Results of a Drainage Investigation On a Soil of the Woodburn Series

SPECIAL REPORT 162
SEPTEMBER 1963

Agricultural Experiment Station
Oregon State University
Corvallis

CONTENTS

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ACKNOWLEDGEMENT: Credit should be given to the author's predecessor, James E. Schoof, who planned and conducted almost all of the field work reported here. The author expresses his appreciation to Larry Boersma and D. D. Evans, Department of Soils and to John Wolfe, Department of Agricultural Engineering, for their many constructive suggestions.

The author also wishes to thank Mr. Hector Macpherson on whose property the measurements reported here were made.

RESULTS OF A DRAINAGE INVESTIGATION ON A SOIL OF THE WOODBURN SERIES

Darrell G. Watts

SUMMARY

In 1961, measurements were made on a tile drainage system installed in a soil of the Woodburn series. The principle objective of the study was to characterize the performance of the system. Records were kept of water table location, outflow rate, and precipitation. Results showed that during a two-month period of abnormally high precipitation, a drainage coefficient of 1/2 inch per day was exceeded less than 10% of the time. Also, nearly all precipitation was removed from the field as drainage effluent.

Empirical equations were developed to allow prediction of system performance under other than measured conditions. Drawdown rates were computed for this system as well as for other systems installed under similar conditions but with different spacings. These results are shown in Table 1. Drainage coefficients for various water table heights and five different spacings are given in Table 2.

The information reported here may be applicable to the better drained portion of the Woodburn series.

INTRODUCTION

Although land drainage is a big and expanding business in Oregon, there are still many unsolved problems. Figures for recent years indicate that the money spent for drainage approaches a million dollars per year. Engineers and contractors working with drainage systems in the Willamette Valley say that much information is still needed to allow the best design for the investment involved. No definite criteria exist for determining the spacing and depth of drains to achieve a given rate of water removal from the soil. For that matter, drainage requirements of many crops grown in the valley are yet to be established. These difficulties are further compounded in several of the more important soil series by the presence at shallow depths of layers of low permeability. Water movement to drain lines is restricted, thus decreasing the effectiveness of sub-surface drains. In attempts to alleviate these conditions, modifications of present installation procedures are occasionally tried haphazardly without an opportunity for adequate testing and evaluation.

To help solve these problems, Oregon Agricultural Experiment Station Project 418, Drainage of Stratified Soils, was initiated in November 1958. The objectives of the project are:

1. To determine depth and spacing criteria for the design of tile drainage systems in stratified soils.

2. To determine the advisability of using certain installation and backfill modifications that appear to have promise for Oregon.

3. To evaluate methods for obtaining improved drainage in the less permeable soils.

4. To improve present methods of measuring hydraulic conductivity.

The first step in meeting these objectives was to characterize the performance of drainage systems installed in the Woodburn, Amity, and Dayton soil series. This paper is a report dealing with part of this work.

THE SITE

From January through April 1961, measurements were made on a tile drainage system located on the Hector Macpherson farm southeast of Corvallis near Oakville. The following two paragraphs, taken from a report by an Oregon State University soil scientist, describe the site. (A detailed soils description is given in the appendix of this report.)

> "The site of the experiment is just south of an abandoned meander of Muddy Creek entrenched about 15 feet below the valley plain on which the experiment is located. The plots begin approximately 100 feet south of the scarp and extend south about 800 feet. Near this scarp there seems to be a slight rise in elevation indicating the presence of a natural levee. This can be better evaluated by study of the topographic mapping. The soils at the north end of the plots, nearest the scarp, were very near the dividing point between the well-drained Willamette series and the moderately well-drained Woodburn series. However, they appeared to be best classed as Woodburn because mottling began just above 36-inch depth, becoming pronounced just below 36 inches. Also, there is evidence of a firm brittle layer or "fragipan" which is typical in the Woodburn series. Near the south end of the plots mottling was found beginning at 30 inches depth, the fragipan was more strongly expressed and the soil was definitely of the Woodburn series, though still at the high side of the drainage class for this series. Some slightly undulating microrelief is present in this part of the plots. Although it wasn't reflected in the morphology, the microrelief may have had some effect on the data through differential runoff and concentration of surface water."
>
> " The differences in morphology observed across the plots were minor. The data should be applicable to the Woodburn series, especially to the better drained portion of these soils. An examination of the substratum below five feet may be pertinent to evaluating the data from this site."

Figure 1 shows the general layout of the drainage system which was installed in 1959. Average depth to the center line of the tile is about 3.6 feet on the laterals. During installation, approximately 3 inches of loose oat straw was placed directly on top of the tile before backfilling. It should be noted that although depth to the fragipan increases from south to north, all the tile lines are below the pan.

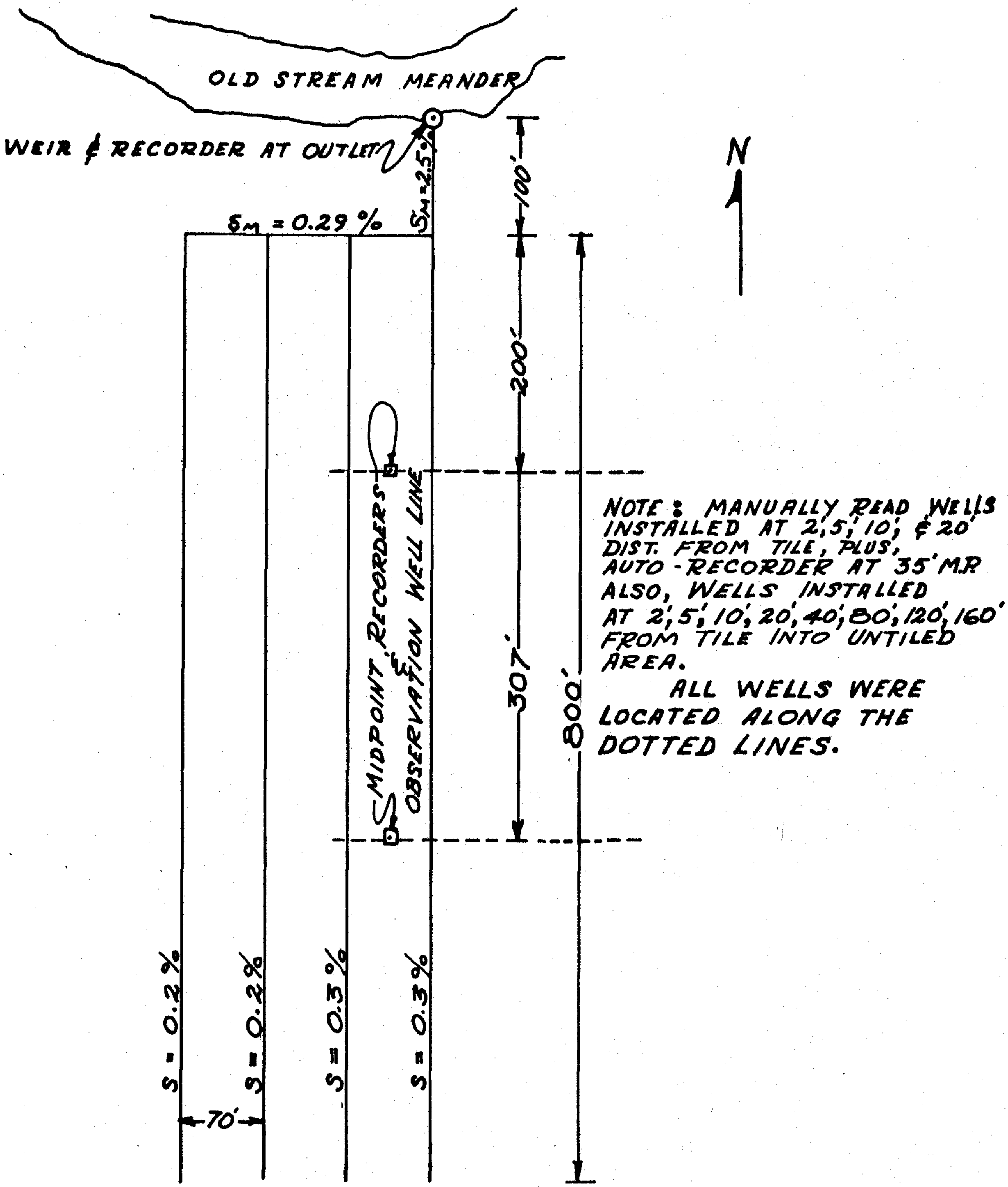

Figure 1. Plan of Macpherson Drainage System

Available records indicate that a cereal crop was grown on the site prior to tiling. In 1960, the north half of the field was in alfalfa while the south half was in peas. The same was true in 1961.

RESULTS OF MEASUREMENTS

Measurements at the experimental site included continuous records of tile flow, rainfall, and water table height midway between two adjacent tile lines. In addition, weekly measurements were made of the water table profile between the lines, as indicated, by a series of open wells. The tile flow was measured at the outlet with a V-notch weir and an automatic water stage recorder.

Rainfall vs. tile flow. Figure 2, a plot of accumulated rainfall vs. accumulated drainage outflow, indicates that practically all of the rain which fell during the period of record was removed from the field by the drain system. A slope of less than one for the regression line is taken as evidence that little or no deep seepage occurred; and, furthermore, indicates a gradual reduction in the volume of water stored above field capacity in the soil. Since the highest water table conditions occurred near the beginning of the period of measurement, this may be a reasonable explanation. At the beginning of the period on February 6 (a time coincident with the beginning of a large storm), the tile was flowing at a trickle. At the end of the period on March 30, the tile flow was again reduced to a trickle. In the time between dates, the tile flowed continuously.

The drainage outflow rate was measured as a volume per unit time and total outflow determined as a volume. Conversion of this volume to a depth (inches) depends on the area which is assumed to be drained. For the system under consideration, the area was taken as the total length of line (including mains) multiplied by the drain spacing, except that the east-west 210 feet of main was considered to drain 35 feet to the north and none to the south. This gave a total drained area of 5.45 acres. If too large an area was assumed, then the slope of the regression line in Figure 2 is too steep. This does not seem likely. On the other hand, if too small an area was assumed, then the regression slope is too flat. However, even if the drained area was 13% larger (thus making the regression slope equal to one), the conclusion that almost all the rainfall was removed through the drains would still be valid.

Examination of the first four points on Figure 2 suggests that initially the soil was not completely up to field capacity, since during the first two or three days of record, moisture fell which was not accounted for by tile flow measurements. This cannot all be explained by a "time lag" between initial rainfall and beginning of flow, since response of the system to rainfall was quite rapid when the soil was at or above field capacity. Of interest also, is the drain-out period indicated in the middle of the graph by the plotting of a series of points on a horizontal line. This occurred during a period of zero rainfall.

During the period of measurement, the recording rain gauge failed for a period of about 6 days. Rainfall data from the nearby Hyslop Agronomy Experimental Farm were used to estimate rainfall at the site. Figure 3, a double mass plot of accumulated rainfall at Hyslop Farm vs. rainfall at Macpherson Farm, was used to correct Hyslop Farm data before applying it to the experimental site.

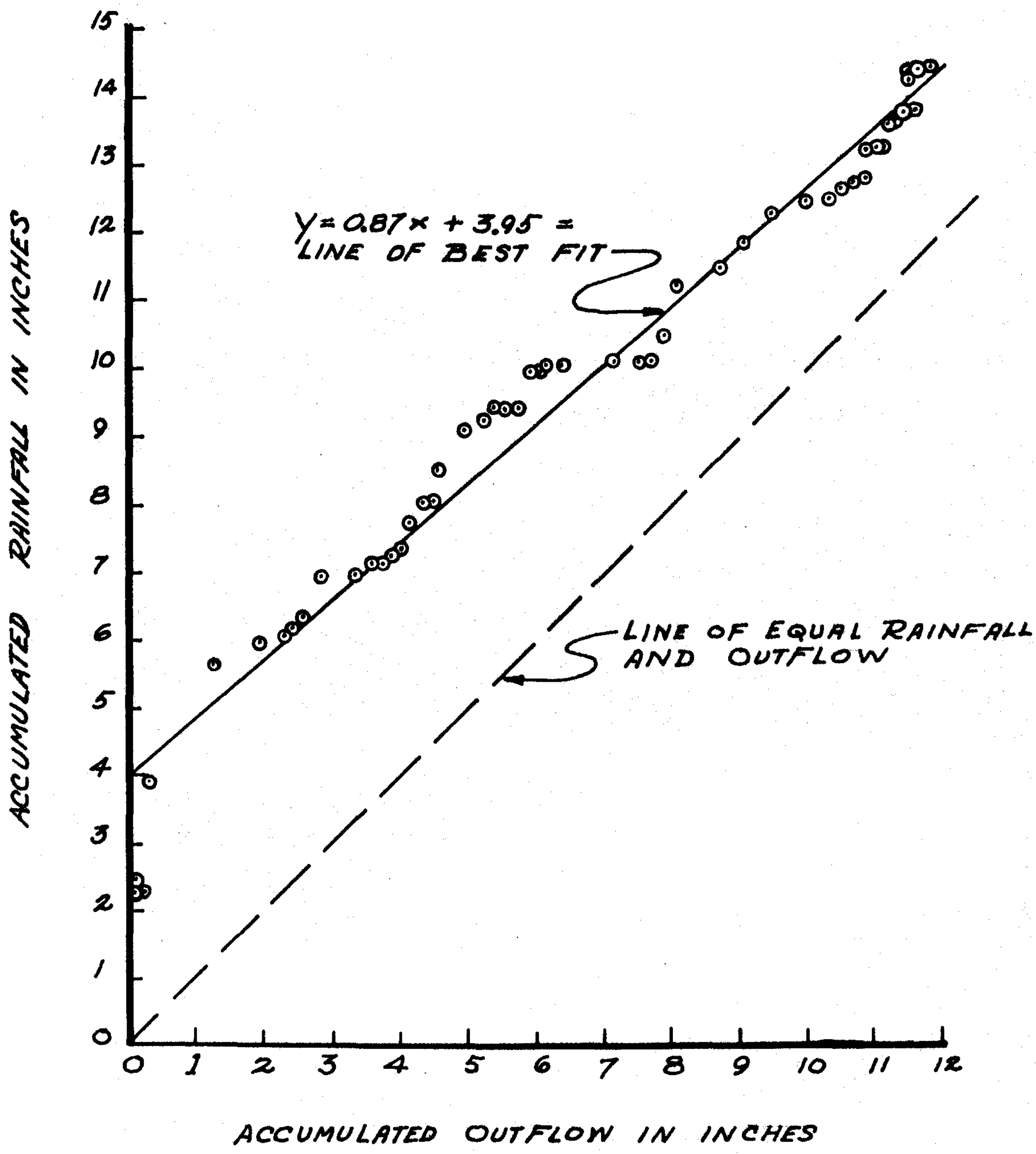

Figure 2. Double Mass Curve of Rainfall vs. Drainage Outflow, February 6 - March 20, 1961

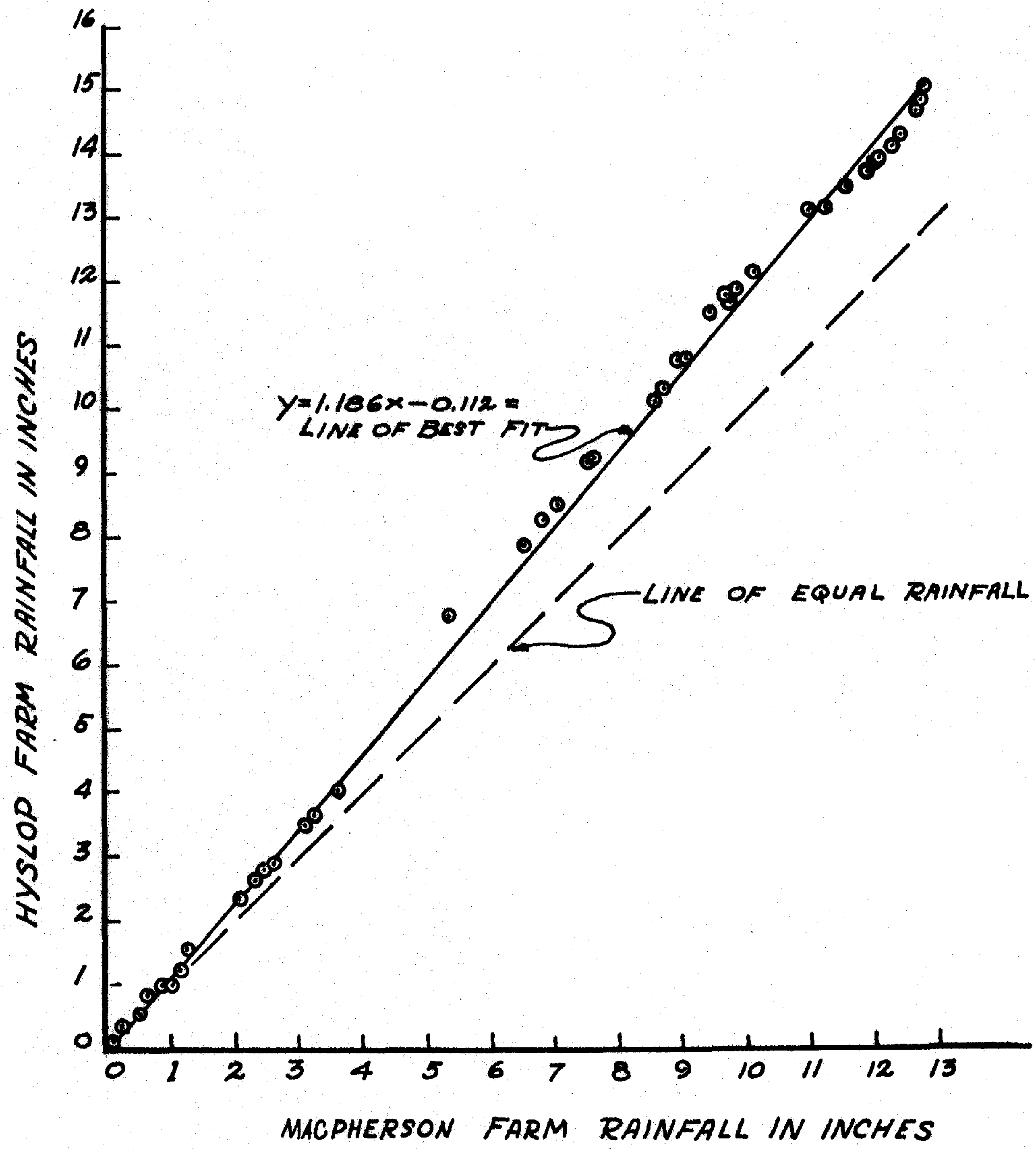

Figure 3. Accumulated Rainfall - Hyslop vs. Macpherson Farm, January 18 - February 14, February 21 - March 20, 1961

It should be noted that rainfall in the area was very high during February and March. At the Hyslop Farm, rainfall was 216% of normal during February and 208% of normal during March.

Tile flow duration. Figure 4, a graph of drainage coefficient vs. percentage of total time during which the given coefficient was exceeded, shows a summary of the flow duration data for February and March 1961. It is interesting to note that for this depth and spacing a coefficient of 1/2 inch per day was exceeded less than 10% of the time, and a coefficient of 3/8 inch per day was exceeded only about 16% of the time. As previously indicated, this was during a period of about twice normal rainfall. This suggests that a design coefficient of about 1/2 inch per day might be adequate for conditions similar to those at the experimental site. This point is discussed further beginning on page 16.

With regard to actual capacity of the system for the acreage involved, the laterals were capable of 2 inches per day; the east-west main about 2 inches per day; and for the short north-south main, more than 4 inches per day.

Hydraulic conductivity. In early April 1963, a trip was made to the site to measure hydraulic conductivity. A very heavy rain storm was in progress, with the result that the water table was near the surface at the north end of the field. At the south end, the water table was at least 0.5 foot lower. No surface flow was observed to take place down the slope from south to north. Conductivity values, as measured by the piezometer method, were too high to be believable. For the soil above the pan, measurements indicated a conductivity of nearly 30 inches per hour. While the numbers may be in question, there is no doubt that the effective conductivity is high. It was difficult to make the measurements since the tubes filled up so quickly after pumping that the water would be almost back up to the original level before the rate of rise could be measured. This was true for a number of holes. Perhaps the high conductivity can be attributed to a combination of good soil structure and the large number of channels opened in the soil by alfalfa roots.

Since over two years elapsed between the time of the hydraulic conductivity measurements and the other measurements reported here, it is possible that the characteristics of the site may have changed somewhat. In the interim period, the south half of the field was seeded to alfalfa so that the entire site was in this crop rather than only the north end as in 1961. However, since the outflow data from 1961 indicate a large rate of flow under high water table conditions, it does not seem likely that the over-all drainage characteristics changed to a great degree.

Location and shape of the water table. Figure 5 is a summary of the frequency distribution for location of the average midpoint water table elevation above the tile. Average in this case means the average of the two midpoint observation wells (locations shown in Figure 1). The shape of this curve will depend on the frequencey, intensity, and duration of precipitation as well as soil conditions and the geometry of the drain installation. During a spring season with more nearly normal rainfall, one might expect the peak of the curve to be displaced to the right since the water table should be lower

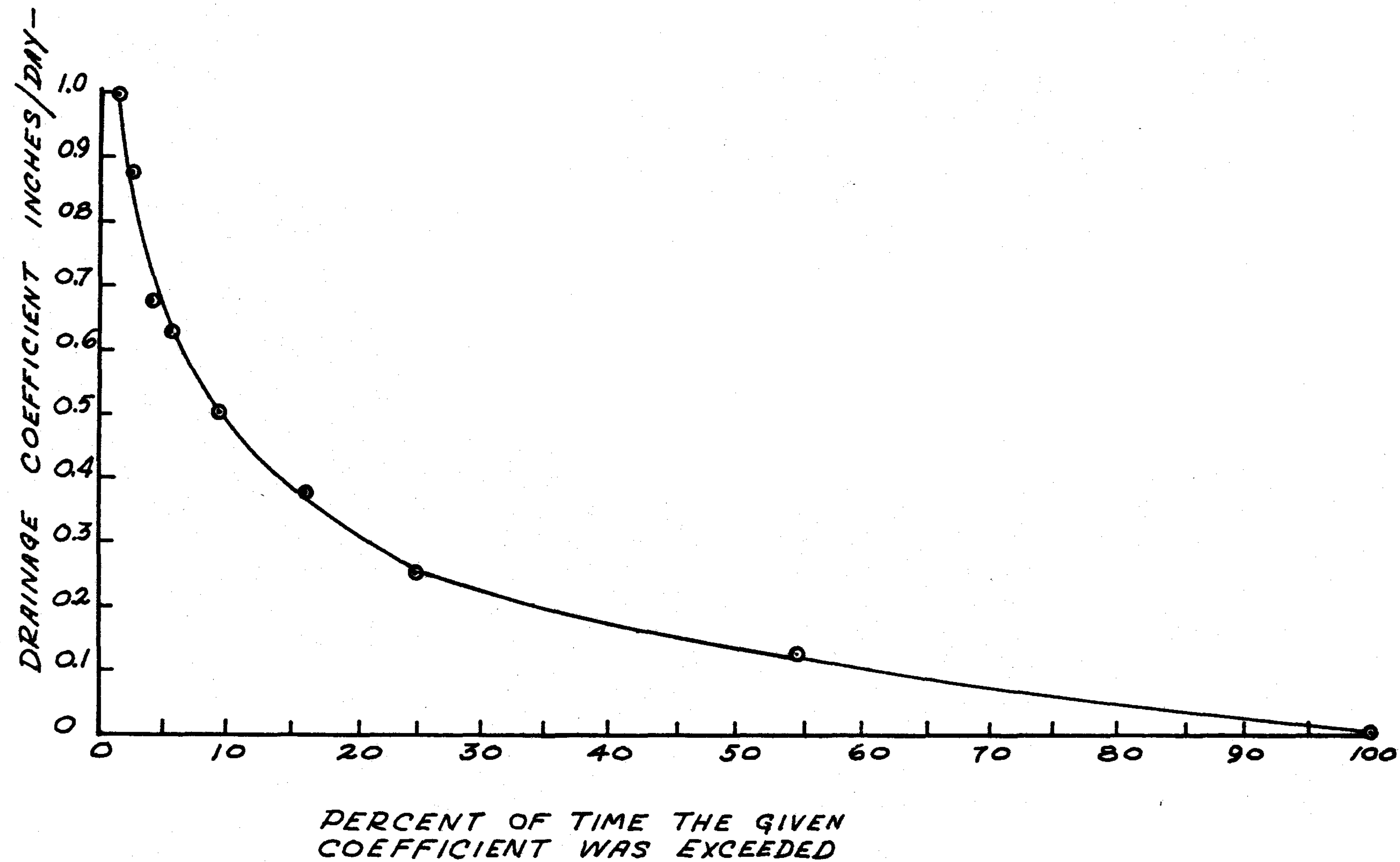

Figure 4. Summary of Flow Duration Data, February 1 - April 1, 1961

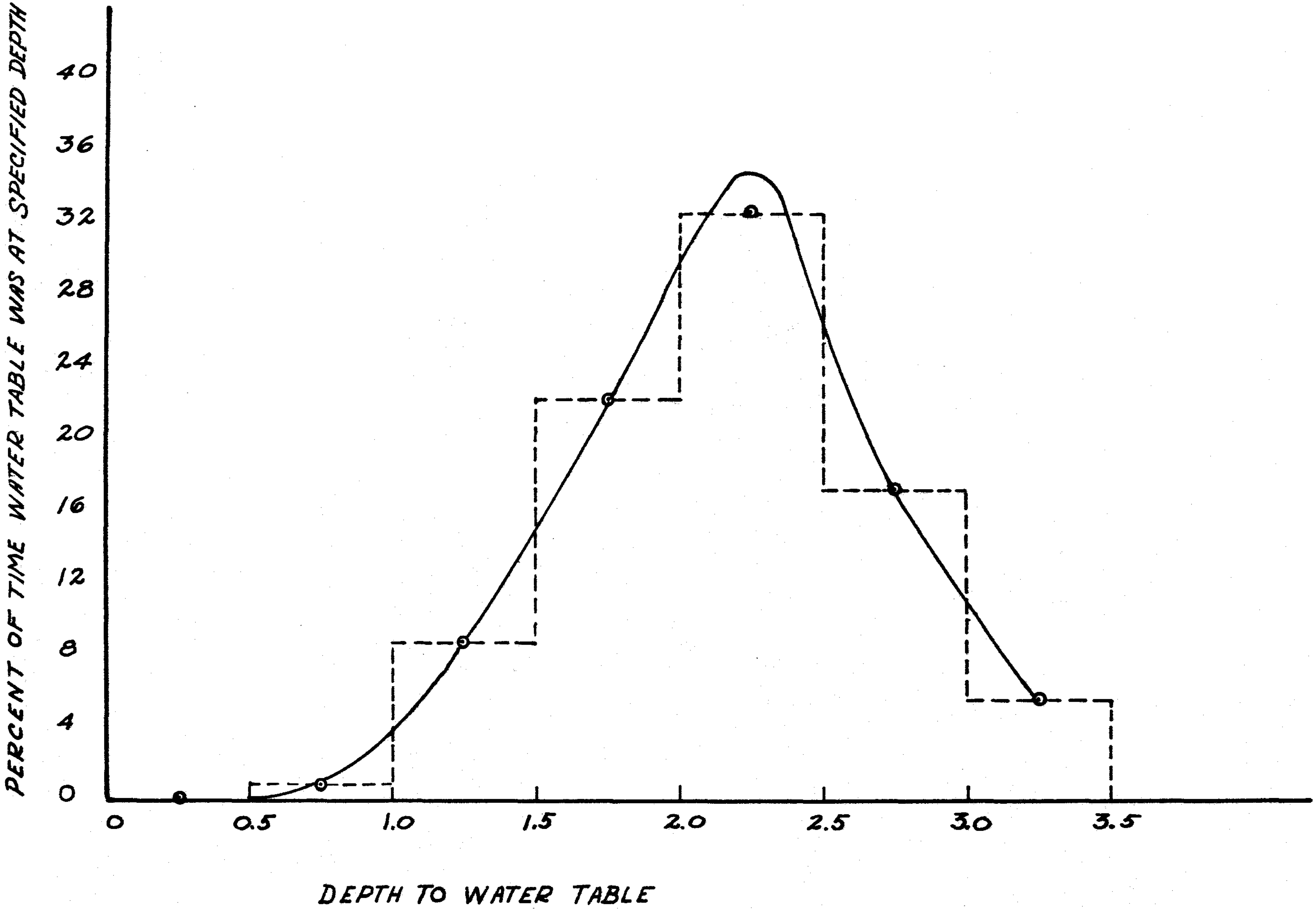

Figure 5. Frequency Distribution for Midpoint Water Table Location, February 1 - April 4, 1961

during a greater percentage of the time.

Figure 6 is a graph showing the shape of water table profiles in both tiled and untiled land during high water table conditions. The profiles were not taken during one drawdown cycle, but were chosen at random to illustrate the water table shape for different depths. Although the vertical scale of the plot is quite exaggerated in comparison to the horizontal, it is seen that the drainage system has a considerable effect on the water table. The midpoint water table between tile is almost twice as far below the surface of the ground as the water table 35 feet from the tile in the direction of the untiled area. The landowner has indicated that the untiled area has better natural drainage than the tiled field.

The shape of the water table profile between tile was actually quite flat. The mean integrated water table height for a number of profiles was determined by planimetering the area under the water table curve and dividing that area by the drain spacing. The mean height was subtracted from the midpoint height to get a measure of profile curvature. For the south line of wells, the differences were all less than 0.26 foot, and for the north line the maximum difference was 0.4 foot, with 3 of 5 measurements less than 0.3 foot. This is not obvious from Figure 6 because of scale distortion in plotting. These measurements are significant in that much of the discussion in this report deals with drain system performance and water table fall as described by measurements at the midpoint. Since mean water table height is very close to midpoint height, midpoint measurements essentially describe the drainage phenomena over most of the tiled area.

The data from the midpoint observation wells are somewhat confusing. As may be noted in the soil survey report, the south end of the field tends to be much more typical of the Woodburn series than the north end. Depth to pan is less at the south end and development of the pan is more pronounced. One might, therefore, expect the south end of the field to drain more slowly. This is not the case. Examination of the midpoint observation well records shows that the water table was nearer the ground surface for a longer period of time at the north end of the field. Also, during water table drawdown, the rate of fall was faster at the south end of the field than at the north.

Since the land slopes from south to north, one explanation of the water table behavior might be that water drained from south to north as a result of the natural gradient. With high soil conductivity, a considerable quantity of water can flow down a low gradient. The data show a water table slope of about 0.1% from south to north during high water table conditions. As the water table continued to recede, the south-north slope decreased. The slope of the ground surface is between 0.2 and 0.3% from south to north.

The foregoing statements may cause the use of the "average" water table to be questioned. Nonetheless, an average of data from the two midpoint wells seems a more reasonable approach to further analysis than using the data from only one well.

Outflow rate vs. water table location. An attempt was made to relate outflow rate to height above the drain of the midpoint water table. A plot

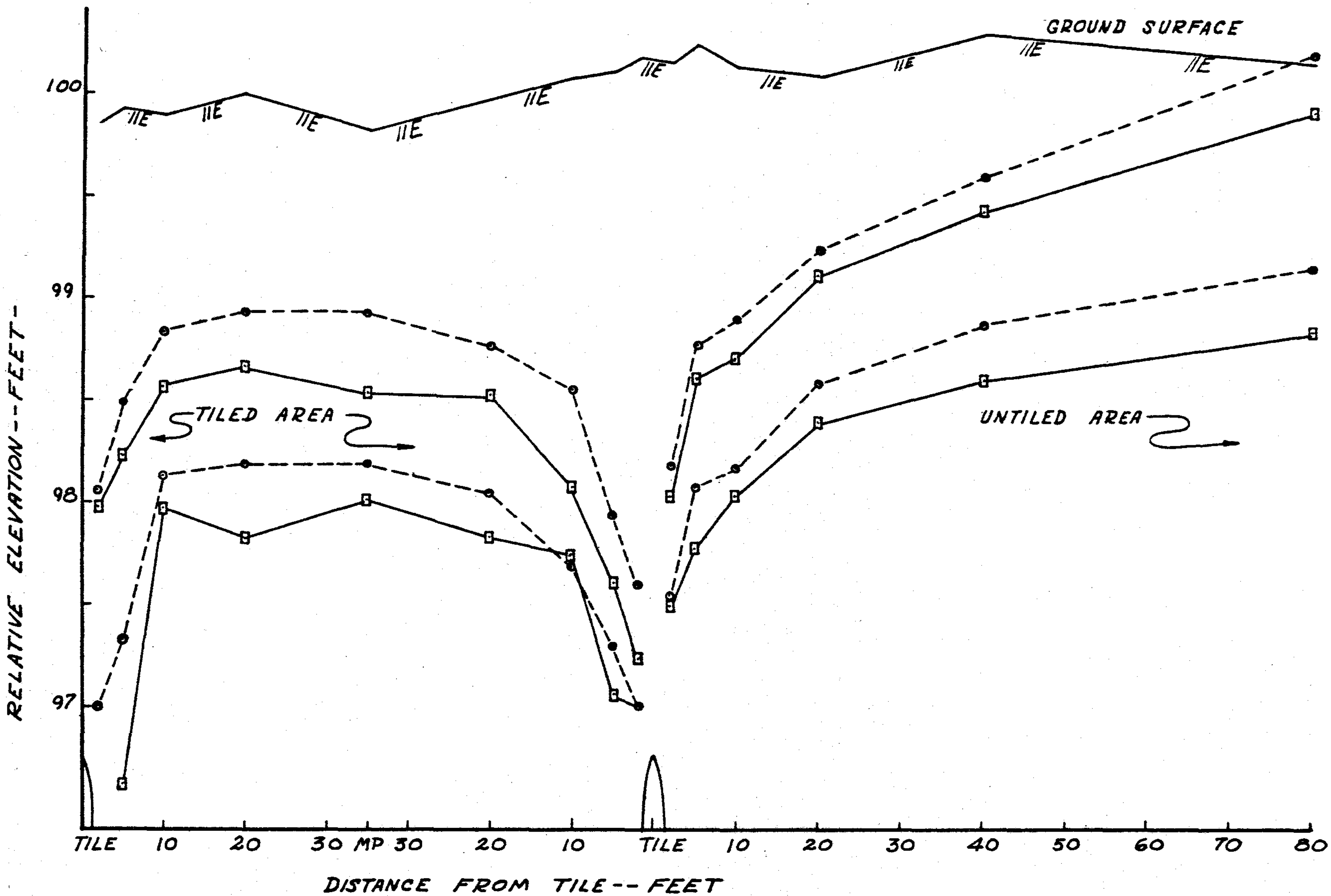

Figure 6. Water Table Profiles in Tiled and Untiled Land

of available data showed only a scattering of points. However, when points were selected which were measured at least 8 hours after rainfall had stopped, the curve of Figure 7 resulted. This graph indicates a logarithmic relationship between drainage outflow rate and midpoint water table height. The equation for the line of best fit to the point is of the form $q = ch^m$, where q is the outflow rate per unit length of drain, h is the midpoint water table height above the tile center line, and c and m are empirical constants which are probably functions of both soil conditions and the geometry of the drain installation. Apparently when rain is falling and infiltrating into the soil, the effective thickness of the capillary fringe is increased. The net result is that for a given water table location, the cross-sectional area of flow toward the drain is greater during a period of rainfall than after. Hence, the relationship determined by Figure 7 would not apply during a storm period.

Decrease of flow rate with time. Figure 8 is a semilogarithmic plot of flow rate vs. time for a part of one particular drawdown cycle. There was no rainfall immediately prior to or during the period these data were recorded. An equation of the general form $q = q_o e^{-bt}$ was found to describe the data. (Here q is the flow rate at anytime, q_o is the initial flow rate, t is the elapsed time since q_o was measured, and b is a constant which, again, is probably a function of the drain geometry and soil.) Statistical methods were used to determine the line of best fit and the constant b. Surprisingly, it was found that the empirical equation developed from these few points also described the time rate of flow decrease for the parts of other drawdown cycles which occurred during periods of little or no precipitation. It therefore appears that the equation can be used with confidence in further mathematical development.

PREDICTION OF DRAINAGE SYSTEM PERFORMANCE FROM EMPIRICAL DATA

Need for the analysis. If the performance of the drainage system under study is to be adequately described, then we should have knowledge of system behavior throughout a drawdown cycle during which no rainfall occurs. However, at no time during the period of measurement did the water table complete a drawdown cycle without being interrupted by precipitation. Although the total rainfall was above normal, the storms were not intense enough to cause ponded or near ponded conditions. It therefore seems desirable to develop a series of equations which will characterize the water table and outflow functions of the system. The equations may be used to extrapolate available data so that performance throughout a drawdown cycle may be described. In addition, such equations may be used to estimate how a system would perform if installed under conditions similar to those at the experimental site, but with different drain spacings.

Use of theoretical equations. A number of equations have been developed and used to determine drain spacing and to predict drainage system performance for a certain range of conditions. Almost all of these equations require that the user determine definite values for hydraulic conductivity and drainable porosity of the soil. In addition, certain assumptions are made concerning the absence or presence of "impermeable" layers. In the later case, knowledge of the location of such layers is also required. For the site under study, the layer was located not below the drain (as is generally the case when the previously mentioned equations are applied) but rather above the drain. This

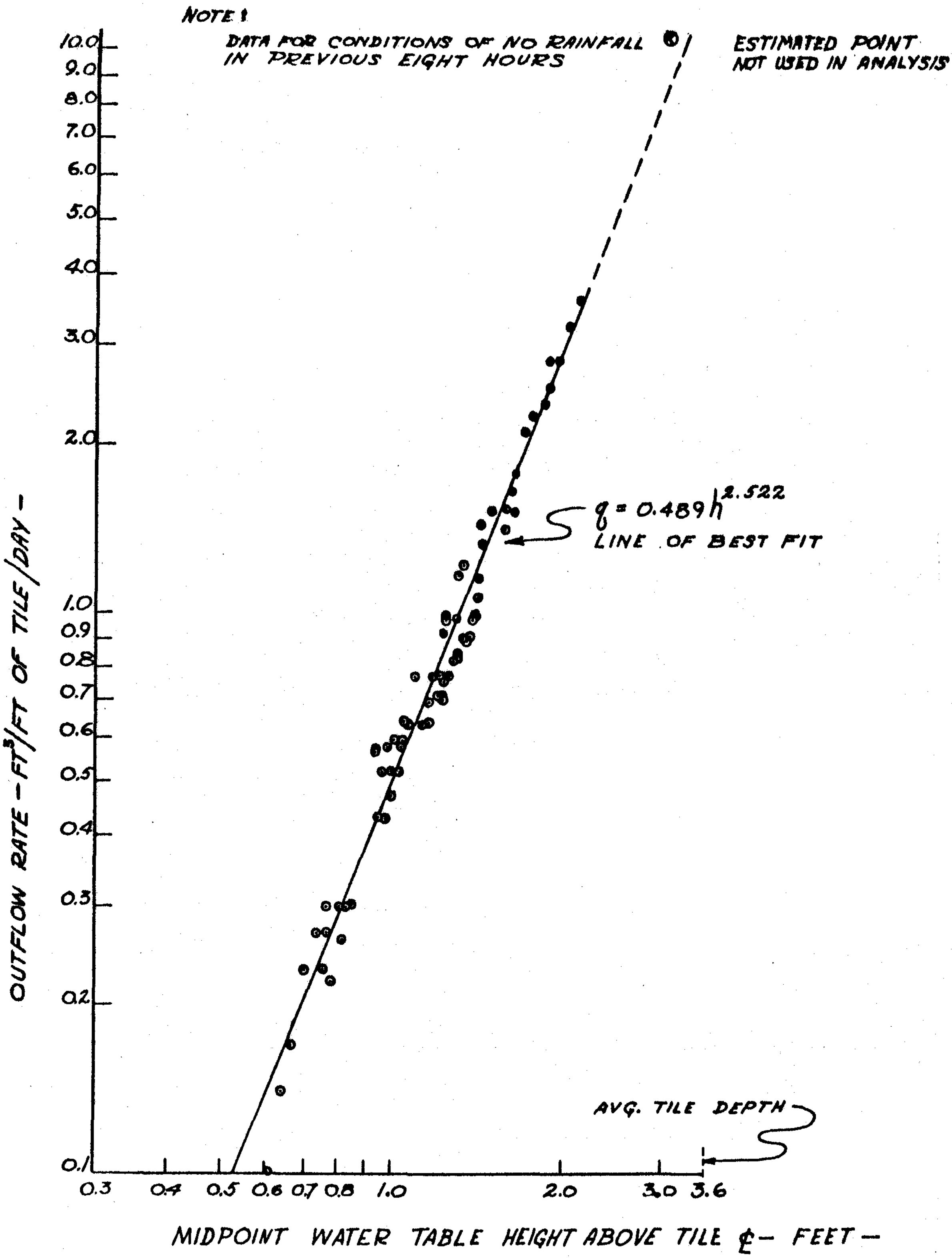

Figure 7. Relationship Between Outflow Rate and Midpoint Water Table Height

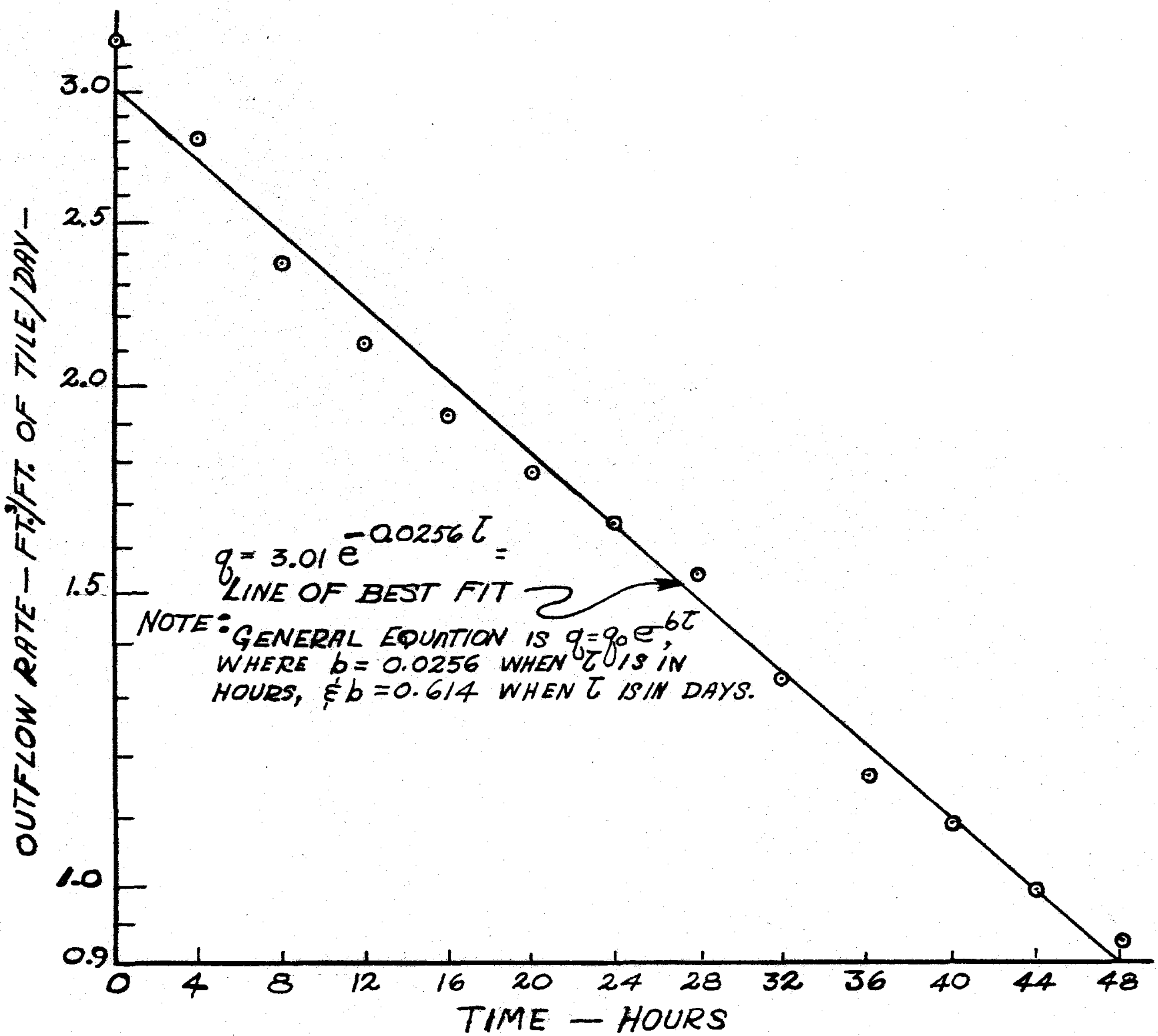

Figure 8. Decrease of Outflow Rate With Time, March 7 - March 9, 1961

statement is made with the assumption that the permeability of the fragipan of the Woodburn soil was low as compared to the soil in the upper horizons. There is some evidence to indicate that practically all of the flow to the drains occurred above the layer and entered the tile by moving vertically through the backfill immediately above the drain line. For this to have occurred, the soil below the tile must have also been less permeable than the backfill. If this is the case, then it is questionable whether the theoretical equations may be applied with any degree of confidence to the conditions of the experimental site. Furthermore, the hydraulic conductivity of the soil is not exactly known, as was earlier pointed out. Also, for a given soil, the apparent drainable porosity is not a constant but is known to vary with the rate of water table fall. (This point will be discussed later in more detail.) It thus appears that an empirical approach using all of the data at hand may be the best solution to the problem.

Development of empirical equations.

Given:

$$q = c\,h^{m} \qquad \text{(from Figure 7)} \quad (1)$$

$$q = q_o e^{-bt} \qquad \text{(from Figure 8)} \quad (2)$$

where the symbols are as described on page 12. Equation (1) may also be written as:

$$q_o = c\,h_o^{m}, \qquad (3)$$

where q_o = outflow rate for some initial water table height, h_o. Substituting (3) into (2):

$$q = c\,h_o^{m} e^{-bt} \qquad (4)$$

Equating (1) and (4): $c\,h^{m} = c\,h_o^{m} e^{-bt}$

Simplifying and solving for h:

$$h = h_o e^{-\frac{bt}{m}} \qquad (5)$$

Equation (5) describes the time rate of decrease of the midpoint water table height during a period of no rainfall. Equation (5) may also be rewritten by solving for t.

$$t = -\frac{m}{b} \ln\left(\frac{h}{h_o}\right) \qquad (6)$$

where t now represents the time required for the water table to fall from h_o to h.

An equation will now be developed which describes the total volume of water drained from a block of soil of unit width and length equal to the drain spacing, when the midpoint water table falls from h_o to h.

When the rate of flow is given as q, then the total volume of water, Q, is discharged during a time period, t, may be written as:

$$Q = \int_0^t q \, dt \tag{7}$$

From Equation (4), $q = c h_o^m e^{-bt}$ Hence, $Q = \int_0^t c h_o^m e^{-bt} dt =$

$$\frac{c h_o^m}{b} \left(1 - e^{-bt} \right) \tag{8}$$

Substituting equation (6) into (8):

$$Q = \frac{c h_o^m}{b} \left[1 - e^{(-b)\left(-\frac{m}{b} \text{Ln} \frac{h}{h_o}\right)} \right]$$

After simplification:

$$Q = \frac{c}{b} \left[h_o^m - h^m \right] \tag{9}$$

Figures 9 and 10 show some of the experimental results compared to the curves described by equations (5), (6), and (9). In general, the experimental and calculated results compare favorably. The flow rate curve of Figure 9 is not a valid comparison of the equation with field results, since some of the points on this curve were used in the original calculation of the empirical equation. However, the midpoint water table and flow volume curves may still be validly compared. The first few points on Figure 9 were measured immediately after a storm. As would be expected, the outflow rate is greater than that predicted by equation (1) because of increased cross-sectional area of flow in the capillary fringe.

Time of drawdown and required drainage coefficient. In the design of drainage systems, it is important to know, for different drain spacings, the time which is required for the water table to recede to a given depth in the soil profile. With this knowledge, the designer can select a spacing commensurate with the drainage requirements of the crops to be grown. Equation (6) was used to calculate the theoretical time of drawdown between several increments of elevation for the 70-foot spacing of the experimental site. For other spacings, the time was approximated by multiplying equation (6) by the ratio of the spacing in question to 70. That is:

$$t = \left(\frac{s}{70} \right) \left[\frac{-m}{b} \text{Ln} \left(\frac{h}{h_o} \right) \right] \tag{10}$$

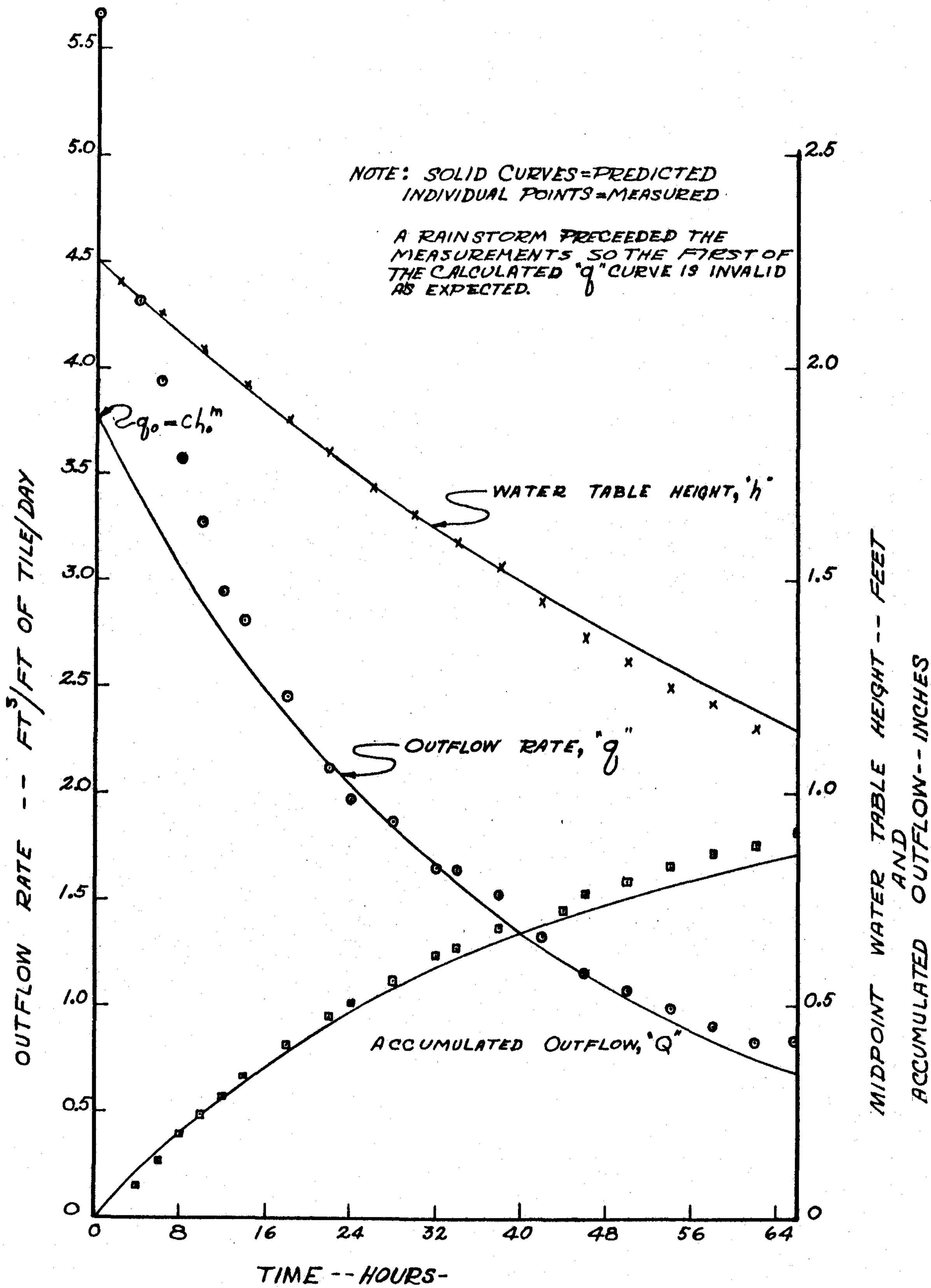

Figure 9. Predicted and Measured Performance of the Macpherson Farm Drainage System Beginning 1400 Hours, March 3, 1961

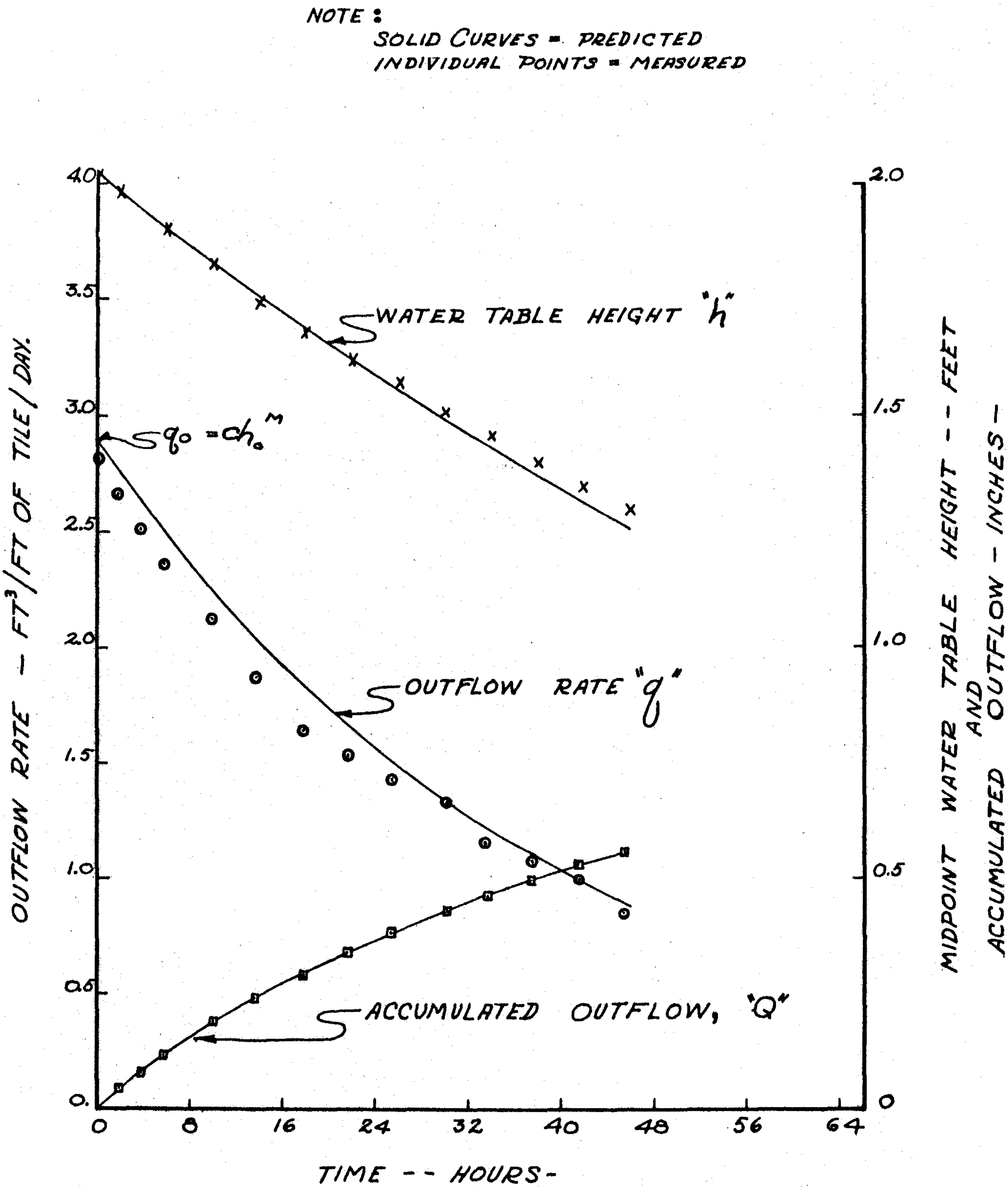

Figure 10. Predicted and Measured Performance of the Macpherson Farm Drainage System Beginning 1800 Hours, February 15, 1961

The results of these calculations are shown in Table 1.

Equation (10) implies that the rate of flow into the drains is a function only of midpoint water table height and is independent of spacing. The time required for the water table to fall a given distance is then directly proportional to spacing. Drainage theory has shown this concept to be only an approximation.

Table 1. Drawdown Time as Determined by Equation 10
(Time in Days)

Height above tile	Spacing				
	60 ft.	70 ft.	80 ft.	90 ft.	100 ft.
feet	days	days	days	days	days
3.0-2.5	0.64	0.75	0.86	0.97	1.07
2.5-2.0	0.79	0.92	1.05	1.18	1.32
2.0-1.5	1.01	1.18	1.35	1.52	1.69
1.5-1.0	1.43	1.66	1.90	2.14	2.37
3.0-1.0	3.87	4.51	5.16	5.81	6.45

After the proper spacing has been selected, drainage lines must still be sized correctly so that the carrying capacity of the system is large enough to remove the water at the prescribed rate. Otherwise, the water table will not fall as rapidly as expected. Hence, the proper design drainage coefficient must also be selected. The rate of water removal in inches per day (or drainage coefficient) was computed for several water table elevations, using equation (1) and appropriate conversion factors. It was assumed that the flow per unit length of tile came from a strip 1 foot wide and with a length equal to the 70-foot tile spacing. Coefficients for other spacings were approximated by multiplying the coefficients for the 70-foot spacing by the ratio of 70 to the spacing in question. That is:

$$\text{d.c.} = \frac{70}{s}(\text{d.c. } 70)$$

The results of the computations are listed in Table 2.

Table 2. Drainage Coefficients* for the Water Table Heights and Spacings in Table 1

Height above tile	Spacing				
	60 ft.	70 ft.	80 ft.	90 ft.	100 ft.
feet					
3.0	1.54	1.32	1.16	1.03	0.93
2.5	0.99	0.85	0.75	0.66	0.60
2.0	0.56	0.48	0.42	0.37	0.34
1.5	0.27	0.23	0.20	0.18	0.16
1.0	0.10	0.08	0.07	0.07	0.06

*Coefficients are given in inches per day

To achieve the drawdown rates indicated in Table 1, the system must be designed to carry a maximum flow equal to or greater than that indicated by the corresponding coefficient in Table 2. It was earlier suggested that a design coefficient of 1/2 inch per day might be acceptable. This would allow a system installed under conditions similar to those at the Macpherson farm to do a satisfactory job of drainage most of the time. However, during very high water table conditions, the drawdown times would be longer for a given spacing than those listed in Table 1.

The empirical constants used throughout the preceding derivations and calculations are undoubtedly a function of drain spacing. This being true, the values listed in Tables 1 and 2 are to some extent in error. However, within the range of spacings given, the error should be relatively small so that the figures should give a reasonable measure of performance of drain systems installed under conditions similar to those of the Macphperson farm.

Drainable porosity. An attempt will now be made to characterize the so-called "effective" drainable porosity, f_a, of the soil under study. The effective porosity is defined as the ratio of the volume of water removed to the volume of the soil drained. Equation (9) defines the volume of water which seeps into a unit length of drain when the midpoint water table recedes from h_0 to h. Thus, the remaining problem is one of defining the actual volume of soil drained. As previously discussed, the shape of the water table was quite flat. However, the small degree of curvature involved should be taken into account. Also, it is generally recognized that the rate of fall of the midpoint may vary somewhat as compared to the rate of fall of the mean water table.

Using a procedure which will be later discussed, it was determined that under high water table conditions, the mean integrated water table height above the tile decreased about 88% as much as the midpoint height. This was true for measurements at both the north and south wells. It follows that the volume of soil drained per unit length of tile may be computed as:

$$V_s = \left[(0.88)(70)(h_o - h)\right] \qquad (11)$$

where 70 = drain spacing in feet.

Combining equations (9) and (11), $f_a = Q/Vs$;

$$f_a = \left(\frac{c}{b}\right) \frac{\left[h_o^{\,m} - h^{\,m}\right]}{\left[(0.88)(70)(h_o - h)\right]} \tag{12}$$

The factor, 0.88, in equation (12) was determined by first plotting a water table profile for high water table conditions. Then, assuming that all points on the profile dropped in porportion to the midpoint, profiles for one and two days later were calculated. The area between successive profiles was determined by planimetering. The areas as measured were compared with the area enclosed by a rectangle with a length equal to the drain spacing and width equal to the midpoint water table drop. A ratio of 0.88 resulted. Since the profiles were actually measured only once per week, no data was available which would allow direct plotting. This procedure gives only an approximate solution of the problem. It does not take into account that the rate of midpoint fall may change with respect to other water table points or that the body of soil above the water table is draining because of unsaturated flow. However, this appears to be the only solution possible under the circumstances.

Equation (12) was solved for a range of values from h = 3 feet to h = 1 foot, in 0.2-foot increments. These heights correspond to an elevation above the fragipan or "impermeable" layer of from slightly greater than zero to about 2 feet. Table 3 shows the results of these calculations.

Table 3. f_a Values As Determined by Equation 12

ho	h	f_a*	For 1-foot increments	
feet	feet			
3.0	2.8	.165		3.0
2.8	2.6	.148		
2.6	2.4	.131	.132	
2.4	2.2	.116		
2.2	2.0	.101		
2.0	1.8	.086		2.0
1.8	1.6	.073		
1.6	1.4	.060	.061	
1.4	1.2	.049		
1.2	1.0	.037		1.0

*For these calculations, the values of the empirical constants were: c = 0.489, b = 0.614, m = 2.522, when t in days, d in ft, q in $ft^3/ft/day$.

This suggests that the "apparent" porosity decreases as the water table falls. This is not entirely consistent with reason since one would expect just the opposite. It seems reasonable to suppose that as the high water table falls initially at a rapid rate only the largest pores would be drained. As the water table height and rate of fall both decrease, the large pores immediately above the capillary fringe would be drained as before, and in addition, an increasing tension would be exerted on the smaller pores causing them to be partially drained and thus increasing, rather than decreasing, the f_a. However, this reasoning is only strictly applicable to homogeneous soil. Soil moisture tension curves for the first two feet of the profile indicate that as depth increases, the soil holds more water at higher tensions. Hence, the computed porosities in Table 3, while certainly open to question as to their numerical value, may indicate the general trend of the situation.

It should be noted that equation (12) if solved for values of h_o greater than about 3 feet yields absurd solutions. This is to be expected since depths greater than 3 feet are beyond the range of the data from which the empirical constants in the equation were determined.

Hydraulic conductivity. Since field measurements of saturated hydraulic conductivity were inconclusive, it seemed advisable to obtain an indirect estimate by some other method. To accomplish this, an electric analog was built which modeled the following dimensions of a field situation: drain spacing, 70 feet; depth to pan or impermeable layer, 3 feet; depth to bottom of drain, 3.8 feet; width of trench in which drain was installed, 1.5 feet. Within these boundaries, the soil was considered to be homogeneous and isotropic. All flow entering the tile was assumed to have moved through backfill material. Ponded water conditions were assumed.

Once the analog was built, a flow net was constructed and the hydraulic gradient and cross sectional area of flow were determined for an area bounded by two adjacent stream lines and equipotential lines. Although it probably gives a low estimate, equation (1) was used to compute outflow when the water table was 3.6 feet above the center line of the tile, a depth corresponding to ponded water conditions. For this geometry and assumed flow rate, the conductivity was determined to be approximately 5.5 feet per day or 2.75 inches per hour. For completely ponded conditions, the flow would be greater than that predicted by equation (1) since there would be no drawdown near the tile when the midpoint water table was just at the surface. Therefore, the computed value of conductivity is lower than the actual value and may be taken as a "minimum" value. It is, perhaps, a more realistic estimate than that obtained in the field.

It is interesting to note that for the assumed flow geometry, over 60% of the potential drop or "head loss" occurred in the backfill trench and within two feet of the tile. This points out the possible advantage of using a highly permeable backfill material, particularly in installations in stratified soils such as the one under investigation.

APPLICABILITY OF RESULTS

The results reported here were obtained from measurements made during a short period of time at only one site. According to the soils report, the body of soil which was studied represents the better drained portion of the Woodburn series. It is therefore doubtful that experimental results can be considered typical for the entire soil series or even as results which would be repeatable year after year at the same site. For a given location, drainage characteristics would likely vary with time, depending upon how cropping and soil management practices affected soil permeability. Our results should perhaps be considered as an "upper limit" of expected drainage system performance in this soil. For the shallower, less permeable part of the series, the drawdown rate and drainage coefficients would probably be lower. The range of these factors for the entire soil series is not known.

APPENDIX

Soil: Woodburn silt loam (experimental site).

Location: McPherson Farm, SW of Oakville, Linn County, Oregon.

Elevation: Nearly 240 feet.

Experiment: Tile drainage study -- Agricultural Engineering.

Crop: Alfalfa.

Site: The plots are on a nearly level terrace of silty water deposited material (Willamette silts). A loop of the Muddy Creek bottom with an abandoned channel lies just north of the plots and is incised about 15 feet below the terrace surface. The plots extend from about 100 to 900 feet south of the scarp. There appears to be a slight natural levee on the terrace surface adjacent to the scarp. There is a slightly undulating microrelief in the south part of the plots. The plots are in a belt of better drained soils extending along the Willamette River. They were mapped as Willamette series soils in the published survey of Linn County.

Description: December 26, 1962, by G. H. Simonson. The profile description below was made about 150 feet south of the north end of the plots. Examination was by spade to 36 inches and auger to 66 inches. The soil was moist. No water table was encountered.

Classification: Brunizem - gray - Brown Podzolic intergrade (no evidence of an A_2 horizon). 7th approximation: Mollic Fragudalf 7.33-5.

Drainage: Moderately well drained (near the well-drained end of the drainage class).

Profile:

Horizon	Depth, inches	
A_p	0-6	Very dark grayish brown (10YR3/2) silt loam; weak, medium granular to massive; friable, slightly plastic, slightly sticky; clear boundary.
A_3	6-12	Dark brown (10YR3/3) silt loam; moderate fine subangular blocky; friable, slightly sticky, slightly plastic, abundant roots; gradual boundary.

B_1	12-19	Dark brown (10YR3.4/3) silt loam; moderate fine and medium subangular blocky; friable, slightly sticky, slightly plastic, common thin patchy clay films; abundant roots; clear boundary.
B_{21}	19-26	Dark yellowish brown (10YR3/4) silty clay loam; weak coarse prismatic, breaking to moderate, medium, subangular blocky; slightly firm, sticky, plastic; thin continuous clay films, few block MnO_2 coatings; common roots; clear boundary.
B_{22m}	26-36	Dark yellowish brown (10YR4/4) silty clay loam; weak coarse prismatic, breaking to moderate coarse angular blocky; firm, sticky, plastic; thin continuous clay films (10YR3/4), few, fine brown mottles in lower part, common block MnO_2 coatings; common roots; clear boundary.
B_3	36-48	Dark yellowish brown (10YR3/4) silt loam-silty clay loam; common distinct brown (7.5YR4/4) and olive brown (2.5YR4/3) mottles; friable, sticky, plastic; few roots; gradual lower boundary.
C_1	48-66+	Dark yellowish brown (10YR3/4) silt loam; massive; friable, slightly sticky, slightly plastic, abundant distinct, large grayish brown (2.5YRS/2) and strong brown (7.5YR5/6) mottles; few roots.

Comments: This profile was near the upper limit for the moderately well drained class. The "fragipan" or firm brittle layer (B_{22m}) was less well expressed than for much of the Woodburn series. Near the south end of the plots the mottling began at about a 30-inch depth, and the fragipan was more gray in color and somewhat more firm. These differences could be expected to be gradational across the plots with distance from the scarp and natural levee. The differences were of minor degree however. The profiles are quite porous throughout except for the interiors of the firm peds in the B_{22m} horizon.