WILSON, Clyde Livingston. A PIEZOMETRIC FIELD STUDY OF SOIL WATER MOVEMENT TOWARD TILE DRAINS IN A NAPPANEE SILTY CLAY LOAM.

The Ohio State University, Ph. D., 1952
Agriculture, general

University Microfilms, Inc., Ann Arbor, Michigan

A PIEZOMETRIC FIELD STUDY OF SOIL WATER MOVEMENT TOWARD TILE DRAINS IN A NAPPANEE SILTY CLAY LOAM

Dissertation

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By

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The Ohio State University

1952

Approved by:

Adviser

ACKNOWLEDGMENTS

The writer wishes to express his sincere appreciation to Dr. G. W. Volk, Dr. G. S. Taylor and Dr. J. B. Page who so helpfully advised him in the study herein presented. Gratitude is also expressed to Professor Virgil Overholt and Dr. R. E. Yoder for their helpful suggestions and criticisms, and to the Ohio Department of Public Welfare, on whose farm the work was conducted.

TABLE OF CONTENTS

A PIEZOMETRIC FIELD STUDY OF SOIL WATER MOVEMENT TOWARD TILE DRAINS IN A NAPPANEE SILTY CLAY LOAM

INTRODUCTION

There is a serious lack of information concerning, and consequently an urgent need to investigate, the effect on drainage of the cropping system, organic matter content, measurable soil structural conditions and the movement of water in the soil profile. Such factual information is required not only to preserve the usefulness of the enormous capital investment in the land drainage works but also to arrive at a more economical design of new drainage systems.

The practices concerning farm tiling have changed surprisingly little since the first tile was laid in this country more than a century ago. The general practice has been to "cut and try" until a drain works satisfactorily. This method is wasteful of both time and money. The importance of the problem can be realized when it is understood that a decade ago there were 50 million acres of land in organized drainage enterprises in the Corn Belt alone, according to the U. S. Census Bureau. This is only a small part of the total artificially drained land because so much of it is not included in organized enterprises.

There has been some laboratory work but little actual field work as to how drainage takes place; the path followed by the water from the soil surface to the tile line, and the entry into the tile. Since it is practically impossible to simulate such a varied and dynamic body as agricultural soil, field studies are required to test the laboratory theories. A large drainage project located in northern Ohio and administered jointly by the Ohio Agricultural Experiment Station, the Ohio Department of Public Welfare and the Soil Conservation Service, U. S. D. A., provided a good opportunity to observe the movement of water within the soil mass.

The purpose of this investigation was to observe and record some phenomena concerning the directional movement of free water in a tiled soil with a heavy texture by utilizing the piezometric technique. The piezometric technique implies the determination of the relative hydraulic head at specific, selected points in the undisturbed soil.

REVIEW OF LITERATURE

Movement of water through soils in both unsaturated and saturated conditions is of very great importance to soil scientists. Buckingham (4) introduced the capillary potential concept of water movement in the unsaturated condition in 1907. This new concept opened the door to much work which has followed since that time. Baver (2) presents a very good review of literature and discussion of this concept.

Since the concept of how water moves in the unsaturated state is more recent and not so "simple", more work has been done in this area in the last few decades than has been done regarding "gravitational" or "free" water movement under saturated conditions. In fact, as far as drainage is concerned, we have very little data or information to refute or modify the recommendations offered by Klippart (17) almost a hundred years ago.

Most of the work done on free water movement in the soil is either used in an attempt to attain a workable soil permeability value (1, 3, 11, 15, 18, 20) or it is used directly (somtimes in streamline flow) in the field of underdrainage (8, 10, 12, 14, 16, 19, 21).

Darcy (9) laid the foundation for all modern day work in water flow, with the formula which is now known as Darcy's law. Darcy's law is given as:

$$v = k \frac{h}{l}$$

where v is the rate in cubic centimeters per second, k is a proportionality constant, h is the pressure head differential in centimeters and l is the length of the column in centimeters. This states that the linear velocity of flow of water through a filter (soil) is directly proportional to the difference in pressure head and inversely proportional to the length of the column. Slichter (23) and several others have modified Darcy's law to include a soil factor so as to determine the quantity of water which will be discharged from a soil column.

If the equation is modified so that h represents the hydraulic head, $\frac{h}{l}$ is the hydraulic gradient. Now the formula shows that the rate of discharge is proportional to the hydraulic gradient if all other factors are held constant. These other factors, represented by k include the effect of temperature, physical factors of the soil and the boundary conditions.

Slater (22) presents a good theoretical discussion of the basic concepts of water movement in the soil, although it is possible that he puts too much stress on tension in saturated flow.

Childs (5, 6, 7) developed a two-dimensional electrical analogy for studying streamline flow by impregnating filter paper with graphite. He used the simulated soil surface as one electrode and the simulated tile as the other electrode. After determining and plotting the lines of equipotential, the streamlines were drawn normal to the equipotential lines. This could be done since the direction of flow follows the steepest hydraulic gradient in a line normal to a line of equipotential (which has a gradient of zero). The electrical analogy is good in the case of irrigated soils or frequent showers where the water continually enters the soil mass, but the analogy develops some flaws when applied to a falling water table in which there is no resupply of water because there is no way of shutting off the flow of electricity and still being able to determine the electrical potential. The lower edge of the filter paper represents an impermeable layer.

Just previous to this work, Kirkham (16) had obtained somewhat similar results by using a sand box with a glass front normal to the tile. A colored dye (potassium dichromate) was introduced at various points along the surface of the sand. When water was added to the surface, it carried the dye in a line according to the path of the water from the soil surface to the tile. Work of this type includes certain boundary conditions not always found in natural conditions. The sides prevent lateral seepage across the point midway between the tile (if only one tile is used) and the bottom of the tank represents an impermeable layer at a definite depth. This is very convenient and oftentimes necessary for mathematical analysis of the flow pattern. When the surface of the sand was flooded, eliminating the "drawdown curve", the streamlines leave the surface in a vertical direction and loop around so that, in general, they come up into the tile. The amount of curvature depends on the permeability of the sand model, with the streamlines assuming less curvature with increased permeability.

Harding and Wood (14), using indigo carmine as a dye, added to this work by introducing artesian pressure from the bottom of the tank which gave the effect of altering the depth of the impermeable layer. Haise (13) used the dye technique in studying the flow of irrigation water from irrigation furrows up into the ridges, and the accompanying salt movement.

Piezometers were first used to any great extent in agricultural soils by Christiansen (8) in 1943. A good discussion of apparatus and techniques is presented in both Christiansen's paper and in the report (10) by Donnan, Aronovici and Blaney. Briefly, the principle is this: measurements of the hydraulic head at definite points on a vertical plane in the soil are made with piezometers. A piezometer is a hollow tube open at each end and installed vertically in the soil. The height to which water stands in the tube is a direct indication of the relative hydraulic head in the soil at the bottom of the tube. When the values of these relative hydraulic heads are plotted according to their location in the vertical plane, lines can be drawn connecting the points of equal hydraulic head. These lines are called equipotentials. The streamlines of water flow are parallel to the steepest hydraulic gradient so are normal to the equipotentials. The term "hydraulic head" is used throughout this investigation rather than "pressure head" because the values obtained include effects of both elevation above sea level and distance below the water table surface.

Experimental Procedure

Field location and arrangement

The work was conducted on a field which was classified as Nappanee silty clay loam. This is a glacial till soil overlying the old lake plain in northern Ohio. Nappanee is a 2-profile soil which means that it is a brownish gray soil with fair surface drainage but poor internal drainage. The field has a natural slope of less than 2%, and is part of a larger drainage experiment. Four tile lines, I, J, K, and L (Fig. 1) are each at different depths and spacings, and continuous records are kept of the discharge from each of these lines. Buffer tile lines are located between the measured tile lines.

Tile line I us 3 feet deep and has a 30 foot spacing, J is 3 feet deep with a 60 foot spacing, K is 2 feet deep, has a 60 foot spacing, and L has a depth of 2 feet and a spacing of 30 feet.

Apparatus and technique

Piezometers used in the study consisted of 3/8-inch galvanized pipe cut to various lengths. A hammer used to drive these pipes into the soil was fashioned of pipe similar to the hammer described by Christiansen (8). A twelve inch section of $1\frac{1}{4}$-inch pipe was filled with lead and a reducer coupling permitted a section of 3/4-inch pipe to be attached at each end. One of the 3/4-inch pipes was five feet long for fast driving while the pipe on the other end was only twelve inches long for driving the pipe after less than five feet extended out of the soil. The hammer was used in the same

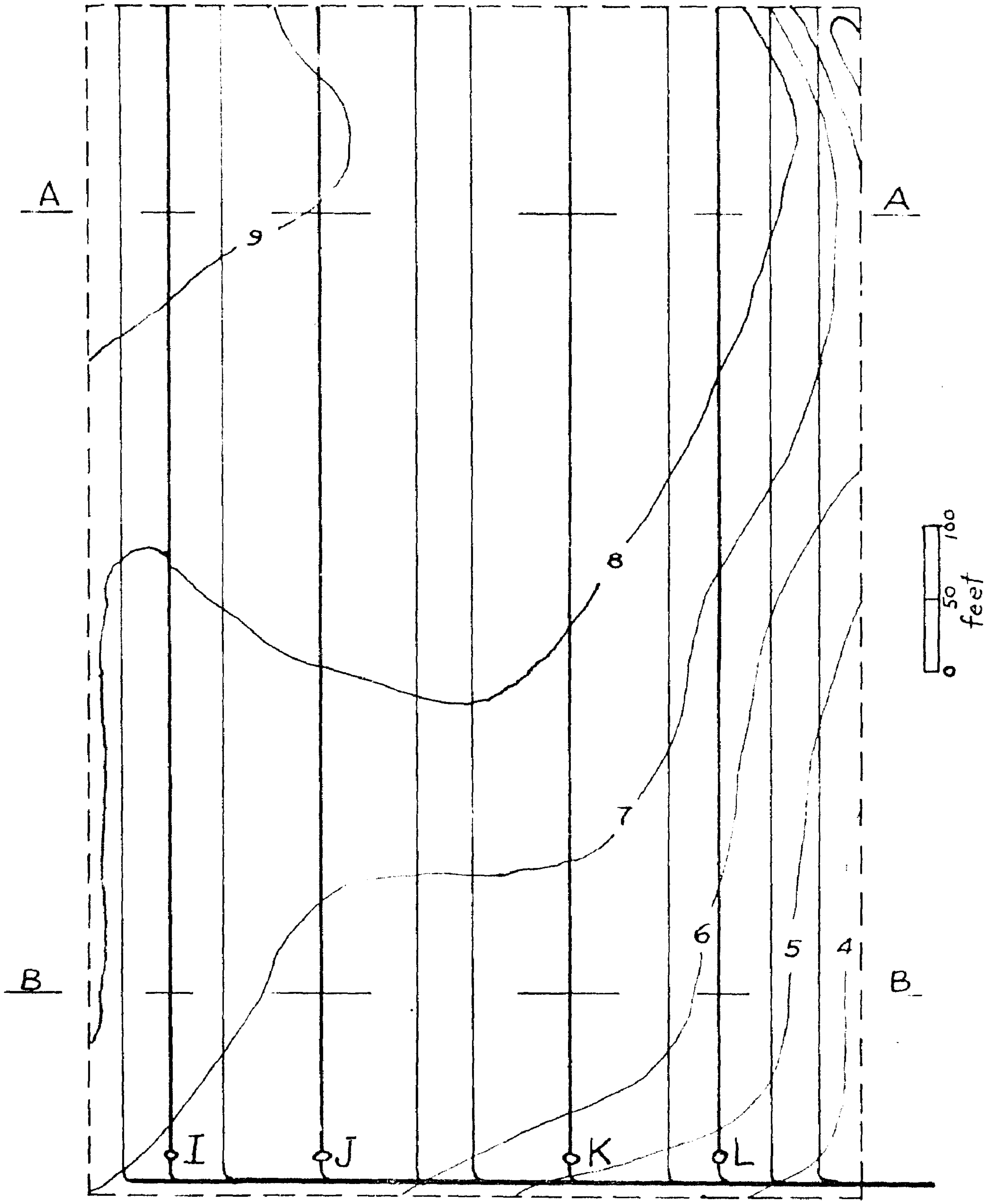


Fig. 1. Tile layout and field arrangement used for flow pattern study. (Contour lines at one foot intervals.)

manner as the common steel fence post driver. The 3/4-inch pipe fits loosely around a 3/8-inch pipe.

The piezometers were installed in batteries of five pipes per battery at depths of about 2, 3, 4, 6, and 8 feet below the soil surface. The tops of the piezometer pipes were driven to the same elevation by the use of an engineer's level for ease in computing results from the readings.

Because the soil in use was so heavy, no plug was used in the bottom of the pipes when they were driven into the soil. The soil plug which did collect in the bottom of the pipe during the driving process was flushed out by a jet of water. A barrel pump was inserted into a milk can and pumped water out through a long 1/4-inch copper tube. This tube was inserted into the piezometer until it contacted the soil plug. The force of the water carried the soil into suspension and this muddy water was forced up in the annular space around the copper tube. Marks on the copper tube showed when the tip had reached the bottom of the piezometer. Then a four-inch cavity was flushed out below the piezometer terminal. This served a two-fold purpose: the compacted soil in front of the pipe is removed, and a greater area of soil surface is exposed to the piezometer lower terminal.

The height to which water will stand in these pipes is a direct indication of the hydraulic head in the soil immediately surrounding the lower end of the piezometer. The water level was read by the use of an electric probe such as was used by the Soil Conservation

Service in the Imperial Valley of California (10). It is made to slip over the top of a piezometer and an insulated wire is lowered by means of a reel until the tip touches the water surface in the piezometer. The water completes the circuit up through the pipe and the probe so that a milliammeter, activated by four penlight batteries is deflected. The wire is marked in feet and a foot scale on the probe itself is graduated to hundredths of a foot. When the milliammeter deflects the scale is read opposite the mark on the wire, giving a reading to 1/100 of a foot. When read in this manner, the data obtained is confusing because it is the distance to the water surface from a higher datum plane. For this work, the datum plane was arbitrarily taken as 10 feet below the tops of the piezometers at the upper end of the field on tile line I. All other data (as presented in the appendix) was converted to this datum. Thus, higher numbers indicate a greater hydraulic head.

Batteries of piezometers were installed in sets of six in a line normal to each measured tile line, (3 on each side). The closest batteries were one foot from the tile line on each side of the tile. The next two batteries were eight feet from the tile line, and the other two were midway between the tile lines; fifteen or thirty feet, depending on whether the tile had a thirty or sixty foot spacing. A row of these batteries was installed across the upper end of the field (line AA in Fig. 1) and a duplicate row across the lower end (line BB, Fig. 1).

Removal of the piezometers is accomplished by means of a pulling head as sketched in Fig. 2. The head is slipped down on a pipe and an upward pull on the chain makes the steel jaws bite into the sides of the pipe. The pulling head is attached to a chain hoist on a tripod.

Seven batteries of piezometers were installed around a tile line in the spring of 1949 in order to become acquainted with the type of procedure and technique required in piezometer work. Plans were then laid to install a comprehensive experiment on the field in the spring of 1950, but unavoidable difficulties were encountered in the purchase of the pipe so that the installation was not completed until July of that year. By then the water table had fallen below the tile lines and the data were of little value. All of these pipes had to be removed in the fall of 1950 in order to work the ground and plant wheat. For these reasons no work is shown for the years 1949 and 1950.

In April, 1951, piezometers were again installed in this field in the same general layout but different lengths of pipes in a battery. Where in 1949 there were nine pipes per battery terminating at one foot intervals from one to nine feet deep in the soil, there were only five pipes per battery in 1950. These pipes terminated at depths of 2, 4, 6, 8, and 10 feet in the soil. The two foot interval was used partially for a saving in cost and labor and because the previous year's work seemed to show that one foot intervals were not necessary. Some of the ten foot pipes were

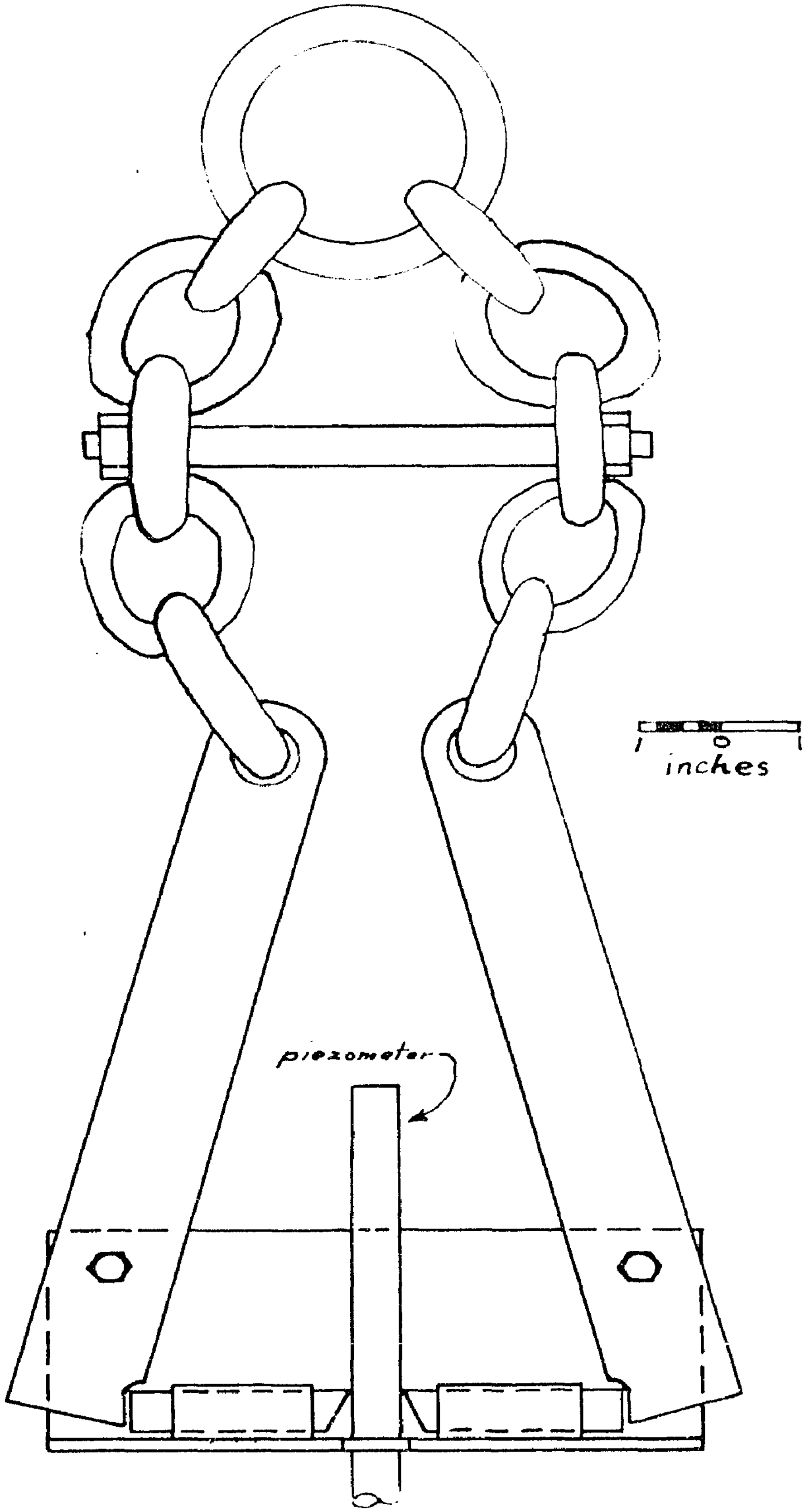


Fig. 2. Sketch of device for pulling piezometers

impossible to extract without pulling the tops off the pipes, so these were eliminated in the 1951 study. However a three foot pipe was added to give closer readings at the shallower depths.

Although the piezometers are much easier to read if about two feet of pipe extends above the ground, only about half a foot was permitted above the ground in 1951 so that the pipes could remain in place when the wheat was combined.

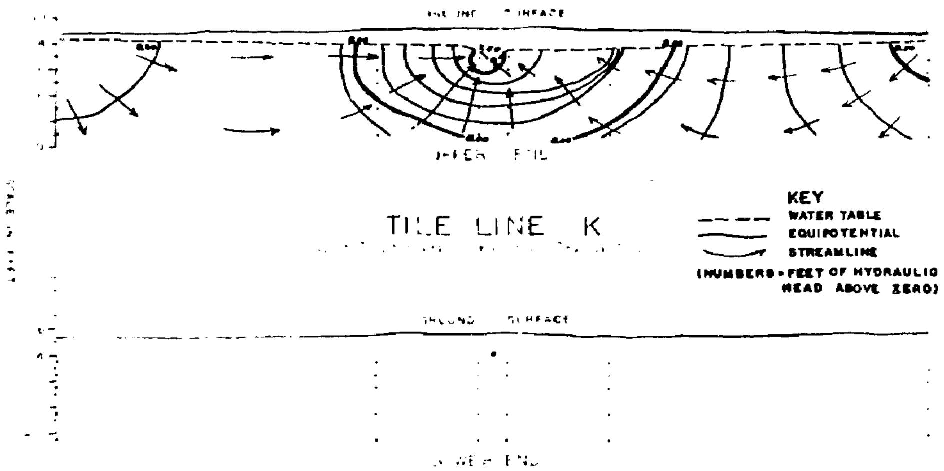
Readings were taken throughout the summer and fall at intervals of one week or less. Of the days when the tile were flowing, nine representative days were selected for the construction of flow patterns. Three of the days are in early summer before the tile stopped flowing and six are the following winter after recharge of the water table. The piezometric data for these nine days, from which the flow patterns were plotted, are given in the appendix. These nine days represent a fairly complete range of water table conditions.

RESULTS AND DISCUSSION

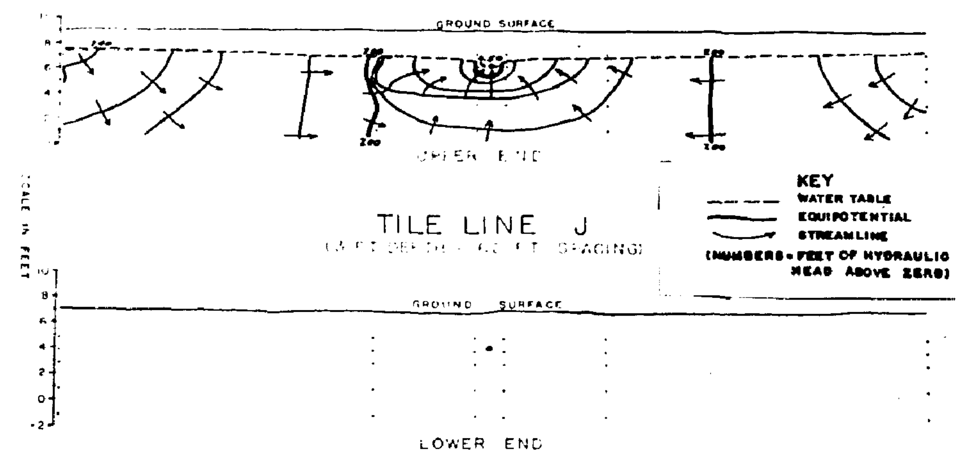
The use of two-dimensional flow patterns such as are presented on the following pages presupposes that all movement of the water is in these two dimensions (i.e., Parallel to the plane of the pattern). This condition is practically never obtained due to the heterogeneous make-up of natural soil. Therefore, from a technical viewpoint, the distance between the equipotential lines in the following flow patterns is actually the component of the hydraulic head normal to the tile line. (Parallel to the plane of the pattern.) However, in the case of water movement toward a tile drain, the flow is essentially normal to the tile line.

The small dots shown in the vertical cross-sectional view of the soil as seen in the bottom half of Figs. 3a and 3b each represent the location of the bottom terminal of one piezometer. (The large dot represents the tile.) The height to which water stands in each piezometer is an indication of the hydraulic head in the cavity at the bottom of that piezometer; in reality it is a manometer. After the relative hydraulic head is indicated at each of these dots, equipotential lines (connecting points of equal potential) are drawn in the same manner as contour lines on a surface map. Actually the equipotential lines represent the intersection of equipotential surfaces with the plane of the chart.

Arrows representing streamline flow are drawn normal to the equipotential lines because that represents the steepest hydraulic gradient, the shortest distance between the equipotential lines.



(A)



(B)

Fig. 3. Flow patterns for tile lines K (A), and J (B) for April 13, 1951. (No data available for the lower end.)

The water table has been constructed from the elevation of the water surface in the shortest piezometer containing water in each battery. It is believed that this method is more accurate than using one perforated pipe to find the elevation of the water table. Childs (6) shows that when the general direction of water movement is down, the use of a perforated pipe depresses the water table, whereas when the general direction is up (which seems to be the case in the vicinity of a flowing tile) the water table is elevated. These two facts would tend to flatten the actual drawdown curve. When the water table is above the tile and the tile is flowing the line representing the water table has been extended from the known point one foot on either side of the tile to the bottom of the tile. This may or may not actually be the situation. All of the equipotential lines have not been included in this area because their location is not certain. In fact it is very probable that the hydraulic gradient between a point just outside the tile and the interior of the tile is constantly changing.

The location of the impermeable layer is not easily discernable on this site. The zone of saturation is never more than about eight feet below the ground surface. So far as is known, then, the saturation zone used in this study is part of the permanent water table. When the water table has fallen below the tile line and discharge from the tile has ceased, the flow pattern (Fig. 4a) indicates that the water table continues to drop due to deep seepage.

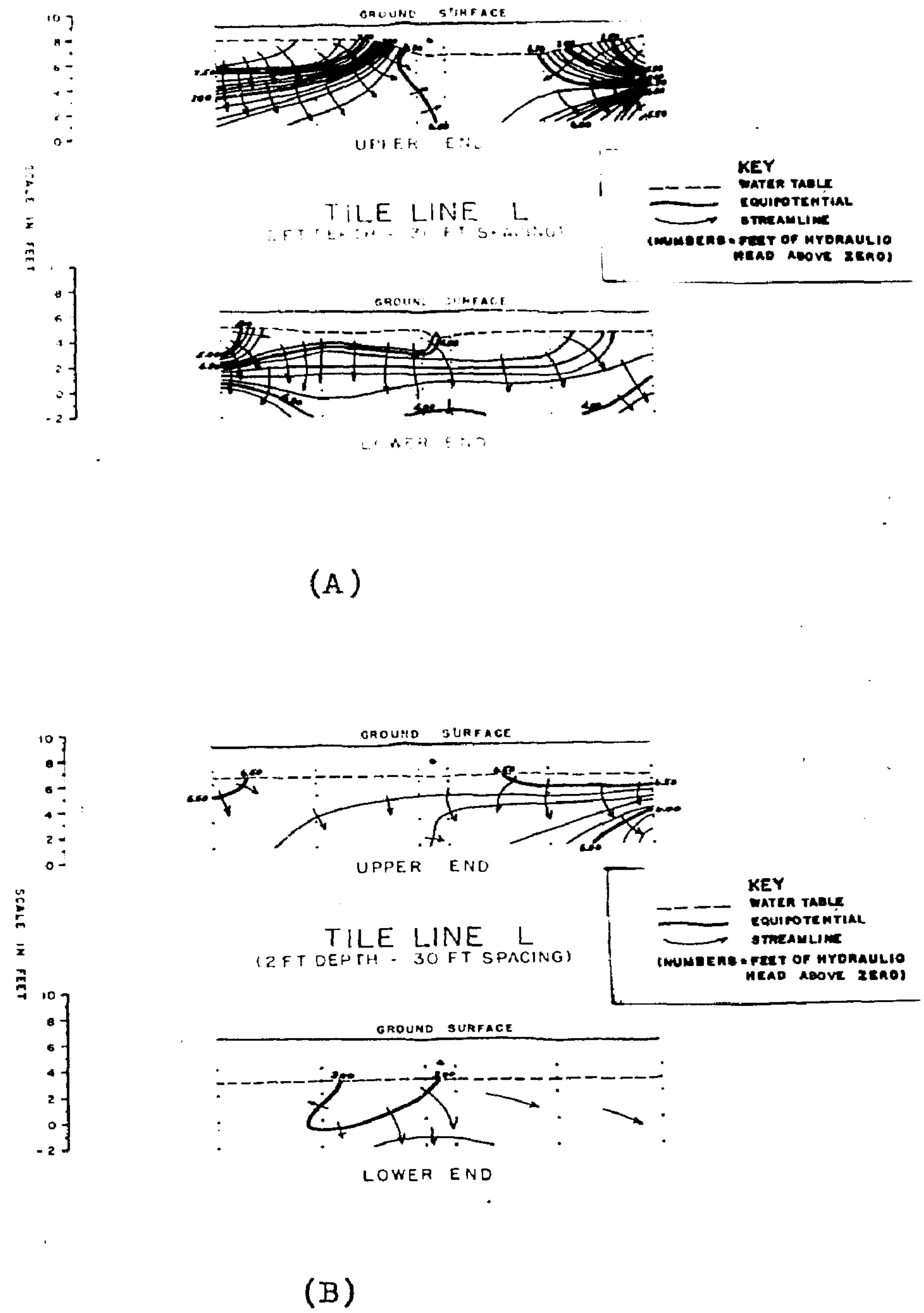


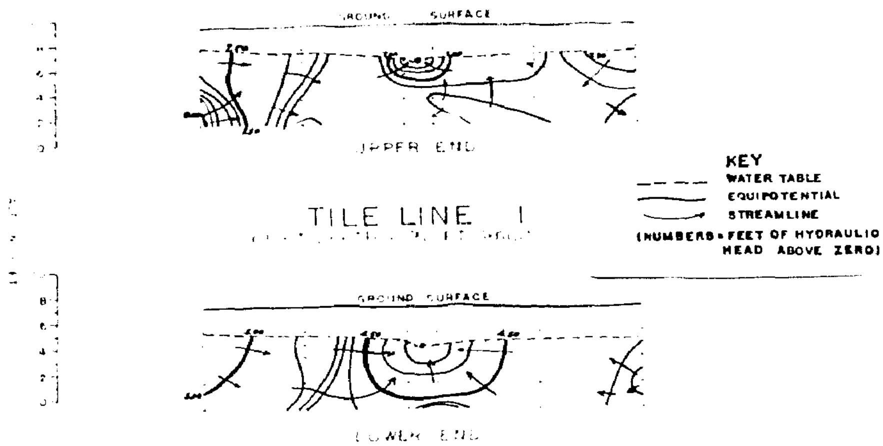
Fig. 4. Flow patterns for tile line L, showing (a) deep seepage on January 16, 1952, and (b) fairly static conditions on May 3, 1951 when evaporation and transpiration also affect the water table.

The downward hydraulic gradient would not be present if a static water table were being depleted by plant roots or upward capillary action.

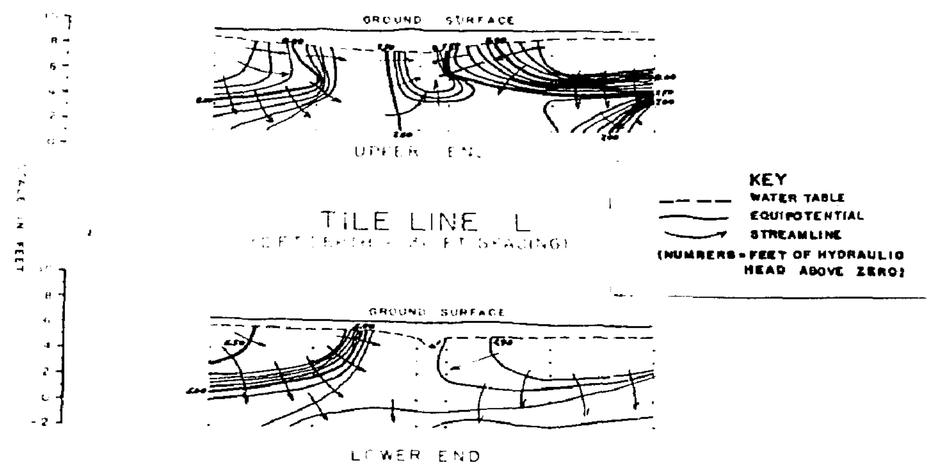
Fig. 4b shows the same tile line at a different time of year. At the time of measurement (May 3, 1951), the weather was warm and a thick stand of wheat was growing on the surface, causing a high rate of evaporation and transpiration. In this case the upward movement of water almost neutralized the downward movement showing a net hydraulic gradient downward with much less potential than in the case of that shown in Fig. 4a, which was plotted from the data of January 16, 1952.

The effect of an apparent claypan is shown in Fig. 5. Borings showed a tight layer about four feet below ground surface under tile line L, while I is in a somewhat homogeneous soil. The readings for both tile lines were made on January 4, 1952. Tile line I shows the expected flow pattern toward a tile drain. Above the claypan, the area around L shows somewhat the same pattern. The lines of equipotential are more nearly horizontal in the tight layer. This is to be expected from Kirkham's work with sands of different permeabilities. Consequently, the tight layer "chops off" the expected flow pattern and a new one (indicating deep seepage) is formed below the tight layer.

A homogeneous soil such as that found in the vicinity of tile line J offers a good opportunity to observe the transformation of the flow pattern (which can be predicted theoretically) accompanying



(A)

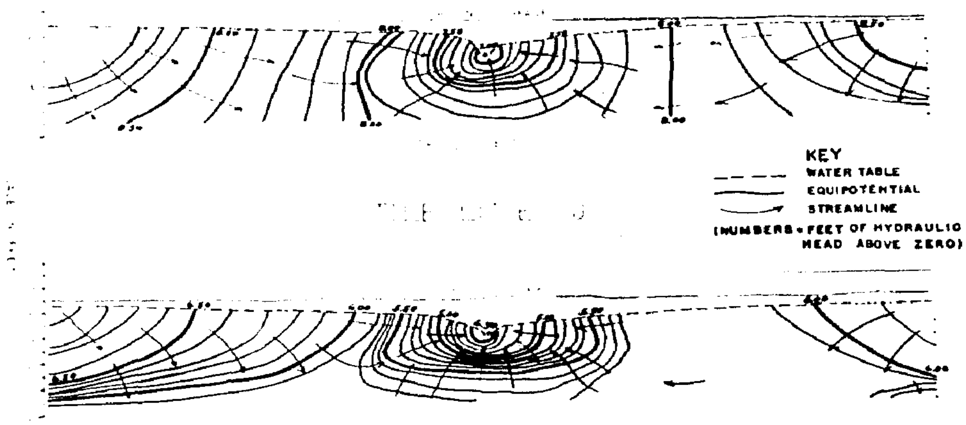


(B)

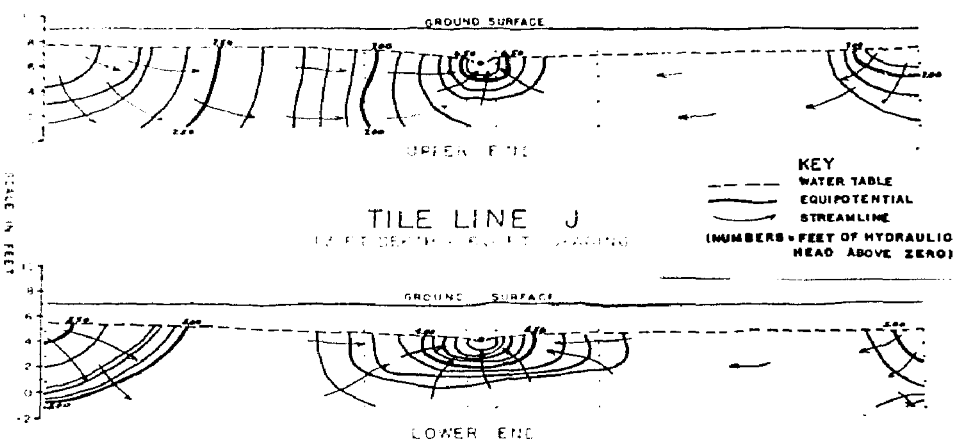
Fig. 5. The effect of a claypan. Tile line I (a) is located in a fairly homogeneous soil while L (b) has a very tight claypan about four feet below ground surface.

a change in the amount of water discharged from the tile. Fig. 6 shows such a change. On December 31, 1951, the flow pattern existed as shown in 6a, and the tile line discharged 745 cu. ft. of water in 24 hours. On January 4, 1952, the discharge was 384 cu. ft. of water in 24 hours, and the flow pattern was as is shown in Fig. 6b. It can readily be seen that the lines of equipotential are much closer together in a than in b, indicating a steeper hydraulic gradient surrounding the tile. According to Darcy's law, if other conditions are constant, the hydraulic head should be proportional to the flow into the tile. Investigation shows that the average hydraulic gradient from a point midway between the tile lines to tile J was 2.57 feet on December 31, and only 1.38 feet on January 4. These values are in the ratio of 1.87 to 1. The respective discharges from the tile lines are in the ratio of 1.94 to 1. If conditions are satisfactory it seems that these flow patterns conform to Darcy's law.

The appearance of flow patterns in a given area is constantly changing due to the overlapping forces simultaneously acting on the soil water. When one dominating effect disappears, a hidden effect may become evident as illustrated in Figs. 7 and 8. In Fig. 7 the flow pattern around tile K is shown to be like the pattern expected when only the tile is influencing the water movement. From experience with this particular location it is to be expected that when the water table falls below the tile, the principle factor acting on the flow pattern is that of deep seepage. (Except as altered by



(A)



(B)

Fig. 6. Flow pattern differences occurring with different tile discharge rates: (a) December 31, 1951 when the discharge from the tile was 745 cu. ft. per 24 hours, (b) January 4, 1952 when the tile discharge was 384 cu. ft. per 24 hours.

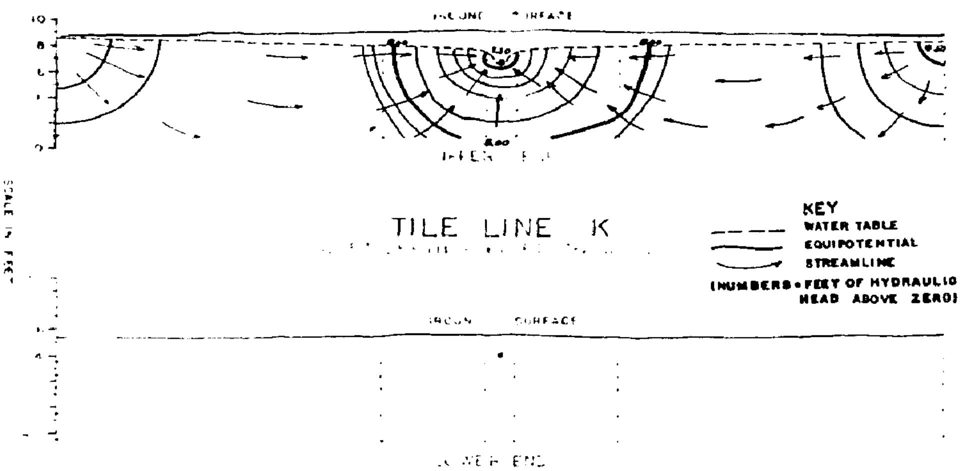
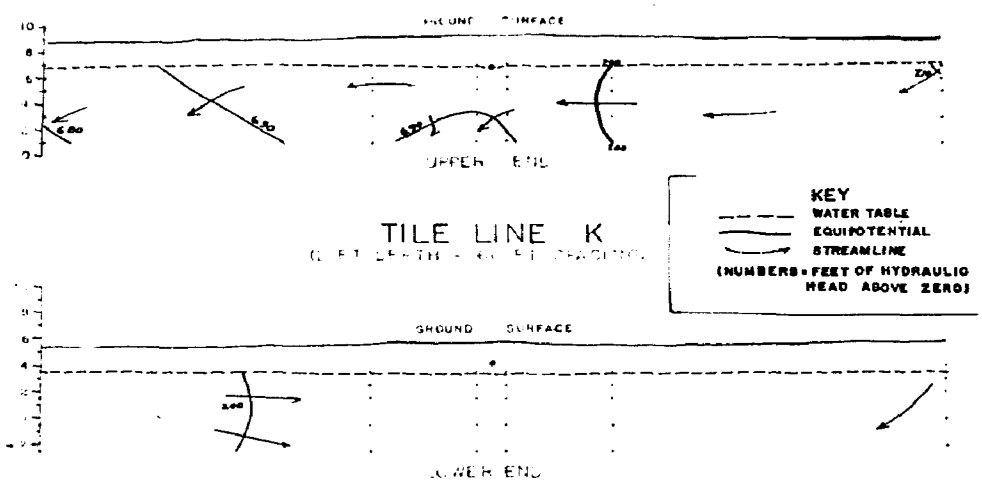


Fig. 7. A typical flow pattern of water toward a tile drain. (Data collected May 11, 1951.)

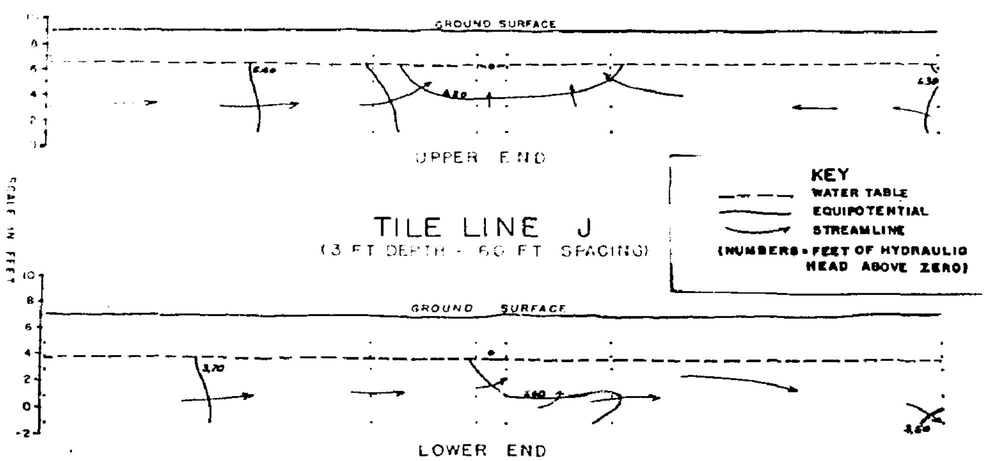
transpiration and evaporation as previously discussed.)

However, there is another hidden factor which appears at tile line K just as the tile flow ceases. Tile K, with its adjacent buffer line is a foot higher than tile J and its buffer line. As the water table falls, K, the shallower tile, ceases flow while J is still flowing. The data for plotting Fig. 8 (a and b) were collected just at this moment. The flow pattern at the upper end of K shows a distinct lateral seepage toward the tile that are three feet deep; the closest of which is 90 feet to the left. The upper end of tile J (Fig. 8b) still shows the typical shape of flow pattern although the gradient is very low and the streamlines are very flat.

Seepage in quantity enters tile I in spite of a buffer line which is supposed to prevent lateral seepage. Referring to a map of the area (Fig. 1), it is seen that I, although in fairly level ground, is close to the edge of the experimental field. The land adjacent to the field on that side is untiled. Consequently when the water table around I falls, lateral seepage occurs from the undrained area. This produces the asymmetric pattern shown at the lower end of Fig. 9a. The similarity between 9a and 9b is very striking, but the cause is different. In the case of tile L the ground surface is not flat but sloping, (again referring to Fig. 1), and since the water table tends to follow the ground surface, the water table slopes. When a slope is normal to a tile line, (i.e. the tile is "laid across the slope") the tile must remove a greater quantity of water

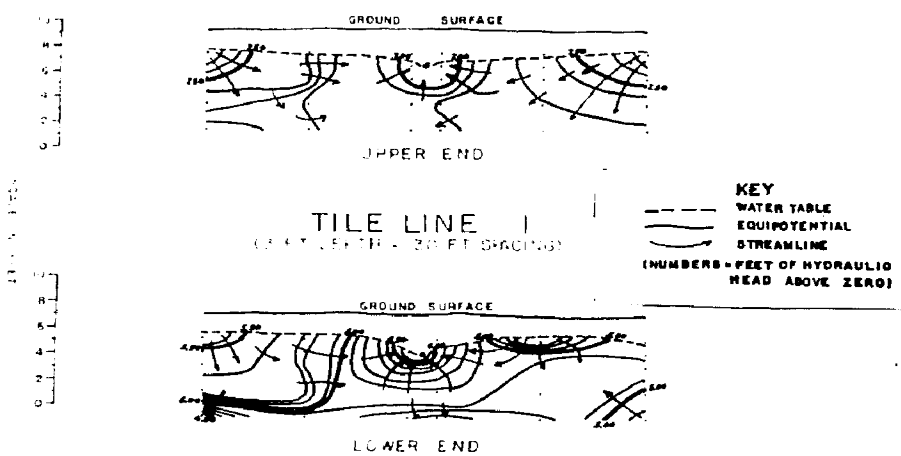


(A)

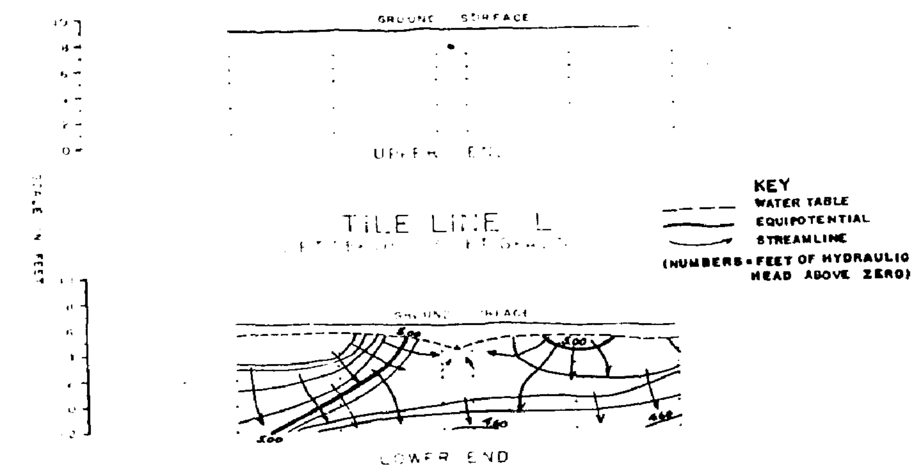


(B)

Fig. 8. Flow patterns of May 3, 1951, showing lateral seepage from tile K (a) to tile J (b). Tile J (3 feet deep) is flowing at the rate of 32 cu. ft. per day and K (2 feet deep) has ceased flow.



(A)



(B)

Fig. 9. Similar asymmetric flow patterns on December 10, 1951 produced (a) by lateral seepage from an untiled area and (b) slope of the soil surface.

from the higher side than from the lower side. For this reason the high pressure area to the right of the tile line is shifted in from its normal position halfway between the tile lines. (Represented by the extreme right of the flow pattern.)

In his work with electrical analogues, Childs (7) showed that streamlines leave the surface of the water table at a downward angle. From observation of these flow patterns (Fig. 10) it appears that the equipotential lines intersect the water table at a right angle which indicates that the water table itself is a flow line in the case of a falling water table with no resupply. In the examples shown here the only streamlines normal to the water table are those which originate at the highest point of a drawdown curve (usually midway between the tile), or those originating directly above the tile (if there is a saturated zone above the tile). These two points are the only points on the curve which have zero slope.

In using sand tank models, Gross (12) was unable to formulate an equation for the drawdown curve of a falling water table, such as we are dealing with, but did propose the formula

$$y = \frac{x}{a + b\,x}$$

Where y = vertical increment and x = horizontal increment.

for lateral flow. Since the streamlines in these flow patterns are relatively more horizontal than vertical, some drawdown curves (Fig. 11) were checked against this formula and found to be in close agreement. However these curves were plotted from only three

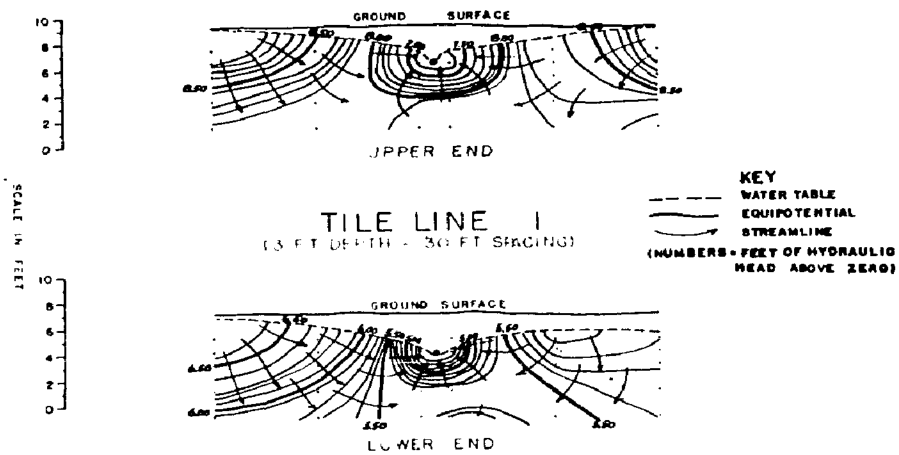
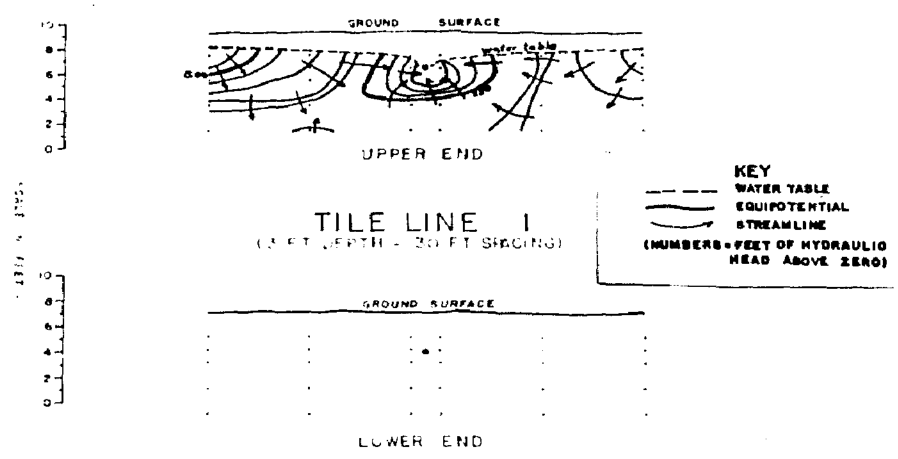
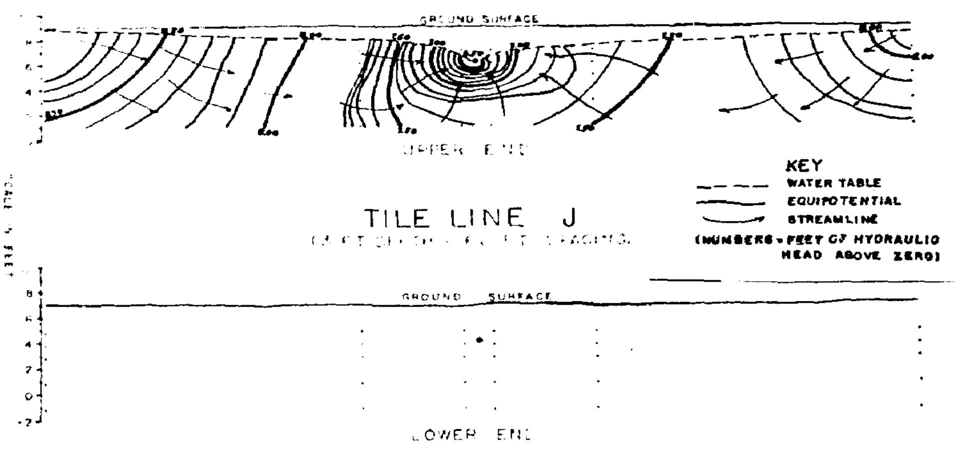


Fig. 10. Flow pattern of tile I for December 31, 1951 showing the water table itself as a flow line.



(A)



(B)

Fig. 11. Flow patterns for tile lines I (a), and J (b) for January 20, 1952.

points so no definite conclusions can be drawn from the apparent agreement.

It is probably true that in fine-textured soils the chief path of moving soil water is through cracks, root holes, worm casts, etc., as maintained by Tolman (24, p. 141). However it is evident from the flow patterns in this study that they do not individually alter the pattern since they are, presumably, evenly distributed throughout the soil mass. The presence of these water channels, through which water can move rapidly, may be an explanation for the relatively flat appearance of the streamlines found in this study. If such is the case, then it follows that the effective permeability of a fine-textured soil in situ may be as great as the permeability of a packed sand or other coarse-textured soil in a disturbed state.

Another point which may explain the relatively horizontal flow to tile lines observed in this study may be that in most laboratory work the ratio of depth to spacing of the tile lines is greater than the ratios found in this study where the range was from 1:10 to 1:30. The larger ratios permit a greater hydraulic gradient above the tile which in turn would cause relatively more vertical flow.

SUMMARY

The flow of water toward tile drains has been investigated under field conditions by the use of piezometers. The piezometers indicated the relative hydraulic head at various points in the soil in a vertical plane normal to a tile line. Points of equal hydraulic head were then connected by equipotential lines. Additional lines intersecting these equipotentials at a right angle represent streamlines and form a flow pattern showing directional water movement.

Flow patterns representing various conditions and situations have been discussed.

It was shown that for a typical location, the quantity of water discharged from the tile line was directly proportional to the hydraulic gradient in the soil around the tile. This agrees with Darcy's law for linear flow. When there was no resupply of water to the water table from above, the idea that lateral, linear flow was the predominate factor was further emphasized by the fact that the water table itself is a streamline. Also, an equation for the drawsown curve, under conditions of strictly lateral flow, appeared to agree with some drawdown curves obtained in this study.

Lateral seepage from an adjacent undrained area produced the same type of asymmetric flow pattern as that found around a tile lying along a slope. It was found that lateral seepage occurred from under a tile line after it had ceased flowing toward another

tile line 100 feet away when the second tile was only a foot deeper than the first.

Large differences in the permeability of successive soil layers can be detected by the use of flow patterns. It was shown that a tight layer interrupts the flow pattern with a concentration of equipotential lines in the tight layer. If the tight layer is horizontal, the flow through this layer is relatively more vertical.

An apparent effect of evaporation and transpiration (absorption by plant roots) on the hydraulic gradient producing deep seepage is illustrated. An increase of upward movement of the water in the growing months, as compared to winter conditions, causes the net hydraulic gradient producing deep seepage to diminish.

The operation of a tile drainage project under field conditions is complicated because of the large acreage required and the difficulty of holding both the grade and depth of the tile constant. It is shown in this study that further complications arise from the lack of definite boundary conditions which would limit the lateral flow of water from one tile line to the next.

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APPENDIX

Table 1. Elevation of water in piezometer pipes on selected days. (Feet above zero datum.)

Date	Piezometer[1]				
	IA-8	IA-6	IA-4	IA-3	IA-2
4-13-51	7.19	7.20	7.30	7.41	7.44
5- 3-51	6.62	6.63	6.73	6.75	
5-11-51	7.21	7.25	7.36	7.56	7.57
5-12-51	7.51	7.46	7.55	7.61	7.62
12-27-51	7.15	7.33	7.52	7.70	
12-31-51	8.08	8.33	8.61	8.99	
1-4-52	8.18	8.34	7.60	7.59	
1-16-52	6.48	6.66	6.79		
1-20-52	7.54	7.66	7.93	8.10	8.11
	IB-8	IB-6	IB-4	IB-3	IB-2
4-13-51	7.06	7.21	7.08	7.13	
5-3-51	6.56	6.64	6.57	6.58	
5-11-51	7.03	7.25	7.16	7.21	7.26
5-12-51	7.48	7.52	7.34	7.37	7.37
12-27-51	7.25	7.15	7.46	7.38	
12-31-51	8.07	8.06	7.57	8.48	
1-4-52	7.06	7.16	7.49	7.33	
1-16-52	6.49	6.56	6.69		
1-20-52	7.64	7.51	7.85	7.78	7.83
	IC-8	IC-6	IC-4	IC-3	IC-2
4-13-51	7.12	7.07	6.81	6.76	
5-3-51	6.58	6.56	6.46	6.44	
5-11-51	7.20	7.13	6.82	6.71	
5-12-51	7.45	7.33	6.94	6.81	
12-27-51	7.12	7.15	6.99	6.90	
12-31-51	8.11	8.10	7.58	7.37	
1-4-52	7.14	7.16	6.92	6.78	
1-16-52	6.50	6.55	6.52		
1-20-52	7.51	7.52	7.20	7.29	

[1]Each piezometer is identified by two letters and a number. The first letter indicates the tile line and the second letter indicates the position of a piezometer battery with respect to the tile line. Batteries A, B, C, D, E, and F represent respective distances from left to right of midway between tiles (30 or 15 ft.), 8 ft., 1 ft., 1 ft., 8 ft., and 30 or 15 ft. across the upper end of the field. (Line A-A in Fig. 1) Batteries G, H, I, J, K and L are in the same relative location at the lower end. The number indicates the approximate depth of the pipe below ground surface.

Table 1 - Continued

Date	Piezometer				
	ID-8	ID-6	ID-4	ID-3	ID-2
4-13-51	7.12	7.06	6.79	6.40	
5-3-51	6.57	6.55	6.43	6.32	
5-11-51	7.19	7.13	6.77	6.34	
5-12-51	7.41	7.35	6.87	6.36	
12-27-51	7.17	7.24	6.91		
12-31-51	8.13	8.15	7.45		
1-4-52	7.12	7.22	6.93		
1-16-52	6.50	6.51	6.49		
1-20-52	7.50	7.54	7.12	6.47	
	IE-8	IE-6	IE-4	IE-3	IE-2
4-13-51	6.95		6.92	6.92	
5-3-51	6.52		6.50	6.49	
5-11-51	6.98		6.98	7.06	7.56
5-12-51	7.38		7.27	7.20	7.32
12-27-51	7.23		7.35		
12-31-51	8.24		8.31	8.33	
1-4-52	7.24		7.08		
1-16-52	6.53		6.50		
1-20-52	7.72		7.73	7.57	7.66
	IF-8	IF-6	IF-4	IF-3	IF-2
4-13-51	7.04	7.07	7.14	7.14	
5-3-51	6.50	6.52	6.54	6.54	
5-11-51	7.13	7.24	7.29	7.35	
5-12-51	7.36	7.40	7.38	7.41	7.44
12-27-51	7.27	7.39	8.00	7.70	
12-31-51	8.11	8.30	8.76	8.96	
1-4-52	7.04	7.10	7.43	7.33	
1-16-52	6.37	6.48	6.59		
1-20-52	7.70	7.78	7.84	7.97	
	IG-8	IG-6	IG-4	IG-3	IG-2
5-3-51	4.15	4.14		4.11	
5-12-51	4.90	4.92		4.85	
12-10-51	4.35	5.31		5.42	5.64
12-31-51	5.86	6.35		6.64	
1-4-52	5.00	5.00		5.04	
1-16-52	4.43	4.35			

Table 1 - Continued

Date	Piezometer				
	IH-8	IH-6	IH-4	IH-3	IH-2
5/3/51	3.98	4.01	4.04		
5/12/51	4.66	4.57	4.60	4.64	
12/10/51	4.83	5.32	5.16	5.25	5.30
12/31/51	5.70	5.88	6.16	6.27	
1/4/52	4.70	4.95	4.83	4.84	
1/16/52	4.13	4.19	4.24		
	II-8	II-6	II-4	II-3	II-2
5/3/51	3.91	3.89	3.85		
5/12/51	4.43	4.31	4.18	4.25	
12/10/51	4.78	4.93	4.55	4.31	
12/31/51	5.46	5.47	4.80	4.66	
1/4/52	4.58	4.48	4.30		
1/16/52	4.02	4.00	3.97		
	IJ-8	IJ-6	IJ-4	IJ-3	IJ-2
5/3/51	3.87	3.86	3.83		
5/12/51	4.11	4.41	4.19	4.15	
12/10/51	4.69	4.90	4.02	4.56	
12/31/51	5.23	5.44	4.17	5.23	
1/4/52	4.85	4.45	4.25		
1/16/52	4.14	3.97	4.30		
	IK-8	IK-6	IK-4	IK-3	IK-2
5/3/51	3.81	3.82	3.85		
5/12/51	4.40	4.35	4.36	4.32	
12/10/51	4 78		4.91	4.88	5.33
12/31/51	5.45		5.71	5.85	5.94
1/4/52	4.51		4.56	4.55	
1/16/52	4.01		4.02		
	IL-8	IL-6	IL-4	IL-3	IL-2
5/3/51	3.76	3.84	3.75		
5/12/51	4.36	4.41	4.41	4.38	
12/10/51	5.14	5.04	4.89	4.91	
12/31/51	5.67	5.33	5.67	5.73	
1/4/52	4.70	4.86	4.55	4.60	
1/16/52	4.00	4.10	4.01		

Table 1 - Continued

Date	Piezometer				
	JA-8	JA-6	JA-4	JA-3	JA-2
4/13/51	7.29	7.37	7.41	7.40	7.44
5/3/51	6.50	6.50	6.50	6.49	
5/11/51	7.75	8.00	8.20	8.19	8.24
5/12/51	8.10	8.03	8.12	8.12	8.16
12/27/51	8.11	8.22	8.49		
12/31/51	8.61	8.72	8.84	8.81	
1/4/52	7.67	7.75	7.91	7.95	
1/16/52	6.41	6.47	6.56	6.56	
1/20/52	8.48	8.52	8.76	8.81	8.85
	JB-8	JB-6	JB-4	JB-3	JB-2
4/13/51	6.92	7.00	6.71	6.91	
5/3/51	6.33	6.33	6.32	6.26	
5/11/51	7.13	7.32	7.47	7.56	7.59
5/12/51	7.52	7.36	7.30	7.18	7.18
12/31/51	8.03	7.96	7.86	8.00	
1/4/52	7.03	6.97	7.07	7.15	
1/16/52	6.18	6.25	6.21		
1/20/52	7.75	7.63	7.96	7.81	
	JC-8	JC-6	JC-4	JC-3	JC-2
4/13/51	6.93	6.89	6.56	6.47	
5/3/51	6.29	6.29	6.15	6.11	
5/11/51	7.13	7.08	6.74	6.55	
5/12/51	7.26	7.11	6.66	6.47	
12/27/51	7.17	7.03	6.61	6.31	
12/31/51	7.80	7.64	7.14	7.19	
1/4/52	6.81	6.75	6.51		
1/16/52	6.18	6.18	6.11		
1/20/52	7.43	7.26	6.71	6.45	
	JD-8	JD-6	JD-4	JD-3	JD-2
4/13/51	6.90	6.86	6.63	6.52	
5/3/51	6.27	6.24	6.16	6.12	
5/11/51	7.09	7.04	6.74	6.55	
5/12/51	7.20	7.09	6.73	6.54	
12/27/51	7.12	7.03	6.69	6.51	
12/31/51	7.74	7.67	7.10	6.90	
1/4/52	6.76	6.71	6.40		
1/16/52	6.15	6.09	6.11		
1/20/52	7.38	7.32	6.80	6.66	

Table 1 - Continued

Date	Piezometer				
	JE-8	JE-6	JE-4	JE-3	JE-2
4/13/51	6.95	6.94	6.86	6.84	
5/3/51	6.26	6.26	6.20	6.19	
5/11/51	7.10	7.12	6.99	6.92	7.00
5/12/51	7.28	7.20	7.04	7.02	7.04
12/27/51	7.20	7.16	7.08		
12/31/51	7.93	7.87	7.80	7.84	
1/4/52	6.77	6.78	6.74	6.72	
1/16/52	6.13	6.09	6.14		
1/20/52	7.50	7.44	7.31	7.31	7.34
	JF-8	JF-6	JF-4	JF-3	JF-2
4/13/51	7.11	7.23	7.22	7.23	7.24
5/3/51	6.31	6.34	6.29	6.31	
5/11/51	7.22	7.40	7.37	7.34	7.29
5/12/51	7.66	7.68	7.62	7.63	7.70
12/27/51	7.30	7.50	7.58		
12/31/51	8.17	8.44	8.52	8.57	
1/4/52	6.79	6.89	7.00	7.19	
1/16/52	6.07	6.19	6.22		
1/20/52	7.65	7.88	7.95	7.99	8.15
	JG-8	JG-6	JG-4	JG-3	JG-2
5/3/51	3.73	3.74	3.72		
5/12/51	4.80	5.01	5.04	5.03	4.95
12/10/51	5.38	5.99	6.10	6.13	6.40
12/31/51	5.90	6.57	6.70	6.79	6.83
1/4/52	4.98	5.37	5.46	5.50	
1/16/52	4.02	3.98	4.05		
	JH-8	JH-6	JH-4	JH-3	JH-2
5/3/51	3.66	3.64	3.62		
5/12/51	4.81	4.72	4.50	4.51	
12/10/51	5.39	5.30	5.18	5.27	5.44
12/31/51	5.81	5.64	5.59	5.81	5.96
1/4/52	4.93	4.84	4.73		
1/16/52	3.94	3.87	3.91		

Table 1 - Continued

Date	Piezometer				
	JI-8	JI-6	JI-4	JI-3	JI-2
5/3/51	3.62	3.63	3.60		
5/12/51	4.79	4.75	4.12	4.07	
12/10/51	5.33	5.25	4.39	4.31	
12/31/51	5.75	5.65	4.51	4.45	
1/4/52	4.85	4.78	4.19	4.11	
1/16/52	3.92	3.92	3.81		
	JJ-8	JJ-6	JJ-4	JJ-3	JJ-2
5/3/51	3.61	3.60	3.59		
5/12/51	4.77	4.75	4.28	4.25	
12/10/51	5.31	5.30	4.61	4.44	
12/31/51	5.70	5.67	4.65	4.60	
1/4/52	4.85	4.82	4.35	4.10	
1/16/52	3.93	3.84	3.81		
	JK-8	JK-6	JK-4	JK-3	JK-2
5/3/51	3.59	3.61	3.59	3.57	
5/12/51	4.79	4.81	4.65	4.66	
12/10/51	5.38	5.39	5.25	5.25	
12/31/51	5.78	5.79	5.58	5.65	
1/4/52	4.84	4.89	4.76	4.77	
1/16/52	3.90	3.88	3.91		
	JL-8	JL-6	JL-4	JL-3	JL-2
5/3/51	3.48	3.51	3.51		
5/12/51	4.75	4.88	4.89	4.88	4.88
12/10/51	5.23	5.52	5.56	5.54	5.61
12/31/51	5.62	6.06	6.10	6.12	6.15
1/4/52	4.72	4.92	5.02	4.94	
1/16/52	3.81	3.81	3.86		
	KA-8	KA-6	KA-4	KA-3	KA-2
4/13/51	8.10	8.24	8.26	8.24	8.24
5/3/51	6.78	6.89	6.85	6.84	
5/11/51	8.22	8.37	8.24	8.44	8.45
5/12/51	8.36	8.52	8.57	8.52	8.54
12/31/51	8.58	8.70	8.66	8.73	
1/4/52	7.97	8.55	8.22	8.28	
1/16/52	7.06	7.26	7.49		
1/20/52	8.46	8.64	8.64	8.67	8.70

Table 1 - Continued

Date	Piezometer				
	KB-8	KB-6	KB-4	KB-3	KB-2
4/13/51	8.17	8.08	7.91	7.91	7.92
5/3/51	6.92	6.97	6.99	6.99	6.99
5/11/51	8.24	8.21	8.02	8.04	8.07
5/12/51	8.36	8.21	7.97	7.99	7.97
12/31/51	8.58	8.58	8.39	8.62	
1/4/52	7.98	7.98	7.78	7.92	
1/16/52	7.16	7.26	7.36		
1/20/52	8.42	8.37	8.12	8.37	8.42
	KC-8	KC-6	KC-4	KC-3	KC-2
4/13/51	7.98	7.82	7.69	7.48	7.44
5/3/51	6.86	6.89	6.92	6.91	6.90
5/11/51	7.94	7.85	7.74	7.53	7.48
5/12/51	8.17	7.92	7.70	7.47	7.39
12/31/51	8.53	8.49	8.38		
1/4/52	8.08	7.87	7.80	7.70	
1/16/52	7.35	7.40	7.43	7.40	
1/20/52	8.47	8.21	8.04	7.75	7.67
	KD-8	KD-6	KD-4	KD-3	KD-2
4/13/51	7.93	7.85	7.60	7.52	7.52
5/3/51	6.88	6.91	6.92	6.92	6.93
5/11/51	7.99	7.89	7.65	7.56	7.55
5/12/51	8.06	7.91	7.63	7.52	7.52
12/31/51	8.60	8.51	8.17	8.12	
1/4/52	8.27	7.91	7.68	7.67	
1/16/52	7.36	7.43	7.38	7.44	
1/20/52	8.31	8.21	7.91	7.83	7.86
	KE-8	KE-6	KE-4	KE-3	KE-2
4/13/51	8.12	7.94	7.95	7.96	7.70
5/3/51	7.00	7.02	7.01	7.02	7.00
5/11/51	8.11	7.95	7.92	7.96	7.96
5/12/51	8.22	8.00	8.02	7.99	8.00
12/31/51	8.56	8.55	8.81	8.77	
1/4/52	7.87	7.84	7.92	7.91	
1/16/52	7.28	7.36	7.25	7.41	
1/20/52	8.26	8.19	8.35	8.27	

Table 1 - Continued

Date	Piezometer				
	KF-8	KF-6	KF-4	KF-3	KF-2
4/13/51	8.41	8.44	8.50	8.50	8.55
5/3/51	7.04	7.06	7.10	7.07	7.13
5/11/51	8.26	8.38	8.47	8.27	8.52
5/12/51	8.55	8.53	8.58	8.66	8.60
12/31/51	8.71	8.72	8.97	8.49	
1/4/52	8.11	8.07	8.40	8.45	
1/16/52	7.33	7.34	7.75	8.08	
1/20/52	8.54	8.52	8.83	8.83	
	KG-8	KG-6	KG-4	KG-3	KG-2
5/ 3/51	3.49	3.47		3.49	
5/12/51	4.91	4.86		4.54	
12/10/51	4.78	4.79		3.65	
12/31/51	5.02	5.00		4.08	
1/4/52	4.65	4.64		4.36	
1/16/52	4.22	4.20		4.05	
	KH-8	KH-6	KH-4	KH-3	KH-2
5/3/51	3.37	3.36		3.35	
5/12/51	4.78	4.73		4.90	4.79
12/10/51	4.59	4.61		4.09	
12/31/51	4.74	4.86		4.95	
1/4/52	4.40	4.65		4.96	
1/16/52	4.07	4.27		4.36	
	KI-8	KI-6	KI-4	KI-3	KI-2
5/3/51	3.37	3.31		3.32	
5/12/51	4.72	4.57		3.91	
12/10/51	4.58	4.48		4.24	4.16
12/31/51	4.70	4.50		4.41	4.34
1/4/52	4.35	4.29		4.08	
1/16/52	4.06	4.03		4.05	
	KJ-8	KJ-6	KJ-4	KJ-3	KJ-2
5/3/51	3.35	3.33			
5/12/51	4.81	4.59			4.28
12/10/51	4.60	4.50			4.29
12/31/51	4.62	4.63			
1/4/52	4.35	4.29			
1/16/52	4.07	4.07			

Table 1 - Continued

Date	Piezometer				
	KK-8	KK-6	KK-4	KK-3	KK-2
5/3/51	3.34	3.31		3.31	
5/12/51	4.79	4.69		4.84	4.86
12/10/51	4.65	4.60		4.53	4.69
12/31/51	4.77	4.68		4.99	
1/4/52	4.50	4.41		4.95	
1/16/52	4.16	4.07		4.57	
	KL-8	KL-6	KL-4	KL-3	KL-2
5/3/51	3.32	3.37		3.40	
5/12/51	5.13	5.19		5.30	5.27
12/10/51	5.04	5.06		5.48	5.35
12/31/51	5.21	5.21		5.75	
1/4/52	4.92	4.95		5.39	
1/16/52	4.46	4.48		5.01	
	LA-8	LA-6	LA-4	LA-3	LA-2
4/13/51	8.18	8.22	8.27	8.26	8.30
5/3/51	6.43	6.45	6.50	6.53	
5/11/51	7.26	7.36	7.42	7.32	7.16
5/12/51	8.10	8.13	8.17	8.16	8.23
12/31/51	8.16	8.50	8.81		
1/4/52	7.65	7.99	8.38		
1/16/52	6.70	6.97	7.46	7.83	
1/20/52	8.07	8.36	8.65		8.75
	LB-8	LB-6	LB-4	LB-3	LB-2
4/13/51	8.11	8.12	8.22	8.15	8.26
5/3/51	6.36	6.35	6.45	6.43	
5/11/51	7.15	7.15	7.35		7.19
5/12/51	8.03	8.05	8.12		8.17
12/31/51	8.11	8.20	8.77		
1/4/52	7.58	7.58		7.52	
1/16/52	6.54	6.61	7.25	7.76	
1/20/52	8.04	8.12	8.32	8.06	8.40
	LC-8	LC-6	LC-4	LC-3	LC-2
4/13/51	8.09	8.08			8.01
5/3/51	6.32	6.32			
5/11/51	7.08	7.10			7.15
5/12/51	8.01	8.01			7.51
12/31/51	8.08	8.12			
1/4/52	7.45	7.46			
1/16/52	6.53	6.54			
1/20/52	8.00	8.00			7.50

Table 1 - Continued

Date	Piezometer				
	LD-8	LD-6	LD-4	LD-3	LD-2
4/13/51	7.99	8.04			8.01
5/3/51	6.23	6.27			
5/11/51	6.95	7.02			7.30
5/12/51	7.95	7.97			7.46
12/31/51	8.07	8.01			
1/4/52	7.47	7.42			
1/16/52	6.42	6.47			
1/20/52	7.97	7.97			7.63
	LE-8	LE-6	LE-4	LE-3	LE-2
4/13/51	7.98	8.02		8.38	8.42
5/3/51	6.14	6.22		6.58	
5/11/51	6.85	6.82		7.88	7.95
5/12/51	7.90	7.05		8.05	8.10
12/31/51	7.94	7.25			
1/4/52	7.41	7.33		8.38	
1/16/52	6.24	6.39			
1/20/52	7.77	7.94		8.70	8.67
	LF-8	LF-6	LF-4	LF-3	LF-2
4/13/51	7.54	7.77		8.15	8.20
5/3/51	5.77	5.87		6.51	
5/11/51	5.91	6.47		6.88	7.63
5/12/51	7.28	7.71		7.85	8.16
12/31/51	7.39	7.52	8.75		
1/4/52	6.74	6.77	8.43	8.32	
1/16/52	5.49	5.68	7.72		
1/20/52	7.56	7.57	8.52	8.67	8.64
	LG-8	LG-6	LG-4	LG-3	LG-2
5/3/51		2.97			
5/12/51		4.64			4.83
12/10/51		5.03			5.39
12/31/51		5.31			6.05
1/4/52		4.90			
1/16/52		3.83			
	LH-8	LH-6	LH-4	LH-3	LH-2
5/3/51	2.94	3.04	2.96		
5/12/51	4.44	4.61	4.68		5.24
12/10/51	4.64	4.95	5.15		5.41
12/31/51	5.11	5.36	5.35		
1/4/52	4.62	4.88	5.10		
1/16/52	4.04	4.12	4.31		

Table 1 - Continued

Date	Piezometer				
	LI-8	LI-6	LI-4	LI-3	LI-2
5/3/51	2.85	2.95		3.01	
5/12/51	3.89	4.49		4.44	4.03
12/10/51	4.01	4.80		4.75	
12/31/51	4.97	5.11		5.07	
1/4/52	4.64	4.72		4.70	
1/16/52	3.98	4.08		4.65	
	LJ-8	LJ-6	LJ-4	LJ-3	LJ-2
5/3/51	2.88	2.93			
5/12/51	4.33	4.47			4.35
12/10/51	4.59	4.78			4.75
12/31/51	5.05	5.16			
1/4/52	4.51	4.74			
1/16/52	3.92	4.03			
	LK-8	LK-6	LK-4	LK-3	LK-2
5/3/51	2.93	2.94	2.95	2.95	
5/12/51	4.42	4.47	4.50	4.47	4.54
12/10/51	4.69	4.78	4.95	4.95	5.00
12/31/51	5.15	5.21	5.60	5.57	
1/4/52	4.60	4.45	4.95	4.95	
1/16/52	4.01	4.05	4.33	4.43	
	LL-8	LL-6	LL-4	LL-3	LL-2
5/3/51	2.90	2.93	2.91	2.90	
5/12/51	4.33	4.40	4.40	4.45	4.31
12/10/51	4.56	4.68	4.76	4.93	4.89
12/31/51	5.02	5.17	5.20	5.62	
1/4/52	4.50	4.66	4.69	4.91	
1/16/52	3.88	3.01	4.02	4.15	

Table 2. Elevation of tile lines at places where piezometer readings were taken. (Feet above zero datum.)

Tile line	Upper end	Lower end
I	6.30	3.80
J	5.80	3.80
K	7.10	3.90
L	7.30	4.00

Table 3. Discharge in cubic feet of water per day from tile lines on selected days.

Date	Tile lines			
	I	J	K	L
4-13-51	191	281	114	107
5-3-51	57	32	0	0
5-11-51	267	402	92	108
5-12-51	266	418	154	136
12-10-51	250	460	95	40
12-27-51	240	430	-	135
12-31-51	632	745	200	279
1-4-52	165	384	122	140
1-16-52	106	117	38	46
1-20-52	454	637	-	228

AUTOBIOGRAPHY

I, Clyde Livingston Wilson, was born in Delaware, Ohio, July 29, 1922. I attended the public school in Sunbury, Ohio where my secondary education was received. I attended Ohio State University from 1940 to 1943 when I was called to military service. Upon receiving my discharge in 1946, I reentered Ohio State University and received my Bachelor of Science in Agriculture degree in 1947. Continuing as an undergraduate, I received the degree Bachelor of Agricultural Engineering in 1948. At this time I received an appointment from the Ohio Agricultural Experiment Station as a Research Assistant in the Department of Agronomy. I have held this position to the present time while completing the requirements for the degree Doctor of Philosophy.