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Permeability, effects of age, and water table fluctuations were studied for nine drainfields in five soil types ranging from well to poorly drained. Three sites were in Willamette, one in Woodburn, two in Amity, two in Concord, and one in Dayton soils. Before permeability of drainfields could be evaluated, methods of determining it were tested. After comparing the Public Health Service (PHS) test and the double tube method, the latter proved to be the more reliable. PHS test results were influenced greatly by sediment that eroded off sidewalls during testing. Double tube tests were variable, but nearly all variation was due to entrapped air and/or the heterogeneous nature of soil. When the double tube method was run in soil adjacent to the nine drainfields, infiltration rates from the inner tube correlated better with performance than hydraulic conductivity.

Detailed observations were made to correlate movement of

effluent in the drainfields with infiltration data. Infiltration rates for the B2t horizon of Willamette soils averaged 74.5 ml/min. Effluent moved mostly vertically from trenches in three drainfields located in Willamette soils. Infiltration rates averaged 9.6 ml/min. at the top of the Woodburn B2t horizon. In Woodburn and Amity (A1) drainfields effluent moved laterally through a porous B1 or A2 horizon and slowly percolated through the B2t horizon. Infiltration rates determined in the middle of the B2t horizons of Amity (A2) and Concord (C1) indicated that these soils should have conducted effluent faster than Woodburn. Such was not the case. Effluent leaving trenches in A2 and C1 drainfields spread laterally through porous subsurface A2 horizons with very little, if any, moving through the subjacent B2t horizons. These observations suggest that the tops of B2t horizons in Amity (A2) and Concord (C1) were less permeable than the middle where infiltration rates were determined.

The very slow infiltration rates obtained for Concord (C2) and Dayton soils were in agreement with the direction effluent moved. Nearly all of the effluent traveled on top of the B2t horizon, which is the way Amity (A2) and Concord (C1) drainfields performed.

Length of time drainfields had been in operation had two noticeable effects. One, the area of intensely mottled soil around drainfield trenches increased with time. Two, the area of high moisture around trenches increased except for Concord and Dayton soils, which are strongly influenced by impermeable clayey B2t horizons. From field observations and thin sections, the clogging material causing drainfields to deteriorate with time appears to be colloidal ferrous iron compounds.

Concentration of coliform microorganisms was used to evaluate the effect of high water tables in drainfields. Coliform densities showed that the area influenced by Amity (A2) drainfield, which is on a nearly level position, increased from 150 sq. meters to 15,000 sq. meters in the winter when the water table remained near the surface for several months. Also it was found that caution is needed in interpreting coliform data when domestic livestock is near (within 0.6 kilometers) of sampling point. Coliform counts in ground water influenced by domestic livestock were the same order of magnitude as those found 5-6 meters away from drainfields.

Septic-Tank Drainfield Performance in Five Willamette Valley Soils

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INTRODUCTION

Growth within, and movement to urban centers has placed a high demand on housing. Rather than expanding vertically, most metropolitan areas have spread beyond the limits of municiple sewer lines. As a means of disposing of domestic wastes, home builders and health officers have relied heavily on soil to absorb and, hopefully, purify effluent from septic-tanks. Agencies regulating septic-tank installations have long been aware that soil properties do differ and that one kind of soil is better suited for drainfields than another.

For the most part, results of a percolation test or a cursory inspection of soil by a sanitary officer have been the main criteria for judging suitability. In the last twenty years, and especially in the last decade, health officers have turned to soil maps and soil information for predicting drainfield performance. Soil surveyors have ranked soil mapping units for this non-agricultural use of soils by drawing on experience gained from farm drainage problems and by evaluating physical soil properties. Research on soil behavior under the influence of a nutritionally rich and complex liquid, such as effluent, has been carried out under laboratory conditions and usually by people other than those interpreting soil maps (McGauhey and Winneberger, 1964; Mitchell and Nevo, 1964).

Performance of a drainfield is dependent upon soil permeability, depth to water table, slope gradient, depth to bedrock, amount and type of effluent, construction practices, and length of time in service. This study used nine drainfields in five soils to evaluate effects of permeability, age, and water table on performance. As nearly as possible, the other factors were kept constant. All systems occurred in very deep silty or clayey soils on nearly level slopes.

In order to evaluate the influence permeability had on drainfield performance, a reliable method of determining permeability had to first be found. The recommended method by the U. S Public Health Service (PHS) has some severe limitations which have already been enumerated (Bendixen, 1962; Morris _et al._, 1962). From a search of the literature, a test described by Bouwer (1962) was thought to be a possible alternative method. After testing these two methods side by side, Bouwer's method proved to be the more reliable test. This method was then used to determine permeability of soil adjacent to the drainfield.

Septic-tank systems generally show a gradual degradation with increasing age. To study effect of age on drainfields, newer and older systems were located in similar soils. Detailed examinations were made of the morphological changes taking place in soil comprising drainfields. The relative change occurring in similar soils was used to evaluate the influence of time.

Water table fluctuations were a third factor considered in relation to drainfield performance. Western Oregon's pronounced wet-dry climate makes this contrast between winter and summer soil conditions particularly striking. Steady low intensity rainfall during winter months causes a steep rise in water tables. In nearly all soils forming in the Willamette Silts (Allison, 1953), water tables are at or near the surface for some period of the winter (Boersma and Simonson, 1969). To illustrate how water tables effect performance, summer and winter levels were measured in and away from drainfields. In conjunction with winter measurements, density of coliform microorganisms was used to detect movement of effluent in ground water.

The major objectives of this thesis were to describe and evaluate the effects permeability, time, and water table height have on drainfield performance in five different soils in the Willamette Valley.

Studies of permeability, water table, and age are treated as separate sections. For each topic, a brief review of pertinent literature, methods used to evaluate its effect, study results, and a summary are presented. After separate discussion of these three factors of drainfield performance, the results from each section are summarized and related to each other in the conclusion.

I. PERMEABILITY AND ITS EFFECTS ON DRAINFIELD PERFORMANCE

Before the effect of permeability on drainfield performance could be evaluated, a reliable method of determining permeability had to be found. Two methods, the Public Health Service test and Bouwer's double tube (Bouwer, 1962), were tested on five morphologically different soils; Bashaw clay, Dayton silt loam, Nekia clay loam, Newberg sandy loam, and Willamette silt loam. After comparing methods, the double tube appeared to be the more reliable.

To test the hypothesis that permeability does affect drainfield performance, nine drainfields in soils that ranged from permeable to impermeable were studied. Performance of these drainfields was determined in the summer by examining them in detail and collecting pertinent information from respective home owners. When drainfields had all been described, the double tube method was run in soil adjacent to each drainfield.

Literature Review

After 1887, when the septic-tank was introduced in this country, the importance of the leaching field's permeability became apparent. Slowly permeable soils did not absorb effluent rapidly enough, and highly permeable ones allowed contamination of ground water. As early as 1903 (Alvord), builders of summer cottages were advised to use only soils of a "porous nature" for drainfields. Reports of attempts to prevent ground water contamination began to appear around 1960. Robech *et al.* (1964) recommended that at least three meters of soil should be maintained between maximum elevation of water table and tile lines in coarse textured soils.

Extremes in permeability of soils have always been easy to distinguish. Assessing permeability between low and high values is, however, somewhat more difficult. Ryon, in 1928 (Olson, 1964), is usually credited with being the first sanitary engineer to try. He dug a square (30 x 30 cm) hole, 50 cm deep, saturated it with water, adjusted water level to 16 cm above the bottom, and recorded the time required for the water level to drop two and one half cm. From loading rates, performance, and percolation rates of 50 systems, percolation vs. loading rates were plotted to indicate a "safe" absorption area. Later examinations of the test showed that infiltration rates were influenced by length of time for which holes were soaked, but not by the diameter of holes (Bendixen *et al.*, 1950). By prescribing a longer soaking time, using a 10 to 15 cm diameter test hole and several minor changes, Ryon's method became the Public Health Service's percolation test (U. S. Public Health Service, 1967). Because the test is extremely simple to conduct, and very little equipment is needed, it has received wide acceptance.

Many investigators have criticized the PHS test as a sole means to determine septic-tank suitability. Some ten years after helping modify Ryon's test, Bendixen (1962) pointed out three major disadvantages: 1) variability of replicate tests is high; 2) intermittent high water tables are not accounted for; and 3) in some cases there is a poor correlation between adequate percolation rates and drainfield performance. Other reports (Morris et al., 1962; Hill, 1966; Cain and Betty, 1965; Mokano, 1968) add to the list of disadvantages that, 4) results are not reliable if water table fluctuates, or 5) if determined in dry soil.

None of the disadvantages listed are unique to the PHS test. Many investigators from different professions have experienced disappointment in trying to quantitatively assess water movement into and through soil. From studies on the effects of time, three phases of infiltration have been described: 1) an initial decrease due to swelling and dispersion of aggregates; 2) an increase as entrapped air is removed; and 3) a long gradual decrease caused by microbial growth clogging pores (Doering, [1965]). To further increase variability, soil is a heterogeneous mixture of pore sizes. Variations in permeability are also related to other factors such as condition of soil-water interface, position of water table, design of equipment, and skill of operator (Reeve et al., 1957).

In 1952, Fedrich suggested using soil maps and physical data in connection with infiltration tests as a way of extrapolating and interpreting results. Since then, many others (Olson, 1964; Clayton, 1959; Bartelli, 1962; Coulter et al., 1960; Obenshain, 1962) have used soil maps and information to assist in evaluating soil permeability. Morris et al. (1962) proposed that soil maps can substitute for percolation tests if mapping units are adequately correlated with drainfield performance and infiltration rates.

There is an apparent need for a way to determine permeability that is more reliable than the PHS test, not only for on-site inspections (Bendixen, 1962), but also to characterize soil mapping units. The literature was searched in hope of finding such a test. Methods were judged as to whether they could be conducted in situ below the surface and without a water table.

Parr and Bertrand (1960), Reeve et al. (1957), Golder and Gass (1962), and Black et al. (1965) list most of the methods which have been developed. Most of the field methods described by Parr and Bertrand are not designed for below the surface measurements. Those listed by Golder and Gass either require a water table or do not use a "natural" soil-water interface. Three methods which meet the criteria are described by Boersma (1965). The shallow well pump-in test is very similar to the PHS test, except that a constant head is maintained. Like the PHS method, an undisturbed soil-water interface on the bottom and sides is difficult to achieve when a small diameter (10-15 cm) hole 90 cm deep is used. Values obtained by this method were lower than those obtained by pumping water out of the same size hole when a water table was present.

A second method, called a permeameter test, is conducted by digging a hole one meter in diameter and pressing into the bottom a cylindrical sleeve, half the diameter of the hole. Tensiometers are placed a short distance away from the sleeve, a few centimeters into the soil to indicate when saturation has been achieved. The main disadvantages of this test are: 1) positive pressures can develop when downward water movement from the sleeve is impeded by a water table or slowly permeable horizon, 2) it cannot be used in coarse textured horizons, and 3) a great deal of time is required to prepare a test hole.

A third method, developed by Bouwer (1961), uses a hole excavated with a post-hole auger. An undisturbed soil surface is exposed by using a specially designed hole cleaner. Two tubes, one 10 cm in diameter and the other 20 cm, are placed concentrically in the hole and connected to standpipes from which water levels are read. This method cannot be used in rocky or gravelly horizones. It is designed to give a dimensionless hydraulic conductivity which is calaulated from flow that occurs between the outer and inner tubes. Since soil is anisotropic, flow rates will reflect the most restrictive hydraulic conductivity. A test hole can be prepared quickly, and through the use of a specially designed piece of equipment (Figure 1),

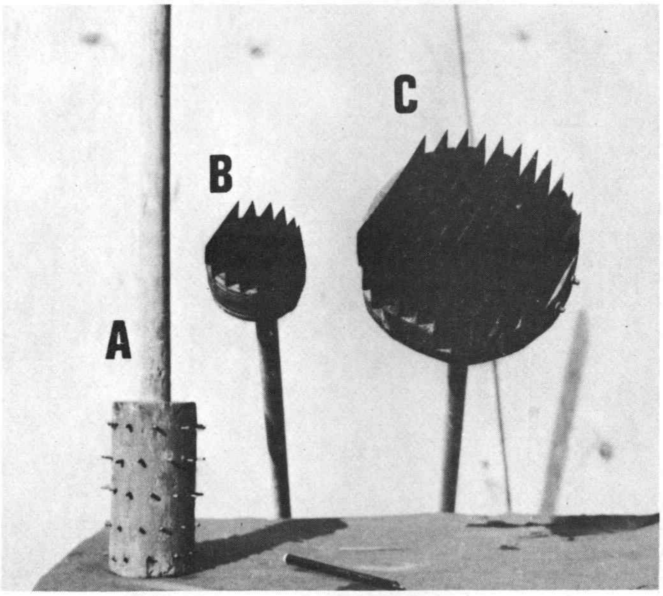

Figure 1. Hole cleaner A and B were used to scarify PHS test holes. By pushing hole cleaner A into a test hole, smeared surfaces resulting from an auger were removed. Hole cleaner B was driven a few centimeters into the bottom of test holes to remove loose soil and any smeared surfaces. Hole cleaner C was used for the same purpose as B on double tube test holes. Design of hole cleaners B and C was after Bouwer (1962).

an undisturbed soil surface can be achieved (Boersma, 1965).

Testing Methods of Determining Permeability

Materials and Methods

Bouwer's double tube method (Bouwer, 1962) and the standard Public Health Service (PHS) test (Public Health Service, 1967) were run side by side on five morphologically different soils: Bashaw, Dayton, Nekia, Newberg, and Willamette. Detailed descriptions of the soils and their location appears in the Appendix.

Because there are several ways of interpreting the procedure for PHS tests, two ways of conducting the test were used. One way, called Intermittently Soaked in this report, followed as closely as possible the procedure outlined in the PHS manual (U. S. Public Health Service, 1967). The other, called Continuously Soaked, consisted of modifying the soaking period before testing and designing a sleeve to prevent erosion of side walls. Instead of intermittent soaking recommended in the manual, a 30 cm head of water was maintained for 24 hours before testing. It was also noticed that side walls of PHS test holes erode. To reduce this erosion and consequent plugging of pores by sedimentation, a 10 cm diameter sleeve with a burlap-lined cavity at the bottom was installed.

In both procedures for PHS tests, bottoms and side walls were prepared in a same manner. Equipment (shown in Figure 1) was used to remove smeared surfaces and loose soil.

Early stages of field testing the double tube method showed that several modifications had to be made. In all soils studied, only dead weight could be used to install the inner tube. Very light taps from a hammer would break the soil seal around the bottom of the inner tube (see Figure 2). Much difficulty was experienced in testing the sandy Newberg soil. Slight vibration while the test was in progress would trigger "blow-outs". On one occasion, a stake was being driven in the surface of the soil a few meters away from the test hole while a test was in progress. At the same time, a small gradient between tubes existed. After several sharp taps on the stake with a hammer, large cavities around the inner tube were created when the seal was broken. To prevent blow-outs in Newberg, penetration of the inner tube was increased from 2 cm to 6 cm.

When an area beneath a test hole is sufficiently saturated, hydraulic conductivities are expected to be consistent. The technique proposed by Bouwer probably did indicate when soil was saturated, but it did not assure that a constant K value would result. Proof of this is seen in a plot, Figure 3, of K values for supposedly saturated soil. Hydraulic conductivities of Newberg determined at 4, 6, and 30 hours of soaking were definitely affected by the length of soaking period even though Bouwer's technique indicated constant K values

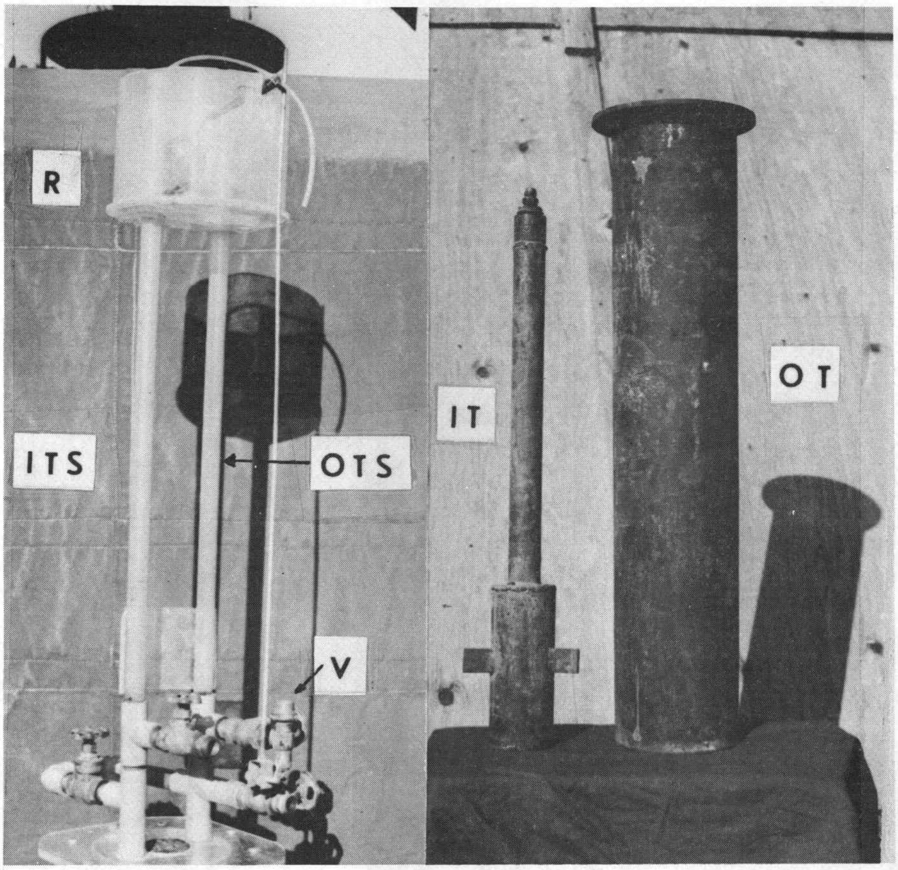

Figure 2. After a hole has been made in the soil, a hole cleaner shown in Figure 1) was used to prepare an "undisturbed" surface. An outer tube (OT) was inserted and pressed several centimeters into the bottom of a hole. An inner tube (IT) was placed inside OT and also pressed several centimeters into the soil, but only dead weight was used. A standpipe assembly, shown on the left, was held above the tubes while one of the standpipes (ITS) was connected via flexible tubing to the inner tube. Then the standpipe assembly was secured to the outer tube. Both the outer and inner tube standpipes were maintained at a constant level by using a reservoir (R), float, and valve (V).

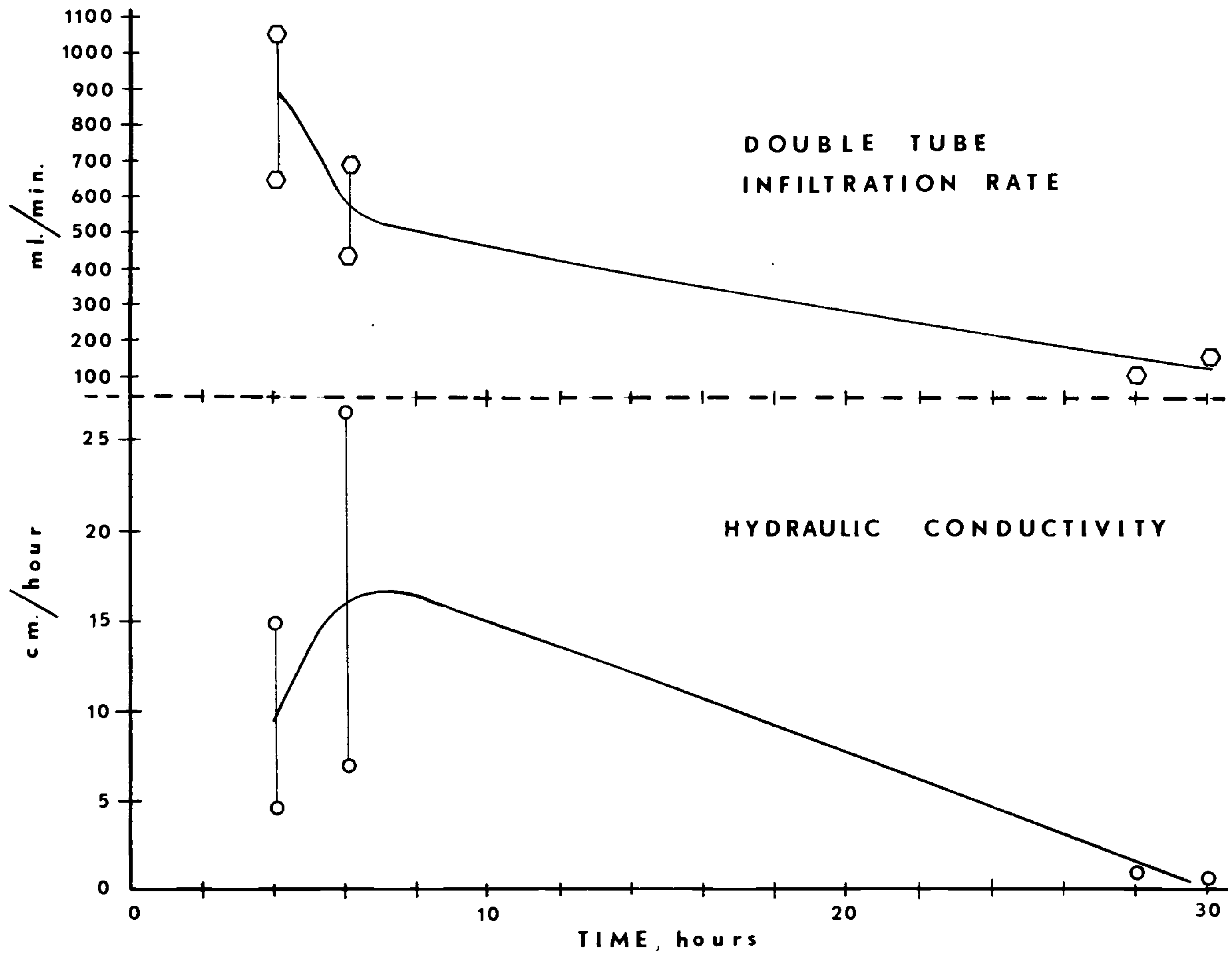

Figure 3. Hydraulic conductivity and double tube infiltration for Newbery sandy loam are a function of time. Each curve is an average of two determinations. Hydraulic conductivity was calculated from results that would supposedly give constant K regardless of soaking time.

were achieved. Tests on Willamette soil showed similar results, but were not as striking as those presented for Newberg soil.

In order to measure the amount of seepage that occurs between the inner and outer tubes of Bouwer's method, the outer tube is kept full of water while the water in the inner tube is allowed to fall (OTS Full). This fall is measured in min. and is plotted against time since testing began. A second curve is plotted on the same coordinates. The second curve is made from minutes it takes the inner tube to fall when the water level in the outer tube is allowed to fall at a rate equal to the inner tube (OTS Falling). Therefore, the vertical distance between the two time curves (OTS Full and OTS Falling) is proportional to the hydraulic conductivity. In Figure 4, a plotting of OTS Full and OTS Falling shows that entrapped air greatly reduced infiltration rates and changed K values. When the water supply was being replenished for a Willamette soil test, the hole emptied and air evidently became entrapped either in the equipment or the soil when testing was resumed.

After observing that length of soaking time and presence of entrapped air affected double tube measurements, all double tube holes were continuously soaked for 24 hours. By using a float, valve, and two water supplies, standpipes were kept full (see Figure 2). After soaking, four to six hours of testing were necessary to get consistent results. Infiltration time of OTS Full and OTS Falling were plotted to visually estimate stable readings.

In addition to calculating dimensionless hydraulic conductivity

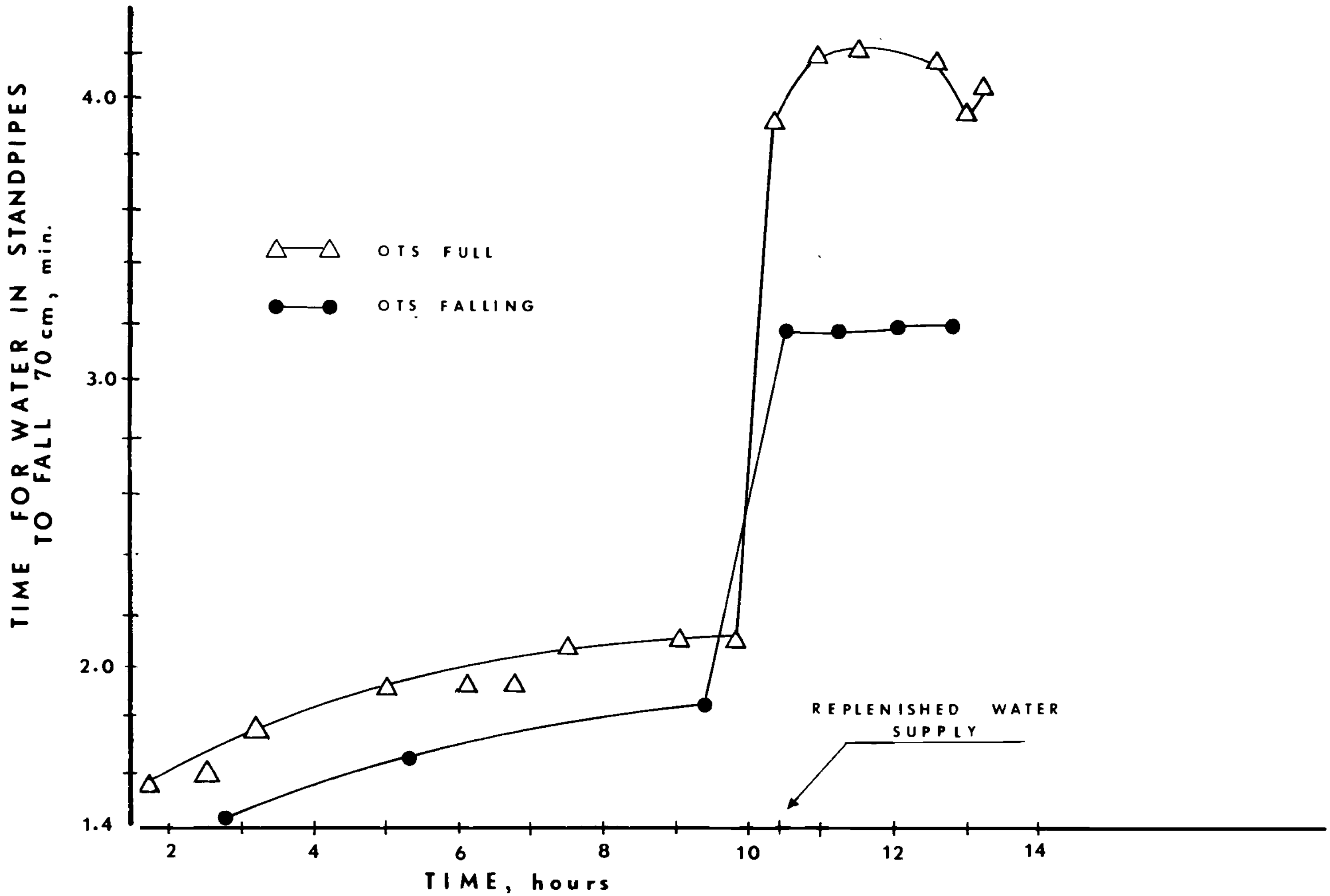

Figure 4. When the water supply was replenished, infiltration was reduced and hydraulic conductivity changed. Most likely this was due to air becoming entrapped either in the soil or the equipment. Triangles represent time for the water level in the inner tube to fall against a gradient and dots show the time required for the inner tube to fall without a gradient. These data, collected in July, 1968, are for a Willamette soil.

according to Bouwer and Rice (1964), infiltration rates from the inner tube (IT) were determined using the following equation:

$$q = AV,$$

where,

q = quantity of water passing a given cross-sectioned area per unit of time, ml/min.

A = cross sectional area of standpipe (ITS, cm^2)

V = velocity of water falling in standpipe, cm/min.

Hydraulic conductivity and infiltration rate from the inner tube were determined from the same set of data.

Water for test holes requiring continuous soaking was supplied from tanks holding 650 gallons. In the case of Willamette, Nekia, and Newberg soils, more than 650 gallons had to be supplied.

Results and Discussion

Comparison of methods is somewhat difficult since only two of the four methods measure the same property of soil. Double tube data yields dimensionless hydraulic conductivity and vertical infiltration rates while PHS test results are a combination of vertical and horizontal infiltration. Rather than compare absolute values, the order of magnitude of difference between results for various soils, relative ranking of soils, and range of values were used to judge methods.

Ranking of soils (Figure 5) by the intermittently soaked PHS test is significantly different from ranking by the other two methods of measuring infiltration. The most obvious disparity is in the positions of Willamette and Dayton B31 soil. They gave slower rates under the intermittent test than the clay B2t horizon of Dayton soil. One possible explanation could be the amount of sediment that accumulated in the bottom of intermittent test holes. Table 1 shows that sedimentation was roughly ten times greater in an intermittent test than a continuously soaked test where a sleeve and burlap liner were used. Sediment build-ups were the highest for Willamette, Dayton, and Nekia soils. Sediment in test holes in Willamette and Dayton soils were thick and compact. Nekia test holes also had thick accumulations, but infiltration rates were not seriously affected when compared to continuously soaked tests. Material in the bottom of Nekia test holes was made up of strong, medium (0.5-1 mm) granular aggregates. Dayton test holes had the same average thickness of sediment as Nekia, but infiltration was reduced by 50 percent. Accumulations of easily dispersed material with subsequent clogging of pores (Figure 6) plus variables described by Bendixen (1962), Cain (1950), and Mokoma (1966) could explain not only why ranking was different, but also the wide range in results. Franzmeier _et al._[1] found that if

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[1] Unpublished laboratory report, Soil Conservation Service Laboratory, Beltsville, Maryland (1964).

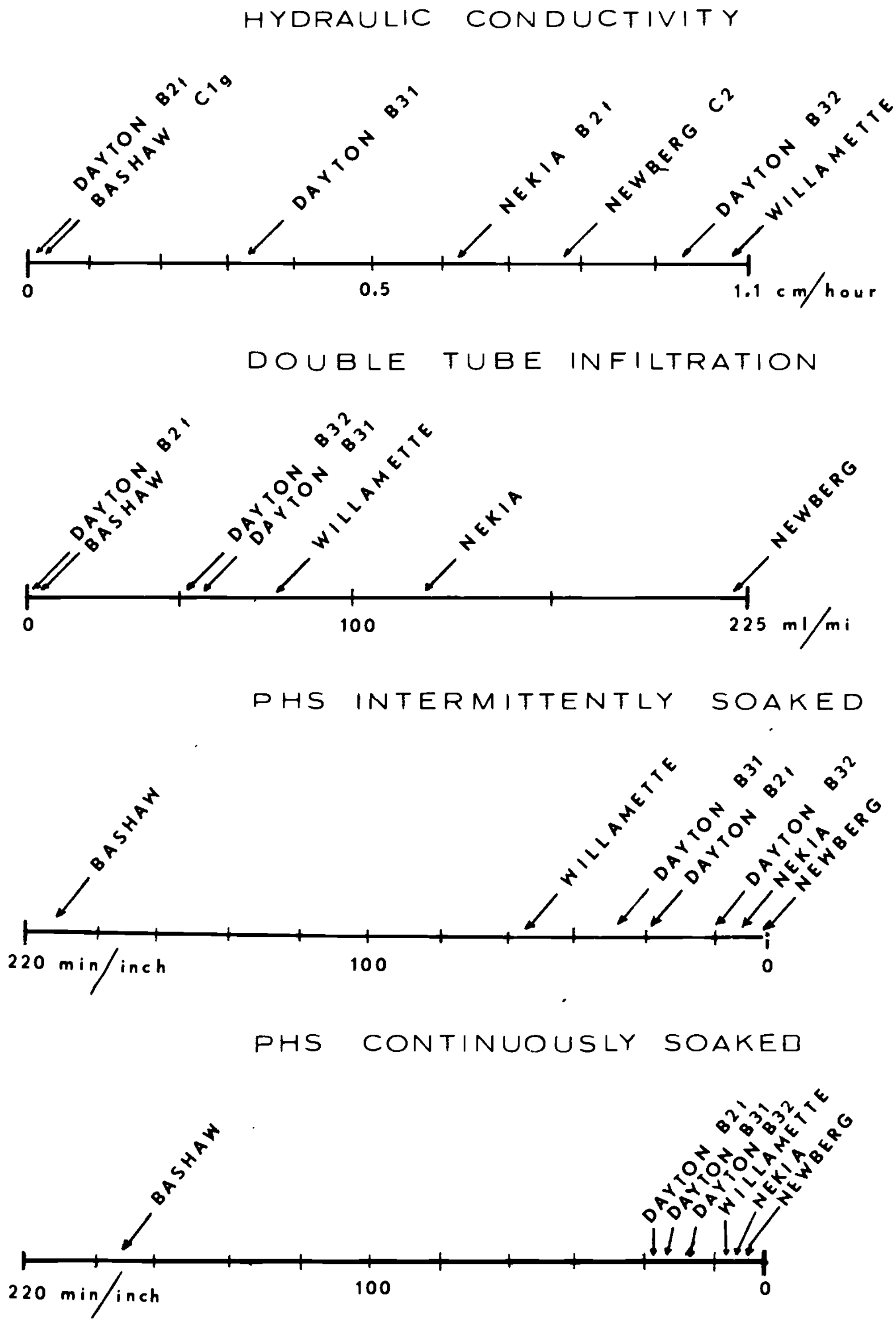

Figure 5. Ranking soil permeability by four methods. Notice that the two PHS results are expressed in the same units; but hydraulic conductivity and infiltration rates are in different units.

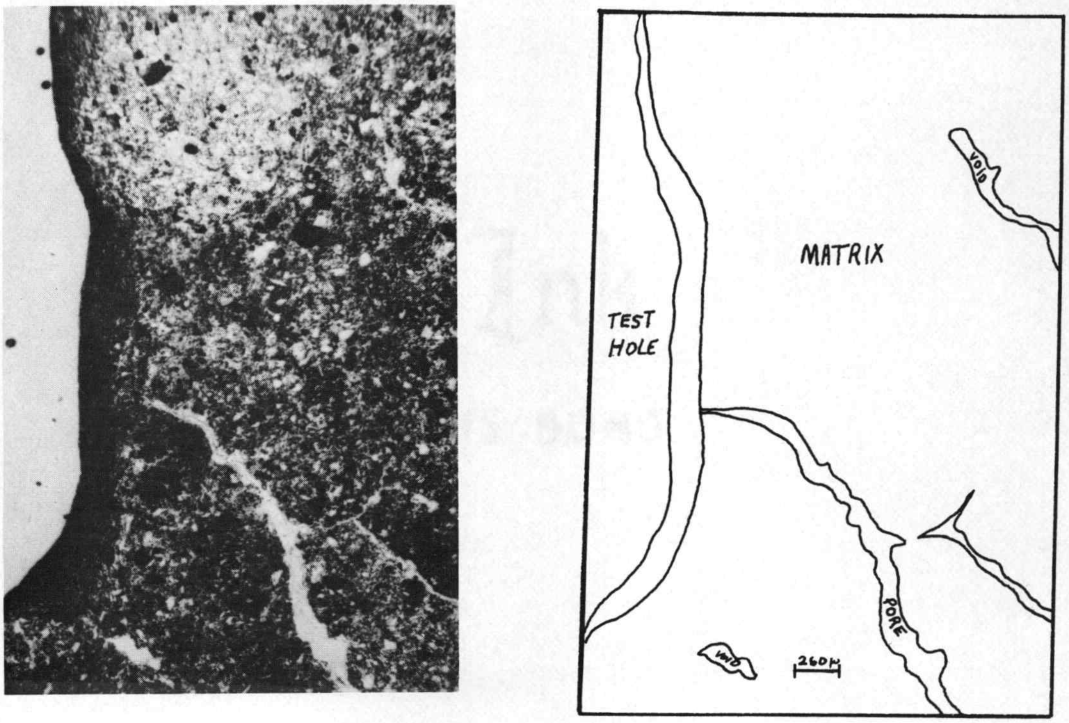

Figure 6. Photomicrograph of a horizontal section of a test hole in Willamette soil showing a dark coating which has blocked a large pore.

Table 1. Comparison of sediment-thickness in PHS test hole with sleeve and burlap and without sleeve and burlap. These data were taken from tests conducted during summer, 1968. *

Bashaw		Dayton		Nekia		Newberg		Willamette	
without sleeve or burlap	with sleeve and burlap	without sleeve or burlap	with sleeve and burlap	without sleeve or burlap	with sleeve and burlap	without sleeve or burlap	with sleeve and burlap	without sleeve or burlap	with sleeve and burlap
6.5	0	10.0	3.5	15.0	7.0	1.5	0	17.0	3.0
6.5		16.0	0.5	6.0	0	2.0	0	18.0	5.5
		5.0	0	3.5	0			14.0	0
		0.5	0	10.0				12.7	
		12.0		25.5				11.4	
		16.5		8.0				20.3	
				9.0				17.0	
				6.5				18.0	
								16.0	
				Mean					
6.5	0	10.0	1.0	10.7	2.3	1.7	0	16.0	2.8

*Measurements in cm.

sidewalls were scarified after testing and then another test was made using the same hole some results were 25 times greater than initial rates.

With the continuously soaked PHS test, variation in results was reduced. This can be seen in the faster rates for the Dayton B31 and Willamette soil. This technique ranked soils closer together than, but similar to, infiltration rates from the double tube test. The position of the Dayton B2t appears to be very much out of line. Values closer to that of Bashaw soil would be expected.

With regard to double tube data, unsmeared surfaces, which broke mostly along natural cleavages, were easily obtained using a specially designed hole cleaner. As Bouwer (1962) points out, the success of the double tube method rests on the effectiveness of this piece of equipment. Examination of soil surfaces inside the inner tube after testing Dayton, Nekia, and Willamette revealed that very little plugging of pores had occurred. Evidently a layer of coarse sand four centimeters thick was adequate to prevent such damage.

K values of some soils are different than would be expected from observations on structure and pore distribution. Newberg is loamy sand in the C horizon with single grain structure and many more medium and large pores than all the other soils tested. One would expect Newberg soil to have a much higher K value than Willamette soil. As Table 2 shows, the average K value for Newberg

Table 2. Comparison of double tube hydraulic conductivity, double tube infiltration, and PHS test infiltration rates. All averages, unless otherwise noted, are based on six tests.

Soil	Double Tube				PHS Test			
horizon and depth	average K (cm/hr)	range	average infiltration from inner tube (ml/min)	range (ml/min)	average infiltration rate after intermittent soaking (min/in)	range (min/in)	average infiltration after continuous soaking (min/in)	range (min/in)
Bashaw 85 cm C1g	.09	0-.34	.25	0-.76	204	24-300	192*	84-300
Dayton								
57 cm B21t	0	0	0	0	45*	40-51	34*	29-40
85-90-B31	.34	0-.81	52.3	25.2-109.0	55	8-300	30	14-59
102-110-B32	.94*	0.19-1.70	49.9*	32.0- 52.9	8	4-11	26	24-30
Nekia 78-83-B2t	.63	.43-.84	119.9	59.6-219.2	6	1-13	6	4-11
Newberg 87 cm-C2	.78	.55-1.02	223	209-237	2	0.5-6	2	2.0-2.3
Willamette 90cm-B2tb	1.07	0.29-1.87	78.1	25.8-152.0	75	1-244	6	1-11

*Based on duplicates.

is lower than Willamette, and close to Nekia soil. One possible reason is suggested in Figure 2. Following a sharp rise at six hours of soaking, which could be attributed to the release of entrapped air, there is a long decline in K value. The short time of testing (30 hours) suggests that microerosion within pores rather than large growths of microorganisms might be causing the decline in K values for Newberg.

K values for the other soils seem to agree with morphology of the respective horizons. Nekia and Willamette soils both have well expressed structures. Nekia soil has predominantly smaller structural units and finer pores, but about the same total porosity as Willamette soil. The dense clay horizons of Bashaw and the Dayton soil were impermeable.

Still another ranking of soils was obtained from the average infiltration rates of double tube data. The relativity rate of Newberg is more in accordance with pore sizes found in the C horizon, than it was when K was the indexing test. Nekia and Willamette soils were reversed in position when compared to K values. This may mean that Nekia soil has more vertical pores than Willamette soil relative to horizontal ones. The B31 and B32 horizons of Dayton had nearly the same average infiltration rates but different K values. The B31 horizon could have about the same number of vertical pores as the B32.

Regardless of method, variation between duplicate tests for the same soil was high. The highest variability occurred using intermittently soaked PHS tests. Because the chances of clogging pores due to smearing and dislodged soil material was greatly reduced, the double tube method was superior to the PHS test. The variability of the double tube test was due largely to natural soil variation and entrapped air.

Drainfield Performance Versus Permeability

By relating four ways of indexing soil permeability to each other, to soil characteristics, and by noting sediment build up in PHS tests, the double tube method was selected as the most reliable to run near septic-tank drainfields. The objectives were to see whether the test values could be correlated with performance of the drainfield and to see which measurement, K or infiltration rate, was most meaningful.

Materials and Methods

Drainfields were selected according to the position they occupied in the drainage sequence of soils developing in the Willamette Silts (Allison, 1953). Selection of drainfields was also based on distance from other systems, age, demands placed on system, and quality of installation. Home owners of potential systems were asked number and age of occupants, whether water from dishwasher, washing machine, and/or water softener passed through septic-tank, age of system, name of installer, past history, size of tank, and whether a food grinder was used. Pertinent information for each system as shown in Table 3. The age of systems and soil series were variables studied and the remaining parameters were, as nearly as possible, kept constant. Only systems less than ten years old were investigated.

From 21 systems investigated, nine were chosen to represent the range of soils developing in the Willamette Silts near Corvallis. Descriptions of the soils appear in the Appendix and their location is shown on the map. Three drainfields were in Willamette (W1, W2, W3), one in Woodburn (WO), two in Amity (A1, A2), and two in Concord (C1, C2), and one in Dayton (D) series. The Willamette series consists of well drained, very deep soils that have a very dark brown[2], friable, silt loam A horizon and a dark brown, firm, well developed, silty clay loam B horizon. Below the subsoil is dark yellowish brown, massive, silt loam. The Woodburn series is moderately well drained, very deep soils that look very similar to Willamette soils except for mottles which start at 40 cm. and a slight brittleness in the B horizon. The Amity series consists of somewhat poorly drained, very deep soils that have a very dark grayish brown, silt loam Ap or A1 horizon, a dark gray, very porous, silt loam A2 horizon, and a grayish brown, well developed,

[2]Colors are for moist soils.

Table 3. Pertinent data on drainfields studied.

Symbol	Soil	Age of system	Water softener	Food disp.	Auto. washer	Dish washer	No. of occup.	Age of children	Size of septic tank	Distance from other systems
W1	Willamette	1	none	none	yes	yes	6	7, 8, 9, 12	2500 liters	90 meters
W2	Willamette	1	none	yes	yes	yes	2		2500	90
W3	Willamette	4	none	none	yes	yes	6	6, 9, 11, 13	2250	180
WO	Woodburn	3	none	none	yes	none	4	13, 17	2500	900
A1	Amity	1	none	yes	yes	yes	5	3, 5, 8	3500	60
A2	Amity	3	none	none	yes	none	5	8, 12, 14	2750	30
C1	Concord	3	none	none	yes	none	4	14, 17	2500	22
C2	Concord	6	none	yes	yes	yes	5	10, 15, 17	2500	15
D	Dayton	1	none	none	yes	none	6	5, 7, 9, 10	2500	15

mottled, silty clay loam B horizon. Massive, olive brown silt loam begins at depths greater than 90 cm. The Concord series includes poorly drained, very deep soils that have Ap or A1 thinner and lighter in color than Amity Ap or A1 horizon. The A2 horizon of Concord is similar to the one found in Amity soils. The B horizon in Concord soils consists of a grayish brown silty clay over dark grayish brown, silty clay loam. Massive, olive brown silt loam begins near 90 cm. The Dayton series consists of poorly drained, very deep soils that have a gray silt loam Ap horizon and a dark grayish brown, very porous silt loam A2 horizon. Below the A2 horizon is a dark gray, massive, clay or silty clay B horizon. Massive, olive brown silt loam underlay the B horizons. The relationships of horizons in the five series are shown in Figure 7. Also, Figure 7 indicates the relative position of each drainfield site on a hypothetical soil continuum.

Detailed diagrams of the nine drainfields were made by making transects perpendicular to trenches, with sample points at 0, 20, 50, 100, 200, and 300 cm away from each trench. On the diagrams (Figures 8-10, 12, 14 15, 17, 19, 20), sampling sites are shown as dots. A transect with less frequent borings was made parallel to trenches. A 2.5 cm diameter push tube 200 cm long was used to make borings. Depth to and thickness of intensely mottled soil, position of tile line with respect to soil horizons, and obvious changes in moisture

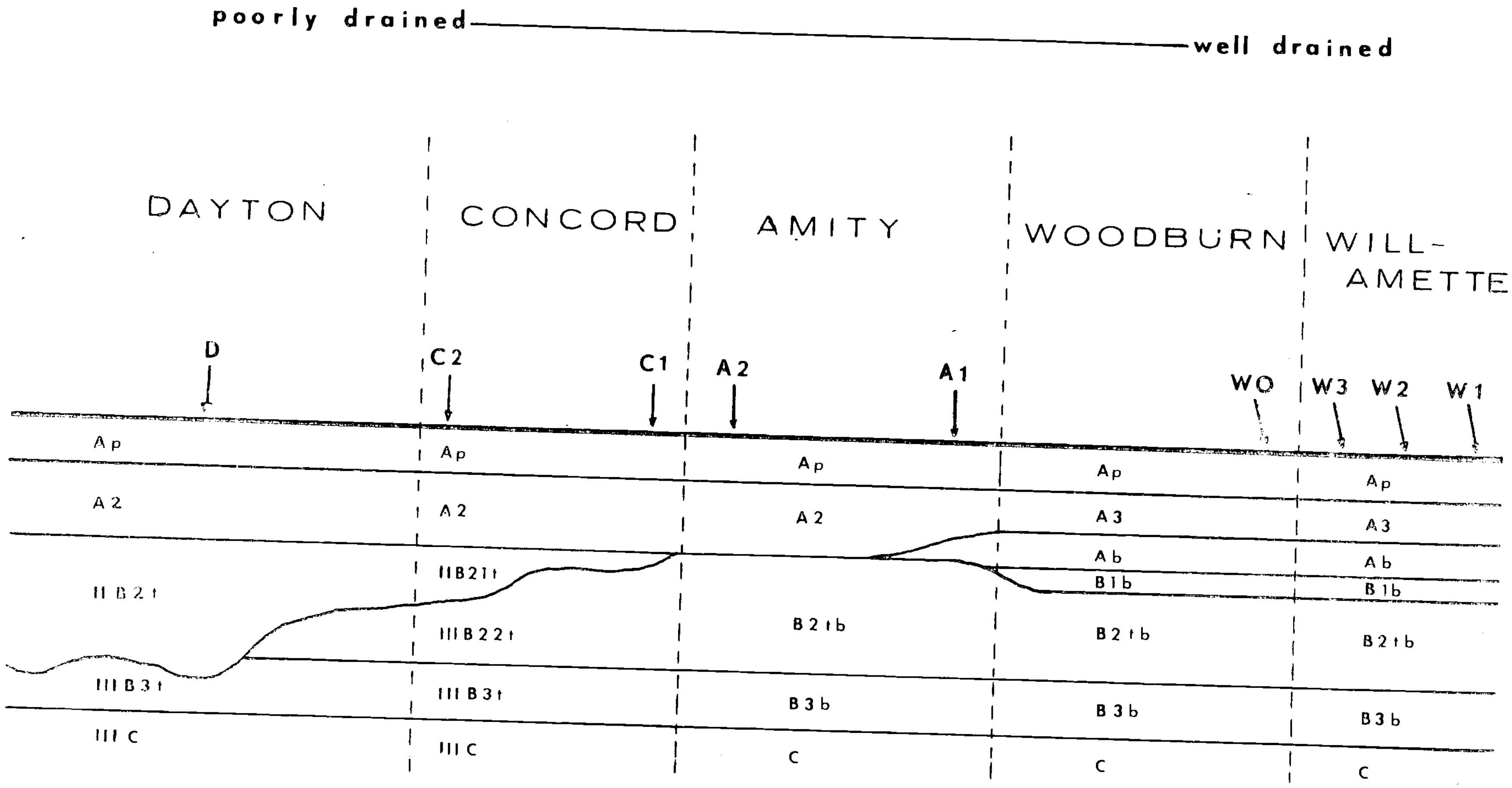

Figure 7. Relationship of horizons of five soil series which are used to classify soils developing in the Willamette Silts near Corvallis. Identifying symbols for drainfield sites, e.g., W1, W2, etc. are placed in the appropriate series.

were recorded on grid paper. From these measurements, two features were delineated on diagrams of drainfields. One separated areas of high moisture which were considered to be the maximum lateral extent of effluent. The other feature shown in the part of drainfields that have noticeably more reduced mottles than soil surrounding drainfields.

Loading rates were determined by dividing average water use per day by the total length of tile line. Water use was estimated by comparing families using septic-tanks to families of the same size and composition having city water service. City water records for November, December, and January were used to determine a daily average.

Results and Discussion

Detailed diagrams of drainfields (Figures 8-10, 12, 14, 15, 17, 19, 20), morphology of soils near trenches and loading rate were used as a basis for judging performance of drainfields. Descriptions given in the following pages for soil five meters away from the influence of effluent and soil near (20 cm) trenches represent the most frequently encountered profiles. Morphological details of profiles are discussed and related to permeability tests and visual evidence of drainfield performance. Observations were made in the dry part of the year. Later, these observations will be compared to operation of drainfields during wet winter months.

W1 Drainfield. The significant feature of the W1 drainfield (Figure 8) is the minor area with increased mottles and high moisture content. Soils of W1 and W3 drainfields are similar and loading rates for the two drainfields were nearly the same, yet only one-seventh as much drainfield was needed by W1. Age of system was the only major difference between these two systems. The W1 system was in its first year of operation and probably represents how the W3 drainfield operated three years ago.

Measured infiltration rates for W1 site appear to be too low. Performance of the drainfield indicates that comparatively large volumes of water were rapidly passing through the bottom of the trenches. An average of six tests for B2t horizons of the Willamette series was 74.5 ml/min (Table 2). Macromorphology of the B horizons at the W1 site and the sites used to obtain 74.5 ml/min is very similar. They both have moderate to strong subangular blocky structure, common, fine and medium pores, and contain remnants of graded silt beds. Within the B horizon, texture and pore distribution are a function of horizontal pores found in beds. Depending on where infiltration rates are determined in the B horizon, a range of 34.9 ml/min to 74.5 ml/min is not surprising. However, in light of how rapidly water moved away from trenches in the W1 drainfield, the value of 34.9 ml/min appears to be too low for describing water movement in this drainfield.

W1 Drainfield

Willamette: 5 meters away from influence of drainfield.

Ap	0-16 cm. Dark brown (10YR 3/3) silt loam.
A3	16-53 cm. Dark brown (10YR 4/3) silt loam.
Ab	53-70 cm. Dark brown (10YR 4/3) silt loam; few, thin 10YR 3/3 coatings on ped surfaces.
B1tb	70-105 cm. Dark brown (10YR 3/3) silt loam; few, thin 7.5 YR 3/2 clay skins in pores and few, thin 10YR 3/4 clay skins on ped surfaces; few, clean silt grains on ped faces.
B2tb	105-125 cm. Dark brown (10YR 4/3) silt loam; many, moderately thick 7.5YR 3/2 clay skins; few, black stains on ped surfaces.
C	125-190+ cm. Dark brown (10YR 4/3) silt loam; common, coarse, distinct 10YR 4/4 mottles; 12-14 cm thick graded silt beds. Each bed is heavy silt loam at the top and gradually changes to coarse silt or very fine sand.

Age: one year
Length of tile: 74 m
Area of mottles: 12 sq. m
Area of high moisture: 20 sq. m
Loading rate: 11.5 l/m/day
K for B2tb: 0.23 cm/hr.
Double tube infiltration for B2tb: 34.9 ml/min.

Willamette: 20 cm from trench.

There were no observable differences in the profile, except for some free water on ped surfaces at 100 to 120 cm. However, under the tile line and down to 165 cm, there were a few medium distinct 2.5GY 4/1 and 7.5Y 4/0 mottles along ped surfaces. Matrix colors were similar to those in a "normal" Willamette. Free water was at the bottom of the trench, and 10 cm below the trench.

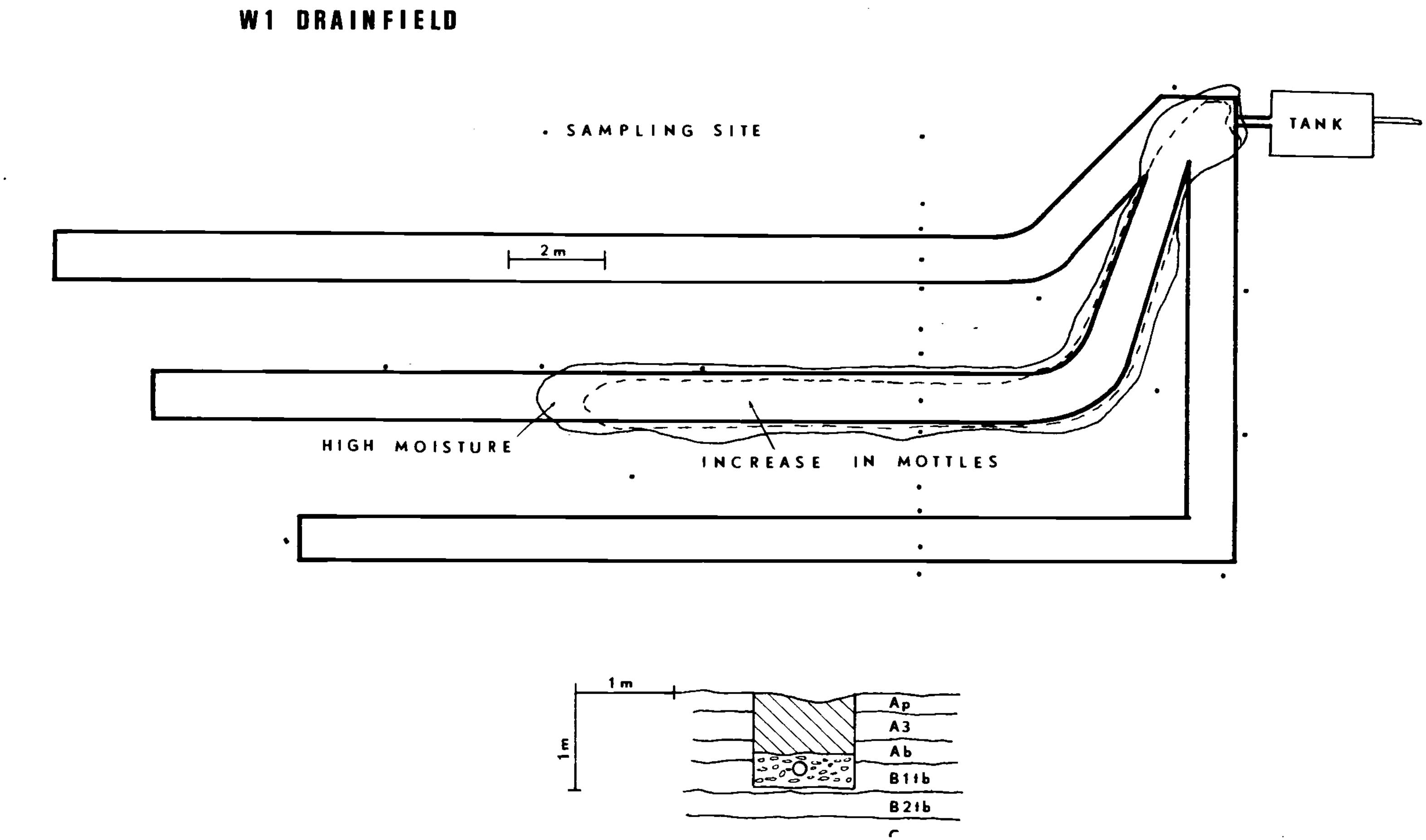

Figure 8. W1 drainfield was in operation one year at the time of observation. Approximately one-fourth of the total drainfield was used. Position trenches have relative to horizons is shown in the sketch below the drainfield diagram.

W2 Drainfield. The W2 drainfield (Figure 9) occupies a level, well drained position on the valley floor terrace. It is located 20 meters from the edge of a 15 meter escarpment. In addition to being well drained, it also has the lowest loading rate of the nine drainfield studied and receives only intermittent use during summer months.

Effluent was moving mostly downward through the bottom of trenches with some slight lateral movement. No increase in mottles was observed. Any increase in mottling should have been easily spotted since soil away from drainfield had essentially no mottles to a depth of 60 cm.

Double tube tests were not run close to the W2 drainfield, but were run at the W3 site which is along the same terrace escarpment less than 1.3 kilometers away.

W3 Drainfield. Compared to W1 drainfield, W3 system (Figure 10) showed signs of gradual deterioration. Coulter et al. (1961) defined performance of systems in terms of satisfactory, surcharged, or failing. Surcharged referred to systems having free water in and near trenches at the time of their investigation. Failure meant effluent was surfacing or the water movement in plumbing was sluggish. By their criteria, this sytem would be surcharged. Free water occurred at 110 cm near trenches and continued to a depth of 190 cm.

The K value of 6.70 cm/hr for the B2tb appears to be in error.

W2 Drainfield

Willamette: 8 meters from influence of drainfield.		Willamette: 20 cm from trench.
Ap	0-16 cm. Dark brown (10YR 3/3) silt loam.	No observable difference from "normal" Willamette except for free water on ped surfaces from 55 to 70 cm.
A3	17-50 cm. Dark brown (10YR 3/3) silt loam.	
B1tb	50-62 cm. Dark brown (10YR 4/3) silt loam; few, thin 7.5YR 3/3 clay skins.	
B2tb	62-105 cm. Dark brown (10YR 4/3) heavy silt loam; common, moderately thick 10YR 3/3 clay skins; common, black stains on surfaces.	
Cb	105-120+ cm. Dark grayish brown (10YR 4/2) silt loam.	

Age: one year
Length of tile: 74 m
Area of mottles: 0
Area of high moisture: 62 sq. m
Loading rate: 3.2 l/m/day
K and double tube infiltration were not determined.

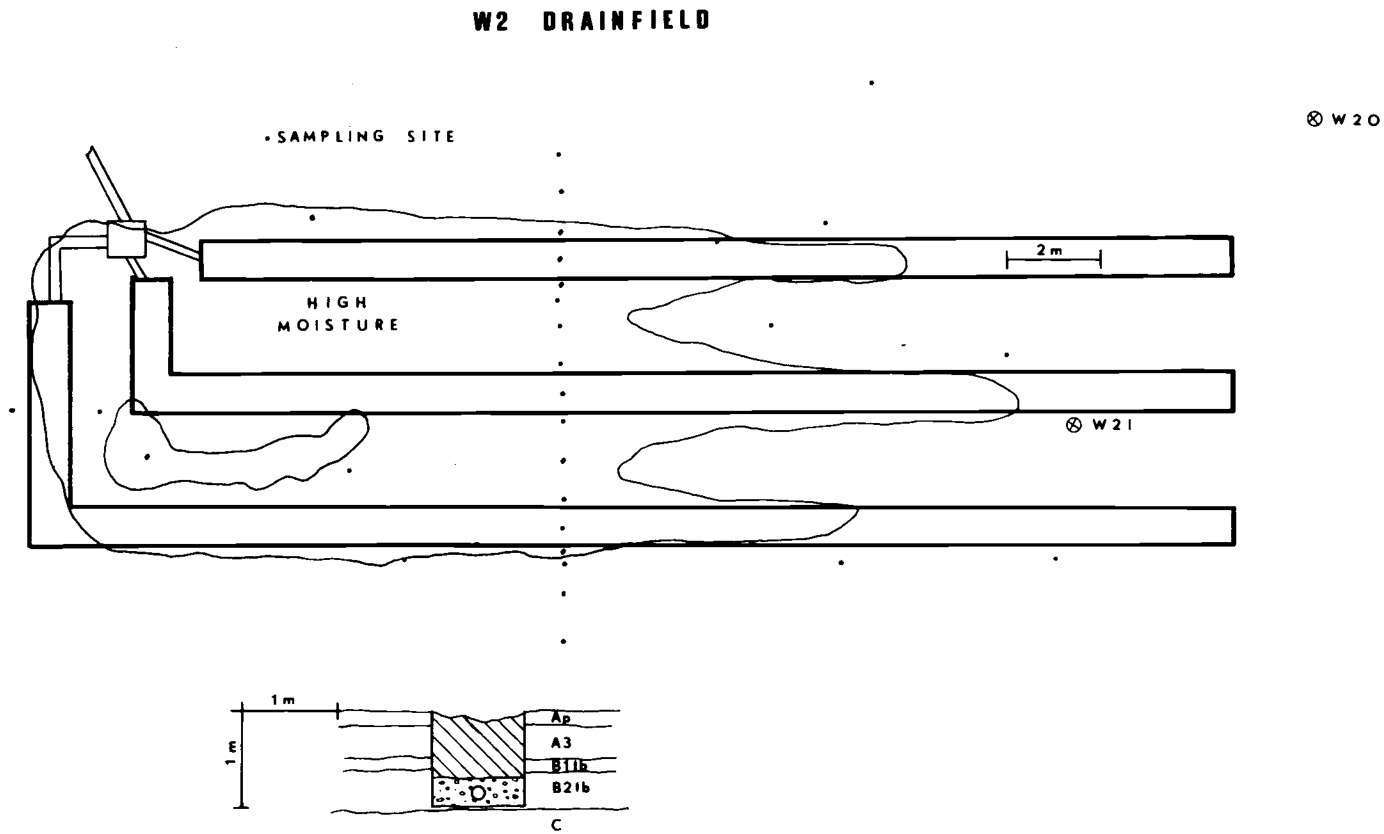

Figure 9. Position trenches have relative to horizons is shown in the sketch below the diagram of the drainfield. Symbols W20 and W21 represent wells used to measure water tables.

W3 Drainfield

Willamette: 5 meters from influence of drainfield.

Ap 0-17 cm. Very dark grayish brown (10YR 3/2) silt loam.

A3 17-54 cm. Very dark grayish brown (10YR 3/2) silt loam.

B1tb 54-97 cm. Dark brown (10YR 4/3) silt loam; thin, 10YR 3/3 clay coatings.

B2tb 97-115 cm. Dark brown (10YR 4/3) heavy silt loam; moderately thick 10YR 3/3 clay skins; few, thin, black stains on peds near the top of horizon.

C 115-130+ cm. Dark, yellowish brown (10 YR 4/4) silt loam.

Willamette: 20 cm from trench.

Ap 0-17 cm. No observable difference from "normal" Willamette.

A3 17-54 cm. No observable difference from "normal" Willamette.

B1tb 54-97 cm. No observable difference from "normal" Willamette.

B2tbg 97-120 cm. Free water at 110 cm; 110-120 cm dark, yellowish gray (2.5GY 3/1), and dark, bluish gray (5B 4/1) matrix, with common N 2/0 coatings and granules.

Cg 120-185 cm. Free water; dark yellowish brown (10YR 3/3) matrix; with 5B 4/1 and 2.5GY 3/1 colors, on 95% of ped surfaces.

Age: four years
Length of tile: 68 m
Area of mottles: 93 sq. m
Area of high moisture: 153 sq. m
Loading rate: 12.5 l/m/day
K B2tb: 6.70 cm/hr.
C: 0.32 cm/hr.
Double tube infiltration:
B2tb: 136.4 ml/min.
C: 111.2 ml/min.

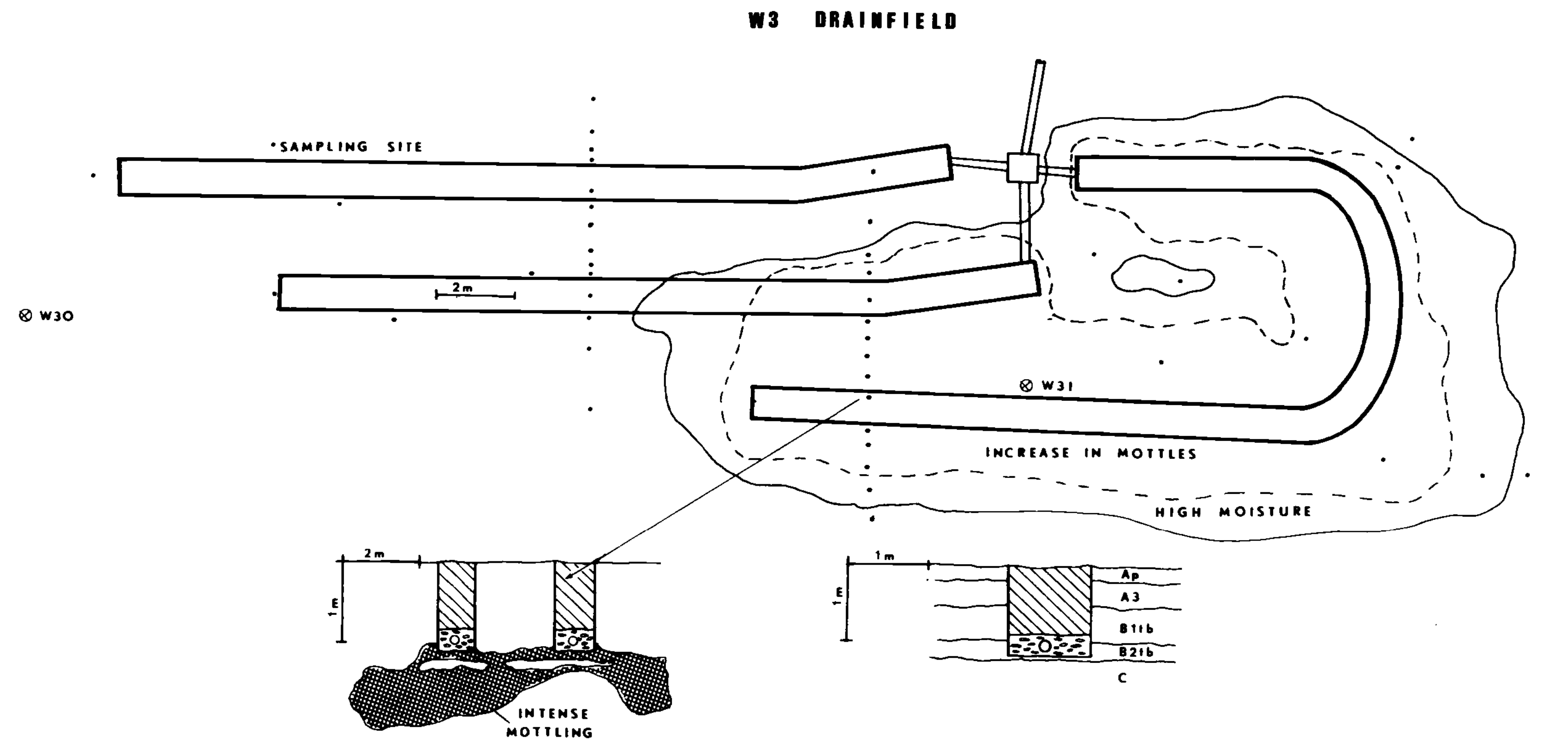

Figure 10. Position trenches have relative to horizons is shown in the small sketch on the right. On the left, a cross section of two trenches show islands of mottle (reduced) free silt loam surrounded by intensely reduced soil. Symbols W31 and W30 represent wells used to measure water tables.

This is the highest value measured for any soil tested. Most likely the seal between tubes was not adequate.

Most of the effluent was moving laterally into the lower B2tb and down through the C along weak structural units and common narrow channels. The C horizon is coarser textured than the B2tb but less permeable. Islands of very tightly packed silt grains in the C within intensely mottled zones show little evidence of being saturated with effluent. These islands could represent fragments of something analagous to a fragipan. Close packing of mineral grains and lack of structure cause this horizon to be less permeable than the B2tb. Figure 11 shows evidence of close packing which can occur in C horizons of Willamette soils.

WO Drainfield. As Figure 7 suggests, the soil at Woodburn drainfield (Figure 12) is close to the Willamette series with respect to drainage, but does fall within the Woodburn series. With exception of a few more clean silt grains on peds and gray mottles, this soil looks very much like soil at the W3 site. There are, however, significant differences in drainfield performance between these two soils.

The top 4-5 centimeters of the B2tb horizon was most influential in the performance of this drainfield. It consisted of strongly developed, slightly brittle peds with black stains of 30 percent of their surfaces. Peds within the B2tb also had common black stains but staining appears to be concentrated at the top of the horizon. Under

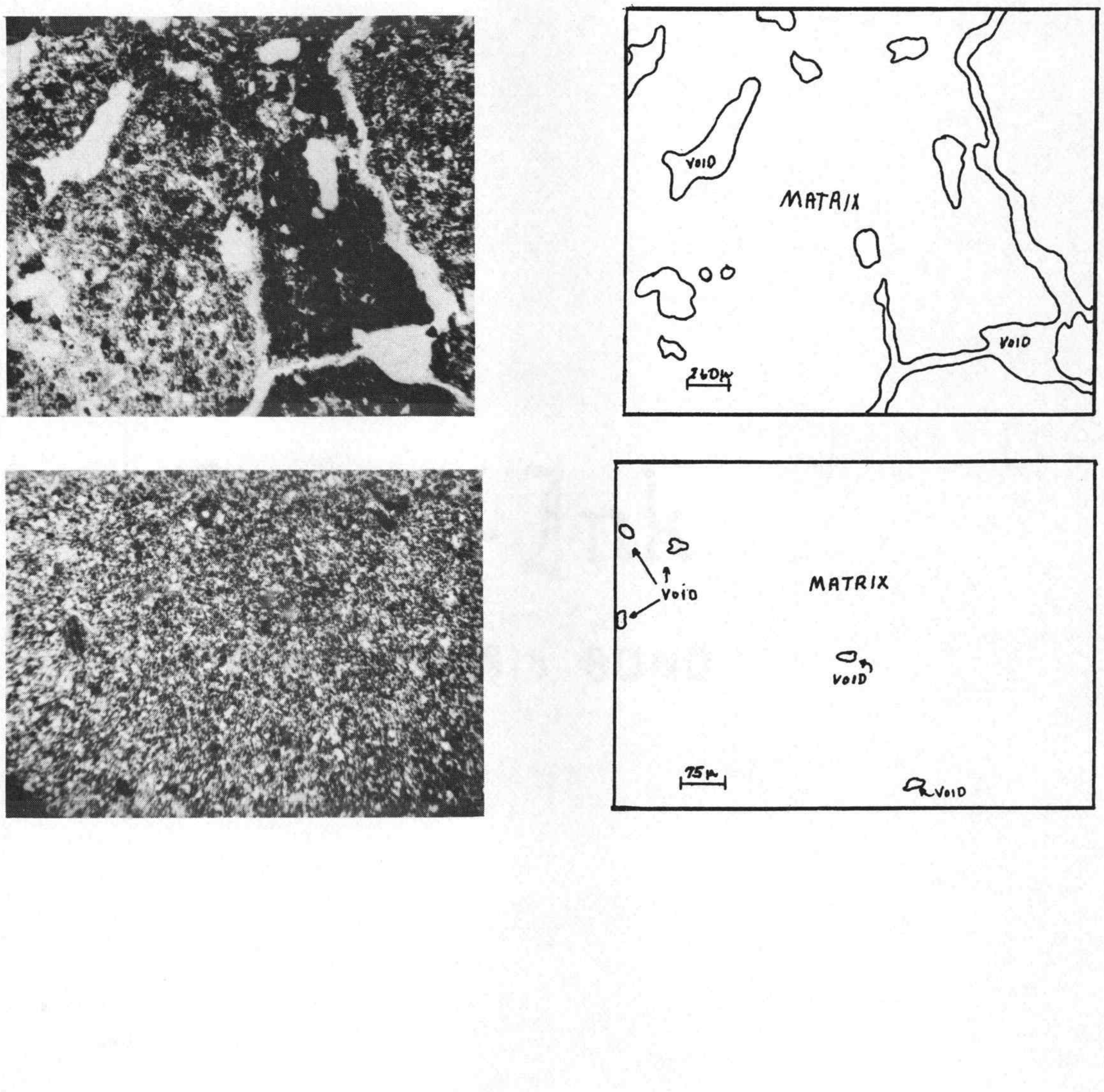

Figure 11. The top photomicrograph is of a B2t horizon of Willamette soil. It shows many more large pores than the lower picture of dense silt loam zones within the C horizon.

WO Drainfield

Woodburn: 8 meters from WO system.		Soil 50 cm from trench.	
Ap	0-17 cm. Dark brown (10YR 3/3) silt loam.	Ap	No observable difference from "normal" Woodburn.
B1	17-42 cm. Dark brown (10YR 3/3) silt loam.	B1	"
Ab	42-56 cm. Dark brown (10YR 4/3) silt loam; few, fine concretions.	Ab	"
B1tb	56-80 cm. Dark brown (10YR 3/3) silt loam; few, fine, distinct 10YR 4/2 mottles, thin 7.5YR 4/4 clay skins.	B1tbg	56-80 cm. No observable difference from "normal" Woodburn in upper 10 cm of horizon 66-68 cm; free water with common, medium, distinct 10YR 3/2 and few, fine, distinct 5B 4/1 and N 3/0 mottles.
B21tb	80-100 cm. Dark brown (10YR 4/3) heavy silt loam; few, fine, distinct 10YR 4/1 mottles; moderately thick 7.5YR 4/4 and 10YR 3/3 clay ckins; 4-5 cm layer of brittle peds with 30% black stains; ped surface occurs at top of horizon.	B21tbg	80-100 cm. Free water; many, medium, distinct 10YR 3/2 and common, medium, distinct 5B 4/1 and 2.5GY 4/1 mottles; common N 3/0 coatings and granules in pores.
B22tb	100-120+. cm. Dark brown (10YR 4/3) heavy silt loam; common, fine, distinct 10YR 5/1 mottles; moderately thick 10YR 4/2 and 7.5YR 4/4 clay skins; black stains on 20% of ped surfaces.	B22tbg	100-130 cm. Free water; many, medium, distinct 5B 4/1, 2.5GY 4/1 and 10YR 3/2 mottles; few N 3/0 coatings in pores.
		C	130-170 cm. Dark grayish brown (10YR 4/2) silt loam; upper 10-20 cm of horizon a few, medium, distinct 2.5GY 4/1 mottles.

Age: three years
Length of tile: 68 m
Area of mottles: 140 sq. m
Area of high moisture: 140 sq. m
Loading rate: 7.5 l/m/day
K for top of B2tb horizon: 0.39 cm/hr.
Double tube infiltration for top of B2tb horizon: 9.4 ml/min.
9.7 ml/min.

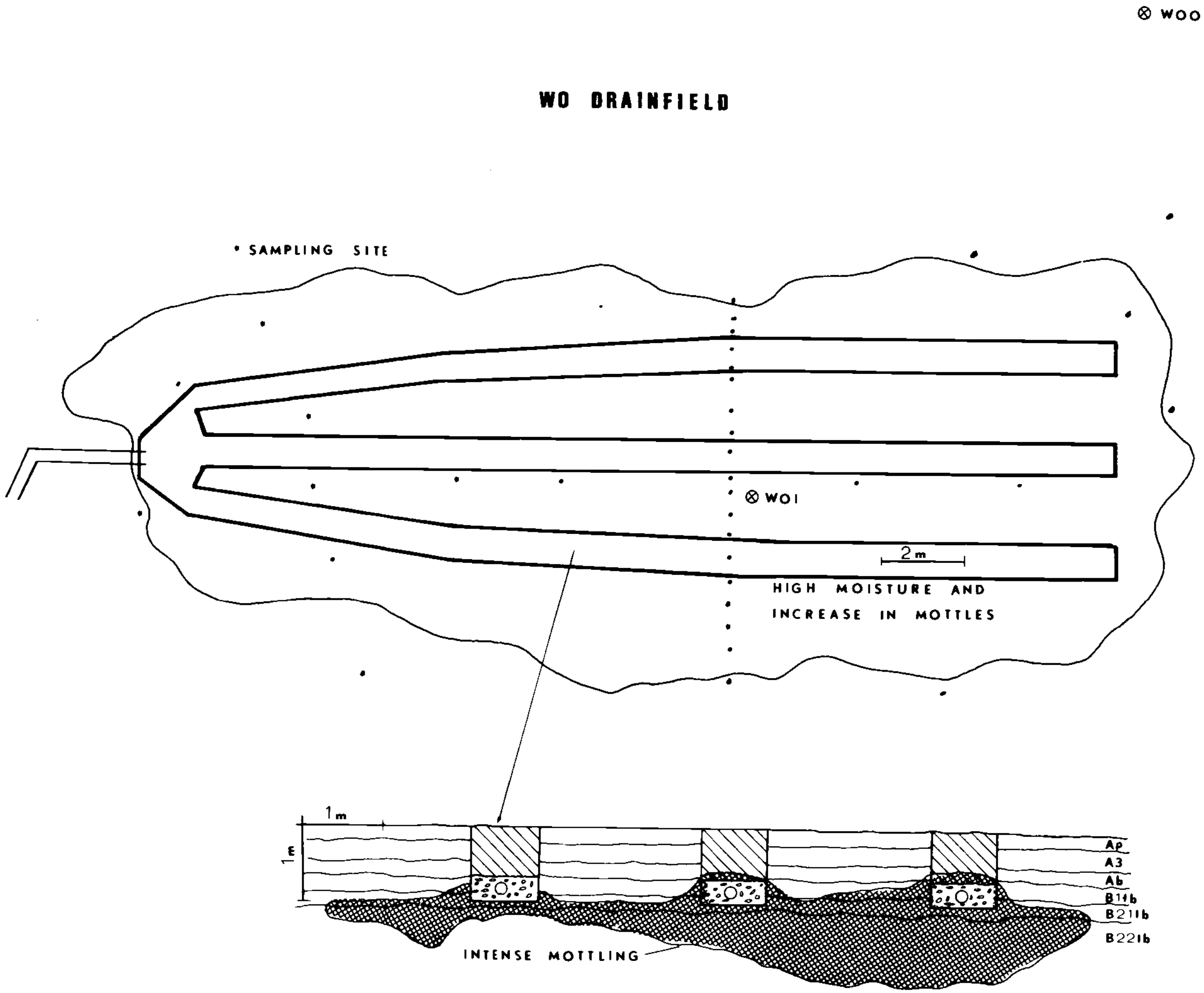

Figure 12. Areas of high moisture and increase in mottles coincided for this drainfield. A cross section of all three trenches show vertical distribution of intense mottling. Symbols W01 and W00 represent points where water tables were measured.

the influence of effluent, black stains were more intense. This layer differs in characteristics and position from fragipan-like horizons reported in Woodburn soils of Marion County (Pomerening, 1961). There, a massive, slightly brittle horizon, 32-42 centimeters thick, occurs below the B2 horizon.

Infiltration rates determined at the top of the B2tb agree closely with each other and the performance of the drainfield. An infiltration test was not run below the slightly brittle layer, but likely would compare with rates obtained of 136.4 ml/min within the B2tb of Willamette. Effluent moved laterally in the Ab and B1tb of Woodburn and slowly penetrated the B2tb. Extent of lateral spread on top of the B2tb shown in Figure 12 can also be distinguished in Figure 13. Vigor of vegetation was helpful at several sites in delineating areas of high moisture.

<u>A1 Drainfield</u>. The A1 drainfield (Figure 14) is the younger of two systems built in Amity. Comparison between them is not entirely legitimate. The soils are different even though they both fall into the Amity series and look very much the same. The most conspicuous difference is in the B horizons. Amity at the A1 site has a coarser textured (light silty clay loam) B horizon with stronger structure than the light silty clay of the B horizon at the A2 site. The B horizon near the A2 drainfield has remnants of 5-6 cm thick horizontal beds which are characteristic of C horizons of soils developing in the Willamette

A1 Drainfield

Amity: 2 meters away from influence of drainfield.		Amity: 20 cm from trench.	
Ap	0-17 cm. Very dark, grayish brown (10YR 3/2) silt loam.	Ap	0-17 cm. No observable difference from "normal" Amity.
A12	17-47 cm. Very dark gray (10YR 3/1) silt loam; common, fine, distinct 7.5YR 4/4 mottles.	A12	17-47 cm. "
IIA2	47-70 cm. Dark gray (10YR 4/1) silt loam; common, fine, and medium distinct 7.5YR 4/4 mottles.	A2	47-70 cm. In addition to common, fine, and medium distinct 7.5YR 4/4 mottles; 20% of the ped surfaces were 10YR 4/1; matrix also had common, medium, distinct 10YR 4/1 mottles.
IIB2t	70-85 cm. Dark grayish brown (10YR 4/2) light silty clay loam; common, medium, distinct 7.5YR 4/4 and 10YR 5/1 mottles; peds near the top of this horizon are slightly brittle with black stains; many fine and medium concretions.	B2t	70-85 cm. With exception of one sample point along the transect, there was no observable difference from "normal" Amity. One point had many distinct 10YR 4/1 mottles on ped surfaces.
IIC	85-90+ cm. Dark grayish brown (10YR 4/2) silt loam; many coarse and medium faint 10YR 4/4 and 10YR 5/1 mottles.	C	85-90+ cm. No observable difference from "normal" Amity.

Age: one year
Length of tile: 116 m
Area of mottles: 52 sq. m
Area of high moisture: 276 sq. m
Loading rate: 7.0 l/m/day
K for IIB2t: 1.75 cm/hr.
2.52 cm/hr.
Double tube infiltration rates for IIB2t: 58.3 ml/min.
211.7 ml/min.

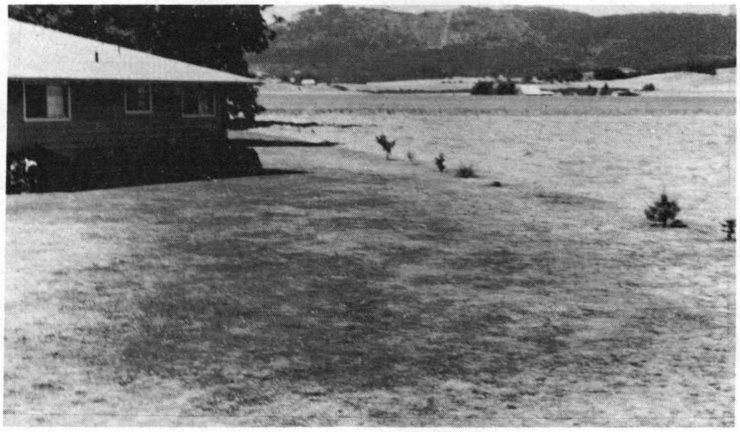

Figure 13. Dark area in the center of photograph is due to effluent moving laterally from trenches of W0 drainfield and subirrigating the lawn.

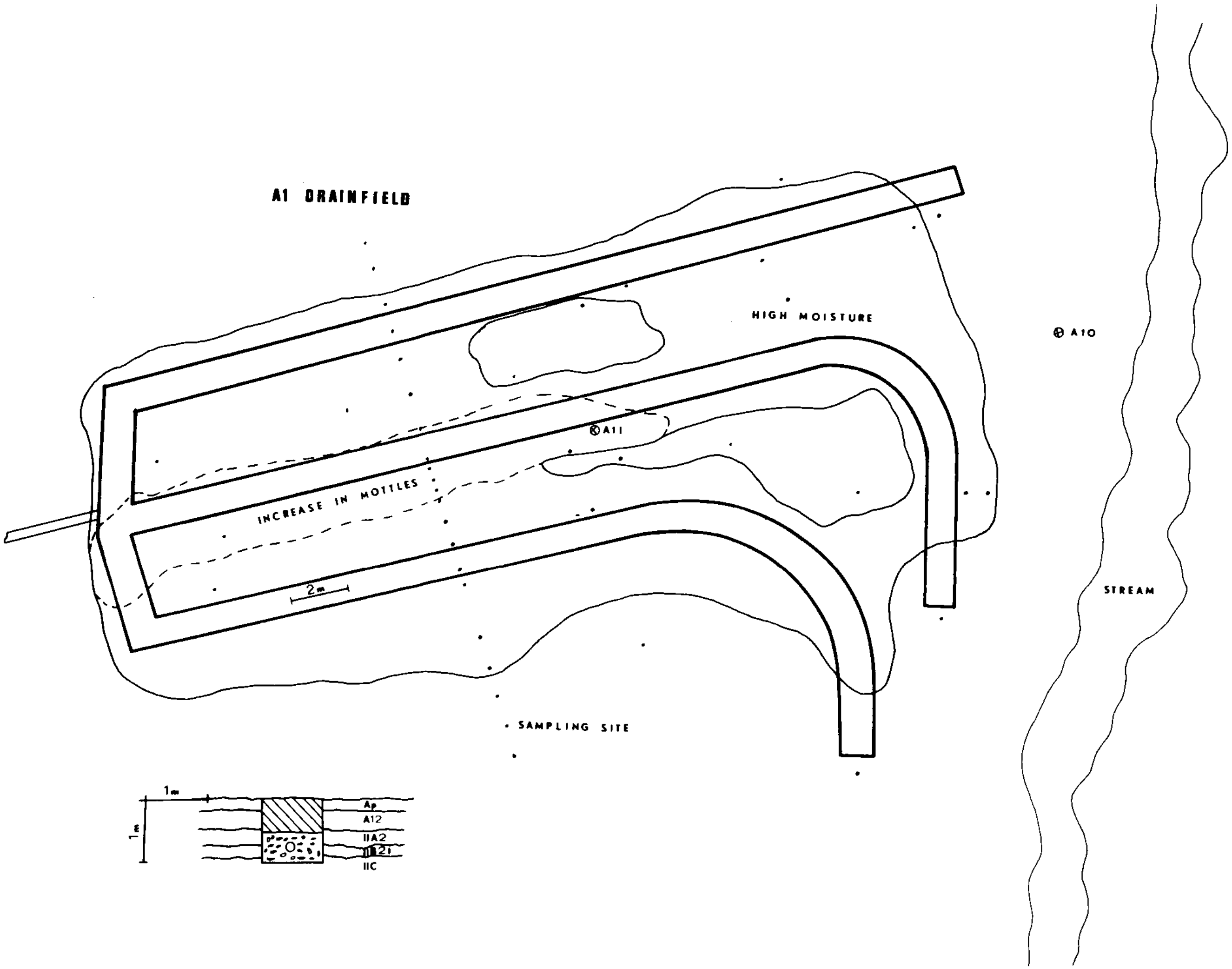

Figure 14. Area of increase in mottles was small in comparison to the area influence by this drainfield. The system, at the time drainfield was described, had been in service one year. Symbols A11 and A10 represent wells used to measure water tables.

Silts. Similar beds are present in the C horizon of Amity near the A1 drainfield.

At the A1 site, the surface horizon appears to be overthickened due to local alluvium from a nearby, intermittent stream. Also, the A1 drainfield was built on a two-three percent slope, whereas the A2 drainfield occurs on a narrow drainage divide where the gradient is low.

One factor which tends to ameliorate some of the differences and make comparison somewhat more reasonable is the similarity between infiltration rates at the two locations. A1 had a 58.3 ml/min rate while A2 gave 59.0 and 92.2 ml/min readings. On the other hand, K values of the B horizon are quite different. The hydraulic conductivity of the B horizon near A1 is higher than for the B horizon of the A2 drainfield. The inter-ped porosity alone is probably enough to explain the differences in K values. Amity near A1 has moderate, medium, subangular block structure in the B. Structure in the B horizon near A2 is also moderate, but tends to be prismatic and coarser.

Delineating differences in mottling within the A1 drainfield was difficult. The line shown in Figure 14 represents an area where dark gray (10YR 4/1) mottles were more common. No dark bluish gray mottles were observed.

Judging from the large area of high moisture content, relatively low loading rate, and lack of gleying below trenches, most of the effluent appeared to be moving through the porous IIA2 horizon. The top of the IIB2t had nearly the same brittleness and tightly fitting, strong peds as did the B horizon of the WO drainfield. Infiltration was not run at the top of the Amity B horizon, but from field observation, there is reason to suspect that it would act very similar to the top of the B horizon at the WO drainfield.

The ratio of length of tile to area of high moisture is nearly the same for WO and A1 drainfields.[3] Although it is not surprising that the ratios are close, the small difference between these ratios is probably somewhat accidental. Boundaries between high moisture and normal moisture represent a 1-1.5 m transition.

The WO drainfield represents how A1 drainfield might appear in two years. As water table data will show, A1 drainfield had a lag in draw-down while the WO site had effluent perched on the B2tb all year. Also, the area of increase in mottles is less in the A1 than in the WO drainfield.

<u>A2 Drainfield</u>. Repeating, graded beds of silt, which begin in lower portions of the IIB2t and continue into the C, explain some of the features observed in the A2 drainfield (Figure 15) and in other

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[3] A1; $\frac{276 \text{ sq. m}}{116 \text{ m}} = 2.3$ WO; $\frac{140 \text{ sq. m}}{68 \text{ m}} = 2.2$

A2 Drainfield

Amity: 6 meters from influence of drainfield.		Soil 20 cm from trench.	
Ap	0-15 cm. Dark gray (10YR 4/1) silt loam; many fine distinct 5YR 4/6 mottles along root channels.	Ap	0-15 cm. No observable difference from "normal" Amity.
A21	15-62 cm. Gray (10YR 5/1) silt loam; many medium 10YR 4/4 mottles; many concretions. Lower part of horizon has very abundant concretions.	A2	15-63 cm. No observable difference from "normal" Amity.
B2tb	62-80 cm. Dark grayish brown (10YR 4/2) light silty clay; common, medium, distinct 10YR 4/4 mottles; moderately thick 10YR 4/1 clay skins; occasional island of horizontal pores; ma y large 1-2 cm wide fissures coated with moderately thick 10YR 4/1 clay skins transect horizontal pores. Subhorizons: 63-70 cm light silty clay loam. 70-75 cm silt loam, very few micropores, common vertical channels coated with 10YR 4/1 clay. 75-80 cm. Heavy silt loam; common horizontal pores with 10YR 4/1 clay skins.	B2tg	63-110 cm. Horizon is made up of 8 to 9 subhorizons. Finer textured subhorizon with predominently horizontal pores, are solid dark bluish gray (5B 4/1) with common N 3/0 coatings and granules in pores. Heavy silt loam, and silt loam layers near the top of the horizon have common, coarse, indistinct 5B 4/1 and 5G 3/1 mottles; silt loam layers lower in profile, have bery few gleyed colors.
B3tb	80-100 cm. Dark brown 10YR 4/3 silt loam; few, fine faint 10YR 4/4 and 10YR 5/1 mottles; few moderately thick 10YR 4/1 clay skins. Most of the pores are horizontal; common large fissures coated with 10YR 4/1 clay skins transect horizontal pores. Subhorizons: 80-85 cm silty clay loam; many medium sized pores with moderately thick 10YR 4/1 clay skins in pores. 85-90 cm. Dark yellowish brown (10YR 4/4) silt loam; very few macropores. 90-95 cm heavy silt loam; common, medium horizontal pores with few, moderately thick 10YR 4/1 clay skins in pores. 95-100 cm; similar to 85-90 cm layer.		
C	100-117+ cm. Grayish brown (2.5Y 5/2) light silty clay loam; few, fine, faint 10YR 4/4 mottles. Horizon is comprised of graded beds of silty material. Within beds are 5-6 cm layers of silty clay, heavy silt loam, and silt loam layers. The heavier textured layers have common, moderately thick 10YR 4/2 clay skins along pores. Most pores are horizontal.	C	100-135+ cm. No observable difference from "normal" Amity.

Age: three years
Length of tile: 72 m
Area of mottles: 225 sq. m
Area of high moisture: 417 sq. m
Loading rate: 11.0 l/m/day
K for IIB2t 5 cm above horizontal pores: .29 cm/hr
.27 cm/hr

Double tube infiltration rates for B2t
5 cm above horizontal pores: 59.0 ml/min
92.2 ml/min

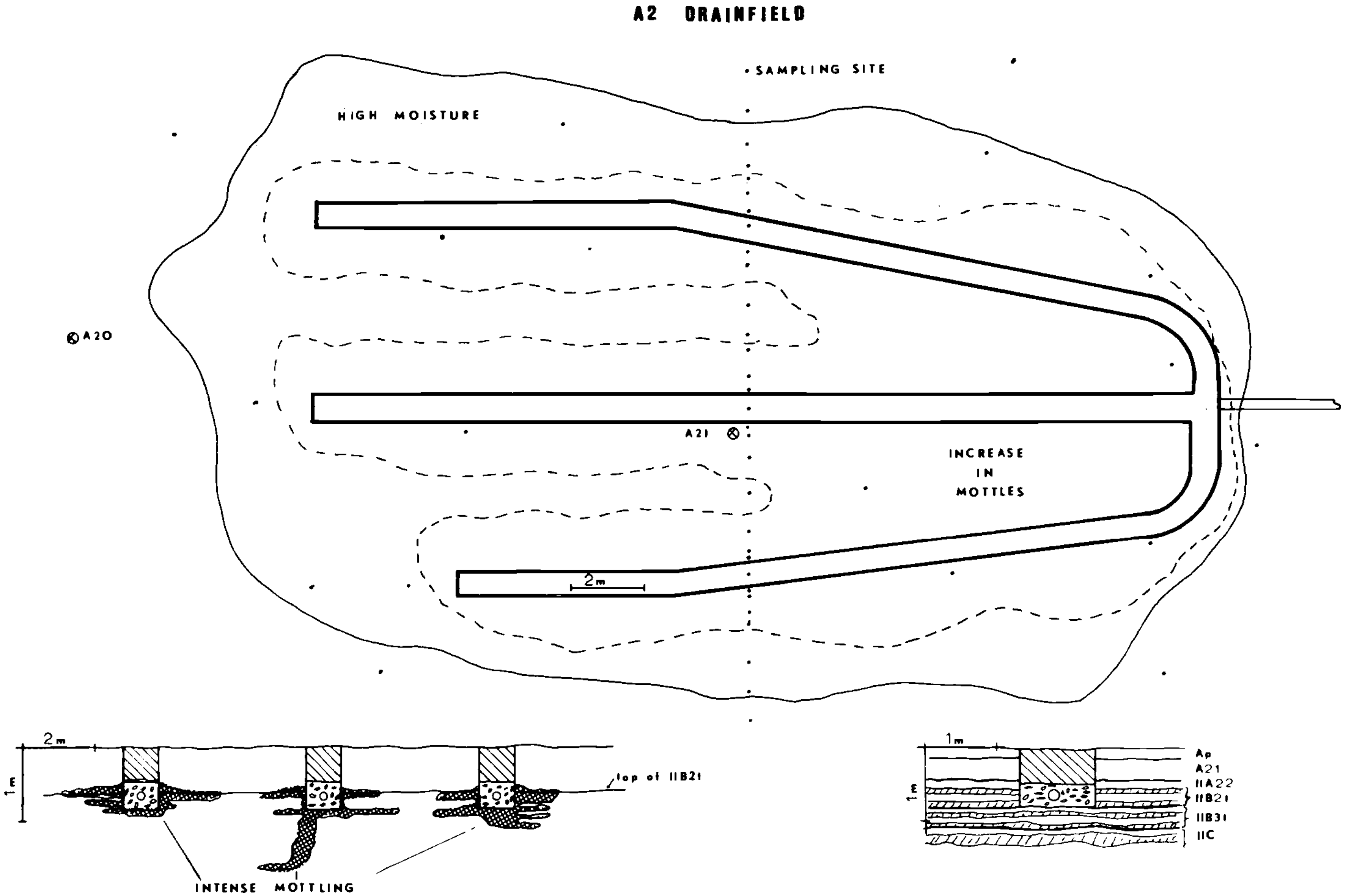

Figure 15. Vertical mottling pattern, shown in the lower left hand sketch, reflect to a large extent differences in permeability of grade silt beds. More permeable layers are intensely mottled. The diagram at right has hatched pattern to indicate more permeable, heavier texture layers within graded beds. Symbols A21 and A20, represent wells used to measure water tables.

drainfields. In the IIB2t horizon, bedding has been obscured by soil forming processes but in the C, beds become more pronounced. Beds having similar characteristics, but thicker and with a wider range of texture within beds, have been described by Glenn (1967) and Pomerening (1961) in the Willamette Silts in Marion County. Glenn shows a photograph (1967, page 66) of a river bank where 30-40 such beds are exposed. In Marion County, these beds average 30 cm thick. Near the A2 drainfield and in other soils forming in the Willamette Silts near Corvallis, beds average 14 cm thick.

Within beds, texture gradually changes from coarse silt loam at the bottom of a bed to heavy silt loam toward the top. Beds consist of a 5-6 cm layer of coarse silt loam at the bottom, grading through a 2-4 cm transitional layer to a 4-5 cm layer of silt loam with a noticeable increase in clay (Figure 16). Heavy silt loam layers have the greatest number of pores and also have what Glenn (1967, page 110) describes as crude laminations. Small, nearly level laminations 6-7 mm thick are separated by thick 10YR 4/1 clay skins in beds near the IIB2t horizon. Presumably the clay skins are pedogentic.

Evidence of bedding in the IIB2t away from the influence of A2 drainfield are subtle differences in texture, some slight color differences (finer textured layers are darked), and an occasional body of soil showing laminations with horizontal pores. Observable pores indicate an equal number of horizontal and vertical pores. However,

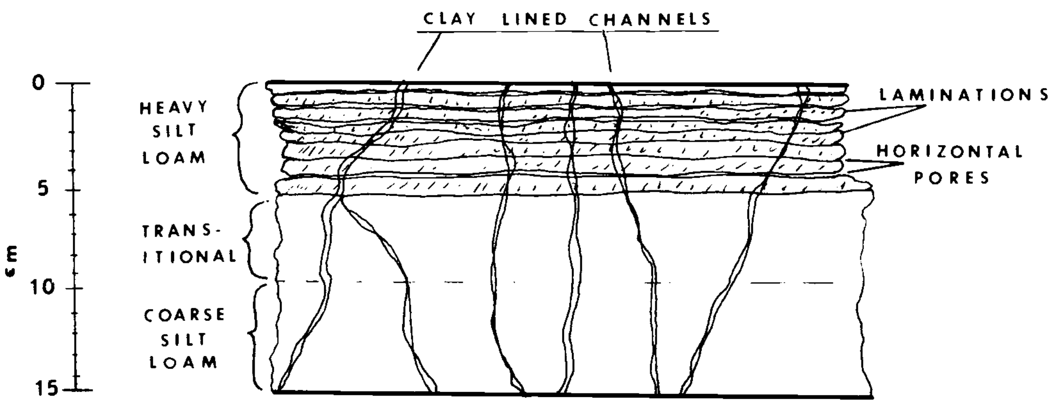

Figure 16. A schematic of a graded bed commonly found.

within the drainfield, beds become quite visible. Intense dark bluish gray mottles occur in 4-5 cm layers corresponding to the heavier textured, laminated layers of the graded beds. Effluent apparently moved laterally in these layers until it reached vertical channels cutting across the dense silt loam layers.

The intense mottling pattern gives the impression that effluent is moving mostly through layers which have horizontal pores. Perhaps this was true when the A2 drainfield was younger and that age has brought about sealing of pores at the effluent-soil interface. Another possibility could be that many of the horizontal pores were destroyed during construction of trenches and it has taken effluent four years to move into these layers to cause intense mottling.

C1 Drainfield. The soil near C1 drainfield (Figure 17) looks similar to Amity near the A2 system. Features making it significantly

C1 Drainfield

Concord: 7 meters from influence of drainfield.		Soil 50 cm from trench.	
Ap	0-22 cm. Dark gray (10YR 4/1) silt loam; many, distinct, fine 7.5YR 4/4 mottles.	Ap	With exception of a higher moisture content, there was no observable difference in these horizons from "normal" Concord.
A2	22-40 cm. Dark grayish brown (10YR 4/2) silt loam; common, medium, distinct 10YR 4/4 and 10YR 5/1 mottles.	A2	"
IIB1t	40-58 cm. Dark grayish brown (10YR 4/2) silty clay; many, fine, distinct 10YR 4/4 mottles.	IIB1	"
IIIB21t	58-74 cm. Dark brown (10YR 4/3) light silty clay; 20% of ped surfaces have black stains; common concretions. Subhorizon: 69-74 cm. Dark brown (10YR 4/3) light, silty clay loam; most pores are horizontal and lined with 10YR 4/1 clay skins.	IIIB21g	70-100 cm. Upper part of horizon and the layers with horizontal pores lined with moderately thick clay skins, are nearly solid 5B 4/1 and N 5/0 mottles, few N 2/0 coatings along large pores and fissures, layers of dense silt loam have few, coarse, faint 5B 3/1 and N 3/0 mottles.
IIIB22t	74-86+ cm. Horizon consists of alternating 5-6 cm layers of heavy silt loam with nearly all horizontal pores, and 6-7 cm layers of friable, dense, silt loam. Subhorizon: 74-79 cm. Dark brown (10YR 4/3) silt loam; friable, dense. 79-86 cm. Looks same as 69-74 layer except texture is heavy silt loam.		

Age: three years
Length of tile: 58 m
Area of mottles: 125 sq. m
Area of high moisture: 218 sq. m
Loading rate: 5.0 l/m/day
K for IIIB21t (69-74 cm): .60 cm/hr.
.40 cm/hr.
Double tube infiltration rates for IIIB21t (69-74 cm): 29.9 ml/min.
70.6 ml/min.

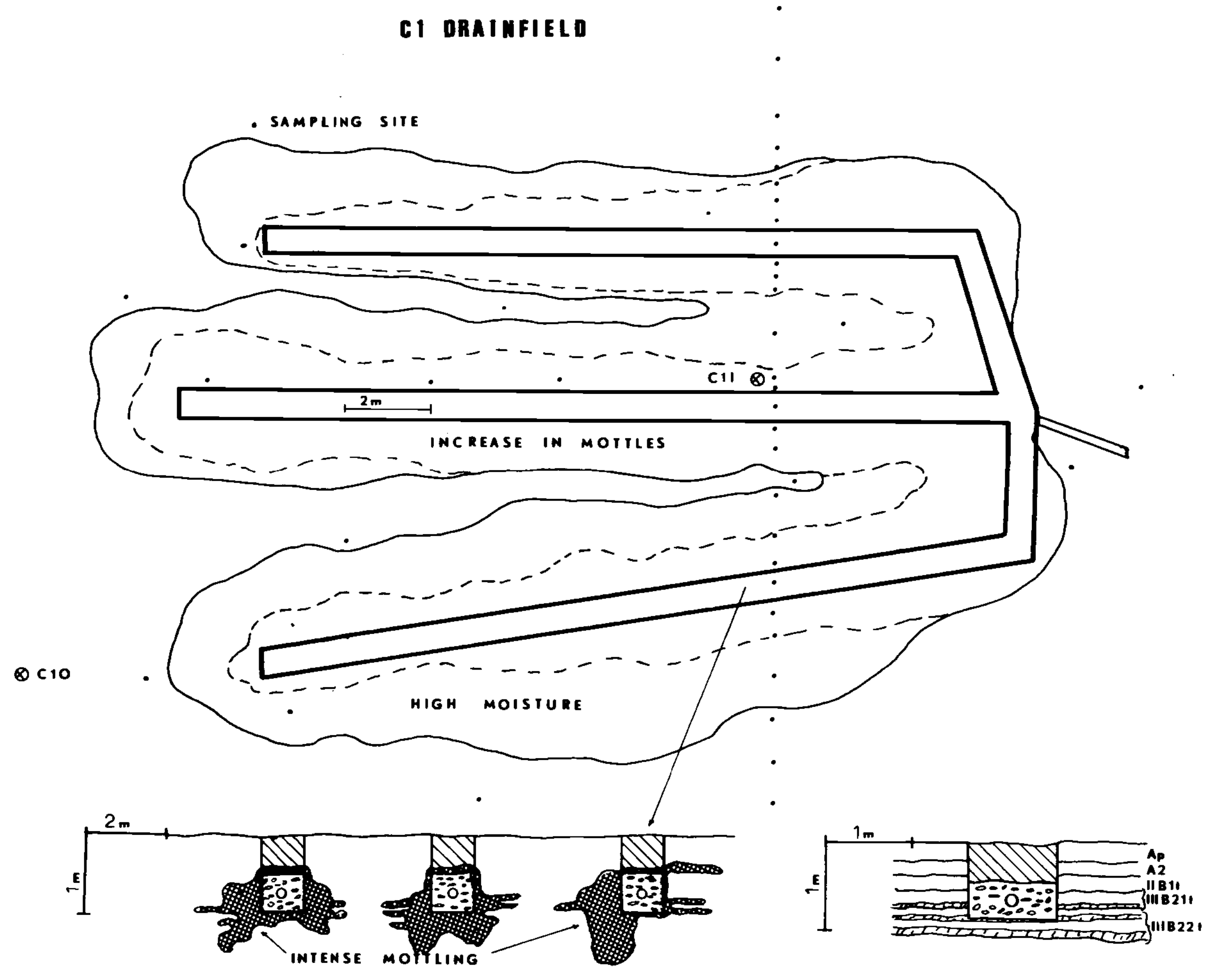

Figure 17. In the lower left hand sketch, mottling pattern around trenches reflect the influence of graded beds. Tongues of intense mottles correspond to the more permeable layers within beds.

different from Amity are the porous silty clay IIB2t horizon and an increase in total clay of the solum and clay skins. Bedding was similar to that described in Amity near the A2 drainfield but had thicker clay skins between laminations. Figure 18 is a thin section of the 69-74 cm bed illustrating these coatings on horizontal pores.

In between layers having mostly horizontal pores are layers of dense, friable silt loam (Figure 16). Infiltration rates determined on these silt loam layers were 2.0 and 1.3 ml/min, which is considerable lower than those for layers having abundant horizontal pores (29.9 and 70.6 ml/min). The 29.9 and 70.6 ml/min values do not represent horizontal infiltration rates, but most likely represent vertical permeability of thin 6-7 mm laminations similar to those shown in Figure 18.

C1 and A2 systems have been in service three years and perform nearly the same. Infiltration rates for the C1 drainfield appear to be somewhat lower than those from the A2 drainfield, but considerably higher than that of Concord soil near the C2 drainfield.

C2 Drainfield. Concord soil near the C2 drainfield (Figure 19) has a heavier textured B horizon immediately below the A2 horizon than Concord of the C1 drainfield. This horizon is much more dense, with a moderate medium prismatic structure rather than a moderate medium subangular blocky structure like the IIB2t horizon of the C1 drainfield.

C2 Drainfield

Concord: 5 meters from system.		Soil 20 cm away from trench.	
Ap	0-17 cm. Dark gray (10YR 4/1) silt loam.	Ap	0-17 cm. Dark gray (10YR 4/1) silt loam; common 5Y 4/4 mottles along root channels; many concretions.
A2	17-60 cm. Gray (10YR 5/1) silt loam; many, medium, and fine, distinct 10YR 4/4 mottles; common concretions.	A21	17-40 cm. Gray (10YR 5/1) silt loam; free water; many, medium 5YR 4/4 and N 4/0 mottles.
		A22g	40-60 cm. Dark bluish gray (5B 4/1) silt loam; free water; many, coarse, faint 5G 4/1 mottles and common N 3/0 coatings.
IIB21t	60-70 cm. Gray (10YR 5/1) clay, many, medium, distinct 10YR 4/2 mottles; common concretions.	IIB21g	60-70 cm. Dark bluish gray (5B 4/1) clay; free water; many, coarse, faint 5G 4/1 mottles; common N 3/0 coatings and granules.
IIIB22t	70-82 cm. Dark gray (10YR 4/1) heavy silty clay loam; many, medium, distinct 10YR 4/4 mottles; common concretions.	IIIB22g	70-82 cm. Dark bluish gray (5B 4/1) silty clay loam; free water; many, coarse, faint 5G 4/1 mottles and few N 3/0 coatings on ped surfaces.
IIIC	82-90+ cm. Dark grayish brown (10YR 4/1 silty clay loam; many, distinct 10YR 4/4 mottles.	IIIC1g	82-124 cm. Dark grayish brown (10YR 4/2) silty clay loam; free water; many, very thin 5B 3/1 and 10YR 4/1 coatings in channels; few N 3/0 mottles along ped surfaces and large pores.
		IIIC2g	124-165 cm. Dark grayish brown (10YR 4/2) silt loam; free water; few medium 5B 3/1 and 10YR 4/1 mottles along large pores and channels.
		IIIC3g	165-180+ cm. Dark grayish brown (10YR 4/2) silt loam; many, medium 10YR 4/1 mottles.

Age: six years
Length of tile: 80 m
Area of mottles: 169 sq. m
Area of high moisture: 316 sq. m
Loading rate: 9.7 l/m/day
K for IIIB21t: 0. 11 cm/hr
Double tube infiltration for IIB21t: 14.0 ml/min

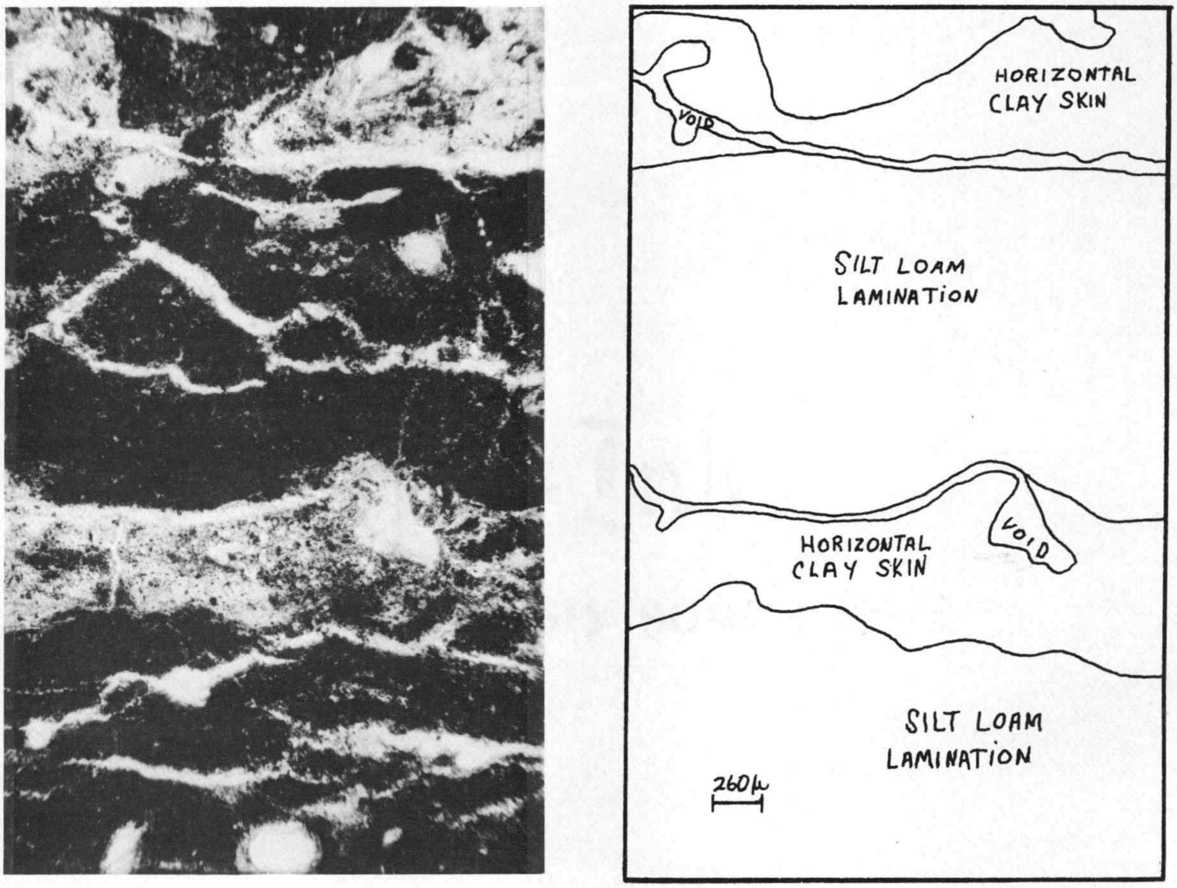

Figure 18. A photomicrograph of the III B2t horizon (69-74 cm) at Concord site. Thick, horizontal clay skins surrounding small pores are separated by laminations of silt loam. Nearly all pores shown are horizontal.

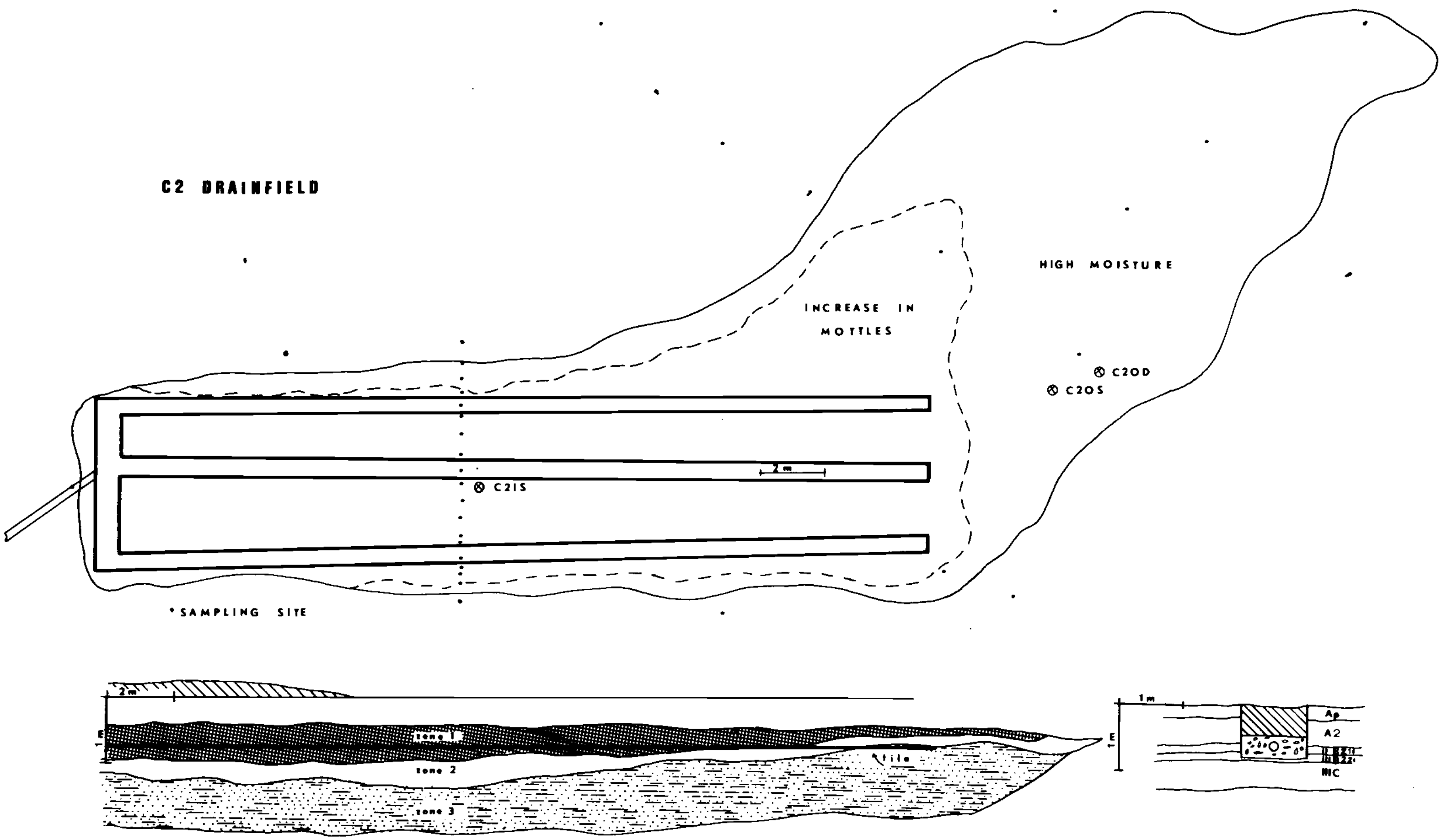

Figure 19. A longitudinal section of C2 drainfield shows vertical distribution of three zones of mottling. Zone one was solid bluish gray color, zone two was 70 percent bluish gray mottles, and three had bluish gray mottles only along pores and channels.

Starting with the top of the A2 horizon, blue and gray mottles extend to a depth of 120 cm. A layer of solid 5B 4/1 and 5G 4/1 colors was consistently present 40 cm below the surface (zone one in Figure 19). Below zone one, an area of predominantly 5B 4/1 and 5G 4/1 mottles with 30 percent of the original soil colors varied in thickness from 44 cm near the distribution box to a thin layer outside of the drainfield. A third zone consisted of 5B 3/1 and 5G 3/1 colors only along pores and channels.

Distribution and type of mottling could be interpreted as the pathway effluent takes as it leaves trenches. In fact, this was the interpretation for W1 and W3 drainfields. But the same interpretation cannot be made for the C2 drainfield. Very little effluent moves vertically below the top of the IIB21. A one percent slope away from the drainfield in the direction of a small ditch some 18 m away caused effluent to move laterally through the A2 horizon. At two meters from the end of a trench, A2 moisture content was 58.0 percent; at eight meters, it was 24.0 percent; and outside the pathway of effluent, it was 5.0 percent. No doubt, some water was removed from the A2 by evaporation before it reached the small ditch.

Intensity of mottling below the A2 horizon represents slow penetration of effluent over a six-year period. Effluent slowly penetrates the B horizons keeping them continually wet. The volume of intensely reduced soil in this drainfield was the highest of any drainfield examined.

The measured infiltration rate is higher than would be expected when compared to those for WO and D drainfields (values of 9.4 and 9.7 ml/min for WO and 0.0 ml/min for D were obtained). For WO, the value meant that effluent, which spread over the surface of the B2t, slowly percolated through the dense 4-5 cm zone at the top of the B2t. That being the case, one would expect the B horizon of the C2 sites, with a 14.0 ml/min rate, to conduct more effluent. This does not happen. Judging from the performance of this drainfield, actual infiltration rates for the IIB21 are probably intermediate between 9.4 and 0.0 ml/min.

D Drainfield. The D system in Dayton soil has a slightly lower loading rate, is five years younger, but still has about the same area of high moisture as the C2 system. Dark bluish and greenish mottles were absent. Evidently, one year is not sufficient time for these kinds of mottles to develop. In all young drainfields (W1, W2, A1, D) dark bluish and greenish mottles were either absent or occurred only at 1-2 cm immediately below trenches. However, in one year a noticeable difference in 10YR 4/1 mottles could be seen. With the exception of having a dense stand of ryegrass and vetch growing over the trenches, this sytem operates in the same way as C2 drainfield. The fact that the claypan in the D drainfield is four times thicker than that in C2 was inconsequential to drainfield performance. In both cases, effluent

D Drainfield

Dayton: 3 meters from influence of drainfield.

Ap 0-8 cm. Dark yellowish brown (10YR 3/4) silt loam.

A2 8-60 cm. Gray (10YR 5/1) silt loam; many, medium, distinct 10YR 4/4 mottles; many concretions.

IIB21t 60-100 cm. Dark brown (10YR 4/1) clay.

IIIB22t 100-130 cm. Dark brown (10YR 4/3) silty clay loam; moderately, thick, continuous 10YR 4/1 clay skins on ped faces; many, medium, distinct 10YR 5/4 mottles; many concretions.

IIIC 130-140+ cm. Grayish brown (2.5Y 5/2) silt loam.

Age: one year
Length of tile: 108 m
Area of mottles: 122 sq. m
Area of high moisture: 293 sq. m
Loading rate: 11.5 l/m/day
K for B21b: 0.0 cm/hr.
Double tube infiltration for B21b: 0.0 cm/hr.

Dayton: 20 cm from trench.

The only observable difference in this profile from "normal" Dayton, is a slight increase in 10YR 4/1 mottles in the lower portion of the A2. Free water occurred at 40 cm next to tile line.

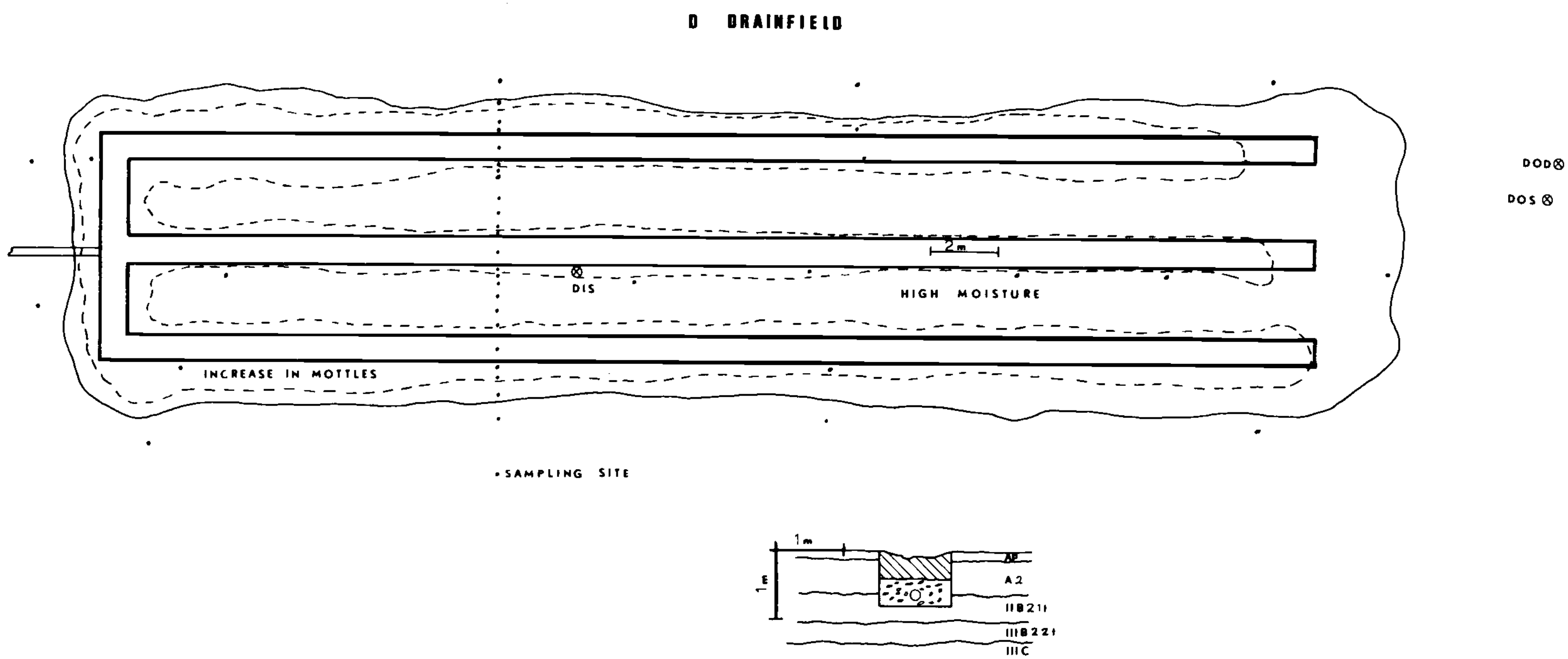

Figure 20. The increase in mottles amounted to a noticeable increase in 10YR 4/1 mottles in the A2 horizon.

moved laterally in an A2 horizon. A negligible amount moved through the claypans.

Summary of Permeability and Its Effects on Drainfield Performance

The double tube method, when compared to the PHS test, is more reliable for determining permeability. Since an unsmeared soil-water surface is used and chances of clogging pores with sediment are greatly reduced, most of the variation in double tube data can be attributed to entrapped air and natural soil variation. When hydraulic conductivity (K) and infiltration rates for soil near the nine drain-fields studied were compared to drainfield performance, infiltration rates were favored over K values. Table 4 shows that W1, W3, WO, and A2 all had about the same K values. However, performance and infiltration rates of these drainfields differed considerably. Hydraulic conductivity by the double tube method reflects resistance to water movement in a flow direction which is highly unlikely to occur in natural conditions. Infiltration, on the other hand, gauges mostly vertical movement and measures a larger volume of soil. After a long soaking period, infiltration rates probably take into account differences in permeability of layers below the surface receiving water.

Infiltration rates for W3, WO, C2, and D drainfields agree reasonably well with their performance. Rates for A1, A2, and C1

Table 4. Comparison of hydraulic conductivity and double tube infiltration determined near drainfields.

Drainfield and Horizon	Depth (cm)	K (cm/hr)	Double tube infiltration (ml/min)
Willamette W1			
B2tb	110	0.23	34.9
Willamette W3			
B2tb	98	6.70	136.4
C	120	0.32	111.2
Woodburn WO			
B2ttb	95	0.39	9.4
Amity A1			
IIB2t	75	1.75	58.3
Amity A2			
IIB2t	65	0.29	59.0
IIB3t	92	.76	85.7
Concord C1			
IIIB21t	67	0.60	29.9
		0.40	70.6
IIIB22t	74	0.07	2.0
		0.06	1.3
Concord C2			
IIB21t	64	0.11	14.0
Dayton D			
IIB2t	65	0	0

drainfields appear to be high. These later systems performed very much like WO, C2, and D drainfields. The disparity between performance and infiltration rates suggests that actual infiltration rates near the top of these B2 horizons are considerable lower than measured infiltration in the middle of these horizons. The effect permeability had on drainfield performance was essentially the same for all drainfields except those in Willamette soil.

Effluent travelled from septic-tanks into trenches which were partially saturated. Trenches were sometimes saturated higher than the top of the B2 horizons and always lower. Effluent entering trenches displaced an equal volume of liquid into the porous A2 or B1 horizon. Effluent moved laterally until there was no more gradient to move liquid or until it was absorbed in B2 horizon or used by plants. The permeability near the top of B horizons in WO and A1 was high enough (9.4 ml/min) to allow effluent to slowly percolate downward. The B2t horizons in A2, C1, C2, and D allowed very little to move downward. In these later drainfields, vegetation was an important mechanism of removing water.

Effluent entering drainfields in Willamette soils moved mostly vertically through the lower part B2 horizons. Infiltration rates determined at W3 suggest that a high permeability might explain why drainfields in Willamette soil behave differently.

In essence, the portion of trenches excavated from B2 horizons in soils other than Willamette acted as an extension of septic-tanks. Roughly, an average of 6500 liters of effluent was stored in some drainfields. For such cases, the term drainfield is somewhat of a misnomer. A more appropriate name would be subsurface lagoons. There is no reason to think degradation taking place in the tank would cease once it entered saturated trenches. Perhaps the longer holding time afforded by trenches permits more degradation before effluent moves away from trenches.

II. EFFECTS OF AGE ON DRAINFIELD PERFORMANCE

Drainfields listed in Table 3 (page 26) were matched according to soil and age to see what effect time has on their performance and appearance. No attempt was made to keep such factors as type of effluent and loading rate uniform for all drainfields. Between young and older drainfields all factors were kept nearly the same. For instance, size of septic-tank is the only factor besides age which could be identified as being different between W1 and W3 systems.

It is helpful to look at Figure 7 in order to understand why soils within different series were matched to study effects of age. Soils near WO and A1 drainfields were similar in many respects, as was pointed out in Section I. In both C2 and D drainfields, the presence of porous A2 horizon over a claypan permits a comparison between these two systems.

Effect of time, Table 5, can most clearly be seen in the area of increase in 10Y 4/1 and 5B 4/1 mottles. As would be expected, older drainfields have more area of intense dark bluish gray mottles; also black stains in large channels and around trenches increased with age.

But what does intensity of mottling have to do with performance of a drainfield? It simply serves as an indication that regardless of natural drainage of soil, drainfields operate under strictly anaerobic conditions. A test of this can be made by taking a piece of dark bluish gray soil from the drainfield and exposing it to air. Reduced

Table 5. Effects of age on area of increase in mottling and area of high moisture.

Drainfield Symbol	Age	Loading rate l/m/day	Area of increase in mottling sq/meters	Area of high moisture sq/meters
W1	1	11.5	12	20
W3	4	12.5	93	153
WO	3	7.5	140	140
A1	1	7.0	52	276
C2	6	9.7	169	316
D	1	8.2	122	293

mottles change from bluish hues to grayish and sometimes yellowish brown hues in a matter of one to two hours. Similar changes of reduced mottles have been reported for soils in Iowa (Daniels et al., 1961). Coulter et al. (1961), in a study of 57 systems from Michigan to Tennessee, also noted that "discoloration" occurred around trenches.

Effect of age on movement of effluent through drainfields is illustrated by the number of square meters of high moisture content. W3 drainfield shows a seven-fold increase in both mottling and high moisture when compared to that of W1, which suggests that deterioration of pores has taken place. Effects of time on WO are best seen from data on water tables in Section I. Effluent was perched in WO drainfield but not in A1. C2 and D drainfields are strongly influenced by slow permeability, which overrides effects of time. C2 drainfield is intensely mottled, but the high moisture area is nearly equivalent in the one-year-old D drainfield.

Literature Review

Soil pores and channels found in trenches of drainfields are particularly susceptible to plugging by many different processes. In addition to swelling of clay particles, dispersion of aggregates, and entrapment of gas; effective porosity can also be reduced by construction practices (Coulter _et_ _al_., 1961), type of cations in effluent (Doering, [1965]), suspended solids (McGauhey and Winneberger, 1964), and microbial action. Earlier work on clogging (McCulla, 1945; Allison, 1947; Coulter, _et_ _al_., 1961; Jones and Taylor, 1965), indicates that biological action at the liquid-soil interface is the main cause of plugging. Allison (1947) demonstrated that under prolonged submergence (10-40 days) reduction of infiltration rates was due to dispersing of soil aggregates by microorganisms using bonding material as a substrate and/or by accumulation of cells, slimes, or polysaccharides. Gupta and Swartzendruber (1962) observed much the same phenomena, but stated that metabolic wastes of microbes rather than cells were responsible.

Sand-columns receiving aerated sewage were clogged more than those receiving deoxygenated effluent. Large growths of aerobic microbes in the aerobic treatment depleted O_2 and rendered the lower part of the column anaerobic. Ferrous sulfide accumulated beneath surface mats in both treatments as the infiltration rates declined. McGauhey and Winneberger (1964) concluded ferrous sulfide was a clogging agent and that the biochemistry of effluent rather than soil properties controlled infiltration rates. Mitchell and Nevo (1964) observed no correlation between ferrous sulfide build-up and reduction of infiltration rates. But effluent was not used in their work. Instead, a solution of ferrous sulfide, sulfur, and casein was added to sand-columns. Large quantities of polysaccharides produced mainly by strains of _Flavobacterium_ were thought to be the clogging agent rather than cells themselves. To refine the theory that polysaccharides were the main clogging agent, Avnimelech and Nevo (1964) found clogging that was reversible after draining lysimeters was due to polysaccharides without uronic acid residues and that stable clogging was the result of polyuronide build-ups. Thomas, Shwartz, and Bendixen (1966) verified Mitchell and Nevo's findings and added phosphate and organic matter to the list of clogging agents. An accelerated phase of plugging coincided with initiation of anaerobic conditions.

With exception of Coulter _et al_. (1961) and Bendixen _et al_. (1950), most of work on clogging has been done under laboratory conditions. Rate of clogging using an undisturbed soil was determined by Bolin (1967). After ponding effluent in small gravel trenches for two months "clogging" occurred. Examination of the test site after clogging revealed that gravel and tile were plugged, but not the soil. His findings cast some doubt on the validity of extrapolating results of lysimeter studies to drainfields.

Materials and Methods

Because most of the extensive work on the subject of soil clogging by sewage effluent has been carried out using laboratory sand-columns, an attempt was made to examine a drainfield microscopically in its natural state.

Of particular interest were pore distribution and any material in pores. In order to examine pores for any "foreign" material such as described in the literature, thin sections were made from samples taken at the effluent-soil interface, 20 cm away from a trench, and seven meters away from the influence of effluent. Before thin sections could be made, a method of impregnating soil in a moist state had to be worked out. This was done to prevent shrinking of pores, oxidation of iron, and dehydration of any organic matter.

Samples slightly below field capacity and air dry, varying in texture and permeability, came from Wapato and Concord soils. Samples of the B horizon of Wapato were silt loam in texture and moderately high in macropores. Concord samples were taken from the lower part of the B2 horizon (69-74 cm subhorizon, see page 46).

Small samples (2 x 4 cm) were soaked in acetone for two days prior to placing them in a dilute solution (three parts acetone to one part resin) Laminac[4].

The amount of catalyst recommended was reduced by half to allow a longer equilibration time between acetone in clods and resin which was added. To observe changes which might take place due to interaction between organic matter and acetone, water-saturated strings of macaroni were draped over clods after samples were impregnated; the procedure described by Norgren (1962) was used to prepare polished sections.

Wet and dry samples were completely impregnated. Effects which air drying had on pore sizes were best seen in Concord samples. Photomicrographs (Figure 21) of wet and dry impregnated Concord show that, as the thick clay skins dehydrated, pore size increased about 30 percent. Evidence for disturbance are cracks and matrix material which has been plucked loose as clay contracted.

A reaction between water saturated macaroni and acetone-resin solution reduced the diameter of macaroni by half and caused it to stiffen. Whether the alleged organic matter associated with clogging would react in such a manner is certainly not known. But based on this observation, shrinkage rather than disintegration would be

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[4] Cyanamid Corp., Stanford, Conn.

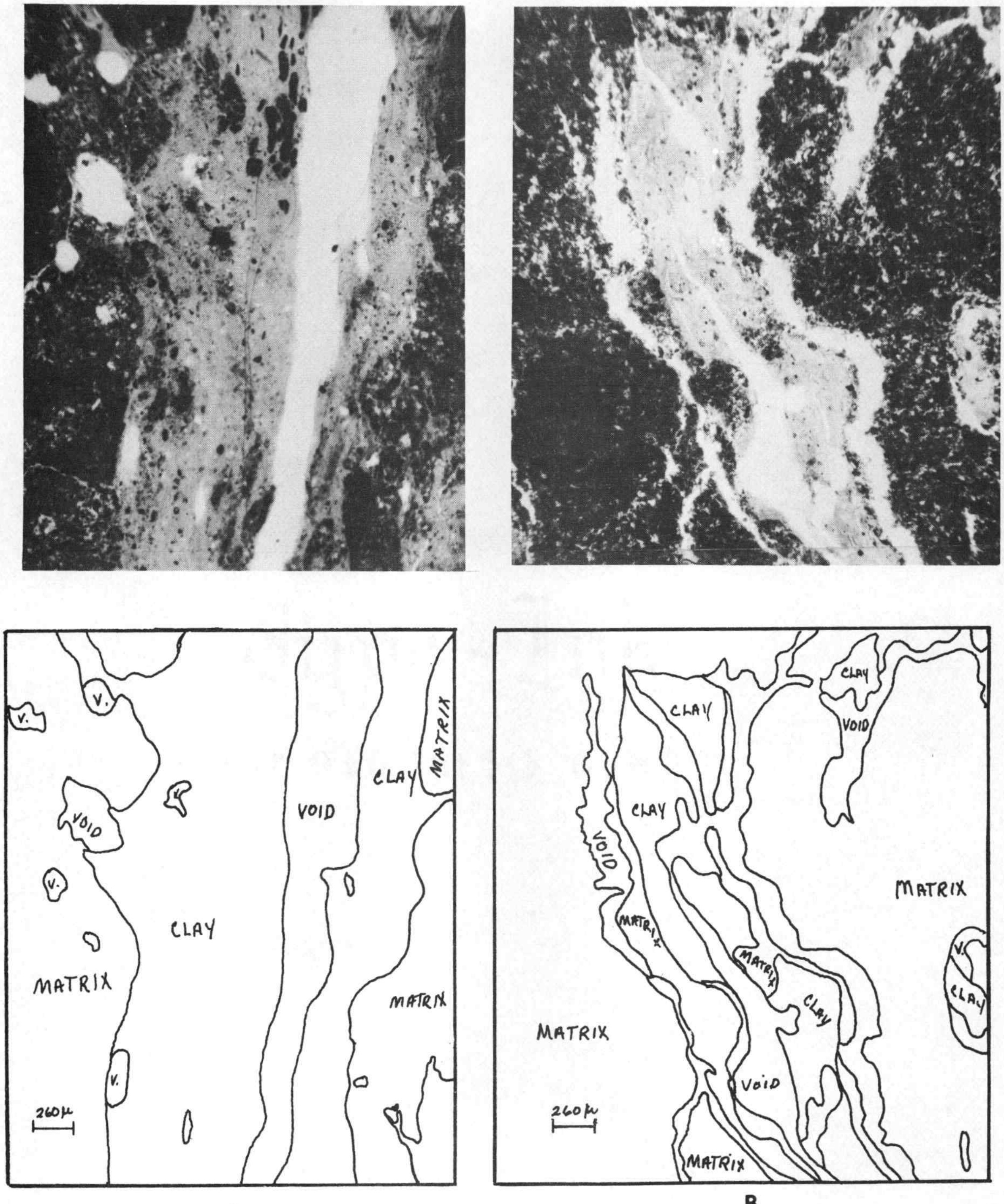

Figure 21. Photomicrographs of the B2t horizon of Concord. A was taken of a thin-section made of a wet impregnated clod. Very thick clay skins show no evidence of shrinking. However, in B, taken from a thin-section of an air dried clod, pronounced shrinking took place. Along edges of shrunken clay bodies is material which was plucked as the clay contracted.

expected.

The C1 drainfield selected for this part of the study has been in operation for three years, was continuously wet, and had black stains along major channels around trenches. It was thought that agents causing clogging should have been present in the C1 drainfield. Horizons for thin sections of the A2, IIB1, IIB2t, and IIIC near a trench were collected by digging a pit parallel to trenches and carefully removing a large block of soil which included the top and side of a trench. Samples away from the influence of effluent were taken from a shallow pit with a five cm diameter push-tube.

Results and Discussion

Despite good success in wet impregnation with a limited number of clods, some serious difficulties were encountered with samples from drainfields. Clods as they came from C2 drainfield were saturated. They were given less than two hours to drain before being immersed in acetone. Larger clods than those in preliminary testing were collected to reduce the possibility of disturbing pores. The saturated A2 horizon in Concord was particularly susceptible to slaking.

Centers of large clods, where water had not been replaced by acetone, were not impregnated. In some sections, as in Figure 22, unimpregnated material remained on the thin section. Figure 22 also

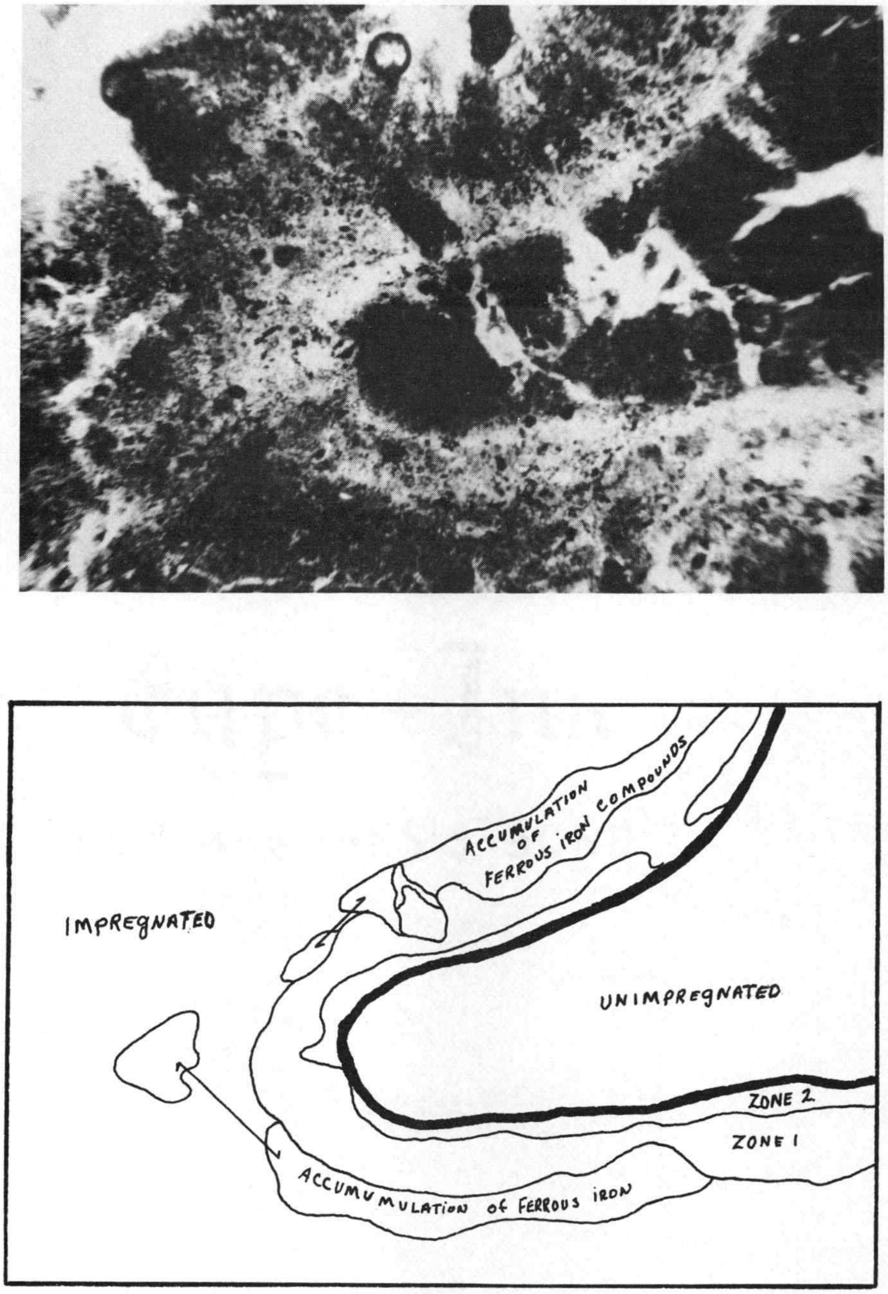

Figure 22. Partially impregnated thin-section of B2t horizon of Concord from 20 cm. away from trench, demonstrating that ferrous iron compounds have been moved during the impregnation procedure. Accumulations of ferrous iron were bordered on the side toward unimpregnated soil by a bleached zone (Zone 1). Between the bleached zone and unimpregnated soil was an area (Zone 2) of pale green amphorous bubbles.

demonstrates a feature which prevents extrapolating the interpretation of ferrous iron compounds in thin sections to actual drainfields. Surrounding the unimpregnated centers of clods taken from a trench interface and from 20 cm away was a black zone. These rings were thought to be colloidal ferrous iron compounds which were either dissolved by the acetone - resin solution and precipitated, or physically moved along a wetting front. Since ferrous iron compounds have obviously been moved during the impregnation procedure, nothing can be said from thin sections concerning whether these compounds were plugging pores.

Thin sections transecting black zones all had in common the relationship shown in Figure 22. Two zones besides the black one were present on the side of the black zones next to unimpregnated soil. Zone one was lighter in color than the soil matrix and graded from darker colors next to black rings to very light next to zone two. Zone two consisted of pale-green amphorous bubbles. The same type of bubbles were present in all samples impregnated wet, but not in dry samples, which suggests they are a result of a reaction between water and the impregnating solution. This type of bubble is not to be confused with the amorphorous pale-green bodies described by Norgren (1962, p. 47). Those amorphorous bodies differ from bubbles in the resin by not being as spherical and having a higher percentage which are slightly birefringent.

Another laboratory phenomenon which prevented thin section analysis of pores is the disruption that took place when A2 and B21 samples were placed in acetone. Breaking up of soil aggregates could be a function of the low viscosity of acetone or it could be the result of acetone destroying bonding material. Disturbance in A2 horizon samples was especially pronounced.

Thin sections of effluent-soil interfaces in Concord samples which did not show signs of being disturbed contain no detectable accumulations of organic material. Field observations of interfaces of all nine systems studied showed no evidence of organic matter build-ups described in sand-lycimeter studies. A noticeable black-blue zone at the interface, gradually becoming dark bluish gray 6-10 cm away from the interface, was present in all systems older than three years. Trench gravel had jet black coatings of what were presumed to be colloidal compounds of ferrous sulfide. Similar coatings were observed in large pores of the A2 horizon. Coatings were not consolidated. They easily washed off stones and soil as colloidal-sized particles.

Summary of Age Effects

Newer and older drainfields (W1-W3, A1-WO, and D-C2) were matched according to soil characteristics. W3 drainfield was three years older than W1 and had seven times more area influenced by effluent than W1. WO drainfield was two years older than A1 and had water continuously perched on top of the B horizon, whereas A1 did not. C2 drainfield was five years older than D, but area influenced by effluent was the same. Evidence from comparing and A1-WO drainfields suggested clogging of soil pores was taking place. A claypan at D and C2 drainfields was the predominant feature influencing their performance.

Attempts to see what factors were causing pores to clog met with serious difficulties. Impregnating clods in a moist condition can be accomplished by replacing moisture with acetone over a two-day period and then placing them in acetone-resin solution. For saturated clods, however, only the outer few centimeters of clods were impregnated. Samples which have weak structure in a moist-to-saturated condition tended to slake when placed in a dilute solution of acetone and resin. Disruption of pore network and relocation of colloidal ferrous iron compounds prevented evaluating the role iron plays in clogging.

All observations on drainfields suggest that under field conditions ferrous iron compounds are responsible for clogging. From thin section analysis, no slimes or other organic accumulation were observed in A2 horizons or along effluent-soil interfaces.

III. EFFECT OF WATER TABLE ON DRAINFIELD PERFORMANCE

Western Oregon's pronounced dry-wet climate makes the contrast between summer and winter drainfield performance particularly striking. Frequent low intensity rains begin in October or November and continue through March. An average of 93 cm of precipitation falls in the vicinity of Corvallis during the rainy season. Water table fluctuations in soils on the valley floor terrace, which have been studied in detail by Boersma and Simonson (1969), are characterized by a steep rise during November and December with a peak in January followed by a steady decline through March and April.

As the water table rises in a drainfield, the chances of contaminating wells and surface water is increased. A study of an infectious hepatitis outbreak in Posen, Michigan, revealed that the first cases of the epidemic were from homes having wells two meters from septic-tank lines. Most of the village wells were poorly constructed and could not keep out surface water (Vogt, 1961). Of the 3,885 cases studied where ground water was used as a water supply, 20 percent of water-borne diseases were due to over-flow or seepage of sewage into wells (Weibiel et al., 1964). From well water studies, 21 percent (Woodward, 1961) of the total number tested contained synthetic detergents. Above a certain concentration, detergents give an off-taste to water, but the main concern over their presence in water has been their relationship to viruses (Nichols and Koepp, 1961).

How much distance is required between drainfield tile lines and a water table in soils other than relatively pure sand is still an unanswered question. Some idea of maximum drainfield efficiency, hence optimum distance, can be obtained by gleaning the literature. This study did not attempt to seek an answer for the soils studied. However, effort was directed toward measuring lateral movement of effluent when drainfields were flooded by a rising water table. To measure movement that might have occurred, density of micro-organisms was selected as an indicator of contamination rather than chemical measurements. The main reason for this being that many reports on travel of sewage in ground water show chemicals travelling further than "biological" contaminants (Grotas, 1954). Until very recently, "biological" contamination, for the most part, has meant that water contained coliform organisms. Fecal coliforms are as good an indicator for bacterial pathogens as is available (Gelderich, 1966), but are in question as an indicator for viruses. Methods for determining their density are relatively simple and accurate, whereas assays for viruses are both expensive and difficult.

Most of the discussion and research on coliforms has centered on their significance in domestic water supplies. Interest in their occurrence in soil has been somewhat indirect. For this study, their density was determined in and away from drainfields during winter months to aid in evaluating drainfield performance.

Literature Review

Very little has been reported in the literature on the efficiency of actual drainfields. The only research to draw on has been carried out using domestic sewage in sand-lysimeters. Much caution has been employed in interpreting results of such studies. Well graded sand is not normally used for drainfields. Rather, soil with higher clay content and a more tortuous network of pores and channels serves as a filter. In many studies, secondary effluent from municipal treatment plants has been used instead of septic-tank effluent.

The one factor which makes interpreting sand studies difficult is the difference in gas movement in laboratory models versus soil. When sand-columns are drained, aerobic conditions probably return rather quickly. Air movement in subsoil horizons is slow and even slower under drainfield conditions. Moisture content around trenches is higher than in surrounding soil, causing a reduction in total pore space available for air movement. Also, gases exuding from trenches such as methane and hydrogen sulfide, could effectively prevent air from entering drainfields either through soil or the plumbing.

Laboratory and surface spreading studies carried out in the presence of sunlight undoubtedly have a different microfauna than drainfields. The fact that some microorganisms are sensitive to light (Berg _et al._, 1966) and others require light (Ewing _et al._, 1961) is enough to suspect some differences.

Since major differences exist between sand-column and drainfield performance, results of several studies are presented to show what could be expected if drainfields were made of sand, an idea which has been proposed by Huddleston and Olson (1967).

Ninety to 175 cm sand-columns intermittently dosed with well aerated sewage effluent produced coliform-free water, greatly reduced BOD[5], removed 90 percent of suspended solids, and degraded two of three synthetic detergents (Greenberg and Thomas, 1954; Klein and McGauhey, 1964). Under anaerobic conditions, 90 cm of sand gave variable removal of coliforms, poor reduction of BOD and suspended solids, and removed two out of three detergents (Orlob and Bulter, 1955; McGauhey _et al._, 1959). Significant findings of these studies are that aerobic processes are more efficient than anaerobic and that 90 cm of aerobic sand is an efficient medium for treating effluent.

Under field conditions and long term testing (19 months), McKee and Michael (1964) substantiated results of aerobic studies and found

[5] BOD - biological oxygen demand.

complete removal of virus after effluent had percolated 50 cm.

Instead of using sand-columns, Bolin (1967) used an undisturbed Miami silt loam soil profile as a filter for surface applied effluent. After 150 vertical cm, the effluent concentration of BOD, suspended solids, ammonia, phosphorus, and potassium was reduced 75 percent, of which half occurred in the first 20 cm.

Fuller (1948) used fecal coliforms as a measure of septic-tank and drainfield performance. Samples taken 60 and 150 cm away from experimental drainfields showed high numbers of non-fecal coliforms while those taken from tile lines had high fecal coliform counts. He suggested that the physiology of fecal coliforms was altered in their journey through soil, causing them to give reactions identifying them as non-fecal coliforms.

The question of whether fecal coliforms are a good indicator of drainfield performance rests on their die-off rate relative to that of pathogenic organisms originating from septic-tanks. Unfortunately, survival time of all of the organisms reported to be transmitted by water has not been tested in soil. The only disease-causing virus that is known to be transmitted in ground water is that of infectious hepatitis (Vogt, 1961; Clarke and Kabler, 1964). Its survival period in drilled wells is at least 10 weeks (Kabler, 1962). *Salmonella typhosa* can survive in "natural soil" in large numbers for five days in sandy soil and 19 days in clay soil (Mallmann and Litsky, 1951).

Survival of _E. coli_ (a member of fecal coliform group) in soil, depending on conditions, can be anywhere from several months to two years (Mallmann and Litsky, 1951). At any rate, under comparable conditions, _E. coli_ lives longer than most water-borne pathogens. Since fecal coliforms do outlive pathogens, they are considered to be a good indicator of fecal contamination.

Materials and Methods

Except for W1 and W2 drainfields, all systems observed in this study appeared to be anaerobic for some distance away from trenches throughout the year. To further study the moisture regime of drainfields, water tables were measured during the wet and dry seasons. Three kinds of observation wells were established; one kind in the active part of drainfields, one kind five to six meters outside drainfields, and remote wells located away from cultural features such as roads, ditches, and houses.

Perforated 8 x 150 cm down-spouting was used to prevent sidewalls of observation wells from collapsing. In the case of Concord and Dayton soils, where perched water tables exist, one well was installed above the claypan and another below it. Readings were taken weekly for nine months. Location of water table wells away from cultural influences are shown in the Appendix (map). Symbols for wells in and near drainfields appear in diagrams shown in Part I (Figures 8-10, 12, 14, 15, 17, 19, 20).

Water samples for coliforms were collected from the same wells used in water table measurements. Samples were collected in sterile 100 ml jars. Standard tests (Standard Methods, 1965) for coliforms were begun the same day of sampling. The elevated temperature test, at 44.5°C, was used to separate fecal from non-fecal coliforms.

Results and Discussion

Water Table Fluctuations

Differences in water table draw-down between wells four meters away from drainfields and remote wells located away from roads, ditches, and houses (Figure 23) are probably more a function of how these sites were selected than actual effects of cultural features. Wells just outside drainfields were placed where they would intercept lateral ground water movement. They were in slightly lower positions than the soil surface in the adjacent drain-fields. In some cases, this difference in elevation was only 5-10 cm; in others, asmuch as 15-20 cm. In choosing the remote well-sites, depressions in micro-relief were avoided as much as possible. Hence, Figure 23 could be interpreted as some measure of the difference in water tables within a given series. Very little can

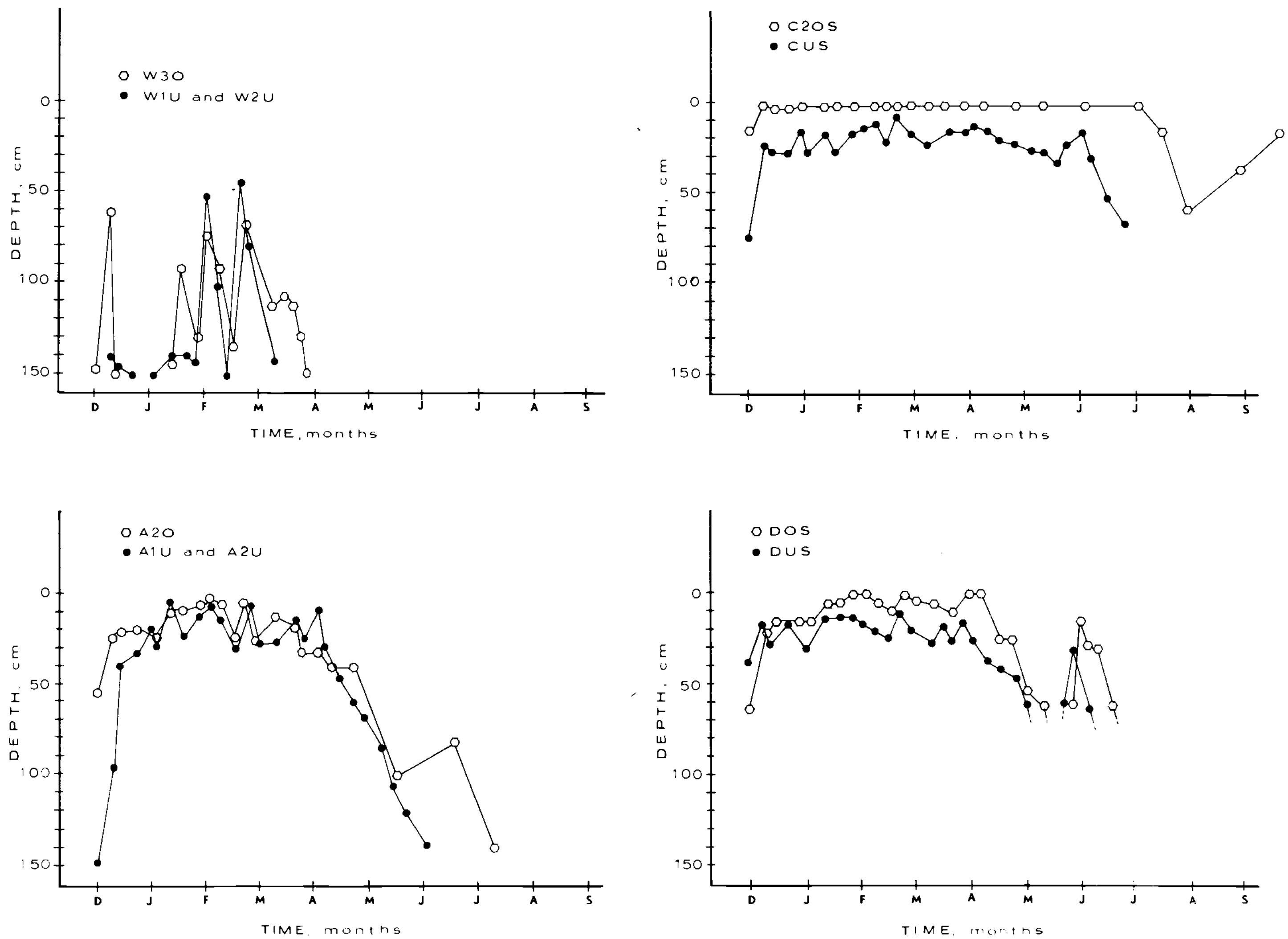

Figure 23. Comparison of wells located 5-6 meters from trenches (hexagon) with those remote from the influence of cultural features such as roads, houses, and ditches (dot). Definitions of symbols are given in the Appendix.

be said about the magnitude of this difference. All water table sites outside drainfields except C20S, responded similarly to sites studied by Boersma and Simonson (1969). Site C20S was in a slight depression where effluent and surface water collected.

Water levels in the active part of drainfields were distinctly different than in areas 5-6 meters away. They were perched rather than being continuous during spring and summer (Figures 24 and 25). Water table data for drainfields are further evidence that even in soils with good natural drainage, drainfields were anaerobic. Only in young systems (A1, W2, and probably W1) did water tables in drainfields act similarly to wells outside. After several years, water table fluctuations of these systems can be expected to be similar to those in WO drainfield. Evidently, clogging of the top of the B2t horizon over the course of three years has caused perching in WO drainfield.

These data also illustrate that study sites do represent a wide range of drainage conditions. Wells at W2 drainfield did not have a water table within 150 cm of the surface while C2 drainfield had water at the surface for six months.

Coliform Density

Wells used for measuring water tables also served as sampling points for coliform tests. As a preliminary caution, coliforms were

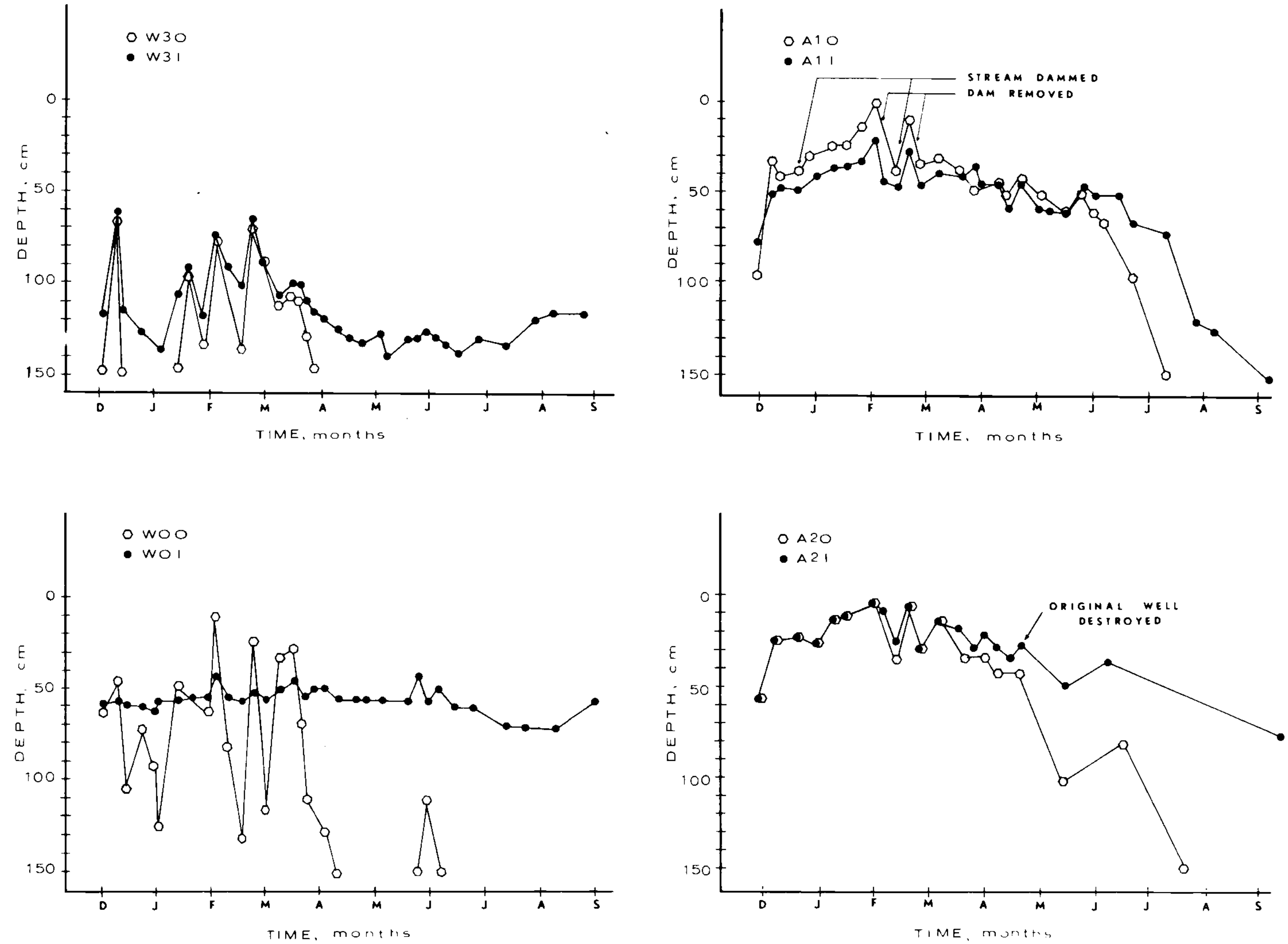

Figure 24. Comparison of wells 5-6 m. away from drainfields (hexagon) with those located in the active part of drainfields (dot). Water levels near A1 drainfield were affected by a small dam placed across a stream 4 meters away.

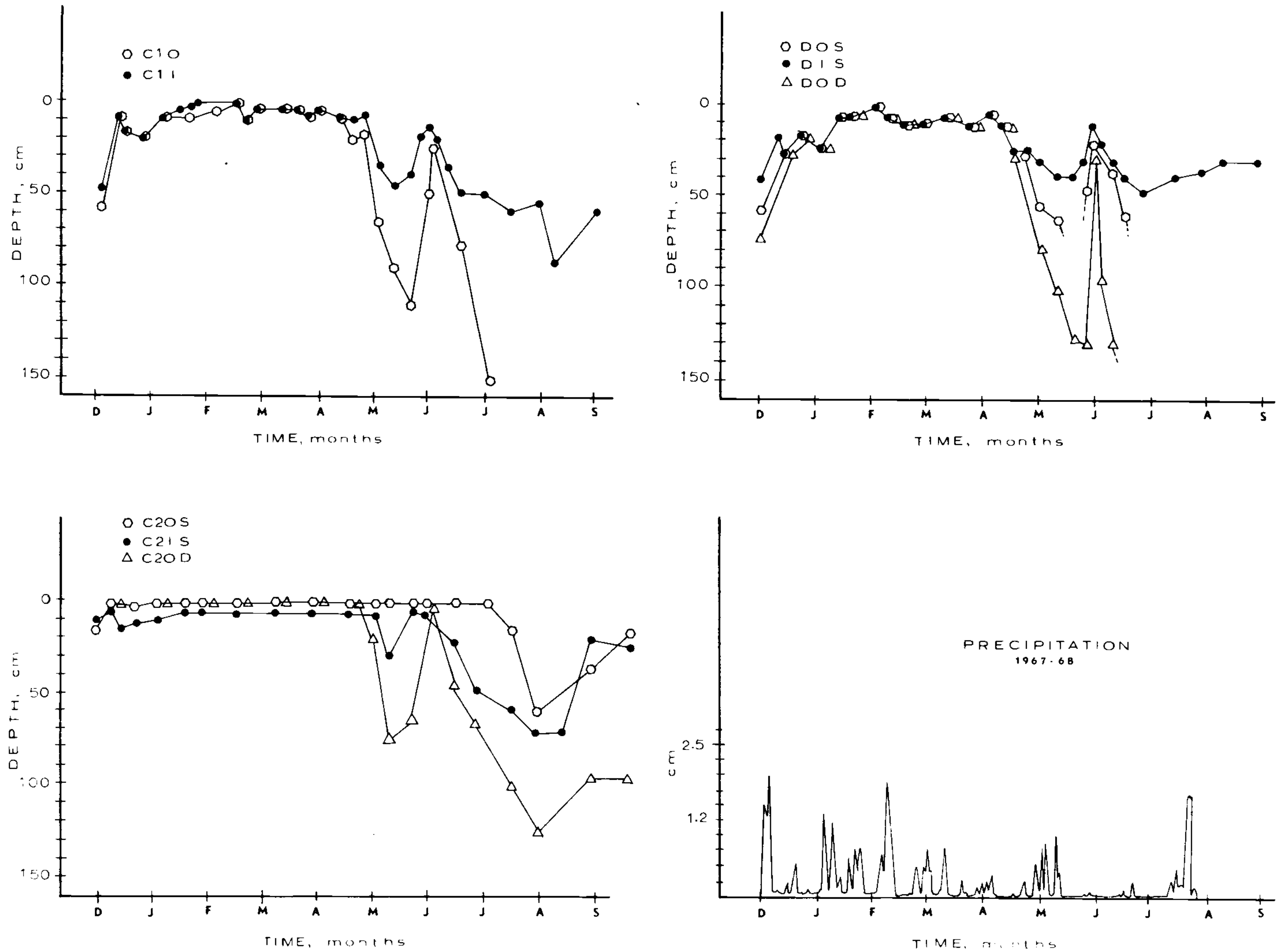

Figure 25. Comparison of wells 5-6 meters away (hexagon) from drainfields with those located in the active part of drainfields (dots). Precipitation data were taken from U. S. Dept. of Commerce, Climatological Data, Vol. 17-18.

run under laboratory conditions in order to determine whether the metal down-spouting had a toxic effect on coliforms. Tests were run on effluent which had been placed in contact with new galvanized pipe in the laboratory. Table 6 shows that no effect other than normal die-off was observed.

Table 6. Coliform concentrations in contact with galvanized pipe.

	Exposure time	Fecal coliform MPN/100 ml
Control	1 day	91,800,000
	4 days	2,400,000
Pipe 1	1 day	54,200,000
	4 days	3,480,000
Pipe 2	1 day	54,200,000
	4 days	1,720,000

A summation of coliform densities for all sites having a water table throughout the winter months is shown in Table 7. Average total coliform densities were higher or equal to fecal coliforms which agrees with Geldrich (1966). Also, the magnitude of total and fecal coliforms corresponded very closely to his figures for "polluted soil" (p. 88) samples. Although there was a great deal of variation between samples from in and near drainfields, roughly one-quarter to one-third of the total coliforms were of fecal origin.

Coliform concentrations were a hundred-fold lower in remote

Table 7 Coliform concentrations for water from the active part of drainfield (I), 5-6 meters away (D) and remote wells (U). MPN/100 ml.

Site	12/24/67 Total Coliforms	12/24/67 Fecal Coliforms	3/25/68 Total Coliforms	3/25/68 Fecal Coliforms	3/29/68 Total Coliforms	3/29/68 Fecal Coliforms	4/19/68 Total Coliforms	4/19/68 Fecal Coliforms	Average Total Coliforms	Average Fecal Coliforms
W3I	1,850,000	1,850,000	54,200	54,200	172,000	2,000	240,000	240,000	579,050	536,550
W30	dry		54,200	54,200	dry		dry			
W0I	8,900	0	49,000	8,000	34,800	2,100	79,000	4,000	42,925	1,725
W00	55,000	1,000	22,100	0	130,000		dry		69,050	500
A1I	63,000	14,000	221,000	34,000	918,000	278,000	348,000	330,000	387,500	164,000
A10	48,800	1,150	240,000	240,000	278,000		172,000	33,000	184,700	91,383
A2I	1,720,000	1,090,000	700,000	20,000	240,000	1,700	542,000	542,000	800,500	168,170
A20	240,000	240,000	22,000	7,000	542,000	2,000	79,000	79,000	220,750	82,800
A1U	950	200	46,000	0	0	0	490	220	11,860	105
A2U	2,450	2,450	34,800	34,800	172,000	172,000	348,000	348,000	139,312	139,312
C1I	155,000	70,000	17,200	0	54,200	1,700	141,000	141,000	94,350	53,122
C10	49,000	1,700	17,200	0	17,200	0	4,900	4,900	22,075	1,650
C2IS	330,000	35,000	600	0	4,900	200	33,000	10,900	92,125	11,520
C20S	2,714,000	16,000	91,800	91,800	240,000	240,000	918,000	918,000	900,950	316,450
C20D	7,000	200	0	0	800	200	21,000	21,000	7,200	5,350
C2US	330,000	330,000	2,300	200	2,300	200	1,720	1,720	84,080	83,030
C2UD	1,700	0	800	0	2,300	0	330	330	1,202	82
DIS	2,300,000	40,000	91,800	800	542,000	2,000	49,000	49,000	745,722	22,950
DOS	7,900,000	0	70,000	7,000	278,000	175,000	490	220	2,012,125	45,555
DUS	49,000	0	7,900	2,700	13,000	3,400	10,900	10,900	20,200	4,250
DUD	17,000	0	0	0	0	0	330	330	4,332	82
Averages:										
In	903,843	314,142	347,475	15,685	280,842	41,100	204,571	181,114		
5-6 meters away	649,433	43,158	73,900	35,285	247,533	104,250	234,880	207,024		
Remote	79,730	66,040	11,400	580	3,500	720	2,755	2,700		

wells than those near drainfields, which strongly suggests that the influence of effluent goes farther than 5-6 meters from drainfields. To investigate this possibility, samples were collected at several times from 1.5 meter deep wells located at six different distances around the A2 drainfield. Distances from the drainfield varied from 7.5-100 meters. Seven sampling wells were located in a semicircle at each distance interval, i.e., seven sampling wells at 7.5 meters, seven sampling wells at 15 meters, etc. The results are presented in Table 8. Data for 3-25-68 shows a decrease in both total and fecal coliform counts with increasing distance from the drainfield. At 100 meters, fecal coliform concentrations were at levels comparable to those sites not influenced by excreta of domestic livestock (AIU, C2UD, DUD). Counts for 3-29-68 and 4-3-68 from around A2 drainfield show a high proportion with no fecal coliforms. The same was true for the 3-29-68 test shown in Table 7. One possible reason might be that fecal coliforms from drainfields are sensitive to temperatures slightly above 44.5°C. For all coliform tests on 3-29-68, the first eight hours of incubation was carried out in an oven before they were placed in a water bath. Temperature of the oven varied from 49°C to a low of 38°C.

Referring to Table 7, wells within W3, WO, A1, A2, and C1 drainfields all have higher fecal coliform densities than those wells 5-6 meters away. This evidence and the 3-25-68 sampling around A2

Table 8. Coliform concentrations at increasing distances around A2 drainfield.

Distance from drainfield	3/25/68		3/29/68		4/3/68	
	Total coliforms	Fecal coliforms	Total coliforms	Fecal coliforms	Total coliforms	Fecal coliforms
7.5 m	5,420 000	4,900,000	141,000,000	2,000,000	9,400,000	0
15.0	17,420,000	10,900,000	330,000	0	1,700,000	0
30.0	221,000	221,000	490,000	0	1,300,000	2,000
45.0	221,000	172,000	1,410,000	0	2,400,000	0
60.0	34,800	34,800	1,609,000	0	330,000	0
100.0	17,200	800	2,400,000	0	200,000	0

drainfield would be support for fecal coliforms as an indicator of contamination by drainfields. Two factors, however, need to be kept in mind when interpreting fecal coliform counts. The increase in fecal organisms with time at AII, A2U, and C20S sites could be evidence that coliforms reproduce when a constant supply of organic matter is present. McKee and McMichael (1964) found that coliforms reproduced in soil receiving effluent. Most investigators have assumed that these organisms do not normally reproduce in soils. A second possibility is that when organisms enter drainfields the lower temperature (13^{o}C) of ground water slows down metabolism of microbes to a point where their survival is increased. Build-ups from December to March could represent an accumulation of those fecal coliforms that are in a quiescent state. Without knowing how much the concentration of organisms was diluted by ground water, it is impossible to say whether counts represent reproduction, accumulation from survival, or both.

The second observation reflecting on the use of coliforms as an indicator for drainfield performance is the high counts obtained from some remote areas. Site A2U was located near a pasture field containing 50 to 75 sheep; C2US was 0.3 kilometers below a field where several horses were kept; and DUS was 0.6 kilometers from the nearest field containing large animals. All of these wells had counts comparable to those located 5-6 meters away from drainfields.

Summary of Water Table and Coliform Measurements

According to published data, aerobic sand-columns are more efficient than anaerobic ones and 90 cm of aerobic sand is effective method of treating effluent.

The difference in water table fluctuation between wells 5-6 meters away from drainfields and the remote wells are thought to reflect the amount of variation that can be expected within the soil series studied. Wells 5-6 meters away from drainfields were in concave positions whereas remote wells were in convex positions in the microrelief. Wells at 5-6 meters distance were used as reference points in studying water table fluctuations within drainfields. Water levels in the active part of drainfields were mostly perched and presisted longer. The water table data plus mottling are evidence that even in naturally well drained soils, drainfields are anaerobic.

Fecal coliforms constituted one-fourth to one-third of the total coliform counts. Where the nearest large animals (e. g., sheep, cows, and horses) were further than 1.2 kilometers away or where water was collected from below a claypan, fecal coliform counts were a thousand-fold lower than those in and near drainfields. Wells, A1U, C2UD, and DUD, which were considered to be unaffected by fecal contamination, had counts of less than 1000 fecal coliforms/ 100 ml. The possibility of fecal contamination from livestock must be considered in interpreting fecal coliform density. Excreta entering ground water from pasture fields can give counts as high as those a short distance from drainfields. Sampling at increasing distances from A2 drainfields, indicated that fecal coliforms reached a level comparable to remote wells at a distance of 100 meters.

IV. CONCLUSIONS

Permeability

The double tube method for ranking soils according to their infiltration rates appears to be superior to the Public Health Service test for hydraulic conductivity measurements. Erosion from sidewalls of PHS test holes and subsequent clogging of pores was responsible for some of the variation. When the build-up of sediment was reduced, results from PHS test were improved but still variable. The Dayton B2t horizon which has a clay texture and is massive when wet had an average infiltration rate by the PHS test, quite different from the Bashaw clay subsoil. From their morphology, the permeabilities for Dayton B2t horizons and Bashaw subsoil horizons would be expected to be nearly the same. Results from double tube tests showed them as such.

Infiltration rates from the double tube method correlated better with drainfield performance than K values. Drainfields in Willamette (W1, W3), Woodburn (WO), and Amity (A2) soils all had about the same hydraulic conductivity, but performance of the drainfields differed. Hydraulic conductivity by the double tube method measures the resistance water encounters in a direction that is unnatural. K values are calculated from water flow that occurs in a U-shaped pathway between two tubes.

In all drainfields studied, except those in Willamette soil, effluent moved laterally in porous A2 or B1 horizons until there was no more gradient to move liquid, until it was absorbed in B2 horizons, used by plants, or combinations of these. Effluent slowly percolated downward into the B horizons of Woodburn (WO) and Amity (A1) soils. Very little effluent was absorbed by the B horizons in Amity (A2), Concord (C1, C2), and Dayton (D) soils. In the latter soils, vegetation was an important mechanism of removing water.

Effluent entering drainfields in Willamette (W1, W2, W3) soils moved mostly vertically through the lower part of B2 horizons. Infiltration rates determined near the bottom of the B2 horizon at W3 site were higher than those for B horizons of soil near other drainfields.

Age

Effects of time were most easily seen in the increase in the area of reduced mottles. Dark bluish gray mottles and also black stains in large channels were present around trenches in drainfields three years and older. After one year in service, only dark gray (10YR 4/1) mottles were associated with trenches. Newer and older drainfields (W1-W3 and A1-WO) were matched according to soil characteristics. W3 drainfield had been in operation three years longer than W1. Seven times more drainfield area was used by W3 to dispose of roughly the same amount of effluent that was handled by W1 drainfield. WO drainfield was two years older than A1 and had water continuously perched on top of the B horizon, whereas A1 drainfield did not.

All field and laboratory observations failed to show any accumulation of organic "mats" at effluent-soil interfaces similar to those reported in previous studies. Large amounts of presumably ferrous iron compounds in effluent and in soil around trenches support McGauhey and Winneberger (1964) findings that compounds of ferrous iron are in part responsible for clogging of pores. Clogging of this nature is most likely occurring in the A2 or B1 horizons and the top of B2t horizons.

Water Table

The vertical distance tile lines in drainfield should be placed above a water table is not known for soil. From published data, 90 cm thick layer of aerobic sand is an effective method of treating effluent. It is also known that anaerobic sand-columns are not as efficient as aerobic ones. Water table fluctuations measured in the active part of eight drainfields along with the presence of reduced mottles conclusively show that drainfields are anaerobic systems.

In drainfields built in Amity (A2), Concord (C1, C2), and Dayton (D), water level fluctuation below tile lines make very little difference in performance. Very little effluent was moving through the B horizons of these soils. The same cannot be said for drainfields in Willamette (W1, W2, W3), Woodburn (WO), and Amity (A1). Effluent left trenches either by passing through the B2t horizon or by going through the B1 or A2 horizons and spreading over the B2t before percolating downward. In these soils, the lower the water table, the faster liquid is likely to move through the B2t.

Contamination of ground water by septic-tank effluent, as determined by fecal coliforms, has to be interpreted with caution. Fecal coliform densities in ground water coming from pasture fields having domestic livestock were as high as those 5-6 meters away from drainfields.

Fecal contamination in the winter around an Amity (A2) drainfield was detected in ground water near the surface of the soil 100 meters away. When this is contrasted with the relatively minor area affected by effluent during summer months, the importance of having ground water levels below drainfield tile lines is evident. Instead of 150 square meters needed for a drainfield, 15, 000 square meters were needed when the water level rose above tile lines.

All the factors studied, permeability, age, and water table, had an affect on drainfield performance. When the B2t horizons of soil had low infiltration rates, the only noticeable effect was an increase in the area of intensely mottled soil. When the B2t horizons had high infiltration rates, age caused an increase in the area needed to dispose of effluent.

If failure is defined in degree of health hazard, then age and permeability of the drainfields studied are of minor importance when compared to water table fluctuations. Percentage of time that water levels are above tile lines is the most important factor causing contamination of ground water and surface water in the drainfields studied. Effluent slowly spread laterally where it could have entered domestic water supplies and streams.

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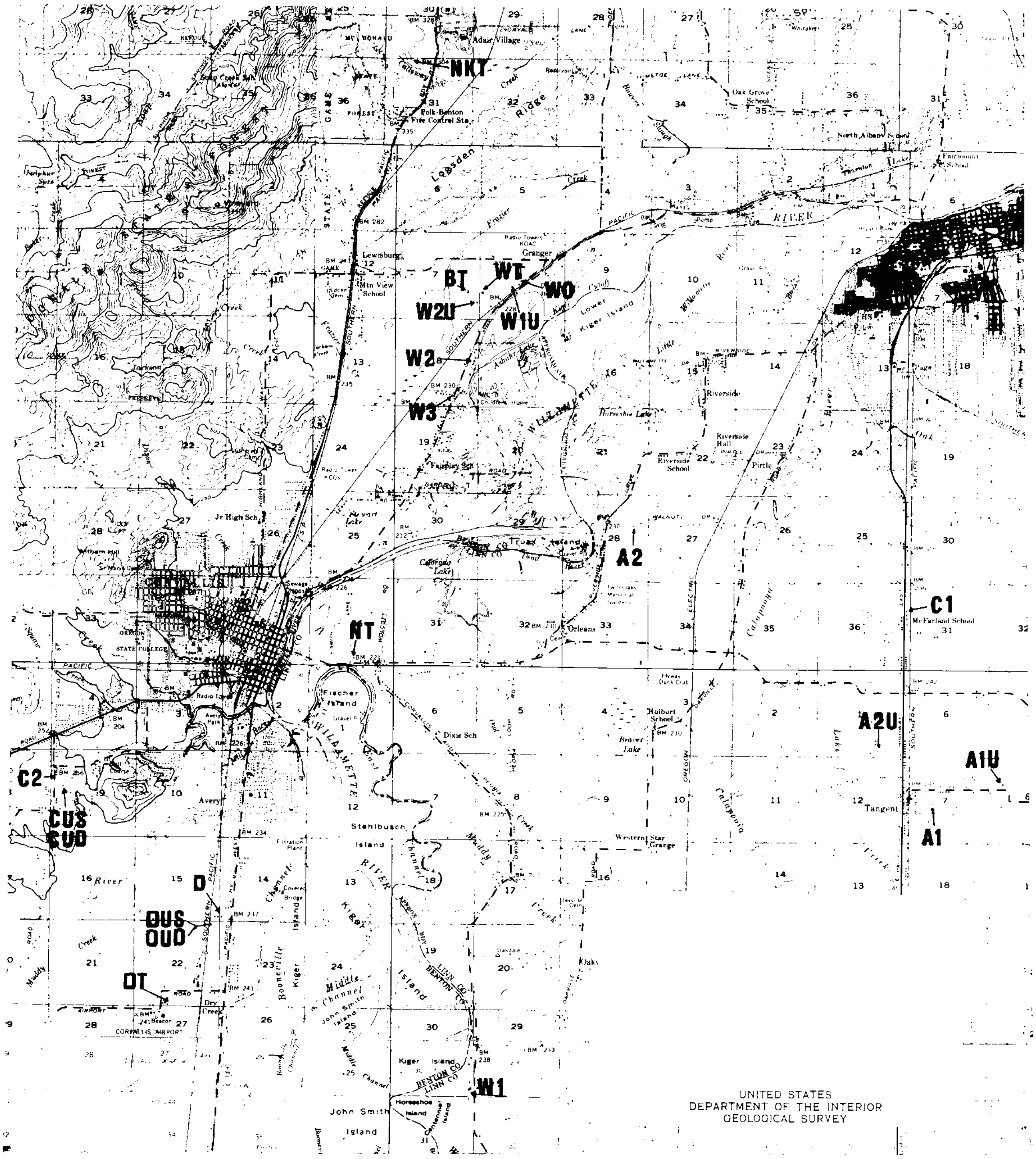

Map. Location of drainfields, water table wells, and sites for testing methods of determining permeability.

DETAILED DESCRIPTIONS OF SOILS STUDIED

Amity

Ap	0-17 cm. Very dark grayish brown (10YR 3/2) silt loam; 10YR 5/2 dry; moderate, fine, granular structure.
A12	17-47 cm. Very dark gray (10YR 3/1) silt loam; 10YR 5/2 dry; moderate, medium, subangular blocky structure; common, fine, distinct 7.5YR 4/4 mottles.
IIA2	47-70 cm. Dark gray (10YR 4/1) silt loam; 10YR 7/1 dry; weak, medium, subangular blocky structure; common, medium 7.5YR 4/4 mottles and concretions, very friable.
IIB2t	70-85 cm. Dark grayish brown (10YR 4/2) light silty clay loam; moderate, medium, subangular blocky structure; thin clay skin, many, fine and medium, distinct 10YR 5/1 mottles; common, medium concretions; few, black stains on ped surfaces, 15% of peds are brittle.
IIC	85-90+ cm. Dark grayish brown (10YR 4/2) silt loam; massive; thick clay skins in large pores; coarse and medium, distinct 10YR 4/4 and 10YR 5/1 mottles.

Colors are for moist conditions unless otherwise noted.

Location: 1/4 mile east of Tangent, SW 1/4, NW 1/4, Section 8, T 12S, R 3W.

Slope: 1-2% Date: 9-14-68 Described by: Steve Wert

Bashaw - BT

A11 0-17 cm. Very dark gray (10YR 3/1) clay; dark gray (10 YR 4/1) when dry; moderate, medium, and fine subangular blocky structure; very hard; firm; very sticky; very plastic; many, fine, distinct yellowish red (5YR 4/6) mottles; abrupt smooth boundary (0-10 cm thick).

A12g 7-37 cm. Black (N2/) clay; very dark gray (N 3/) when dry; massive when wet, but weak coarse prismatic breaking to weak coarse angular blocky structure when moist or dry; very firm; very hard; very sticky; and very plastic; common very fine roots; many very fine pores; few, fine, distinct yellowish red (5YR 5/6) mottles; common, fine, red and black concretions; few small slickensides; clear smooth boundary (15-37 cm thick).

A13g 35-77 cm. Black (N 2/) clay; very dark gray (N 3/) when dry; massive; very hard; very firm; very plastic; and very sticky; few, fine, distinct, yellowish red (5YR 4/6) mottles; few slickensides; few, very fine roots; few, very fine pores; common, fine, red and black concretions; gradual smooth boundary (35-50 cm thick).

C1g 77-110 cm. Very dark gray (N 3/) clay; dark gray (N 3/) when dry; massive; very hard; very firm; very sticky and very plastic; common, medium, faint, light olive brown (2.5Y 5/6) mottles; common, large slickensides; common, fine, light colored fragmants; few roots; few, very fine pores; neutral (pH 7.0); abrupt smooth boundary (25-50 cm thick).

C2g 110-150+ cm. Dark grayish brown (2.5Y 4/2) clay; light brownish gray (2.5Y 6/2) when dry; massive; very hard; firm; sticky; and plastic; many, medium, distinct, strong, brown (7.5YR 3/2) and dark reddish brown (5YR 3/2) mottles and few mediuml faint dark gray (N 4/) mottles; common, very fine pores.

Tentative Series
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Concord

Ap	0-22 cm. Dark gray (10YR 4/1) silt loam; 10YR 5/2 dry; moderate, fine, granular structure; many, distinct, fine 7.5YR 4/4 mottles; abrupt smooth boundary.
A2	22-40 cm. Dark grayish brown (10YR 4/2) silt loam; 10YR 6/1 dry; weak, medium, subangular blocky structure; very friable; common, medium, distinct 10YR 4/4 and 10YR 5/1 mottles; few, black stains on ped surfaces; abundant concretions; few, thin 10YR 3/3 clay skins in pores; clear, smooth boundary.
IIB1	40-58 cm. Dark grayish brown (10YR 4/2) silty clay; moderate, medium, subangular blocky structure; many, fine, distinct 10YR 4/4 mottles; abundant concretions; friable; thin 10YR 3/3 clay skins in pores; clear, smooth boundary.
IIIB2t	58-74 cm. Dark brown (10YR 4/3) silty clay; strong, medium and coarse subangular blocky structure; common, medium, distinct 10YR 5/6 mottles; moderately thick 10YR 4/1 clay skins in most pores and on structural units; black stains on 20% of peds; common concretions; clear wavy boundary. Subhorizon: 69-74 cm. Dark brown (10YR 4/3) light silty clay loam; 5-10 mm horizontal layers of 10YR 4/3 silt loam are separated by very thick 10YR 4/1 clay skins; a few vertical fissures transect the horizontal beds and are also lined with clay; abrupt, smooth boundary.
IIIC1	74-86+ cm. Horizon consists of alternating 5-6 cm layers of heavy silt loam with nearly all horizontal pores and 6-7 cm layers of friable silt loam. Subhorizon: 74-79 cm. Dark brown (10YR 4/3) silt loam; few, moderately thick 10YR 4/1 and 2.5YR 4/2 clay skins in pores; friable; abrupt, smooth boundary. 79-86 cm. Looks the same as 69-74 cm layer except texture is heavy silt loam.

Colors are for moist soil unless otherwise noted.

Location: 100 yards east of Highway 99E near McFarland School. Section 31, T11 S, R3W.

Slope: 0-2% Date: 10-1-68 Described by: Steve Wert

Dayton - DT

Ap	0-19 cm. Very dark grayish brown (10YR 3/2) silt loam; 10YR 5/1 dry; fine and medium moderate granular structure; very friable; non-sticky; common fine, distinct 10YR 5/6 and few fine distinct 10YR 5/8 mottles, abrupt smooth boundary.
A2	19-40 cm. Dark grayish brown (10YR 4/2) silt loam; (10YR 6/1) dry weak coarse subangular blocky structure; very friable; non-sticky; common, medium, distinct 10YR 3/4 mottles; common, medium, FeMn concretions; clear, smooth boundary.
IIB21t	40-70 cm. Dark gray (5Y 4/1) clay; 10YR 6/2 dry; large polygons 25-40 cm in diameter have abundant roots clinging to ped surfaces; very coarse strong prismatic microstructure; very firm; very plastic; clear irregular boundary (20-30 cm thick).
IIB22t	70-79 cm. Dark gray (10YR 4/1) silty clay; 10YR 6/3 dry; coarse prismatic breaking to moderate medium,platy structure; common,faint 10YR 4/3 mottles; many,distinct,stains; many continuous 10YR 4/1 clay skins around 1 mm and smaller pores; firm; sticky; plastic; clear wavy boundary (4-7 cm thick).
IIIB31	79-100 cm. Dark grayish brown (10YR 4/2) silty clay loam; very coarse; weak, subangular blocky breaking to moderate medium platy; few, fine, faint 10YR 5/6 and 10YR 4/4 mottles; common, thick continuous 2.5YR 4/2 clay skins; below major joints in the polygonols of the IIB21 are fan-shaped clay coatings with appex at joint; clear irregular boundary (17-34 cm thick).
IIIB32	100-127 cm. Dark grayish brown (10YR 4/2) silt loam; moderate, medium, subangular blocky structure; many medium 10YR 4/4 mottles; moderately thick continuous clay films; few 1-2 mm pores; friable; slightly sticky; slightly plastic; clear,wavy boundary 27-29 cm thick).
IIIC	127-143+ cm. Dark grayish brown (10YR 4/2) light silty clay loam; weak, medium subangular blocky to massive structure; many, fine, faint 10YR 4/3 and 10YR 4/4 mottles; common, moderately thick 10YR 4/1 clay skins; very few pores; friable; slightly plastic.

(Dayton - DT, continued)

Colors are for moist conditions unless otherwise noted.

Location: 150 yards northeast of Corvallis Airport water tower, SE 1/4, SW 1/4 of Section 22, T 12S, R 5W.

Slope: 0-1%   Date: 9-3-68   Described by: Steve Wert

Nekia - NT

Ap	0-16 cm. Reddish brown (5YR 3/4) moist; (7.5YR 4/4) dry; silty clay loam; moderate, medium, granular structure; friable; slightly sticky; clear, smooth boundary.
A31	16-36 cm. Reddish brown (5YR 3/4) moist; (7.5YR 4/4) dry; heavy clay loam; moderate, medium angular blocky structure; friable; sticky; less than 1% 3-7 cm size basalt pebbles; clear, smooth boundary (20-22 cm thick).
B1	36-63 cm. Reddish brown (5YR 3/4) moist; (7.5YR 4/4 dry; clay loam; weak, coarse, subangular blocky structure; very friable; sticky; clear, wavy boundary (25-28 cm thick).
IIB2t	63-81 cm. Dark reddish brown (2.5YR 3/4) clay; moderate, medium, subangular blocky structure; firm; sticky; few thin discontinuous (5YR 3/4) clay skins; distinct black coatings on ped surfaces; stone line at 63 cm made of rounded and flat fragments of weathered basalt; gradual, wavy boundary (15-24 cm thick).
IIR1	81-100+ cm. Reddish brown (5YR 3/4) clay loam; many 7.5YR 5/6 and 2.5YR 5/6 mottles; strong, medium, and coarse angular blocky structure; firm; non-sticky; thick (2.5YR 3/4) clay skins; black stains on 60% of ped surfaces.

Colors are for moist conditions unless otherwise noted.

Location: 100 yards south from MacDonald Forest in NE 1/4 m, SW 1/4 Section 31, T 10S, R 4W.

Slope: 8-10% Date: 8-30-68 Described by: Steve Wert

Newberg - NT

Ap	0-17 cm. Dark brown (10YR 3/3) sandy loam; brown (10YR 4/3) dry; moderate, fine granular structure; soft; very friable; non-sticky; nonplastic; few,fine roots; many interstitial pores; clear smooth boundary (17-30 cm thick).
AC	17-47 cm. Dark brown (10YR 3/3) sandy loam; dark yellowish brown (10YR 4/4) dry; weak,fine,subangular structure; soft; very friable; non-sticky; nonplastic; many interstitial pores; clear, smooth boundary (15-30 cm thick).
C1	47-70 cm. Brown (10YR 4/3) coarse sandy loam; pale brown (10YR 6/3) dry; massive; soft; friable; non-sticky; nonplastic; many interstitial pores; clear, smooth boundary (20-35 cm thick).
C2	70-120 cm. Dark grayish brown (10YR 4/2) loamy sand; pale brown (10YR 6/3) and light brownish gray (10YR 6/2) dry; single grain; loose, non-sticky; nonplastic; many interstitial pores; gradual, smooth boundary (45-60 cm thick).
C3	120-160 cm. Dark grayish brown (10YR 4/2) coarse loamy sand; light brownish gray (10YR 6/2) dry; single grain; loose, non-sticky; nonplastic; many interstitial pores.

Colors are for moist conditions unless otherwise noted.

Location: Five miles north of Albany, Oregon; 300 feet west of Interstate Highway #5; SE 1/4, SE 1/4, Section 4, T 10S, R 3W.

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Willamette - WT

Ap	0-17 cm. Very dark grayish brown (10YR 3/2) silt loam; 10YR 5/2 dry; moderate, fine, subangular blocky structure; friable; smooth boundary.
A3	17-45 cm. Very dark grayish brown (10YR 3/2) silt loam; 10YR 5/2 dry; moderate, medium, subangular blocky structure; friable; slightly sticky; many worm casts; clear smooth boundary.
B1tb	45-75 cm. Dark brown (10YR 3/3) silt loam; moderate, medium, subangular blocky structure; firm; slightly sticky; slightly plastic; few, thin discontinuous clay skins; some mixing of A3 material in upper part of horizon; clear smooth boundary.
B2tb	75-120 cm. Dark brown (10YR 3/3) heavy silt loam; moderate, medium, subangular blocky structure; firm; sticky; plastic; common, moderately thick clay skins; black stains on 15% of ped faces; 25% of peds are brittle; gradual smooth boundary.
C	120-135+ cm. Dark yellowish brown (10YR 4/4) silt loam; massive; friable; few thick clay skins.

Colors are for moist conditions unless otherwise noted.

Location: Plant Material Center, NW 1/4, SW 1/4, Section 8, T 11S, R 4W.

Slope: 0-2% Date: 6-6-68 Described by: Steve Wert

Woodburn - WO

Ap	0-17 cm. Dark brown (10YR 3/3) silt loam; coarse, weak, angular blocky structure; friable; abrupt, smooth boundary.
B1	17-42 cm. Dark brown (10YR 3/3) silt loam; coarse, moderate angular blocky structure; very few pores; firm; gradual smooth boundary.
Ab	42-56 cm. Dark brown (10YR 4/3) silt loam; moderate, medium, subangular blocky structure; few, fine pieces of charcoal and baked aggregates; few fine concretions; friable; gradual smooth boundary.
B1b	56-80 cm. Dark brown (10YR 3/3) silt loam; weak, moderate, subangular blocky structure; thin (7.5YR 4/4) clay skins; few fine, distinct 10YR 4/2 mottles; baked aggregates; specks of charcoal; few concretions; friable; clear smooth boundary.
B21tb	80-100 cm. Dark brown (10YR 4/3) heavy silt loam; strong, medium, subangular blocky structure; moderately thick 7.5YR 4/4 and 10YR 3/3 clay skins; moderately thick black stains on ped surfaces; about 50% of peds are brittle; firm; slightly sticky; few fine distinct 10YR 4/1 mottles; common, fine distinct 10YR 5/1 clean grains; gradual smooth boundary.
B22tb	100-120+ cm. Dark brown (10YR 4/3) heavy silt loam; moderate and strong subangular blocky structure; moderately thick 10YR 4/2 and 7.5YR 4/4 clay skins; black stains in most of pores and on 40% of ped surfaces; 60% of peds are brittle; common, fine distinct 10YR 5/1 mottles; firm; slightly sticky.

Colors are for moist conditions unless otherwise noted.

Location: 20 yards west of Southern Pacific Railroad, center of Section 8, T 11S, R 4W.

Slope: 0-3% Date: 9-27-68 Described by: Steve Wert