DRAINAGE RESEARCH IN COLORADO[1]

by

N. A. Evans[2] and A. R. Robinson[3]

INTRODUCTION

This paper summarizes some of the drainage research which has either been completed or is currently active in Colorado. It should be pointed out that there is other work in progress which is not being discussed at this time. Reported herein are two field studies, one pertaining to the evaluation of existing interceptor drains and the other to the operation of a drainage well. The third section relates to a model study which was conducted on interceptor drainage.

These studies were conducted jointly by the Western Soil and Water Management Research Branch, Soil and Water Conservation Research Division, Agricultural Research Service, and the Colorado Agricultural Experiment Station. The Soil Conservation Service cooperated on certain phases of the research.

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1. For presentation at the Winter Meeting, American Society of Agricultural Engineers, Chicago, Illinois, December 1957.

2. Head, Agricultural Engineering Section, Colorado Agricultural Experiment Station, Fort Collins, Colorado.

3. Agricultural Engineer, Western Soil and Water Management Research Branch, Soil and Water Conservation Research Division, Agricultural Research Service, and Civil Engineering Section, Colorado Agricultural Experiment Station, Fort Collins, Colorado.

I. Laboratory Investigations on Interceptor, Tile Drains.

The purpose of this investigation was to study the interceptor type drain where the source of seepage was at some finite distance from the proposed location of the drain. The factors investigated were the flow into the drain after installation and the resulting shape of the water table. In the experiment, an impermeable boundary with constant slope existed at some measurable distance below the water surface. The source of seepage was such that the water depth at the source would remain essentially unchanged after drainage and additional water required after drainage could be supplied without a change in depth.

The experiment was designed to establish the relationship between the pertinent variables and to obtain data for comparison with results obtained by other studies. A check on the accuracy of theoretically derived relationships was one of the objectives.

Equipment

This study by Keller (5) was conducted utilizing a large tilting flume which is shown schematically in figure 1. The flume was 70 feet long, 2 feet wide and 4 feet high and could be adjusted for slope from horizontal to a maximum of 3 percent. A head and tail box with adjustable overflow devices were provided to control the water table levels. Tile drains were placed at three levels near the downstream end of the flume with an additional one near the midpoint. Any one of these could be operated with the remaining three plugged. Banks of manometers connected by plastic tubing to piezometers placed at intervals along the flume were used to determine the water table profile. The outflow from the drains was weighed to determine the discharge. The field condition which the model simulates is shown in figure 2,

The soil used in this study was a decomposed granitic sand having a mean size of 0.107 inches and a uniformity coefficient of 2.0. The material was compacted to uniform density as indicated by conductivity measurements made with various depth of ground water in the flume. The porosity of the in-place material was determined to be 36.8 percent and the specific yield was 25.7 percent.

Procedure

The test sequence was such that the drawdown curve being investigated was preceded by a higher drawdown curve. A minimum of three hours was allowed after a given set of boundary conditions were imposed. This was accomplished either by opening the valve for any one of the tile drains or by adjusting the level of tail water. The tail box actually simulated an open, interceptor drain.

Head water depths were varied over a range from 8 to 40 inches. Various tile drains were operated with each constant head water depth. The slope was varied in one-half percent increments from 0 to 3 percent.

Analysis

Flow Into Drain

In the preliminary analysis, dimensional analysis was used to relate the pertinent variables. As a result of this analysis the following general relationship was developed and used in plotting the data resulting from the study.

$$q_d/q_o = \phi\ (sL/(H + sL),\ h/H) \qquad (1)$$

where q_d is the flow from the drain; q_o is the undrained flow or unit flow before the drain is installed; L is the distance from the drain to the source of seepage; H is the depth of ground water above an impermeable boundary of general slope s; and h is the height of the drain above the impermeable boundary. The function is denoted by ϕ.

Figure 3 is a plot of the data using the relationship given in equation 1. The parameter h/H is a ratio of height of drain above the impermeable layer to the depth of water bearing stratum. A value of h/H equal to zero indicates the drain was placed on an impermeable layer. The parameter $sL/(H + sL)$ shows the relationship of energy in a system because of slope to that due to slope and depth. This approaches a value of one for a great length or small values of H and decreases as the distance from the source to the drain decreases or H increases. The alignment of points in figure 3 indicates that all factors influencing the problem had been considered. By using a dimensionless plot, the results can be used for the solution of problems of any size.

Shape of the Drawdown Curve

One purpose of this study was to check by use of model techniques a previous theoretically derived relationship for determining the shape of the drawdown curve. This relationship which was developed by Glover and presented by Donnan (1) is:

$$xs = H \log_e (H-h)/(H-y)-(y-h) \qquad (2)$$

where x and y are the coordinates of any point on the drawdown curve as shown in figure 2 and the remaining variables have the same meaning as in equation 1.

The comparison of equation 2 and experimental data is shown in figure 4. The results of two tests are shown, one of which could be considered a relatively short system (H = 40, L = 811, h = 0.0) and the other relatively long (H = 13.3, L = 794, h = 5.0). For the short systems there was a considerable difference between the observed drawdown curve and the computed curve. Some adjustment was therefore necessary in equation 2. This was accomplished by computing a new value for H in equation 2 which was termed H' and was done by substituting x = L and y = H back into the equation and solving for H'. Using this new value for H', equation 2 checked with observed data as can be seen in figure 4. Equation 2 then becomes

$$xs = H' \mathrm{Log}_e (H'-h)/(H'-y)-(y-h) \qquad (3)$$

As the system gets relatively long then $H \longrightarrow H'$ so that equations 2 and 3 are the same. Figure 5 is a plot which was computed using equation 3.

Applications

Flow Into Drain

In many cases, the flow which can be expected after a drain is installed is needed to properly design the drain. Figure 3 can be used to make an estimate of the flow if sufficient data are gathered before the drain is installed. For this determination, it is necessary to: (1) make an estimate of the distance (L) which is the length from the drain to the seepage source or to a point where the installation of the drain will not change the elevation of the water table to any appreciable extent; (2) determine thickness of the water bearing aquifer; (3) find general slope of the water table or impermeable layer before drainage; and (4) determine an average hydraulic conductivity.

As a practical example let it be assumed that the length (L) is 200 feet, the water bearing stratum is 10 feet thick (H) overlying an impermeable boundary of slope 0.01 (S) with a tile drain installed 4 feet (h) above the barrier layer. Solving for the known variables yields

$$sL/(H + sL) = 0.17 \quad \text{and} \quad h/H = 0.4.$$

From figure 3

$$q_d/q_o = 2.6 \quad \text{or} \quad q_d = 2.6\ q_o$$

The discharge in the drain (q_d) would be 2.6 times the flow per linear foot which was occurring before drainage (q_o). If the hydraulic conductivity is known, the actual drain discharge can be computed. Assuming a conductivity (k) of 0.0001 foot per second (4.3 inches per hour)

$$q_o = HKs = (10)(0.0001)(0.01) = 0.00001 \text{ cfs/linear foot}$$

or

$$q_o = 4.5 \text{ gal/min/1000 linear feet}$$

The worst possible condition which the uphill irrigator could cause would be if the water table was maintained permanently at the ground surface at his field boundary. A steady state drain flow could then be determined, as in the foregoing example, using the distance from proposed drain location to the uphill field boundary as L and the depth from the ground surface at the field boundary to the lower confining layer as H. The flow so determined would be larger than would actually occur except immediately after the drain was installed.

Shape of Drawdown Curve

The shape of the drawdown curve resulting from the installation of an interceptor drain can be determined using figure 5. As a practical problem, suppose that the original depth of water bearing strata (H) was 10 feet, the drain was 5 feet above the barrier layer (h) which had a slope (s) of 0.02 and was installed at a distance (L) of 500 feet from the known source of seepage. Then

$h/H = 0.5 \quad sL/(H + sL) = 0.5$

from figure 3

$(H' - h)/H = 0.69$

$H' = 11.9$

The problem is to determine the distance (x) from the drain that the ground water would be lowered 2.5 feet from its original level.

Then

$$y = 5.0 + 2.5 = 7.5 \text{ feet}$$

$$h/y = 5/7.5 = 0.67$$

$$(H' - h)/y = 0.92$$

from figure 5

$$sx/(y + sx) = 0.27$$

$$x = 139 \text{ feet}$$

Therefore, the ground surface would be 2.5 feet below its level before drainage at a distance of 139 feet from the drain. Figure 5 can be used for finding the coordinates of any point on the drawdown curve.

Summary

A method has been proposed for determining both the resulting flow and shape of the drawdown curve of an interceptor drain using plots developed from a model study and analytical methods. This method is applicable for cases where the source is either known or from engineering judgment an equivalent source is determined, and an impermeable layer is confining the flow through a relatively shallow strata.

The study showed that installation of a drain near a source, such as a canal, might materially increase the quantity of seepage due to increasing the gradient.

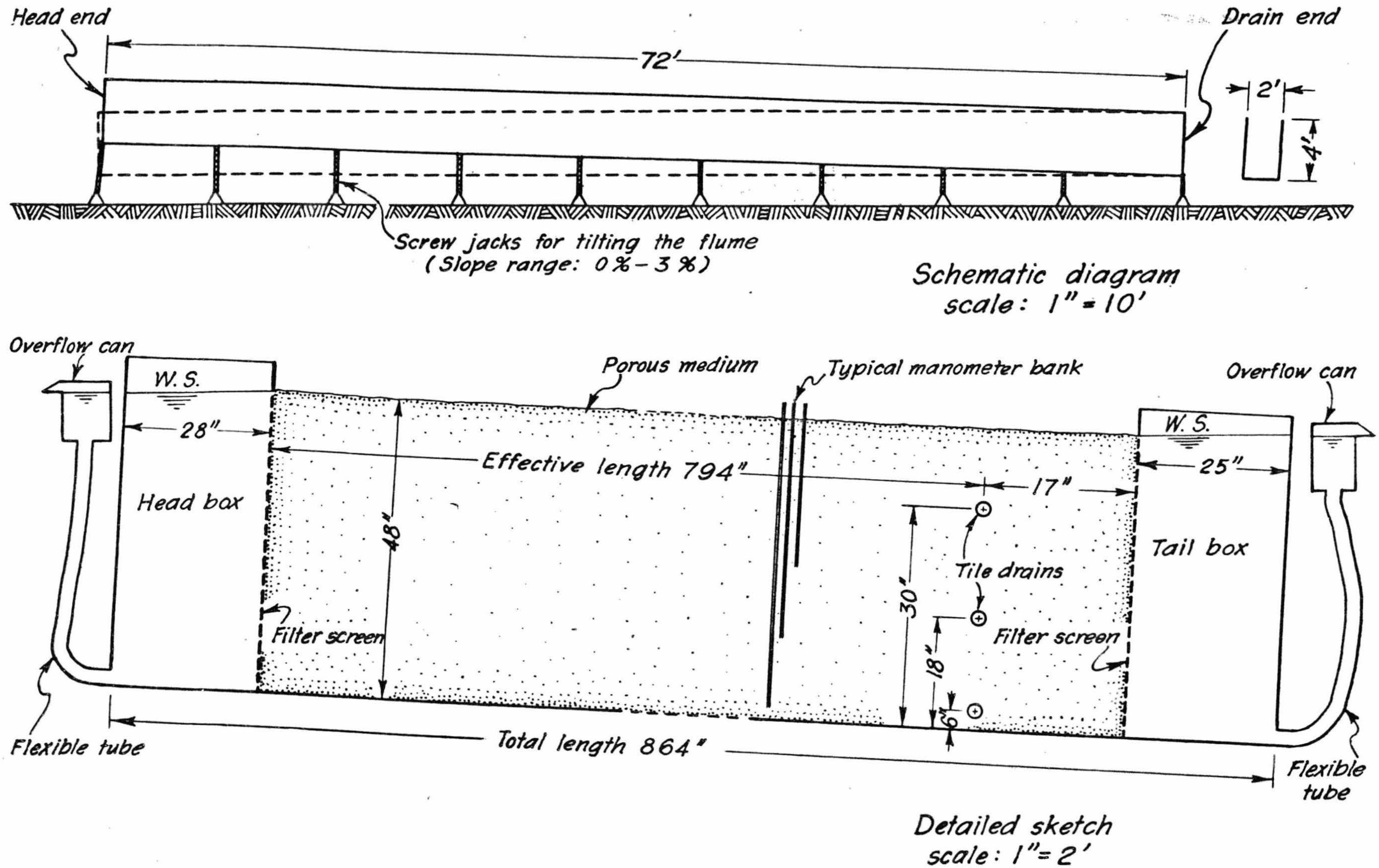

Fig. 1 Lay-out of tilting flume.

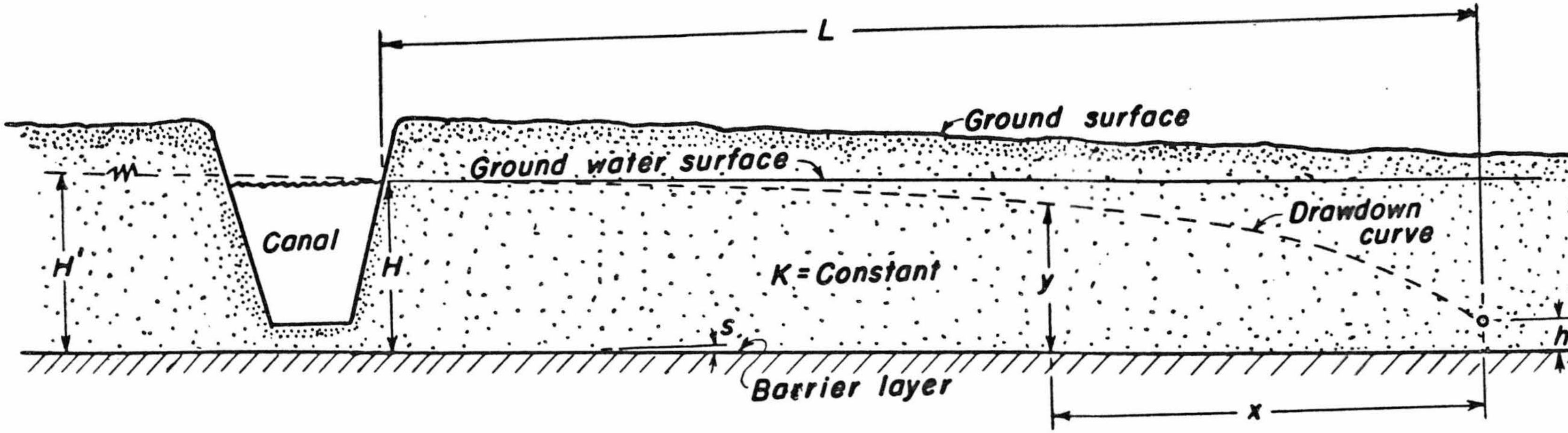

Fig. 2 Layout of a tile interceptor drain.

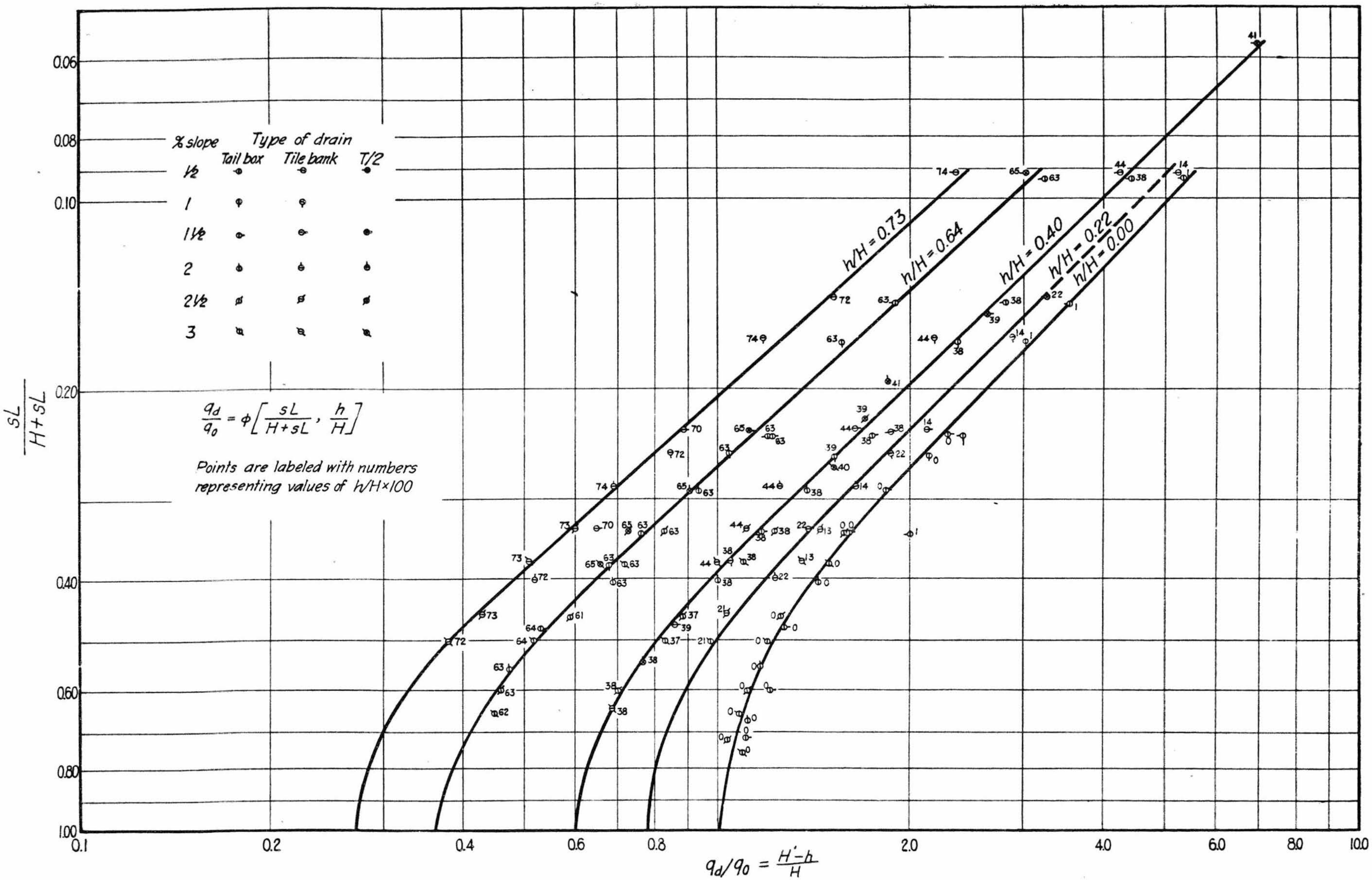

Fig. 3 Discharge of interceptor drains for slopes greater than zero.

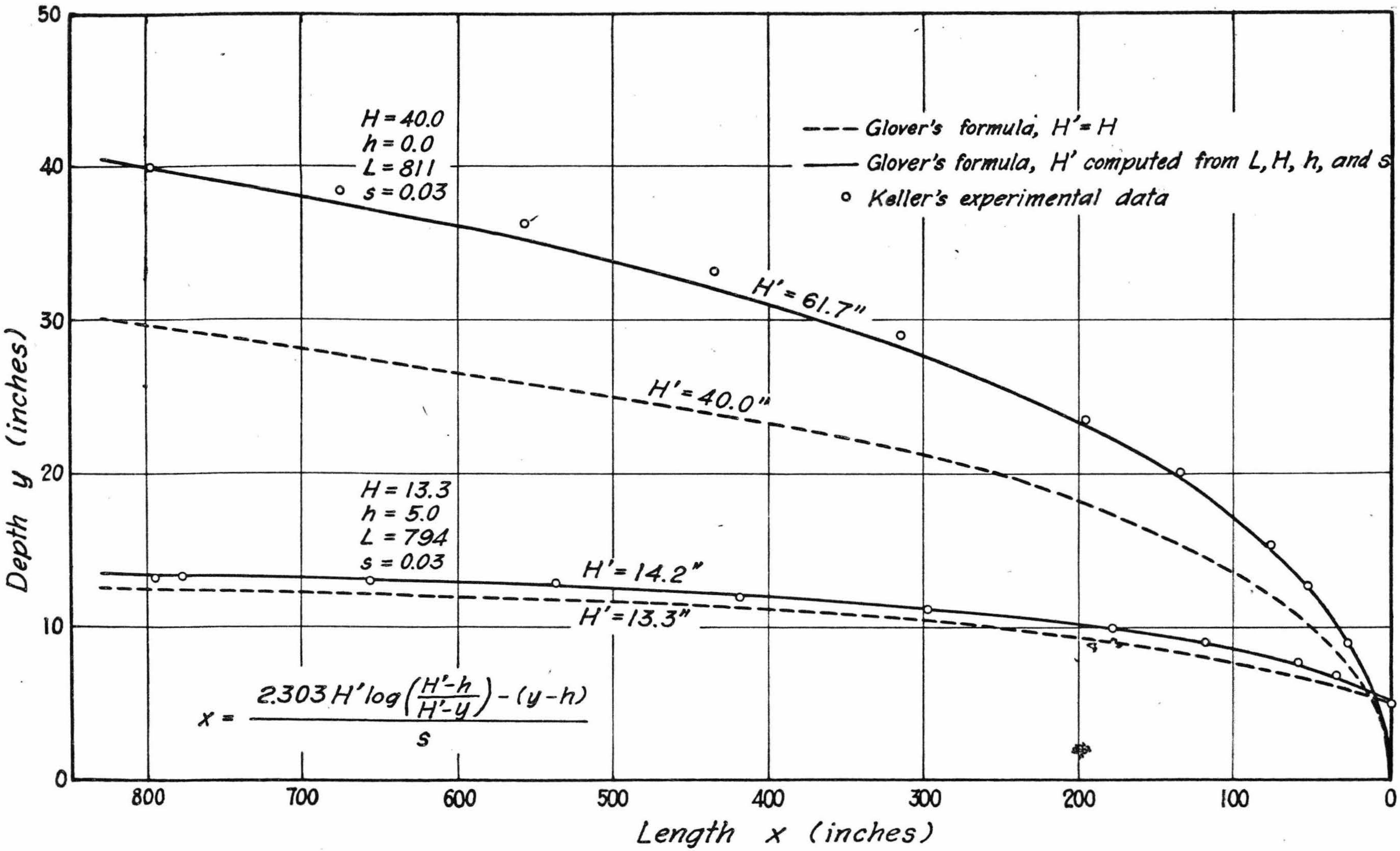

Fig. 4 Comparison of observed drawdown curves with Glover's formula for slopes greater than zero.

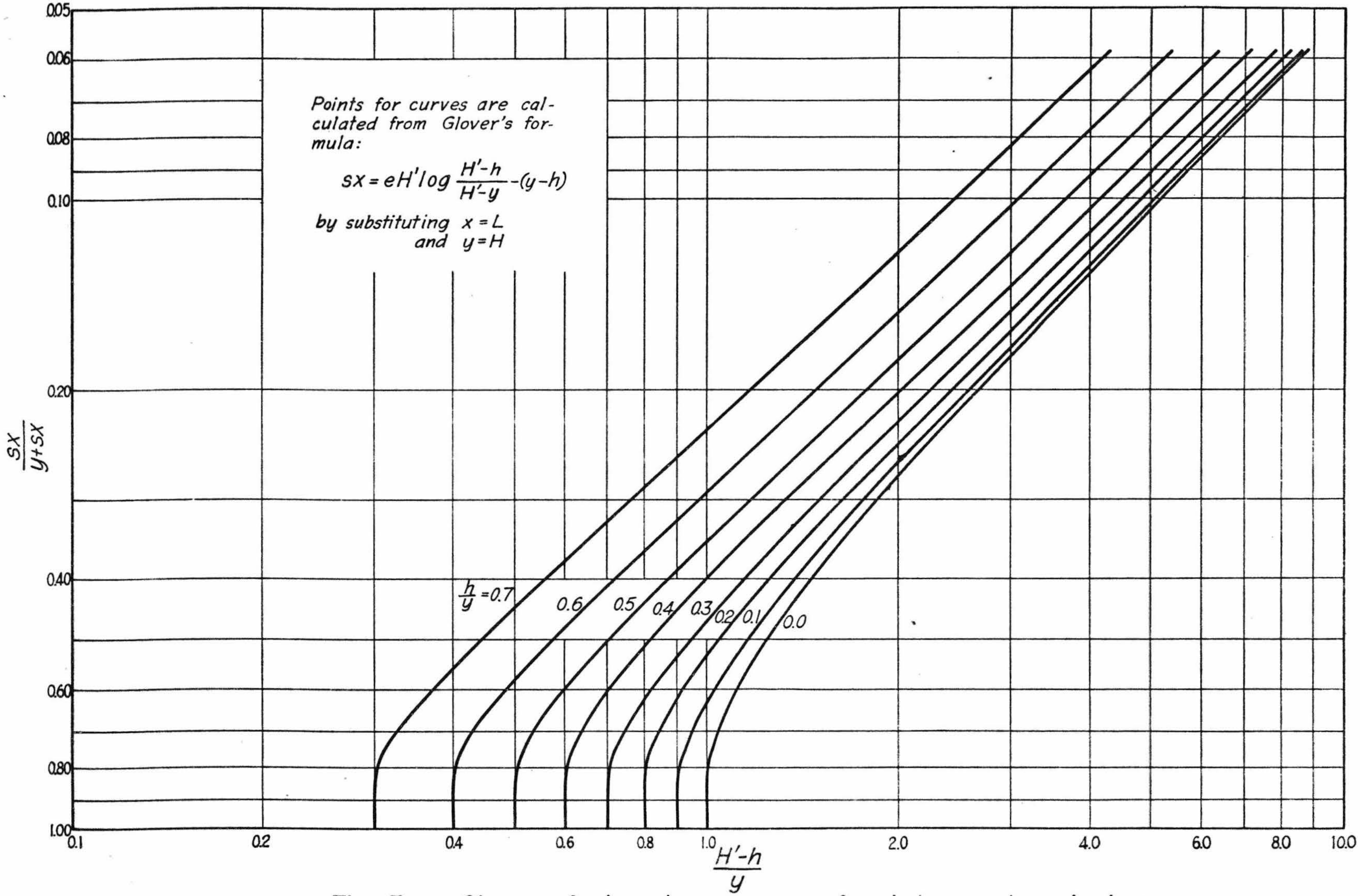

Fig. 5 Shape of drawdown curves for interceptor drains

II. Development of Drainage Design Criteria for Irrigated Lands.

The general objective of this study is to provide data upon which to base the design of new drains on irrigated lands in the West, particularly in Colorado. Specifically, the objectives are:

1. To determine if a relationship exists between measured drain discharge, water supply, physical features of the system and drainage characteristics of the soil so that a prediction of water yield can be made for proposed drains.
2. To determine by field observations the applicability of the finding from previous interceptor drain studies.
3. To check by field data, the theoretically derived relationship for determining the shape of the water table drawdown profile after drainage.

An estimate of yield from a drain system is needed for a determination of tile size. An underestimate of yield results in failure of the drain to function efficiently while overestimation results in undue cost for larger sized tile. Information on location and depth of the tile system for maximum benefit in any particular situation is needed for design purposes.

Design and Procedure

This study was planned to evaluate existing drain systems so as to gather general design data. Several tile systems on farms in Northern Colorado have been studied during two irrigation seasons. All of these systems are of the interceptor type and were chosen to represent the most prevalent drainage problems in the area. These systems generally utilize 6-inch clay tile placed with an envelope of filter gravel. The lines vary in length from 600 to 3200 feet. In some cases, the source of ground water is a canal while on others the source is from both irrigation and canals or from irrigation alone.

The discharge from the drains has been determined using small flumes equipped with recorders which were visited once each week during the irrigation season to remove the charts and for servicing. The farmers were consulted relative to time of irrigation, rainfall, etc., and these were noted on charts. Measurement of tile discharge during the winter months was made at two-week intervals.

The ground water levels as indicated by test holes were determined at weekly intervals during the irrigation season. These test holes were cased with perforated pipe. Generally, one line of holes was placed normal to each drain line. In this line, holes were placed near the drain both upstream and downstream with the spacing increasing as the distance from the drain increased.

Hydraulic conductivity measurements using the auger hole method (6) were made on each farm. The soils varied in texture from a fine sand to a heavy clay. The data on physical features and soils were assembled from the records of the Soil

Conservation Service, whose engineers designed the drain systems. Samples were taken of both the supply and drainage water from each location several times during the irrigation season for total salt determinations.

Analyses

In order to make an analysis of data such as was collected in this study, it is necessary to "group" or form classes of systems based upon similarities in the major features. Such a system of classification was devised using the U.S.D.A. system of land capability classification as a model. The factors which were selected to form the basis for classifying the drainage systems were: stratification or uniformity of soil profile, average hydraulic conductivity of the profile, thickness of soil material over barrier, land slope and major source of ground water. Table 1 shows the details of the classification scheme. Table 2 lists each system studied with its classification and other data.

The conductivity value for a particular location shown in table 2 is the average of several measurements made by the auger hole method. For some locations these averages represent a range of measurements of more than threefold variation. Such a range is to be expected in measuring hydraulic conductivity of heterogeneous soils. The average, however, represents a fair indexing criterion for the purpose of classifying the drainage system.

The average flows for monthly periods tabulated in table 2 reflect the available water supply. The year 1956 was a very dry year in which the rainfall and irrigation supply was limited over the entire area. In contrast, during the year 1957, the rainfall was above normal and irrigation water was plentiful. The average monthly discharges during 1957 were, in most cases, much greater than 1956.

The elevations of the water tables were higher in 1957 than in 1956, which of course would result in higher drain discharges. Of interest is the effect of a greater water supply on the shape of the water table profile downstream from the tile interceptor drain. During the first year the profile had a flat slope continuing downstream from the tile. However, during 1957 the downstream curve resembled, to a lesser extent, the upstream curve indicating that flow was entering the tile from both directions.

It has been thought that in a particular area where soils, topography, design of drain and method of irrigation are similar, that a simple relationship between hydraulic conductivity and unit drain flow could be developed. Due to the number of other variables involved, there seems to be no simple relationship such as this which will apply in the area in which this study covers. Figure 6 is a plot of the measured hydraulic conductivities and average drain yield per 1000 feet of drain for the month of August. It is noted that with essentially the same value of hydraulic conductivity, a tenfold variation in yield was observed. This plot emphasizes that other variables must also be considered for a prediction of the expected yield.

One of the very important variables not considered in figure 6 is the hydraulic gradient causing flow to the drain. The hydraulic gradient could be considered to be a manifestation of all the variables involved. It will reflect the influence of the geometry of the system, of the water supply, and of the drainage characteristics of the soils. For example, in the case where the excess water is due to seepage from a nearby canal, the gradient will be normally greater than if the canal were a large distance away.

The water supply effect on hydraulic gradient was noticed particularly during the two seasons of observation. The first season (1956) was very dry and the irrigation supply was very short, while the second season (1957) was one of the wettest of record and irrigation supply was ample. The gradients were markedly different between these seasons, being greater during the last season.

In figure 7, the hydraulic gradient has been considered. The unit of flow has been divided by the gradient resulting in a transmissibility parameter. With this relationship, a fairly good relationship was found when the stratification of the soils was considered. Figure 7 indicates that a higher transmissibility exists for stratified than for uniform soils with the same conductivity.

Summary

An attempt is being made to collect sufficient data on drain yields under the most usual conditions prevailing in Northeastern Colorado, so that an informed estimate of expected yield can be made for new drain designs. As was to be expected, the variance in yields between similar physical systems is rather high. The task of predicting with precision the yield from any proposed drain would be almost impossible. It would certainly not be economically feasible. However, if the factors of stratification, hydraulic conductivity, depth of soil, land slope, and water supply are considered, a fair estimate of yield can be made.

The average hydraulic conductivity is the most difficult factor to obtain, as might be expected. A many-fold variation will almost always be found within even a small area on any field. However, it is found that the general order of magnitude of the average of several measurements is usually a fairly reliable index to apply. Used in this way, it is unnecessary to expend the time and effort necessary to refine the value of this factor.

Table 1. -- Farm Classification Scheme
for Characterizing the Drainage Situation

Stratification or uniformity of soil:

No. 1	highly stratified -	>50 percent of profile is unlike material
2	moderately stratified -	10 - 50 percent of profile is unlike material
3	uniform -	<10 percent of profile above rock is unlike material

Hydraulic conductivity - average value by auger hold method:

No. 1	very slow	<0.06 in./hr
2	slow	0.07 - 0.29 in./hr
3	moderate	0.30 - 3.0 in./hr
4	rapid	3.1 - 6.0 in./hr
5	very rapid	>6.0 in./hr

Thickness of soil material over barrier:

No. 1	<48 inches
2	48 - 72
3	72 - 120
4	>120

Slope of land (in vicinity of effective drain line):

A	0 - 1 percent
B	1 - 3
C	3 - 6
D	>6

Probable source of ground water:

F	Canal
G	Canal and irrigation
H	Irrigation

Table 2. -- Summary of Interceptor Drain Study

Drain Installation	Drainage Classification	Average Hydraulic Conductivity in./hr	Length of Drain Line ft	Year	Symbol	Maximum Flow Date	Maximum Flow cfs	Maximum Flow cfs per 1000 ft	Average Flow July cfs	Average Flow July cfs per 1000 ft	Average Flow August cfs	Average Flow August cfs per 1000 ft	Average Flow September cfs	Average Flow September cfs per 1000 ft
EPH Corp	353 BF	7.65	1045	1956	○	7-12	0.042	0.040	0.027	0.026	0.029	0.028	0.015	0.014
			1445	1957	-○-	7-22	.180	.124	.090	.062	.085	.059	.090	.062
Kluver	233 BF	2.54	1700	1956	⦶	--	--	--	--	--	.220	.129	.200	.118
				1957	-⦶-	8-18	.710	.420	.330	.194	.300	.176	.280	.165
McCormick	232 AH	3.16	1436	1956	⊖	7-30	.510	.350	.025	.017	.015	.010	.035	.024
				1957	-⊖-	5-30	.520	.360	.080	.056	.035	.024	.035	.024
Ragan	253 CH	15.6	600	1956	◑	8-19	.280	.470	.120	.200	.150	.250	.100	.167
				1957	-◑-	5-26	.380	.630	.220	.370	.220	.370	.220	.370
Stewart	353 BG	12.6	1570	1956	◐	8-25	.068	.043	.039	.025	.048	.031	.037	.024
				1957	-◐-	7-6	.200	.127	.130	.083	.065	.041	.085	.054
Sprenger	343 AF	3.98	600	1956	◓	7-27	.095	.160	.026	.043	.030	.050	dry	--
				1957	-◓-	7-18	.090	.150	.072	.120	.010	.017	dry	--
Franz	233 BH	2.37	1095	1957	-⊘-	7-10	.092	.084	.075	.068	.030	.027	.025	.023
Wagoner	232 BG	2.35	3220	1957	-⊘-	7-31	.450	.140	.210	.065	.200	.062	.150	.048

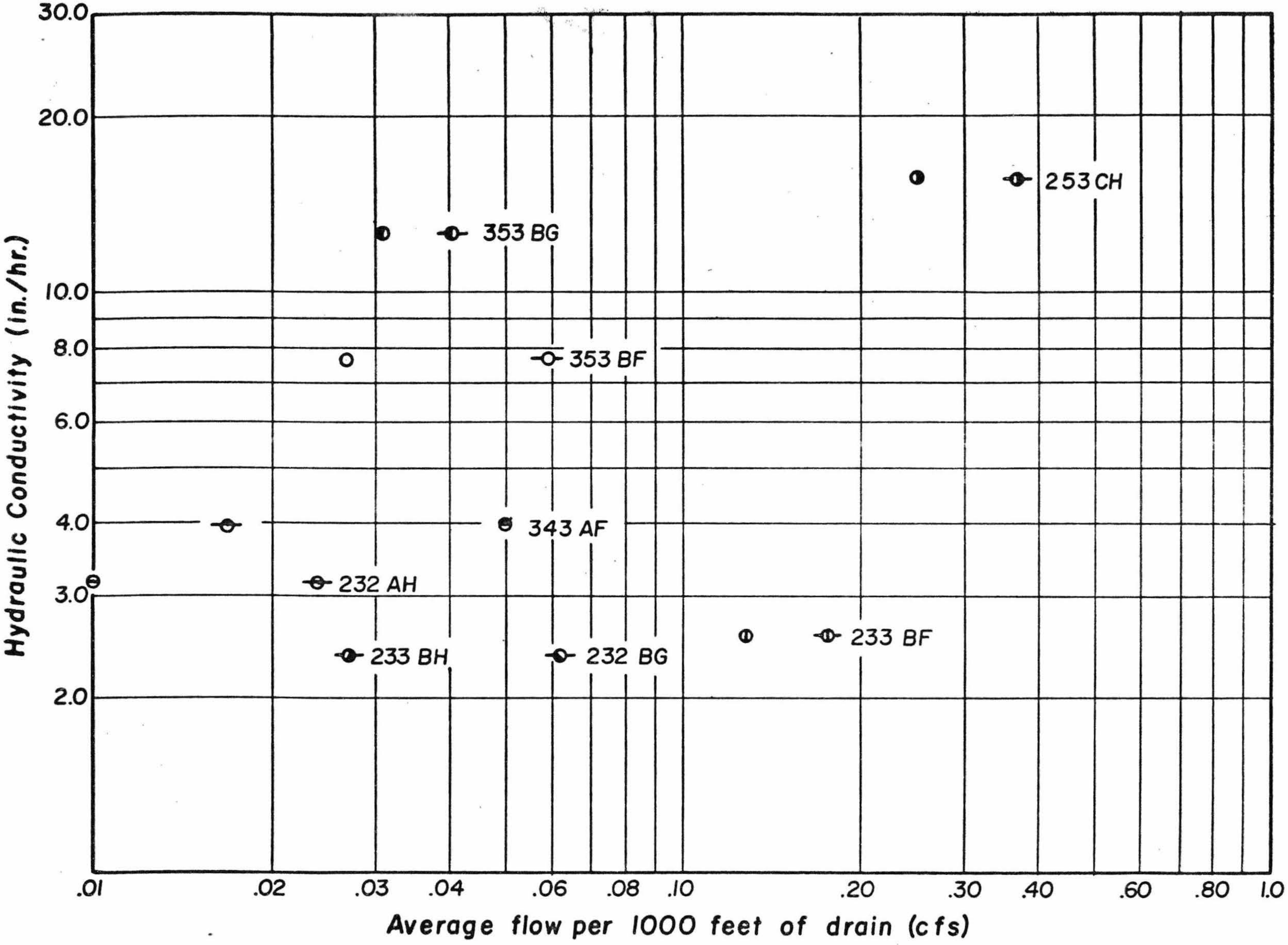

Figure 6.-- Relationship of average monthly flow to hydraulic conductivity. August 1956-57.

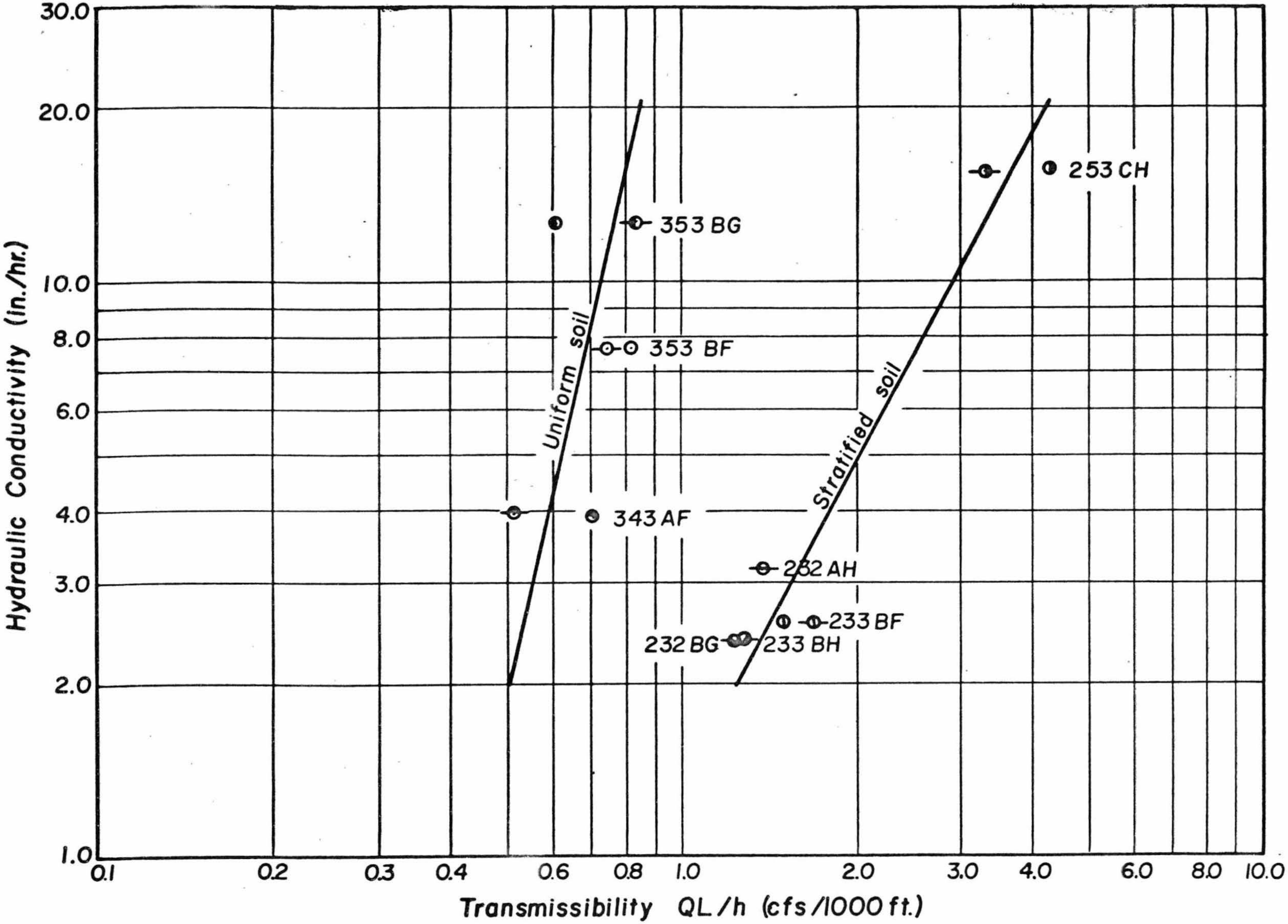

Figure 7.-- Relationship of transmissibility to hydraulic conductivity. August 1956-57.

III. Analysis of Drainage Problems in the Upper Colorado River Basin.

The purpose of this field investigation was to develop improved methods for analysis of typical drainage problems in the irrigated West. Objectives include diagnosis of the problem, or of potential problems; methods and equipment for determining drainage properties of the soil mantle; means of reducing or preventing recurrence of the problem; and general water management techniques related to ground water control.

A paper was presented by Evans (2) at the 1956 annual meeting in which several advances in investigational technique and equipment were reported. Of most significance perhaps, is the development of the geophysical technique of electrical resistivity for determining stratification. A simple inexpensive instrument for this work was designed, and used with notable success in mapping the thickness, depth, and areal extent of an artesian aquifer underlying the study area. About four man-months were required to do the mapping over an area of 26 square miles.

This report will review some of the other developments resulting from the study related to the operation of a drainage well.

Drainage by Pumping

The study area is the Grand Valley, Colorado, situated near the Colorado-Utah line on the Colorado River. Comprised of about 260 square miles of relatively level land in a climate suitable for fruit, the valley was settled in 1882 and quickly became a garden spot in the desert. The Grand Valley Irrigation Company holds the first priority irrigation water right on the Colorado River, and the water supply is generally ample.

From the geological standpoint the valley is a typical Western valley, being composed of an alluvial fill over a shale base. Within the fill is an artesian aquifer charged from canal seepage and irrigation excesses. The piezometric surface lies near or slightly below the ground surface in the lower elevations of the valley.

It was expected that pressure relief and some drainage could be accomplished by pumping from the aquifer. Early results indicated satisfactory pressure relief, but no water table decline. Further investigation disclosed that observation piezometers, which were located along highways, gave misleading information due to the fact that they were influenced by the close proximity of irrigation ditches or open drains. Observations subsequently taken away from such influence indicated considerable water table recession, but in an area unsymmetrical to the well.

Stratum surveying on an intensive scale (200-foot grid) in the neighborhood of the well disclosed discontinuities in the confining clay layer over the aquifer. Piezometric gradient data also showed ready exchange of water between the aquifer and the overburden in areas where the clay layer was thin or missing.

Putting all the above information together leads to the hypothesis that the well is effective as a drainage tool if there exists the possibility of interchange of water between the overburden and aquifer, i.e., if the confining clay is thin or missing in places. This was confirmed by intermittent operation of the well.

The well serves an irregular shaped area of approximately 200 acres with rather rapid drainage. Intermittent operation of the well has shown the water table recession to range from at least 0.01 foot per day to 0.10 foot per day over the 200 acre area during the first two and one-half months of pumping. The center of the drawdown area coincides with the location at which the confining clay is very thin in a spot about 200 feet in diameter. Upon stopping the pump, the ground water builds up in a mound at this location which gradually spreads.

Economics of Pump Drainage

The economics of pump drainage for this particular location has been appraised by economists and the following results determined.

Gross income attributed to pumping*
(income from increased yields)

Corn	1155.00		
Barley	311.00		
Sugar Beets	546.00		
Gross Annual Income			2012.00

Annual Expense of Pumping
(Operating Expense)

Electric power for 4800 hours at 8.95/hr	430.00		
Repairs	40.00		
Labor (1 hr/day at 1.50/hr for 200 days	300.00		
Total Operating Expense		770.00	

Depreciation Expense

Depreciation on well ammortized over 20 years	135.00		
Depreciation on pump ammortized over 20 years	126.00		
Total Depreciation Expense		261.00	

Interest and Taxes

Interest on investment at 5%	100.00		
Taxes at 35 mills	84.00		
Total Interest and Taxes		184.00	
TOTAL ALL EXPENSES			1215.00

PROFIT AND LOSS STATEMENT

Gross Income (Annual)	2012.00
Less Total Costs (Annual)	1215.00
Net Annual Income	$797.00

*Assumes 160 acres effectively drained by the well, and 1/2 alfalfa, 1/6 corn, 1/6 barley and 1/6 sugar beets.

Since the initial investment in the well was $3963.00, the annual return to the initial investment is about 20 percent. The operation is thus economically feasible.

Well Maintenance

After four years of almost continuous operation, the pump was removed and examined. Three holes, each about 1-1/2 inches in diameter, were found in the discharge column at the elevation of the top of the well screen. Since the water contains 10,000 p.p.m. of salts which is a good electrolytic solution, a cell was created between the iron column pipe and the lead packer at the top of the screen. The reversible cell potential between iron and lead of 0.3146 volts apparently caused the iron in the pipe to be oxidized to ferrous iron and carried away in the water.

No other serious deterioration was found in the pump. Impellers which were porcelain coated showed no deterioration, and the turbine shaft was only slightly coated with tubercles after four years under severe salt conditions.

The well screen - a Johnson Red Brass screen - has apparently suffered no noticeable deterioration since the discharge following the repairs to the column was even greater for the same drawdown than it had been initially.

Hydraulic Characteristics of the Aquifer

The well was used as an instrument with which to study the hydraulic properties of the aquifer. Numerous possible methods of hydraulic analysis of an aquifer by means of a pumped well are available to the engineer. Some are based upon the existence of equilibrium state, while others are based on a non-equilibrium condition. It is possible to make an analysis during either a drawdown period or a recovery period.

The many possibilities were examined and the non-equilibrium drawdown analysis of Theis as modified by Jacob (3) was selected for determining the hydraulic character of the aquifer. In this analysis, only one observation point is required.

The recovery analysis of Jacob (4) was also used for the same 12 observation points for purposes of comparison. Specific capacity, a characteristic of the well, was determined in the course of the aquifer studies by decreasing the discharge to zero in five steps.

The modified non-equilibrium analysis yielded average values of T (Transmissibility) and S (Storage Coefficient) for the 12 observation points as follows:

T = 13,900 gal/day/foot

= 0.022 cu. ft/sec/foot

S = 0.020 cu. ft. water/cu. ft. aquifer

The recovery analysis yielded an average value for T at the 12 observation points of:

T = 0.022 cu. ft/sec/foot

No value for storage coefficient may be obtained from the recovery analysis.

It was found, therefore, that the two methods of analysis yielded comparable results for transmissibility. That they were identical as an average of 12 is only coincidental.

The specific capacity was found to be 16 gal/min/foot drawdown.

The effect of time on transmissibility was observed by using data collected over the six years of pumping. For this purpose the equilibrium analysis developed by D. F. Peterson and Associates (7) was applied. The transmissibility for 1952 data was T = 0.032 cu. ft/sec/foot, and that for 1956 data was also T = 0.032 cu. ft/sec/foot. There appears to have been no change in transmissibility.

It is interesting to notice the comparison between the last analysis and that of Theis. The values of transmissibility are respectively T = 0.022, and T = 0.032. Although the difference is considerable it is perhaps a reasonable agreement.

Summary

Some phases of an extensive study aimed at developing improved methods of diagnosing drainage problems and selecting the best treatment or preventive measures are reported. An adaptation of a geophysical technique has been made and found highly useful in stratum investigations.

The philosophy of an intensive stratum investigation in at least a small part of the problem area proved helpful in that the knowledge so gained enabled a quick diagnosis of the mode of operation of the drainage well. Without the intensive study, much speculation would have been necessary, and the

investigator would have been led to the correct conclusion with much greater difficulty.

The economics of the pump drainage system was studied and the annual return to the initial investment was estimated to be 20 percent based upon 160 acres as the area drained. The system is thus economically feasible. Physical feasibility on the other hand, depends almost entirely upon the existence of discontinuities in the confining clay layer within the zone of pumping influence, in order for the well to effectively reduce ground water levels.

The Theis non-equilibrium drawdown analysis, as modified by Jacob, and the non-equilibrium recovery analysis were found to give comparable values for transmissibility. The equilibrium analysis of Peterson, et al., was found to yield a slightly higher value for transmissibility. Six years of continuous pumping did not change the transmissibility of the aquifer near the well.

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