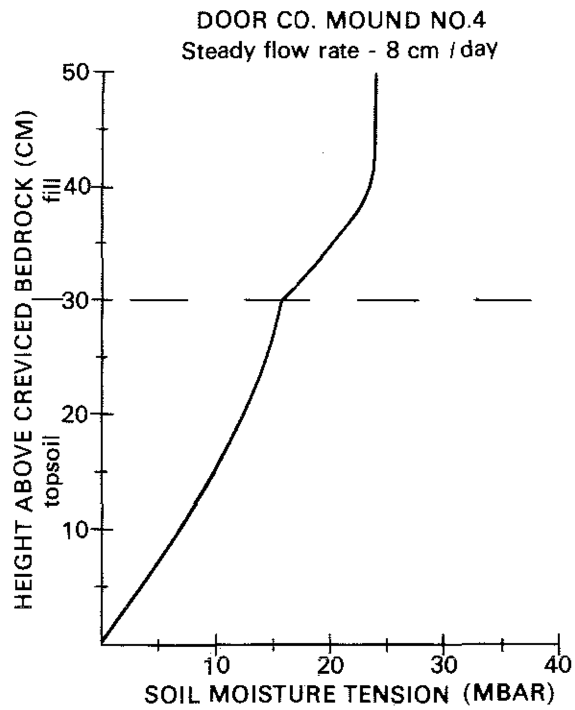


Fig. 8.3.18. Soil moisture tensions in a sand fill and in the topsoil beneath mound 4 at a steady infiltration rate of 8 cm/day.

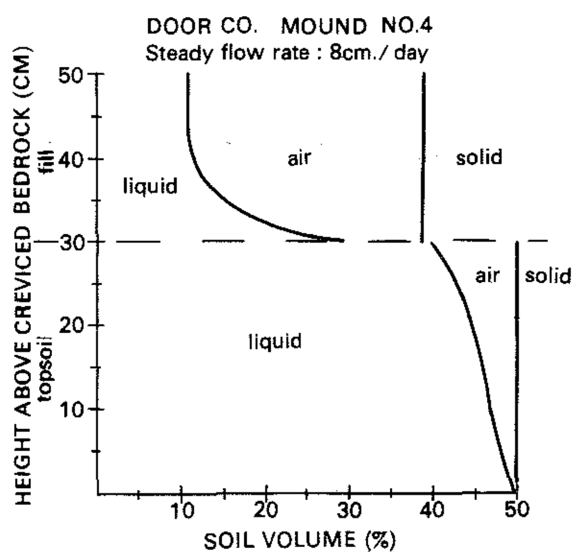


Fig. 8.3.19. Phase distribution corresponding with the flow system in Fig. 8.3.18.

Table 8.3.14. Chemical analyses of effluent and well water for mound No.4.

	NH_4-N	(NO_2+NO_3)-N	Total N	Ortho-P	Total P	Cl
Influent of mound (distribution box)	169.88	0.74	194.68	1.22	2.84	100
Well water	<0.05	1.98	8.95	<0.03	0.04	3

Table 8.3.15 Bacterial Analyses, Mound System 4, Door County, Oct. 12, 1971

(bacterial counts per gram of soil or per ml in liquid samples)

Sample (See Fig. 8.3.16)	Enterococci	Fecal coliform	Total coliform	Total bacteria	pH
a, (1) fill material	**	**	8	7,800	7.4
above topsoil	**	**	**	18,200	7.6
b (1) natural	136	**	2,100	169×10^5	7.2
topsoil	12	**	7,200	90×10^5	7.4
Mound influent(2)	5,760	1,160	10,400	67.1×10^5	8.3
Well water(2)	*	*	*	34	8.3

(1) duplicate samples taken

(2) liquid samples

* = organisms not detected, $\angle$1/ml in average of triplicate platings

** = organisms not detected, $\angle$6/gram in average of triplicate platings

The tension distribution in Fig. 8.3.18 and the corresponding phase diagram in Fig. 8.3.19 are, however, basically similar to those for Mound 2, showing a well aerated fill and a relatively poorly aerated underlying topsoil. Natural topsoil had been removed below this mound to a depth of about 15 cm (6"), as in the case of Mound 3. This practice should be discouraged since topsoil is an effective filter. The chemical analyses of the influent of the mound (Table 8.3.14), sampled in the distribution box, showed a very high NH_4 content, whereas the P content was also relatively high. This points to the occurrence of a concentrated waste at this site, possibly as a result of the fact that the house was not equipped with an automatic washing machine. Fecal coliforms and FS were not detected in the sand fill on top of the truncated original soil surface at a location in the mound which was directly below the effluent-inlet, the sampling point considered most critical (Table 8.3.15).

Conclusion: This system can be classified as very effective.

8.3.3. Discussion

The data presented in Chapter 8.3 have demonstrated the potential of mound systems for disposal of septic tank effluent in soils that are unsuitable for the conventional type of subsurface soil disposal, either because of very slowly permeable soil, periodic high ground water level or the occurrence of bedrock close to the soil surface. Dimensions of mounds can be calculated only when hydraulic conductivity and moisture retention characteristics of fill and natural soil have been determined. It was found that seepage beds inside mounds on top of slowly permeable soils should be elongated and located perpendicular to the general direction of the slope. Seepage beds in mounds over creviced bedrock could be more square, which offers esthetic and economic advantages. Hydraulic conductivity and moisture retention characteristics were also used to calculate moisture tensions and moisture contents in fills below seepage beds and in topsoils as a function of different infiltration rates. A minimum thickness requirement of two feet of fill below the seepage bed between it and the original soil surface was based on this calculation. Fill should preferably have a sandy or loamy sand texture. Coarse, gravelly fill materials are unsuitable as indicated by bacterial data in Chapter 8.3.2.5. A very crucial point in the operation of a mound system is the method of application of effluent. In most mounds effluent will have to

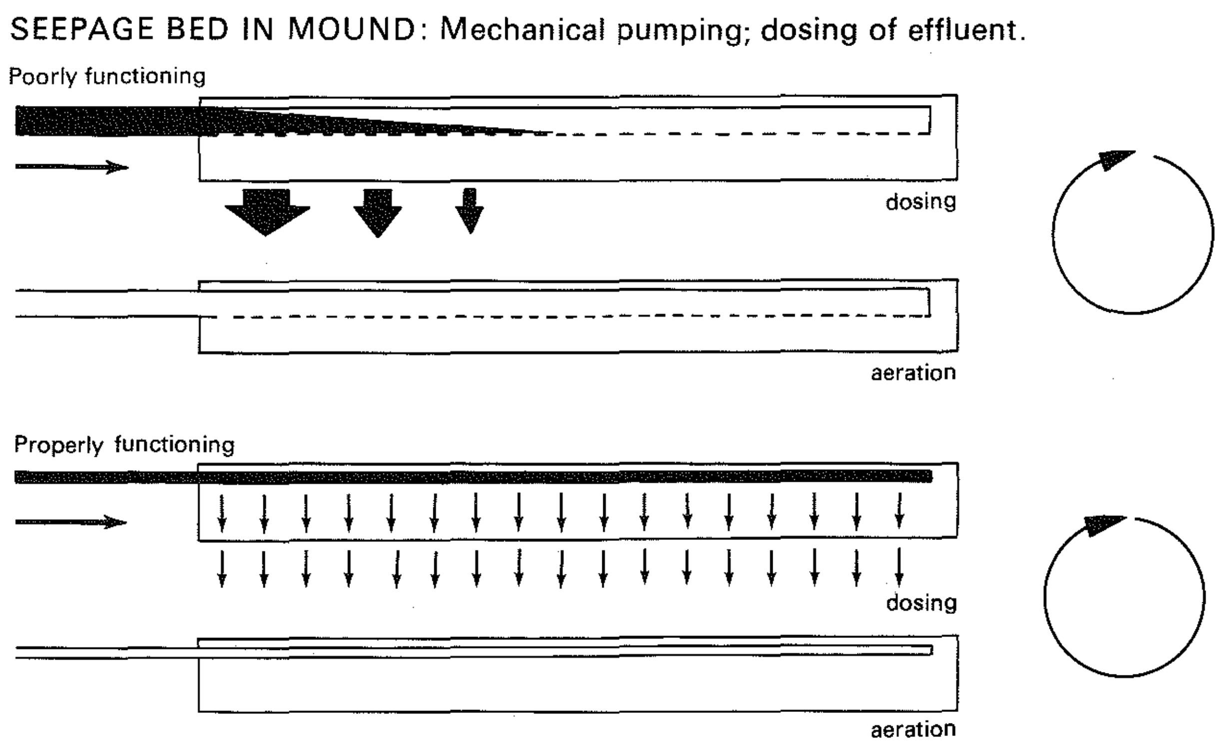


Fig. 8.3.20. Different systems of effluent distribution by pumping into seepage beds inside mounds.

be pumped into the seepage bed at regular intervals. A good distribution of effluent over the entire seepage bed area at each dosage is essential for proper hydraulic functioning (see Fig. 8.3.20). The upper picture shows a poor distribution of effluent due to the use of a highly perforated pipe (see Mound 1 in Door County study area where local overloading resulted in poor overall bacterial purification. A better system, now in development, is illustrated in the lower part of the figure: effluent is equally distributed over the entire bed area, thereby avoiding local overloading. The surface of infiltration in the fill adjacent to the seepage bed is in contact with air after a period of dosing and infiltration of the effluent. This will strongly decrease the possibility of crust formation there (see Chapters 6.2.2.2 and 8.2). The size of the bed, however, has to be designed large enough to avoid failure of the system from overflow in case of eventual crusting. Since flow rates through natural crusts around seepage beds in sand were measured elsewhere (Chapter 5), sizing could be calculated accordingly. In all mounds studied to date no problems were encountered with freezing in wintertime. This is probably due to the relatively warm temperature of the effluent and, in particular, to the insulation provided by two feet of topsoil and the usual snowcover over the seepage bed (see Chapter 5.2.4). More chemical, physical and bacteriological data will be obtained in coming seasons, to make possible further evaluation of the mound system concept.

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Appendix

Table 1.--Observation Well Data at 5 Study Sites in Adams County

Observation Well	Well construction: Casing	Depth (feet)	Screen	Altitude well curb (feet) Aug.18	Nov.11	Height of well curb above Land Surface (feet)
A	$\frac{3}{4}$" Conduit	9.90	None	18.96	18.85	0
B1	"	9.60	"	18.09	18.10	0
B2	"	9.20	"	18.08	18.09	0
B3	"	9.80	"	17.49	17.50	0
B4	"	9.80	"	17.52	17.53	0
B5	"	9.80	"	17.28	17.30	0
B6	"	9.90	"	17.16	17.17	0
B7	"	8.90	"	17.18	17.20	0
B8	"	9.60	"	16.87	16.88	0
C1	"	9.90	"	17.34	17.33	0
C2	"	9.70	"	16.65	16.67	0
C3	"	7.80	"	16.33	16.34	0
C4	"	9.80	"	16.83	16.85	0
C5	"	9.90	"	16.35	16.35	.4
D1	"	9.80	"	16.65	16.67	.5
D2	"	10.00	"	16.67	16.66	.5
D3	"	9.70	"	16.31	16.31	.4
Site 1				(Assumed datum 20 feet)		
A1	$\frac{3}{4}$" Conduit	5.0	None	8.03	8.02	0
A2	"	5.0	"	8.15	8.14	0
A3*	"	1.9	"	8.19	8.18	0
A4	"	5.3	"	8.29	8.17	0
A5	"	4.7	"	8.26	8.23	0
B1	"	4.4	"	7.90	7.90	0
B2	"	3.9	"	7.72	7.71	0
B3*	"	1.4	"	7.55	7.54	0
B4	"	4.8	"	7.45	7.40	0
C	"	5.0	"	8.69	8.68	0.1
D	"	3.3	"	7.18	7.16	0
E	"	2.8	"	7.09	7.04	0
F	"	5.9	"	9.95	9.95	2.0
H	$1\frac{1}{4}$" iron pipe	16.90	12" 80 mesh well point	17.53	17.50	1.0
*Taps Gravel filled Trench	Site 2			(Assumed datum 10 feet)		
A (House well)	2" iron pipe	?	?	51.72		?
B1	$1\frac{1}{4}$" iron pipe	18.0	12" 80 Mesh	50.90		1.3
B2	"	16.1	"	50.76		1.1
B3	"	16.9	"	50.87		1.4
B4	"	16.9	"	50.40		1.5

Site 3

Observation Well	Well construction			Altitude well curb (feet)		Height of well curb above Land Surface (feet)
	Casing	Depth (feet)	Screen	Aug.18	Nov.11	
C1	"	16.9	"	49.57		1.7
C2	"	12.9	"	47.20		1.2
				(Assumed datum 50 feet)		
Old club House Well	2" iron pipe	35 (rep'd)	?			1.6
New club House Well	6" casing	100 (rep'd)	?	109.86		2.3
B1	1¼" iron pipe	51.3	12" 80 Mesh	98.93		1.4
B2	"	34.2	"	100.00		0.1
B3	"	34.8	"	98.72		2.8
B4	"	52.5	"	98.32		2.2
B5	"	57.2	"	98.43		3.5
C1	"	34.2	"	97.49		1.4
C2	"	55.4	"	98.51		2.9
Site 4				(Assumed datum 100 feet)		
House well	?					
A	1½" iron pipe	27.2	12" 80 Mesh	31.85		3.0
B1	"	26.0	"	30.10		2.0
B2	"	24.0	"	27.64		.9
B3	"	22.0	"	27.52		1.3
B4	"	23.8	"	25.91		0.6
C1	"	24.0	"	26.30		1.7
C2	"	27.2	"	26.96		2.5
Site 5				(Assumed datum 30 feet)		

Table 2.--Depth to ground water data

Well		Depth to Water below well curb (feet)		
		Aug. 5, 1971	Aug. 18, 1971	Nov. 11, 1971
A		----	8.44	8.01
B1		7.72	7.65	7.20
B2		7.73	7.64	7.20
B3		7.16	7.07	6.63
B4		7.21	7.11	6.67
B5		6.97	6.86	6.44
B6		6.86	6.76	6.17
B7		6.89	6.79	6.35
B8		6.61	6.51	6.08
C1		----	6.81	6.40
C2		6.29	6.19	5.76
C3		5.98	5.66	5.24
C4		6.54	6.43	6.04
C5		----	5.97	5.57
D1		6.55	6.19	5.76
D2	Site 1	----	6.23	5.81
D3		----	5.90	5.47
		July 28, 1971	Aug. 18, 1971	Nov. 11, 1971
A1		2.40	2.26	2.37
A2		2.52	2.37	2.49
A3*		1.56	1.57	1.48
A4		2.62	2.51	2.54
A5		2.62	2.01	2.59
B1		2.26	2.09	2.28
B2		2.08	0.35	1.63
B3*		0.91	0.91	.81
B4		1.79	0.98	1.78
C		3.05	2.95	3.03
D		1.59	1.44	1.55
E		1.52	1.27	1.43
F	Site 2	4.42	4.29	4.44
H		----	11.73	11.82
		Aug. 18, 1971	Nov. 11, 1971	
B1		10.86	10.19	
B2		10.61	9.97	
B3		10.69	10.03	
B4		10.16	9.42	
C1	Site 3	9.53	8.87	
C2		7.27	6.59	

Well		Depth to Water below well curb (feet)		
		Aug. 11, 1971	Aug. 18, 1971	Nov. 11, 1971
Old club house well		flowing	flowing	flowing
New club house well		58.78	58.75	-----
B1		48.23	48.25	48.39
B2		32.93	31.91	32.44
B3		33.32	33.29	33.43
B4		47.60	47.62	47.73
B5		-----	47.82	47.92
C1	Site 4	-----	34.20	33.41
C2		-----	55.40	48.20

		Aug. 18, 1971	Nov. 11, 1971
A		23.39	23.36
B1		21.62	21.64
B2		19.10	19.13
B3		18.80	18.67
B4		17.33	17.33
C1	Site 5	17.71	17.77
C2		18.38	18.45

SOILS OF WISCONSIN

A GENERALIZED MAP

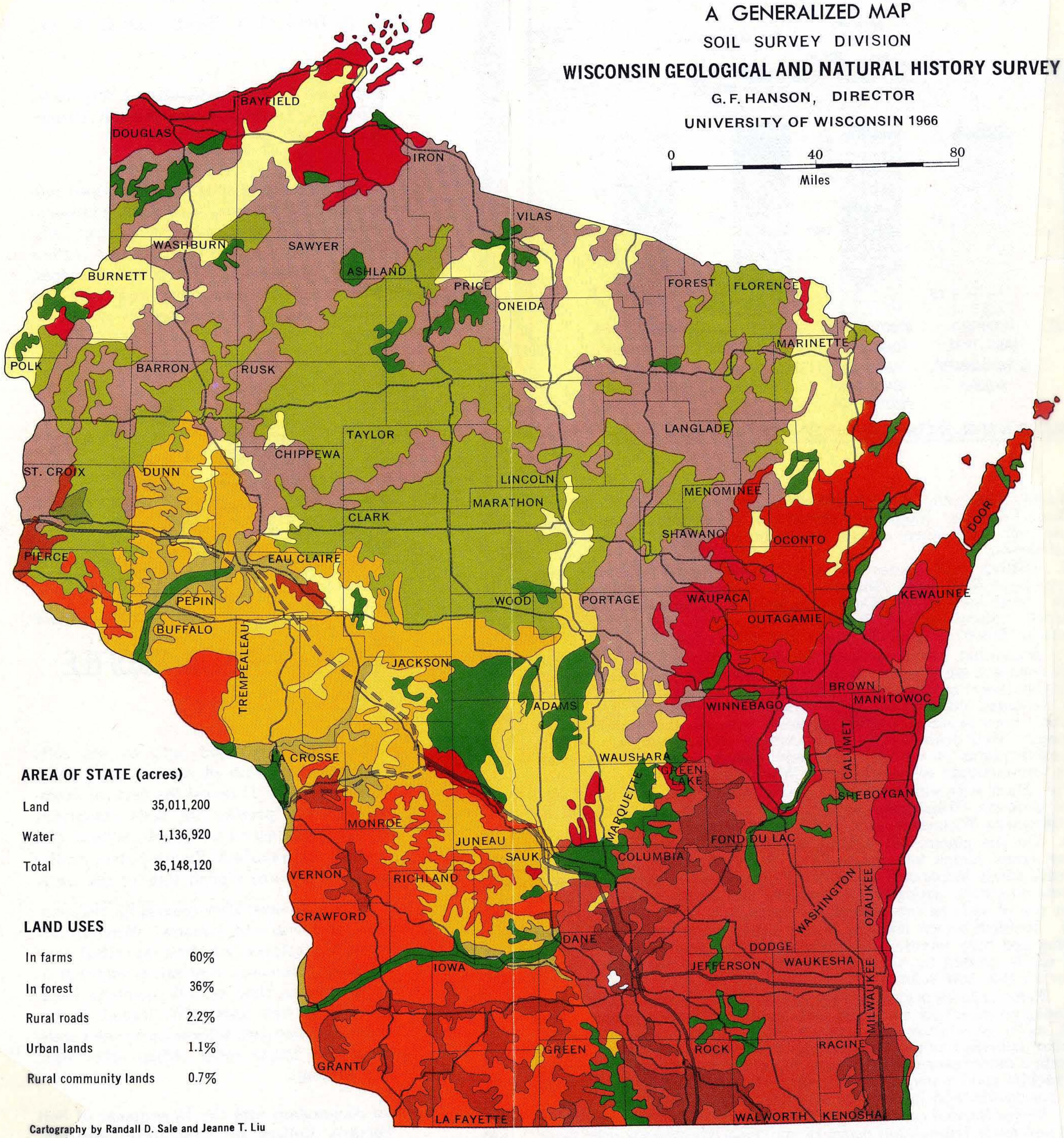
SOIL SURVEY DIVISION

WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

G. F. HANSON, DIRECTOR

UNIVERSITY OF WISCONSIN 1966

0 40 80
Miles



AREA OF STATE (acres)

Land	35,011,200
Water	1,136,920
Total	36,148,120

LAND USES

In farms	60%
In forest	36%
Rural roads	2.2%
Urban lands	1.1%
Rural community lands	0.7%

Cartography by Randall D. Sale and Jeanne T. Liu

MAJOR SOILS	MILLIONS OF ACRES	REGIONWIDE RATINGS* OF SOIL LIMITATIONS FOR: General Livestock Farming	Forestry	Urban development
A. Fayette, Dubuque	3.0	2	2	3
Ap. Tama, Dodgeville	0.8	1	4	1
B. Dodge, Casco, Morley	4.1	1	3	2
Bp. Waupun, Wea, Varna	0.6	1	4	1
C. Plainfield, Oshtemo	1.7	4**	2	2
Cp. Sparta, Gotham	0.5	3**	3	2
D. Hixton, Norden, Gale	3.1	3	2	3
E. Onaway, Emmet, Shawano	1.5	3	2	3
F. Withee, Santiago, Antigo	5.7	3	3	3
Fp. Jewett, Waukegan	0.1	1	3	1
G. Iron River, Kennan	6.3	4	1	3
H. Omega, Vilas	2.7	4**	1	2
I. Hibbing, Kewaunee	2.9	2	3	3
J. Elba, Poygan, Newton, Houghton, Arenzville	2.0	4**	3	4

*RATINGS ARE AVERAGES BY REGIONS. In each region there are many localities with soils of better and/or poorer ratings than that indicated.
1=slight limitation; 2=moderate; 3=severe; 4=very severe **Some areas are highly productive of vegetables, specialty crops and field corn with irrigation and/or drainage.

USES OF LAND ON FARMS
(21,400,000 acres)

Cropland	59%
Pasture	15%
Woodland	8%
Permanent Woodland & other	18%

USES OF CROPLAND
(12,250,000 acres)

Hay	33%
Corn	22%
Small grain	19%
Canning specialty crops	3%
Other crops	11%
Idle land	12%

Above data based on information from the Wisconsin Crop and Livestock Reporting Service.

For additional information on soils see your local County Agent, Soil Conservation Service Conservationist or write to: Soils Building, University of Wisconsin, Madison, 53706.

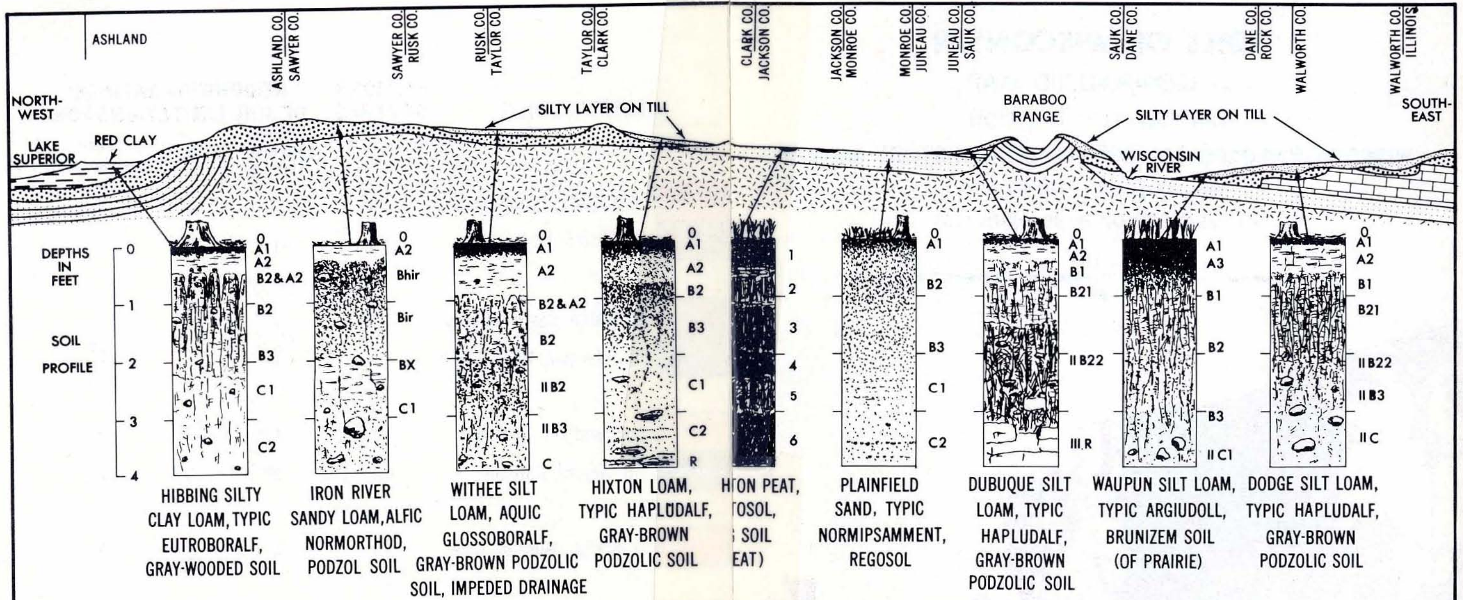


FIG. 2. TYPICAL SOIL PROFILES OF MAJOR SOIL REGIONS. DIAMMATIC NW-SE SECTION OF WISCONSIN (Vertical Scale 60 X Horizontal)

A. Silty, deep (Fayette) and more shallow (Dubuque) soils, over stony reddish-brown clay and limestone bedrock, are extensive on uplands. Very shallow and stony soils, largely in forest and pasture, occupy steep valley slopes. Silty soils similar to the upland soils are on foot-slopes and natural bench lands. Sandy soils (Dakota, Sparta) also occur on bench lands. Erosion control practices, such as contour strip cropping, are used widely. The soils of this region are productive of farm crops and offer great resources for recreation and wildlife habitat.

Ap. Black silt loams, deep (Tama) and more shallow (Dodgeville) over stony clay on limestone bedrock, occur on broad, gently rolling ridges. These soils have formed under prairie vegetation from wind-blown silt called "loess."

B. Dodge, McHenry and related soils have developed from loess and limey glacial tills of loamy texture. They are found in all but the eastern-most parts of this region. Shallow to moderately deep loamy (Casco) and stony (Rodman) soils of the hilly Kettle Moraine extend in an irregular belt from western Waukesha County to central Manitowoc County. Near Milwaukee and Kenosha are clayey soils (Morley, Blount) underlain by limey, clayey glacial till. These soils present drainage problems, particularly with respect to disposal of sewage effluent in suburban areas. Wet soils occur throughout the region.

Bp. Dark silt loams and loams (Wea, Warsaw) occur over glacial sand and gravel on the plain in Rock and Walworth Counties. On the till uplands of eastern Racine and Kenosha Counties are dark, clayey soils (Varna, Elliott). On rolling uplands of central and northern parts of the region dark silt loams (Waupun, Mendota) occur over loamy glacial till.

C. Droughty, light colored sandy soils (Plainfield, Oshtemo) and imperfectly drained soils (Morocco) have formed from level to rolling sandy glacial drift. Abundance of ground water allows substantial irrigation farming on nearly level outwash plains. Windbreaks are needed on cultivated fields to check wind erosion.

Cp. These dark sands (Sparta, Gotham), formed under prairie vegetation, are very similar in texture to soils in region C.

D. These soils developed from hard (Northfield) and soft (Boone) sandstones; from brown (Hixton) and green (Norden) siltstones and sandstones; and from a thin silty layer over sandstone (Gale). Slopes are gentle to steep, short and irregular. Water erosion is a serious hazard. Wet soils (Merrillan, Vesper) have formed from silty material and acid, shaley, impermeable sandstone in parts of Wood, Clark and Jackson Counties. Slopes are mostly gentle but some buttes occur. These wet soils have severe limitations for farming and road construction.

E. Rolling pink loams (Onaway), sandy loams (Emmet) and nearly level fine sands (Shawano) are underlain by limey glacial drift. Most soils of the Door peninsula are shallow to limestone bedrock. Many soils of the region are suited to dairy farming, others to forestry, specialty crops and recreation.

F. Somewhat poorly drained silt loams (Withee, Almena) over acid, compact, stony loam till are more extensive than well drained soils (Santiago) on the gently rolling plains. Intensive fertilization and drainage make these soils productive of forages and small grains. Poor drainage causes problems with roadbeds and sewage disposal. Well drained silty soils (Antigo, Stambaugh) are on less extensive plains of outwash sand and gravel, and, with Goodman soils, predominate in northeastern Wisconsin.

Fp. Dark silty soils on rolling glacial till (Jewett) and on nearly level outwash (Waukegan) have formed under a small prairie in northwestern Wisconsin, now used for farming.

G. On the glacial till upland of northern Wisconsin are acid, stony sandy loams and loams (Iron River, Kennan). Pence and Onamia sandy loams and loams occur on outwash plains. Irregular slopes, stoniness, droughtiness, wetness and short growing season limit use of soils in this region for farming.

H. Reddish-brown (Omega, Vilas) sands occur on nearly level, rolling and hilly terrain. They are droughty, acid, low in fertility and easily eroded by wind when bare. Most of the state's lakes occur in this soil region.

I. Near Lake Superior reddish-brown clayey soils (Hibbing and Ontonagon) occur on moraines and nearly level lake plains. The cool, moist growing season severely limits many kinds of farming. Similar soils (Kewaunee, Manawa) occur in eastern Wisconsin, where climate is more favorable for crops. These clayey soils are productive but require good management. Problems may arise in building roads and basements, and in disposal of septic tank effluent.

J. Wet or flooded mineral soils (Elba, Poygan, Newton, Arenzville), peat and muck (Houghton) occur in countless depressions over most of the state. The map shows only a few of the largest areas. Some of these soils are used for crop production, pasture and sod farming. Many others constitute the state's prime wetland wildlife habitats.

SOILS OF WISCONSIN

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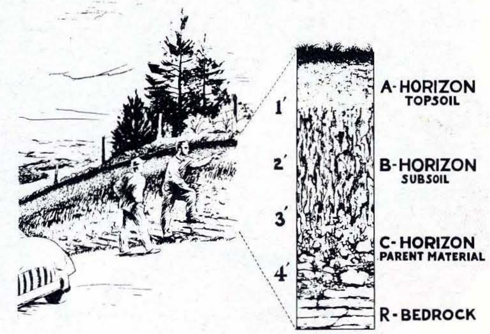
Wisconsin's 350 soils can be grouped into ten general regions, with four additional subregions of predominantly prairie soils. As you travel across the state the regions appear as distinctly different landscapes. Differences in land form and land use between regions are related to characteristics of the soils.



A SOIL PROFILE

Figure 1.

In many bare road cuts we see soils exposed to a depth of several feet. Such exposures (Fig. 1) reveal the vertical cross-sections or "profiles" of soils comprised of horizons (layers) of topsoil, subsoil and underlying materials. Figure 2 gives profile sketches of some typical soils of the state.

Soils are named after geographic features, such as towns and streams. Waupun silt loam, for instance, was first described near Waupun, Wisconsin. Soil names may change from time to time as soil scientists learn more about the soils. The legend of this map identifies each soil region by the names of several major soils. Many other soils are present.

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