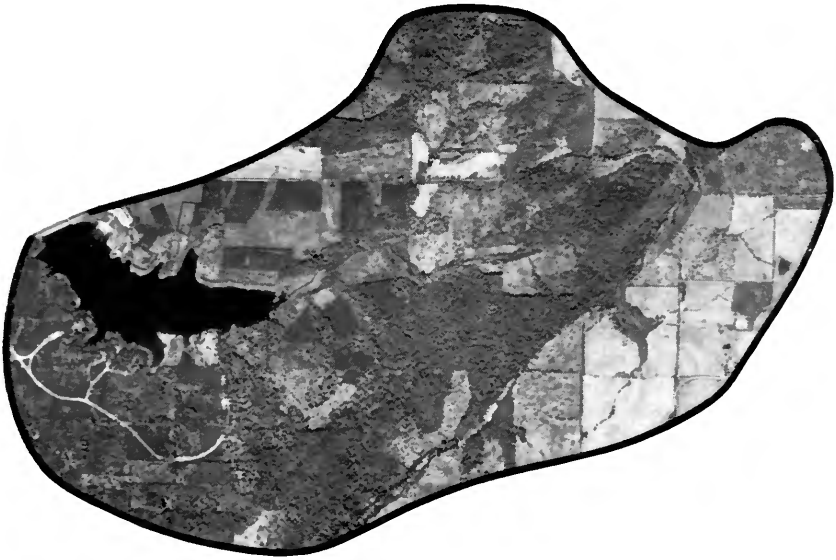
PRECIPITATION AND WATER-YIELD RELATIONSHIPS ON THE LAKE GLENDALE WATERSHED

Pope County, Illinois

W. R. Boggess, R. L. Russell, A. R. Gilmore



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This bulletin was prepared by W. R. Boggess, Professor, R. L. Russell, formerly Research Assistant, and A. R. Gilmore, Associate Professor, all in the Department of Forestry, University of Illinois. R. L. Russell is now a Forester with the U.S. Forest Service. The authors gratefully acknowledge the cooperation and participation of the Illinois State Water Survey and the U.S. Geological Survey, who financed and maintained the two gaging stations. The State Water Survey also supplied the recording equipment for the ground-water wells and supervised the survey work in mapping the lake basin. John B. Stall of the State Water Survey deserves particular recognition for his advice and assistance.

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PRECIPITATION AND WATER-YIELD RELATIONSHIPS ON THE LAKE GLENDALE WATERSHED

By W. R. BOGGESS, R. L. RUSSELL, and A. R. GILMORE

SURFACE WATER IS A PRIMARY SOURCE OF WATER SUPPLY for many communities, municipalities, and cities throughout Illinois. The southern part of the state, with its limited ground-water resources, is particularly dependent upon rivers, streams, or impoundments for water to meet domestic and industrial needs (Illinois State Water Survey, 1957[1]). Except for the major rivers, stream flow is very low during the summer months, making it necessary to store water during periods of high runoff. This involves the construction and maintenance of dams and reservoirs.

Siltation is a serious problem in maintaining reservoir capacity and may become critical in hilly sections of the state. Planning good watershed management should be an integral part of reservoir planning and design, but this is seldom the case. Stall (1962) reported that the mean annual loss in reservoir storage capacity was 0.62 percent for 78 lakes in Illinois and represented a deposition of 1.52 tons of sediment per acre of watershed per year. He estimated that soil losses on these watersheds could be reduced by 43 to 92 percent by the use of good management practices.

Siltation can be virtually eliminated by the establishment of complete vegetative cover. This fact has been illustrated by two long-time studies in Tennessee by the Tennessee Valley Authority on the White Hollow (TVA, 1961) and Pine Tree Branch (TVA, 1962) Watersheds. White Hollow is in Union County and its steep topography is typical of the Ridge and Valley Province which lies between the Appalachian Mountains and the Cumberland Plateau. Pine Tree Branch is in Henderson County. Topography is hilly, and the soils are loessial silt loams intermingled with sandy coastal plain sediments of the old Mississippi Embayment. In both cases, the severly eroded, cultivated, and abandoned lands were reforested between 1935 and 1940. Existing woodlands were protected from fire and grazing, thus allowing stocking to build up to near normal. Sedimentation rates on both areas, with their widely different soils and topographic conditions, were reduced more than 90 percent. Greatest reductions occurred during the early years following treatment.

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[1] This and similar references are listed in the bibliography.

The yield of water from a given drainage area is related to the amount, kind, composition, and condition of the vegetative cover. In most cases when forest stands are cut, increased water yields may be expected. Reinhart and Eschner (1962) found that in West Virginia hardwood stands a light cut of 1,700 board feet per acre increased stream flow about 0.3 inch per year. A heavy cut of 8,500 board feet, however, increased stream flow ten times as much. Kovner (1956) found that stream flow increased 14.45 inches during the first year after a 39.8-acre watershed at the Coweeta Hydrologic Laboratory in the southern Appalachian Mountains had been clear-cut. Stream flow, however, declined steadily with natural regrowth of the forest cover, and after 13 years was only 4.99 inches greater than the stream flow during the base period prior to cutting. In the same area, Johnson and Kovner (1956) reported an annual stream-flow increase of 2.0 inches per year for a 6-year period following the removal of the rhododendron and mountain laurel understory on a 70-acre watershed. In contrast to these findings, there were no significant decreases in stream flow on the White Hollow Watershed (TVA, 1961) during the 24-year period following treatment despite a very great increase in the amount and density of the vegetative cover. TVA states: "The effects of greater shading, reduced wind velocity, and greater humidity have evidently resulted in reductions in evaporation approximately equal to the increased consumptive use by plants." (TVA, 1961, p. 44.)

Siltation can be controlled and water purity insured by well-maintained vegetative covers. The possible effects of the vegetation on water yields, however, should be considered in reservoir planning and design whether the over-all objective is water supply or flood control.

Water-yield data from small watersheds, particularly those with well-established vegetative covers, are limited in Illinois. This is especially true in the southern part of the state, where future growth is largely dependent upon development of the potentially great surface water resource. For this reason a study of water yields from the Lake Glendale Watershed was implemented in 1954 by the Department of Forestry of the University of Illinois in cooperation with the State Water Survey. The U.S. Geological Survey also participated actively in the project through its cooperative agreement with the State Water Survey in establishing and maintaining stream-gaging stations throughout the state. The objectives of the study were to determine annual, monthly, and individual storm yields as related to storm characteristics and soil moisture conditions. This report covers eight water years, beginning October 1, 1954, and ending September 30, 1962.

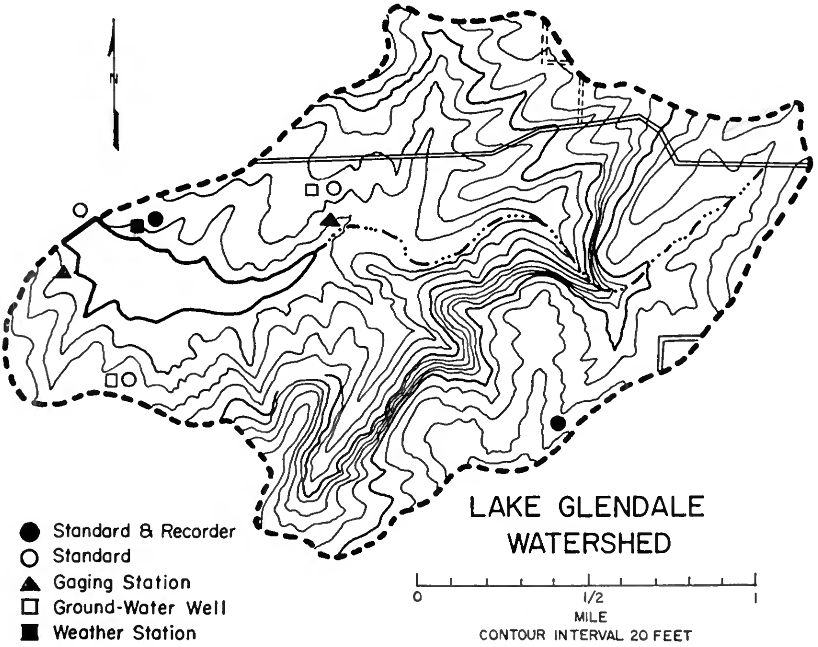
LAKE GLENDALE WATERSHED

Location and Description

The Lake Glendale Watershed (Fig. 1) is located in the SE¼, S4, and the SW¼, S3, T13S, R5E, Pope County, Illinois (37° 25′ N. latitude; 88° 40′ W. longitude), and is adjacent to the Dixon Springs Agricultural Center of the University of Illinois. The area is in the Shawnee Hills section of the Interior Low Plateaus Province (Leighton *et al.,* 1948) and is commonly known as the "Illinois Ozarks."

Lake Glendale has a surface area of 82 acres at spillway level and is maintained as a recreational area by the U.S. Forest Service. Facilities are available for camping, picnicking, swimming, and boating. Public use of the recreational facilities has increased greatly in the past decade.

The watershed has an area of 1,350 acres (2.11 square miles), and about two-thirds of the land is owned by the Forest Service. Topography ranges from gently sloping land to steep bluffs. Seventy percent of the land area is on slopes less than 10 percent, 27 percent on slopes



Topography and location of instruments in the Lake Glendale Watershed. (Fig. 1) between 10 and 20 percent, and 3 percent on slopes greater than 20 percent. The steepest land consists largely of bluffs along the southeastern rim of the watershed.

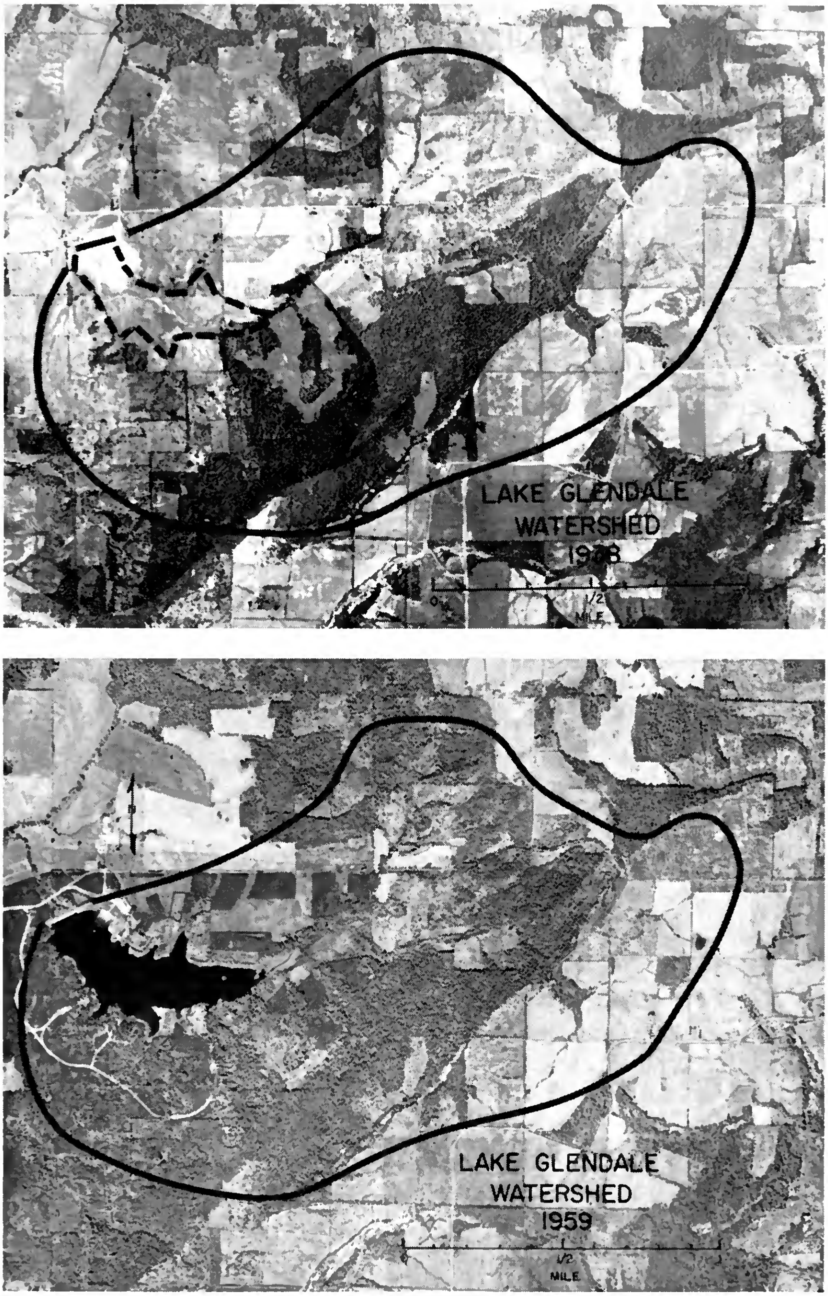
In 1938, when the lake was constructed, 11 percent of the watershed was cultivated, 59 percent was in unimproved pasture or abandoned, and 30 percent supported stands of native hardwoods (Fig. 2). Erosion was moderate to severe on all lands that had been cultivated. The timber stands were understocked as a result of poor cutting practices, grazing, and indiscriminate burning.

A tree-planting program was initiated along with the lake construction, and by 1941 forest plantations, largely shortleaf pine (*Pinus echinata* Mill.), had been established on all of the open lands owned by the government. The privately owned land, located largely on the periphery of the watershed, has either been withdrawn from cultivation or maintained as pasture. Land withdrawn from cultivation in this area soon develops a cover of broomsedge (*Andropogon virginicus* L.) which may persist for 20 years or more before it is replaced by wood species (Bazzaz, 1963). A broomsedge cover has high capabilities in preventing soil and water losses (Meginnis, 1935). The same is true for reasonably well-maintained pastures (Gard *et al.,* 1959). By the time the present study was initiated, the entire watershed was well stabilized with vegetation. About three-fourths of it is now forested with stands of native hardwoods or plantations of shortleaf pine.

Soils

The soils on the watershed have developed under deciduous forest cover in varying depths of loess deposited over residuum or bedrock. Surface horizons are light-colored silt loams, and the B horizons are generally well developed. Permeability is moderate to very slow, and internal drainage ranges from poor to excessive.

Soils that were once cultivated are primarily those of the Grantsburg series, with a lesser amount of Zanesville and Robbs. The Grantsburg soils are Gray-Brown Podzolic soils, intergrading with Red-Yellow Podzolic soils that developed from 80 inches of loess over sandstone rock. They occur on slopes ranging from 2 to 12 percent. The A horizon is a yellowish-brown silt loam. The B horizon is a silty clay loam with a subangular, blocky structure. A well-developed silt pan (fragipan) occurs in the lower part of the B horizon at depths of 30 to 36 inches (less if the soil is severely eroded). The pan is hard and brittle when dry, is nearly massive, and limits root penetration and the downward movement of water.



Aerial photographic mosaics of the Lake Glendale Watershed in 1938 (while the lake was being constructed) and in 1959. (Fig. 2)

The associated Robbs series are imperfectly drained Planasols intergrading with Gray-Brown Podzolic soils that occur on slopes of 1 to 4 percent. The silt loam A horizon may be up to 16 inches thick. The silty clay loam B horizon has a higher clay content than that of the Grantsburg and is slowly permeable to water. Because of the low slope gradient, erosion has never been a serious problem with these soils.

The Zanesville series developed in about 40 inches of loess over sandstone. Profile development is somewhat similar to that of the Grantsburg soils, but is shallower, and the fragipan development is weaker or entirely missing.

Practically all of the better soils were cleared for agriculture during the early days of settlement. Only those that were either too steep, rocky, or shallow were excluded from cultivation. Thus soils under the native hardwood stands are in this category. They largely belong to the Wellston and Muskingum series, a complex of Muskingum and Wellston, and the steeper phases of Zanesville. There is also some rough, stony land and rock outcrops, but these are more of a "land class" than a definite soil series.

Soil characteristics that are hydrologically important include (1) the slowly permeable fragipan of the Grantsburg soils, (2) the shallow profiles of the soils occupied by native timber, and (3) the amount of erosion of the formerly cultivated soils. In general, these factors have resulted in soil profiles that have relatively low moisture-storage capacities. Thus they contribute heavily to the precipitation-runoff characteristics of the watershed.

COLLECTION OF FIELD DATA

A network of five standard and three recording rain gages, well distributed over the watershed, was used to measure precipitation (Fig. 1). However, only four standard gages were in operation for the entire 8-year period; data from these were used in the analyses. The recording gages were equipped with 12-hour charts and provided information on storm intensity and duration. Data were collected as soon after each storm as practicable.

Precipitation was measured in the open at each gage site. No allowance was made for interception by the vegetation, even though such data are available for shortleaf pine plantations in this area (Boggess, 1956). This procedure was followed because all data from weather bureau stations are based on open gages, thus making possible the use of the precipitation-water yield relationships of this watershed in other similar locations.

Two gaging stations were established to determine flow into the lake and to record water levels. These installations were made by the U.S. Geological Survey and the State Water Survey as a part of their statewide stream-gaging network. Each station consisted of a Stevens Stage Level Recorder, installed over a stilling well in a USGS standard, corrugated iron shelter.

The headwater station was specifically designed to measure low flows over a concrete control structure. The drainage area for this station was 1.04 square miles, or approximately half of the entire watershed.

The lake-level recording station was located near the spillway and provided continuous records of water levels to the nearest 0.01 foot. The instrument was not effective when the water levels fell to more than 3 feet below the spillway.

Heights recorded by the instruments were checked each week by visually reading staff gages that had been established at each station and referenced to spillway level. At the same time each instrument was checked for possible malfunction and the observation time was noted on the strip chart of the stage recorders. This permitted adjustment of time over the month-long period represented by each chart.

Rating tables to translate gage heights into water discharge were prepared by the USGS from stream-gaging data collected over a wide range of water levels at each station. However, these tables could not be used to determine discharge from the entire watershed when the lake was below spillway level. For these conditions discharge was calculated from equivalent gage height-lake volume curves prepared from surveys of the lake basin topography. The underwater elevations were determined from soundings along permanently marked range lines. The 420-, 422-, and 424-foot contour lines were established by the Topographic Division, U.S. Geological Survey, and allowed the extension of the capacity tables to water levels above that of the spillway. The spillway level was 418.38 feet above sea level.

Data from the lake-level gage are incomplete for the water years of 1957-58, 1959-60, 1960-61, and 1961-62, when the lake was lowered during the winter months by the U.S. Forest Service to repair facilities. Storm yields during these periods were estimated by predicting equations which will be discussed later.

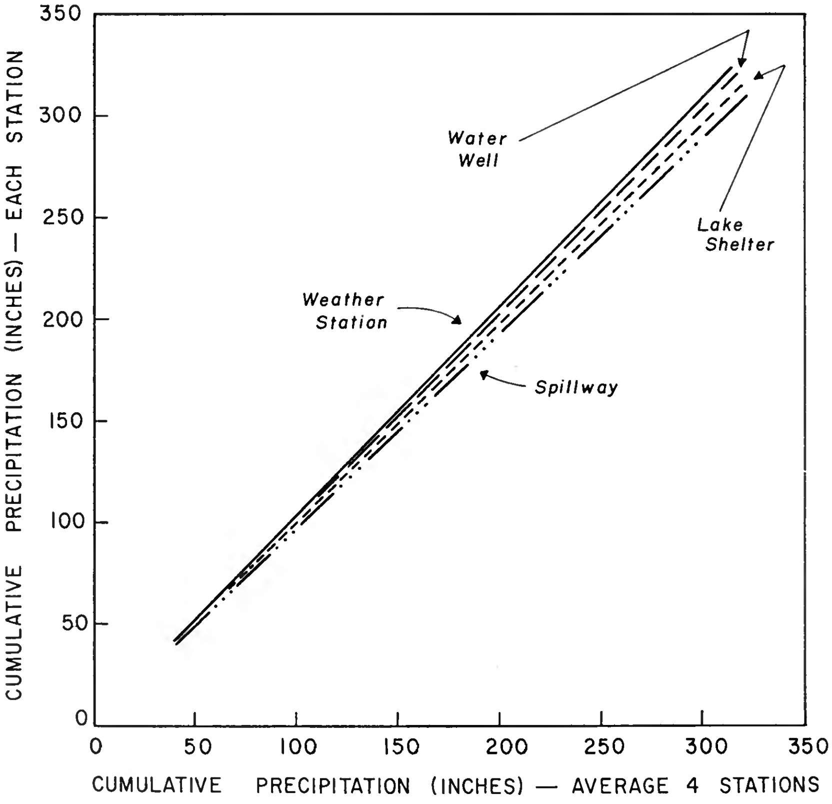
Ground-water levels were measured in two wells, one located in a pine plantation and the other in an abandoned field (Fig. 1). The wells were dug to bedrock (10 to 12 feet) and cased with 10-inch bell tile. Continuous-stage level recorders were placed on each well. The recorded heights were checked by visual measurements of water levels in the well.

Gravimetric soil-moisture determinations were made weekly adjacent to each ground-water well. These were discontinued after two years, as it was possible to use the ground-water levels as an index of soil moisture storage capacity.

ANALYSIS OF DATA

Precipitation

The precipitation data collected from the four standard gages were tested by a double-mass curve technique to find whether any inconsistencies existed in the record of any one gage (Schneider and Ayer, 1961). The results are shown in Fig. 3. This curve was constructed by



Relationship between cumulative precipitation for gages in the study area and cumulative precipitation from average of four stations. (Fig. 3)

plotting the cumulative precipitation for one gage against the average for the group of gages during the same period of record. Since the plotted curves showed no abrupt change in slope, it was assumed that there were no inconsistencies in the data. The unweighted mean of the four gages was used to express the equivalent uniform depth of precipitation over the watershed. The consistently low readings of the gage on the spillway were probably related to its greater exposure to wind.

In the 8-year period of record for the watershed, 727 storms (measurable precipitation occurring 6 hours or longer after the preceding storm) were recorded. This is an average of 91 storms per year. The number of storms occurring in a given water year varied from 66 storms in 1955-56 to 108 storms in 1954-55 (Table 1).

The average annual precipitation on the watershed was 48.66 inches for the 8-year period. This is slightly above the 24-year recorded average of 46.64 inches at the Dixon Springs Agricultural Center, located about 1 mile north of the watershed. Annual precipitation varied from 37.75 inches to 68.30 inches during the period of record on the watershed. These amounts were within a 5-year recurrence interval for all years except 1957-58, when the total was 68.30 inches. This amount would be expected to occur only once in 25 years (State Water Survey, 1957). The precipitation data are summarized in Table 2.

The minimum monthly total of 0.46 inch occurred in December, 1955, and the maximum of 16.30 inches in July, 1958. Monthly precipitation totals of less than 1 inch are not uncommon in this area, but the maximum total of 16.30 inches has been exceeded only twice in the history of weather bureau records for this area in southern Illinois.

Table 1. — Yield-Producing Storms and Evapotranspiration and Losses

Water year	Number of storms	Number of storms producing yield	Percentage of storms producing yield	Evapotranspiration plus losses (inches)
1954-55	108	53	49	30.32
1955-56	66	35	53	27.39
1956-57	100	56	56	33.05
1957-58	105	63	60	41.09
1958-59	80	44	55	33.76
1959-60	71	39	55	26.40
1960-61	100	50	50	32.86
1961-62	97	36	37	30.50
Average	91	47	52	31.92

Table 2. — Water-Year Precipitation in Inches, 1954-55 to 1961-62

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1954-55	1.65	1.13	5.28	.75	3.59	4.61	4.26	3.70	3.75	7.22	2.02	1.46	39.42
1955-56	5.63	2.27	.46	2.55	6.59	3.18	5.60	3.50	1.96	4.96	1.84	1.97	40.51
1956-57	1.88	3.02	2.85	5.36	3.31	2.43	7.76	11.03	5.11	2.73	3.54	.49	49.51
1957-58	4.43	10.20	9.26	3.10	.98	5.37	3.62	3.73	4.75	16.30	3.47	3.09	68.30
1958-59	1.55	4.12	1.07	7.33	2.88	1.83	1.60	6.01	2.81	1.49	9.01	8.18	47.88
1959-60	3.42	2.30	4.16	2.36	1.90	2.92	3.18	3.62	5.23	3.07	2.90	2.69	37.75
1960-61	1.71	4.80	5.31	1.72	5.13	6.43	4.49	9.41	3.22	4.90	5.80	.57	53.49
1961-62	1.54	7.48	5.54	5.40	7.34	5.42	4.45	1.79	2.63	3.88	4.36	2.59	52.42
Average	2.73	4.42	4.24	3.57	3.96	4.02	4.37	5.35	3.68	5.57	4.12	2.63	48.66
Departure from normal[a]	+.21	+.65	+.69	−.66	−.08	−.84	−.08	+.84	−.13	+1.63	+.21	−.28	+2.02

[a] Departure from normal based on 24 years of record at Dixon Springs Agricultural Center.

New Burnside and Golconda reported 16.94 and 18.52 inches, respectively, in January, 1937, and 17.59 inches was recorded at the Dixon Springs Agricultural Center in January, 1950. The recurrence interval for the July, 1958, total is probably once in 75 to 100 years.

The average storm size was 0.54 inch, ranging from .01 (trace) inch to a maximum of 5.08 inches (July, 1958). This maximum storm has a recurrence interval of once in 18 years (Huff and Neill, 1959). Storm size and the distribution of storms by day of occurrence are shown in Figs. 9-16, pages 27-34. The distribution and size of the individual storms varied considerably, although yearly and monthly totals compared favorably with long-term averages. Storm variation during the 8-year period, however, is perhaps not abnormal.

Intensities for the 727 storms ranged up to 3.30 inches per hour, which occurred during the storm of July 20, 1955. Several storms had higher intensity rates but for shorter intervals of time.

Reduction of Hydrographs

Since an objective of this study was to determine individual storm yield, the normal method of hydrograph reduction, in which daily yields are calculated (U.S. Department of Agriculture, 1962), could not be used because of carryover of storm yield from one day to the next. Therefore each storm was analyzed separately to determine individual storm yield.

Yield of each storm was reflected by a rise in the lake level. The rise for each storm was corrected for precipitation on the surface of the lake by subtracting the volume of water as read from the gage height-capacity curve that was equivalent to the amount of precipitation. Thus the yield from the watershed, or land area, could be determined.

Storm yields fell into four classes: (1) storms in which the lake rise did not exceed spillway level; (2) storms during which spillway level was exceeded; (3) storms when lake levels were already above spillway level; and (4) storms whose discharge overlapped that of preceding storms.

The yield of storms in which the lake rise did not exceed spillway level was computed from gage height-volume curves to the nearest thousand cubic feet of water.

Storm yields during which spillway level was exceeded were computed by a combination of the gage height-capacity relationship and the integration of the storm hydrograph. This procedure is outlined below.

- Volume of lake rise from start of storm to spillway level was computed from the gage height-volume curves.
- Discharge over the spillway was calculated by first integrating the storm hydrograph into segments of one-half hour up to 20 hours duration, the length of time depending on changes in the hydrograph slope. The average gage height during each segment was determined, and discharge in cubic feet per second for this height was obtained from the rating table based on gage height-discharge relationship. The cubic-foot-per-second discharge was then corrected to a cubic foot volume figure. This second step was required only when the lake was above spillway level at the beginning of a storm.
- Total storm yield was equal to the volume increase up to spillway level, plus the discharge over the spillway.

In calculating the yields from overlapping storms, it was first necessary to separate flow from the first storm from that of the second. This involved approximating the recession leg of the first storm on the basis of that actually recorded for the combined storms. This was done by beginning at the point on the recession leg of the first storm where runoff from the second storm first appeared, and then constructing the remainder of the first recession leg parallel to that shown on the hydrograph for the combined storms. The method was simple but had a tendency to overestimate the yield from the first storm, particularly during periods when the soil was wet and subsurface flow was high. This was probably related to the fact that the recession leg on the hydrograph showed the effect of both storms, particularly on subsurface flow (along the top of the silt pan). Thus the estimated recession leg of the first storm was lengthened somewhat, because it was drawn parallel to that of both storms combined. The overestimation of yield, however, was not great for an individual storm and was compensated for in total yields by a like reduction in the yield for the last storm in an overlapping series. A procedure somewhat similar to the one described above was reported by Reinhart (1964) but appeared after our analyses were completed.

Regression Analysis

Equations were developed to express water yields in relation to precipitation. However, some of the storms that fell during the 8-year period could not be utilized in the analyses. These included 108 storms in the 1954-55 water year, when ground-water records were not available, and 99 storms that occurred when the lake was drained. After considering several factors including storm intensities, antecedent precipitation, days since last significant storm, and ground-water levels, it was found that ground-water level was the most consistent and reliable single factor that could be used to predict whether or not water yield might be expected from a given storm.

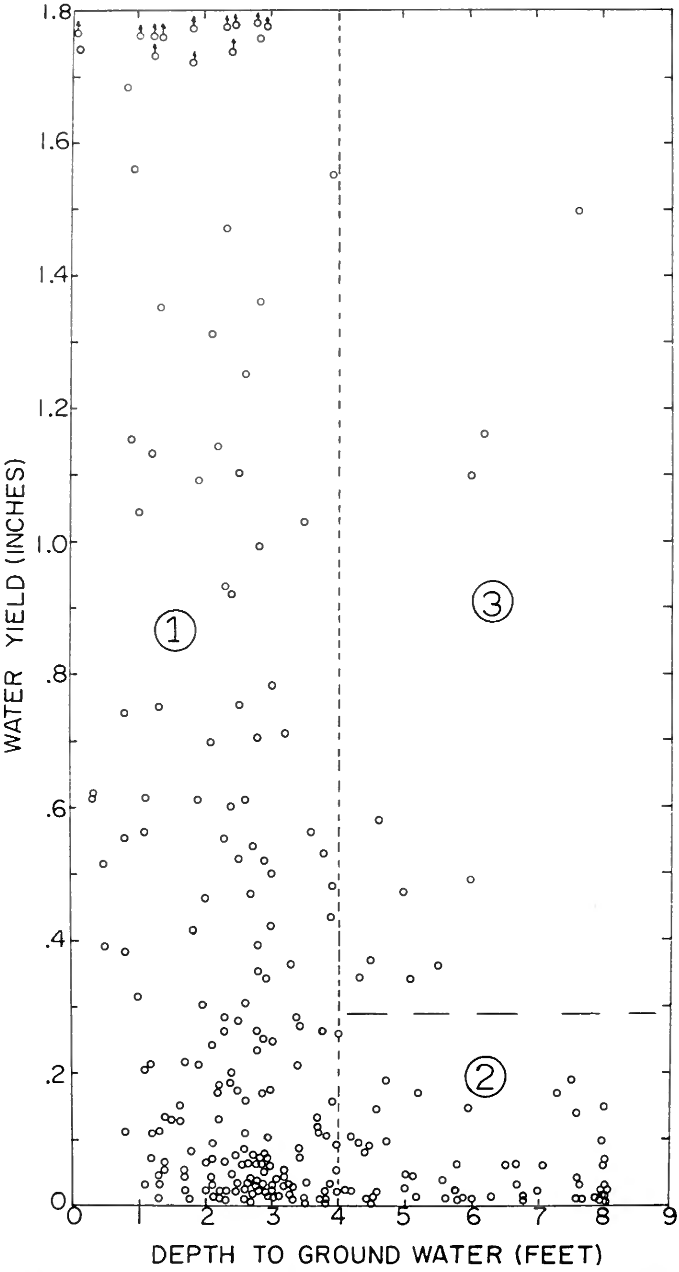
Data from the ground-water well in the southwest corner of the watershed (Fig. 1) were used because its location more nearly represented the watershed, both from the standpoint of soils and of vegetation, than did the well in the abandoned field near the headwater. The specific ground-water level used in connection with a given storm was the low point on the recorder chart prior to the rise resulting from subsurface storm flow.

When ground-water levels were plotted against storm yields, it appeared that yield was related to levels either above or below a point approximately 4 feet below the ground surface (Fig. 4). Water yields occurred for most storms greater than 0.20 inch in size when ground-water levels were less than 4 feet from the surface. At levels greater than 4 feet, yield occurred only when the storage capacity of the soil was exceeded during the storm, or when storm intensity was greater than the infiltration rate.

The 4-foot ground-water level was an index of soil moisture storage capacity. For the Grantsburg soil, the most abundant on the watershed, it indicated the point where the soil horizons were wet to field capacity or above, down to the fragipan. Additional precipitation either (1) ran off the surface (overland flow), (2) percolated downward to the fragipan and moved down the slope along the top of this slowly permeable layer, or (3) slowly wet the pan itself and the rest of the soil mantle down to bedrock. A rise in ground-water levels was largely due to (2).

From the standpoint of water-yield prediction, the storms were grouped into three classes:

1. Storms falling on "wet soil," with no moisture storage capacity available in the profiles (ground-water levels less than 4 feet from the surface). There were 330 storms in this category, and 191 resulted in water yields (Area 1, Fig. 4).
2. Storms falling on "dry soil," with moisture storage capacity available as indicated by ground-water levels greater than 4 feet from the surface. This group included 279 storms; those having some yield are shown in Area 2, Fig. 4.
3. Transitional storms that began on "dry soil" but during which the moisture storage capacity of the soil was exceeded. Only 10 storms fell in this category (Area 3, Fig. 4).



Relationship between water yield and depth to ground water.
(Fig. 4)

Water yields for the various storms were plotted against storm size and a linear regression line was fitted to these points, according to the following formula:

$$\hat{Y} = \bar{y} + b\,(X - \bar{x}),\text{ where}$$

$\hat{Y}$ = point on the regression line or the predicted value of the water yield,

$\bar{y}$ = mean of water yield,

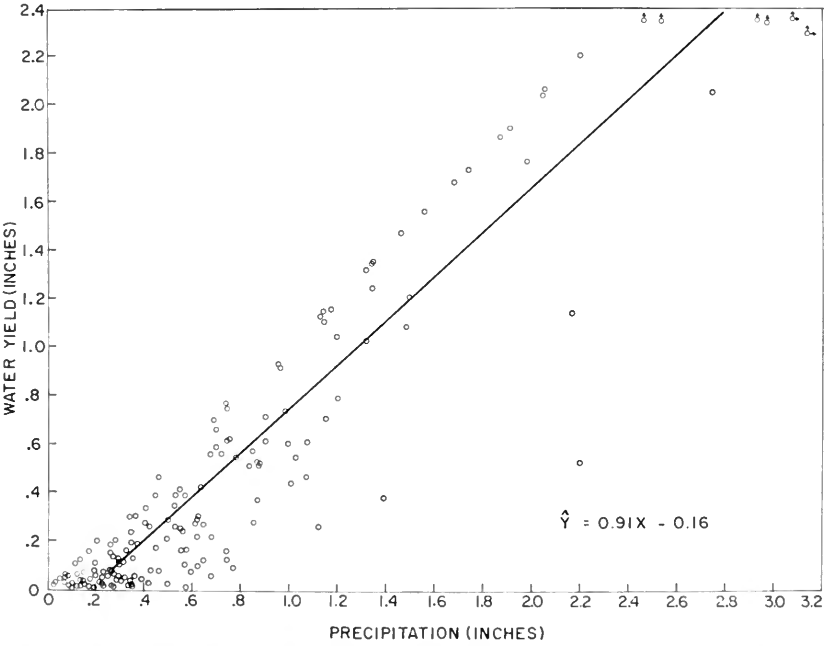
$\bar{x}$ = mean of precipitation,

X = amount of precipitation (uniform depth over entire watershed),

b = the regression coefficient.

In each case an analysis of variance was used to test the significance of the regression relationship.

The regression equation $\hat{Y} = 0.91X - 0.16$ defined the precipitation-water yield relationship on "wet soil" (Fig. 5). The equation was



Relationship between water yield and precipitation for storms on wet soil. (Fig. 5)

significant at the 1-percent level. The correlation coefficient (r) was 0.95 and the coefficient of determination (r^2) was 0.90.

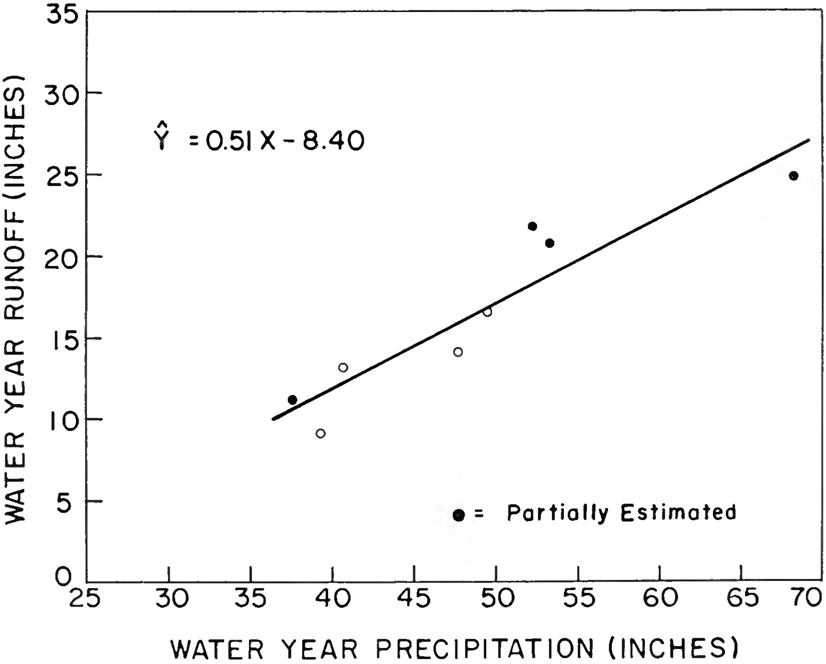
The predicting regression equations for a precipitation-water yield relationship often yield a result of zero even though precipitation is not zero. This occurs because it takes a certain amount of precipitation to exceed the moisture storage capacity of the vegetation and allow throughfall to reach the ground.

Water yields resulted from about one-fourth of the storms that fell on "dry soil," and these yields were relatively small. The relationship between water yield and precipitation for the "dry soil" condition was

$$\hat{Y} = 0.035X - 0.03.$$

While the relationship was significant, the correlation coefficient (0.50) was much weaker than that for the "wet soil" storms. Thus the increase in yield was small in comparison with increase in precipitation.

The transition storms were first classified as "dry soil" storms, since soil moisture storage was available at the beginning of the storm. However, this caused an overestimation of yield from storms falling on



Relationship between water yield and precipitation by water year for eight water years beginning October 1, 1954. (Fig. 6) dry soil. As there were only 10 transition storms, compared with 279 "dry soil" storms, it seemed advisable to develop an equation for the transitions. The relationship could be expressed as

$$\hat{Y} = 0.416X - 0.069.$$

It was significant at the 5-percent level and had a correlation coefficient of 0.72.

The equation expressing the precipitation-water yield relationship for the eight water years (Fig. 6) was

$$\hat{Y} = 0.51X - 8.40,$$

which was significant at the 1-percent level. The correlation coefficient (r) was 0.93 and the coefficient of determination (r^2) was 0.86. This equation could be used to predict water field from annual precipitation ranging from 37.75 to 68.30. These amounts cover a recurrence interval of 5 years for the minimum and 25 years for the maximum yearly amounts.

WATER YIELD

Of the 727 storms measured during the 8-year period, 376, or 52 percent of the total number, produced some yield from the watershed. The number of storms producing yield varied from 35 to 63, with an average of 47 per year (Table 1).

Water yield was composed of both surface (overland) and subsurface flow. No attempt was made to separate these two elements, since total yield was the main objective of the study. However, subsurface flow was a major contributor to total yield, due both to the presence of the slowly permeable fragipan and the relatively low moisture storage capacities of the soil profiles.

Subsurface flow was believed to be largely made up of down-slope seepage along the top of the fragipan, since a perched water table formed there during prolonged periods of wet weather. Deep seepage (moisture that moves downward to bedrock and then into drainage channels) may have made some contributions to subsurface flow but the amount was probably small in comparison with the movement of perched water along the pan.

A summary of the monthy and annual water yields from the watershed is shown in Table 3. The totals are based on individual storm yields which eliminated monthly carryover, since the yield of each storm was recorded in the month during which it began.

Annual water yields varied from 9.10 to 27.21 inches, with the lowest yield in 1954-55 and the highest yield in 1957-58. The average was 16.74 inches, or 34 percent of the average annual precipitation.

Table 3. — Water-Year Yield in Inches, 1954-55 to 1961-62

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1954-55	.00	.02	.36	.04	1.04	3.39	2.29	.14	.13	1.69	.00	.00	9.10
1955-56	.03	.06	.02	.87	5.55	2.55	3.67	.32	.01	.04	.00	.00	13.12
1956-57	.01	.04	.03	1.70	1.58	.98	5.15	6.28	.60	.00	.09	.00	16.46
1957-58	.03[a]	2.68[a]	6.81[a]	2.27	.41	3.95	.95	1.42	.23	8.27	.18	.01	27.21[a]
1958-59	.01	.43	.17	6.43	2.07	.59	.23	1.39	.00	.00	1.30	1.50	14.12
1959-60	.26[a]	.65[a]	3.15[a]	1.35[a]	1.02[a]	1.91[a]	1.06	1.33	.43	.13	.00	.06	11.35[a]
1960-61	.00	.00	.46[a]	.97[a]	3.31[a]	3.50[a]	3.23	7.65	.09	.02	1.40	.00	20.63[a]
1961-62	.00	2.34[a]	3.06[a]	4.22	6.04	3.71	2.44	.04	.00	.07	.00	.00	21.92[a]
Average	.04	.78	1.75	2.23	2.63	2.57	2.38	2.32	.19	1.28	.37	.20	16.74
Percent of average monthly precipitation	1	18	42	62	66	64	54	43	5	23	9	8	

[a] Totals partially estimated.

Monthly water yields varied from none to 8.27 inches. There were no water yields largely during the fall and early winter months when the soil profiles were in the process of recharge following depletion during the growing season by evapotranspiration. The maximum amount occurred in July, 1958, when precipitation was far in excess of normal. At the beginning of the month, ground-water levels were following a normal downward trend, which was reversed with storms that produced 3.3 inches of rainfall on July 6 and 7. From July 15 to July 21 more than 12 inches of rain occurred in storms from 0.10 to 5.08 inches in size, and ground-water levels reached the highest point recorded during the 8-year period. Soil profiles were completely waterlogged, and about 50 percent of the precipitation was returned to the lake as surface or subsurface runoff. Average July yields for the rest of the study period amounted to 7 percent of the precipitation.

The seasonal aspects of water yield are shown in Fig. 17, page 35. Monthly averages expressed as a percentage of precipitation are shown in Table 1. Winter and spring had high yields and may be considered a period of moisture surplus. Normally the low-yield period occurred in the summer and fall and was composed of two distinct periods. The first was a period of depletion that resulted when evapotranspiration requirements exceeded precipitation and moisture was withdrawn from soil storage. It was closely related to the growing season. The second period was that of recharge. It occurred at the end of the growing season and continued until the soil moisture storage capacity was satisfied. The beginning of the recharge cycle usually marks the low point of soil moisture storage and stream flow during the year. For this reason October 1 was selected as the beginning of the water year. This date is generally used as a basis for compiling hydrologic data in the United States.

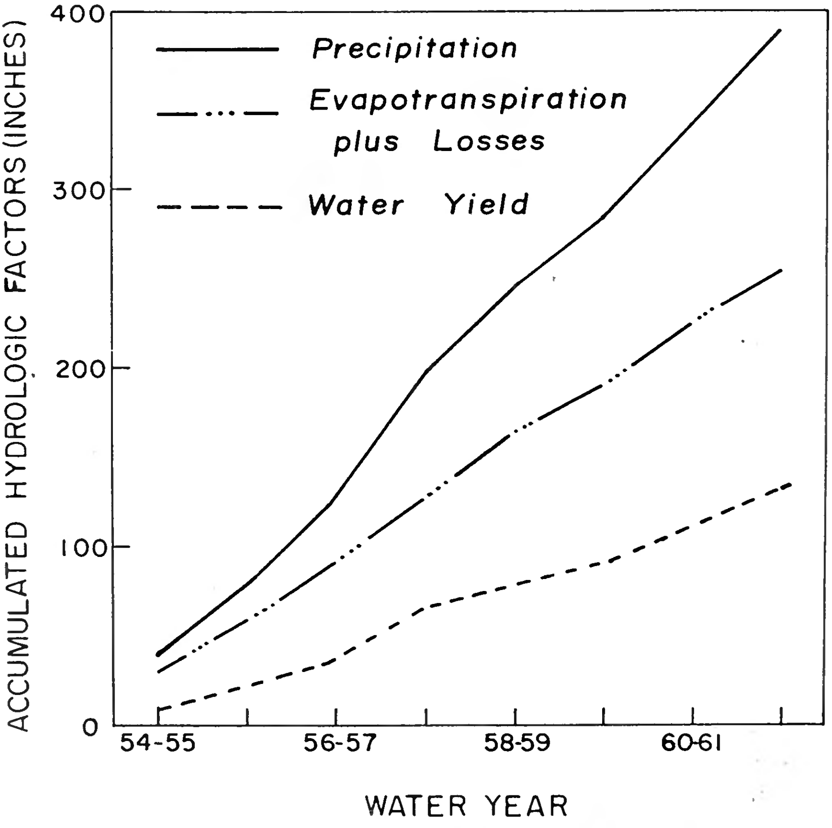
The annual soil moisture trends are illustrated by the plot of ground-water levels in Figs. 9-16. The periods of moisture excess, depletion, and recharge are easily recognized. The moisture excess period was marked by water levels less than 4 feet from the ground surface, depletion by a downward trend, and recharge by an upward trend of the curve. The beginning and ending of each period varied considerably from year to year, depending largely on precipitation patterns. All three periods — excess, depletion, and recharge — occurred in July, 1958 (Fig. 12, page 30). July is normally characterized by rapid moisture depletion.

The relationships between storm size, ground-water levels, and water yields are also shown in Figs. 9-16. Yield from a given storm depended largely on whether precipitation fell on dry soil or wet soil as previously discussed in relation to height of the ground-water table. Occasional storm flow occurred when the soil was dry. This resulted from storms of very high intensity that caused surface runoff, or when the soil moisture storage capacity was reached during a storm.

The relationships of monthly precipitation, water yield, and ground-water levels for the eight years of record are shown in Fig. 7.

Relationships Between Hydrologic Factors

Mass curves were used to study the relationships between hydrologic factors on the watershed (Fig. 7). When accumulated values for annual precipitation, water yield, and evapotranspiration plus losses are



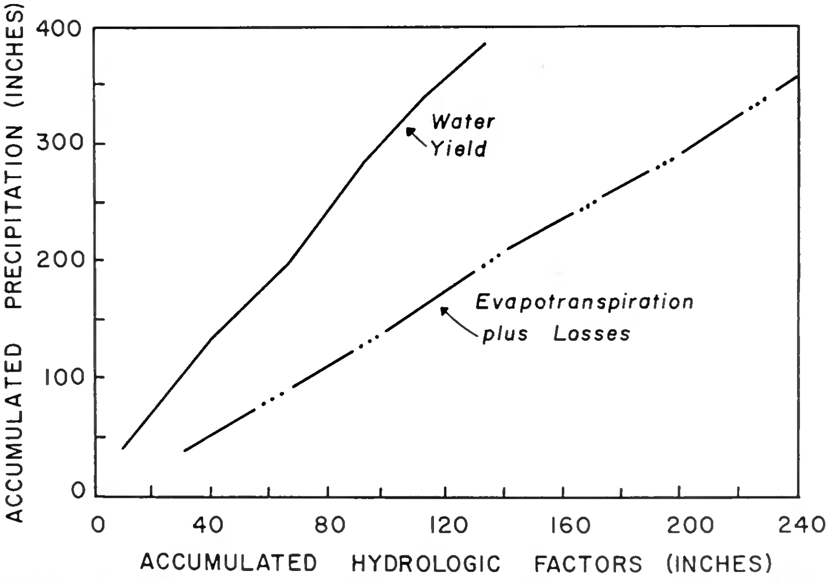
Relationship between accumulated hydrologic factors and water year.
(Fig. 7)

plotted against time, the slope of the curves indicates the rate of accumulation of each factor, and changes can be more readily detected than from tabular values (TVA, 1963).

The high precipitation in 1957-58 was reflected by an increase in slope, while a corresponding decrease resulted from the below normal precipitation in 1959-60.

The yield curve has three different slopes, each lasting about three years. The greatest increase in 1957-58 resulted from the high yields for July, 1958. Other changes were mainly due to seasonal distribution of precipitation.

Evapotranspiration and other losses represent the difference between precipitation and water yield. Included are interception by the vegetation, evaporation from the ground surface, transpiration, and losses due to deep seepage (moisture used in wetting the soil from the fragipan to bedrock). The greatest slope change is again related to the wet year of 1957-58, when more water was available for evapotranspiration than in other years. The slope for the last three years is about the same as that at the beginning of the study. Maximum losses were 41.09 inches in 1957-58, and the minimum of 26.40 inches occurred in 1959-60 (Table 1). Average annual losses from the watershed were 31.92 inches.



Relationship between accumulated precipitation and accumulated hydrologic factors. (Fig. 8)

Double-mass curves were also plotted for water yields and evapotranspiration plus losses to determine any possible changes in the relationships between the hydrologic factors for the period of study (Fig. 8). The slope of the evapotranspiration-plus losses curve is about constant, although a small change occurred in 1957-58. More changes, however, are evident on the water-yield curve. This is related to the fact that the ratio between annual precipitation and water yield is not strictly linear, as the ratios appear to be higher in wet years than in dry years. The slope of the double-mass curve might also be affected by changes in the land-use pattern or in the vegetation. However, these two factors appeared to be relatively unimportant. Land-use patterns are known, and the vegetation cover on the watershed was well established at the beginning of the study. While density of the vegetation no doubt increased due to normal growth, it did not cause an apparent increase in evapotranspiration. At least such changes are not apparent on the curve; thus variations in the slope of the water-yield curve are probably related to the amount of precipitation and its seasonal distribution during each year.

DISCUSSION

The results of this study emphasize some important points in the management of watersheds. First of all, yields from this forested watershed are essentially the same as those given for the general area in the Atlas of Illinois Agriculture (1958), which were based on 20- to 40-year records from a number of stations. The average annual yield of 16.74 inches is equivalent to approximately 455,000 gallons per acre. With an average daily use of 50 gallons per capita, each acre would supply about 25 persons, or the 1,350 acres would support a population of about 34,000 people. Of paramount importance is the fact that the water in Lake Glendale is usually clear and seldom more than murky. Little treatment, other than chlorination, would be required to make it potable.

Based on observations made when the lake was drained, siltation has been negligible during the 25-year life of the reservoir. Low-cut stumps in the basin were clearly visible and showed little evidence of silt accumulation. Thus the reservoir should have a long period of usefulness.

Adequate water yield, clear water, and control of siltation are the main objectives of watershed management. The latter two are a direct result of the excellent cover of vegetation. The yields were obtained in spite of the vegetation which transpired large quantities of water.

As the potential surface water resources of southern Illinois are impounded for domestic use, it is hoped that the reservoir planners and developers will be cognizant of the values that accrue from establishing and maintaining good covers of vegetation on the watersheds. The kind of vegetation, either grassland or forest, is relatively unimportant in this area of relatively shallow soils. Either will prevent erosion, provide clear water, and improve the general infiltration capacities of the soil. The salient point is to make reservoir development and watershed management a joint operation.

SUMMARY

Hydrologic factors on the Lake Glendale Watershed were measured for eight water years, beginning October 1, 1954, and ending September 30, 1962. This 1,350-acre watershed was well covered by vegetation, with forest making up about two-thirds of the total area at the beginning of the study. Little vegetation change, other than normal growth, occurred during the measurement period.

The hydrologic data were analyzed to determine annual, monthly, and individual storm yields as related to storm characteristics and soil moisture conditions.

In the period of record, 727 storms were recorded on the watershed with an average of 91 storms per year. The average annual precipitation was 48.66 inches, which was 2.02 inches above the long-time average. Monthly precipitation varied in distribution from year to year with the range of 0.46 to 16.30 inches. Average monthly totals agreed closely with the long-time averages. The precipitation of 16.30 inches in July, 1958, was very unusual and has a recurrence interval of approximately 75 to 100 years. The maximum storm size was 5.08 inches, which occurred during July, 1958. Hourly storm intensities varied from a trace to 3.30 inches.

Each storm was analyzed separately to determine individual storm yield. Yields were reflected by a rise in the lake level due to flow from the watershed and precipitation on the lake surface. A method was devised to estimate storm flow when storm yields overlapped in time. The equivalent volume of water was computed by stage height-volume tables and stage height-discharge tables. The volume was corrected for the precipitation on the lake surface to find water yield from the land area only.

Water yield to the lake was made up of three component flows:

1. Overland flow, when infiltration capacity was exceeded by the intensity of precipitation and surface flow occurs.

2. Perched flow, when the percolating water reached the fragipan, much of it flowing along the pan to be contributed to the lake.

3. Base flow (from water below the fragipan). When the pan was wetted, downward percolation occurred below the fragipan and the source of base flow from ground water was recharged.

Ground-water levels were found to be an index of soil moisture or storage capacity. When the ground-water levels were less than 4 feet from the surface ("wet soil"), the soil had little or no moisture storage capacity. When the ground-water levels were more than 4 feet from the surface ("dry soil"), storage capacity was available and moisture was required to recharge the profile. Ground-water levels that defined soil moisture conditions were the most reliable single factor studied that could be used to predict water yield.

Storms for water-yield prediction were separated into three precipitation-water yield relationships:

1. Storms falling on "wet soil," represented by the regression equation $\hat{Y} = 0.91X - 0.16$.

2. Storms falling on "dry soil," represented by the equation $\hat{Y} = .035X - .03$.

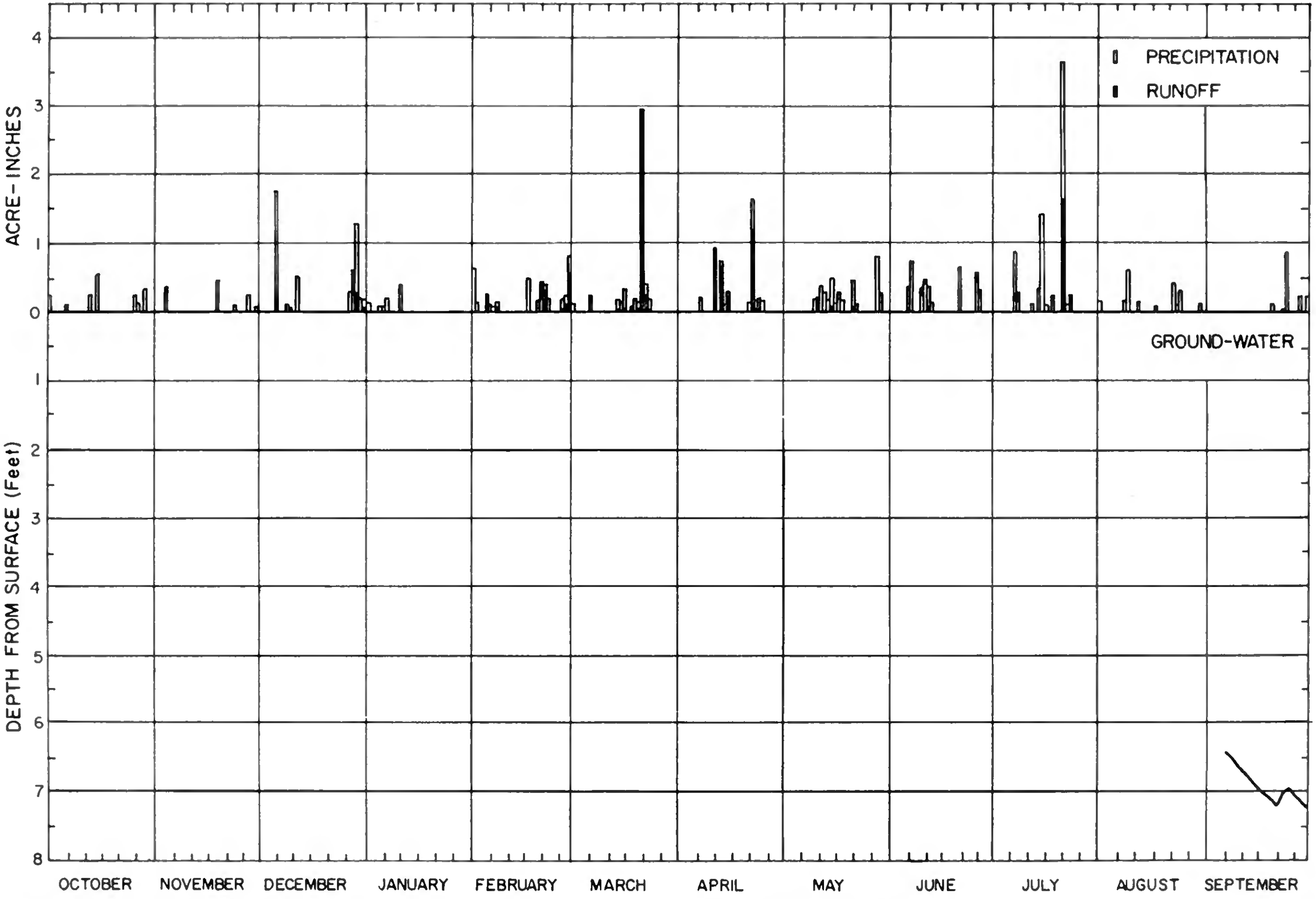
3. Transition storms during which the soil moisture storage capacity was exceeded, represented by the equation $\hat{Y} = .416X - .069$.

A uniform depth of precipitation over the entire watershed was assumed in each case.

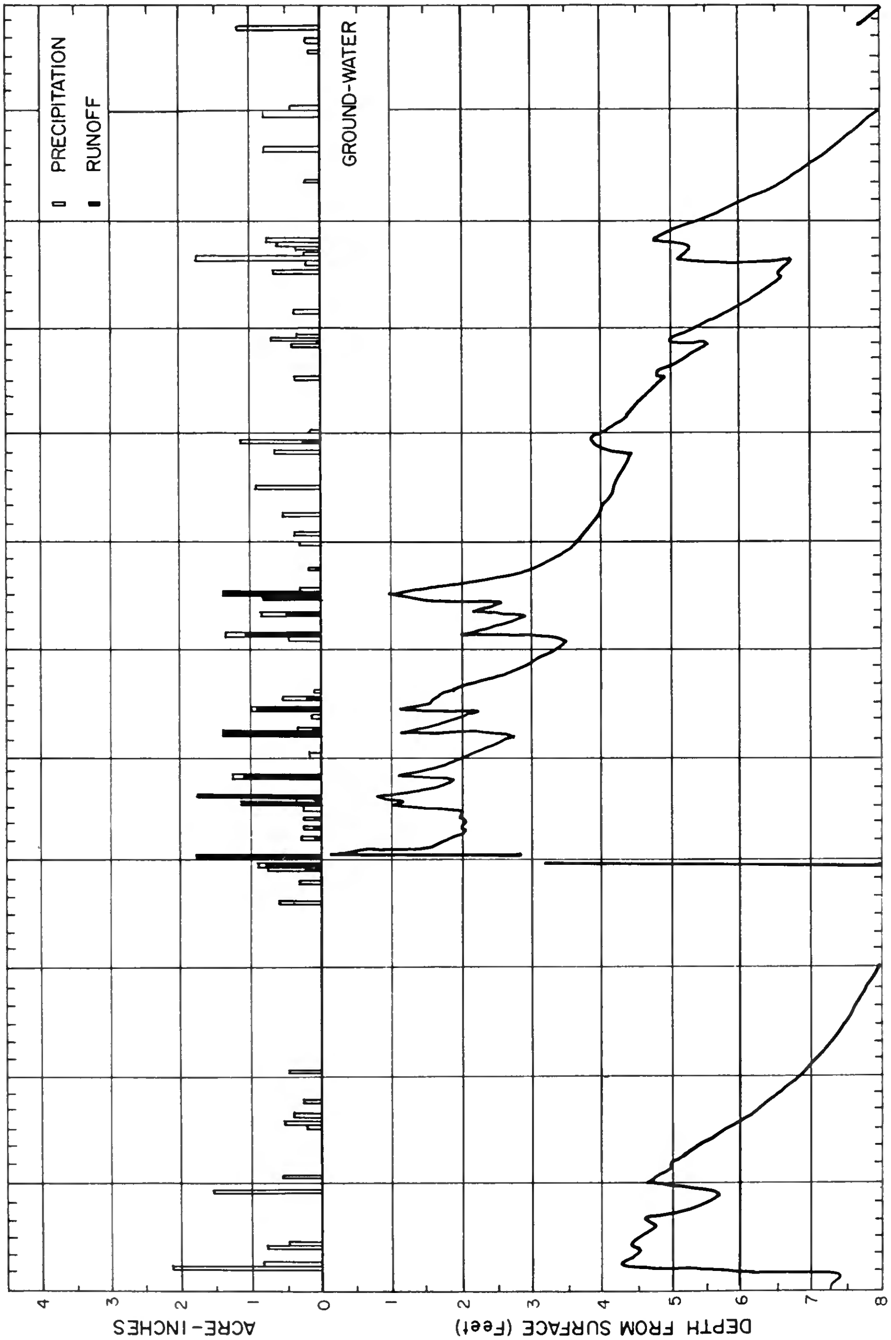
A water-year precipitation-water yield relationship was developed. This relationship could be represented by the equation $Y = .51X - 8.40$, which was tested statistically and found significant at the 1-percent level.

Measureable yield was produced from 376 storms or 52 percent of the total number of storms. Water-year yield-producing storms varied from 35 to 63, with an average of 47 per year. The water-year totals varied from 9.10 to 27.21 inches, with an average of 16.74 inches. Monthly water yields varied from none to 8.27 inches. Water yields were seasonal with the high yields occurring in the winter and spring and the low yields occurring in the summer and fall.

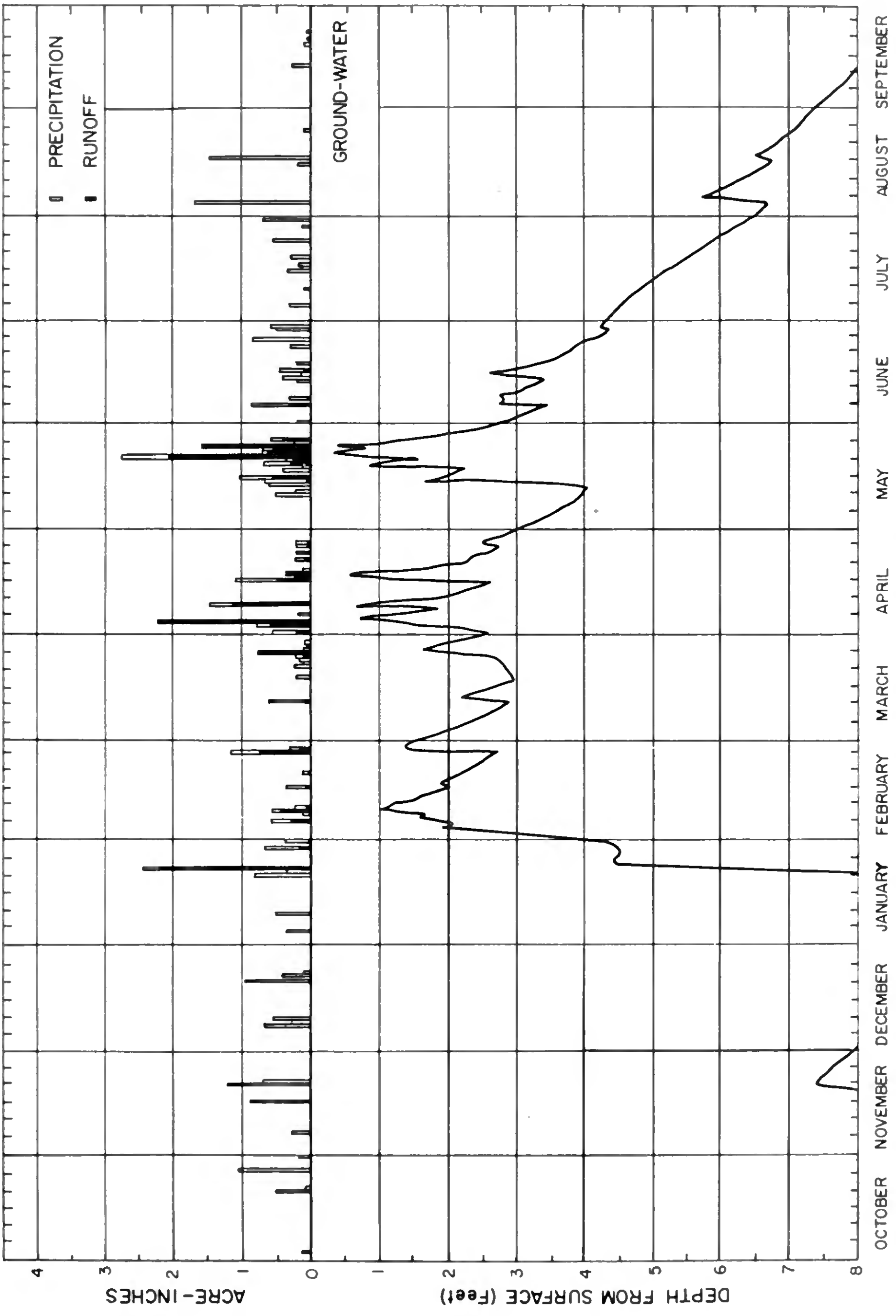
Changes in the precipitation-water yield relationships for the period of study were related to changes in amount and distribution of precipitation during each year.



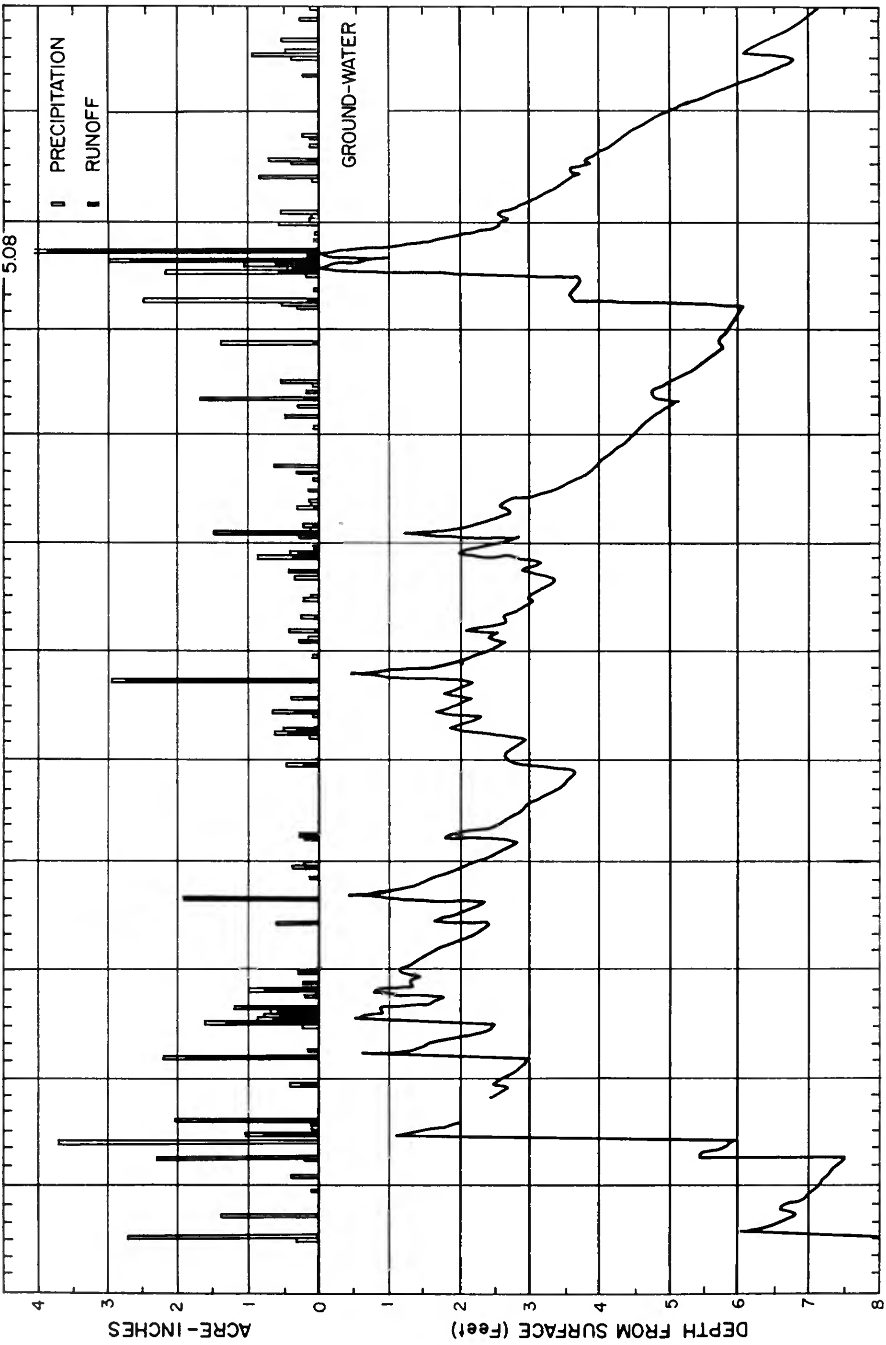
Precipitation, runoff (water yield), and ground-water levels for the water year 1954-55. (Fig. 9)



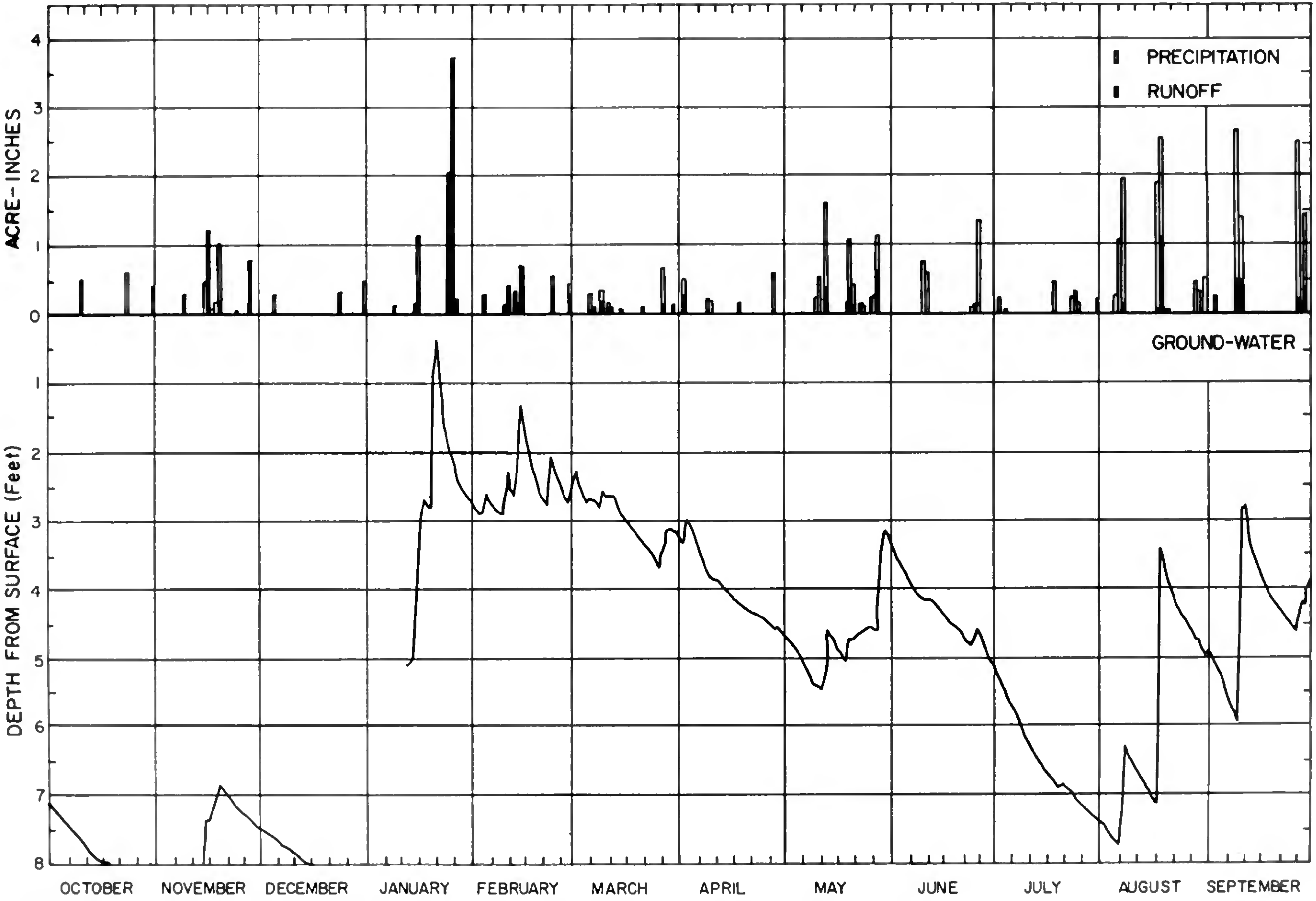
Precipitation, runoff (water yield), and ground-water levels for the water year 1955-56. (Fig. 10)



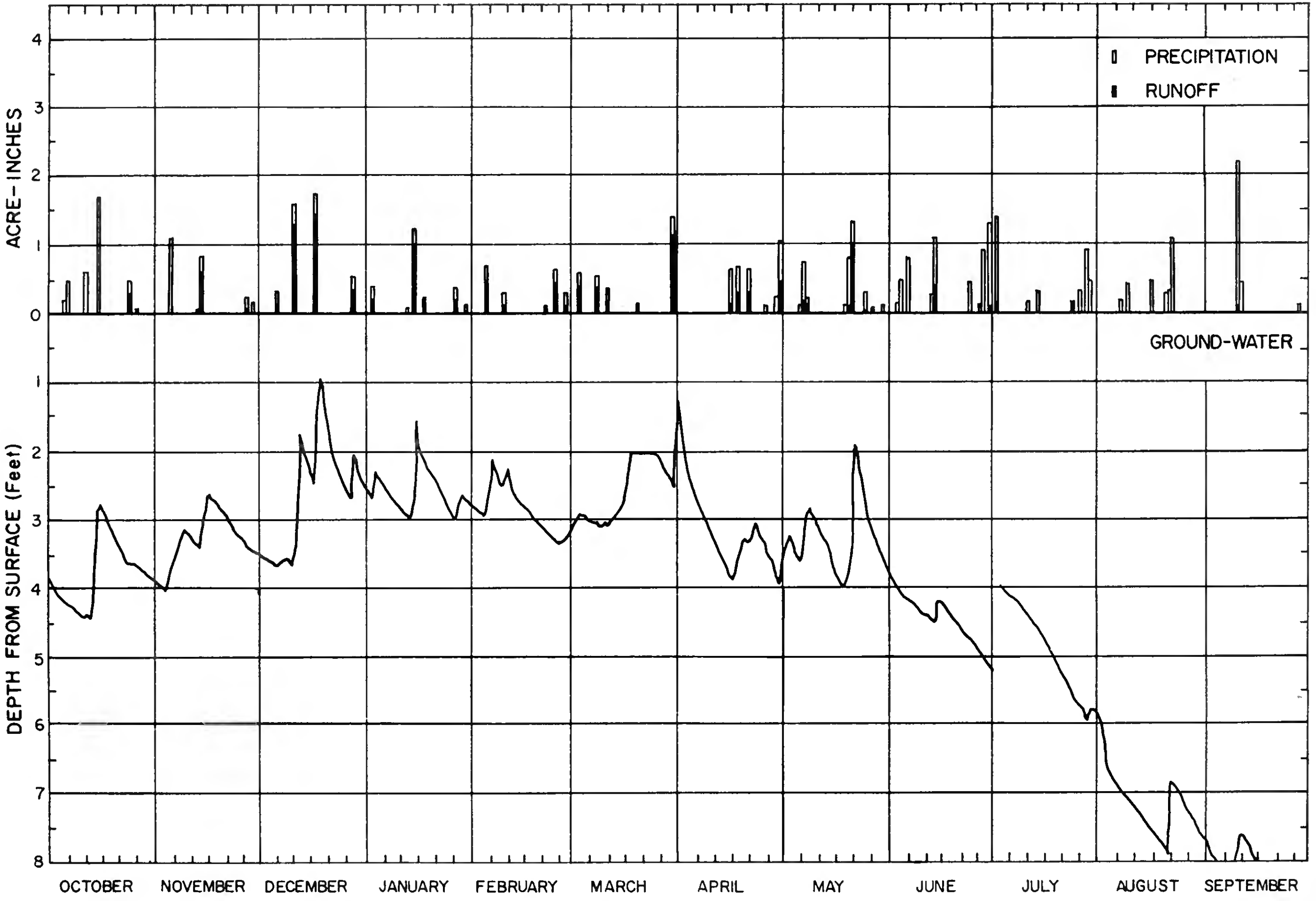
Precipitation, runoff (water yield), and ground-water levels for the water year 1956-57. (Fig. 11)



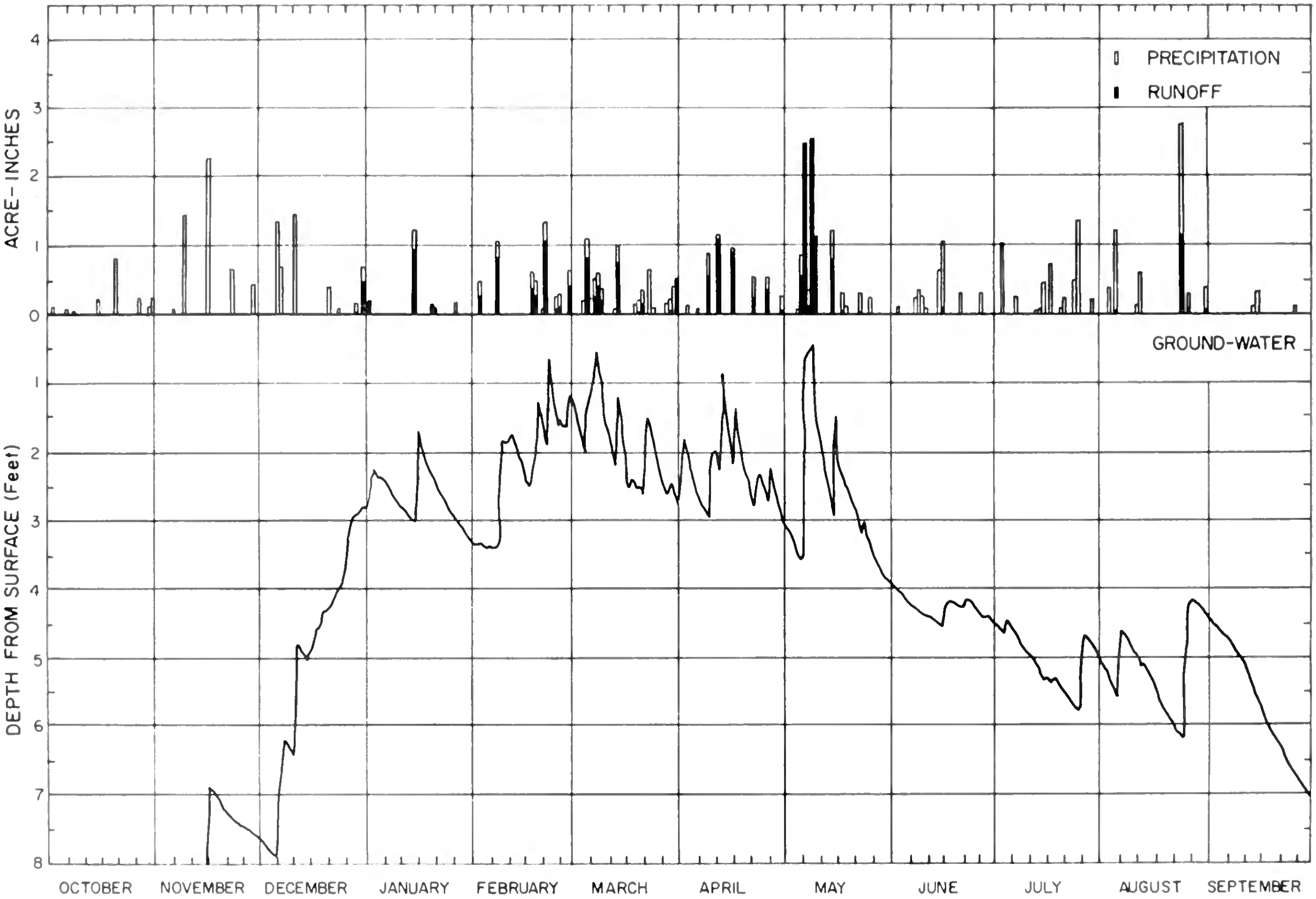
Precipitation, runoff (water yield), and ground-water levels for the water year 1957-58. (Fig. 12)



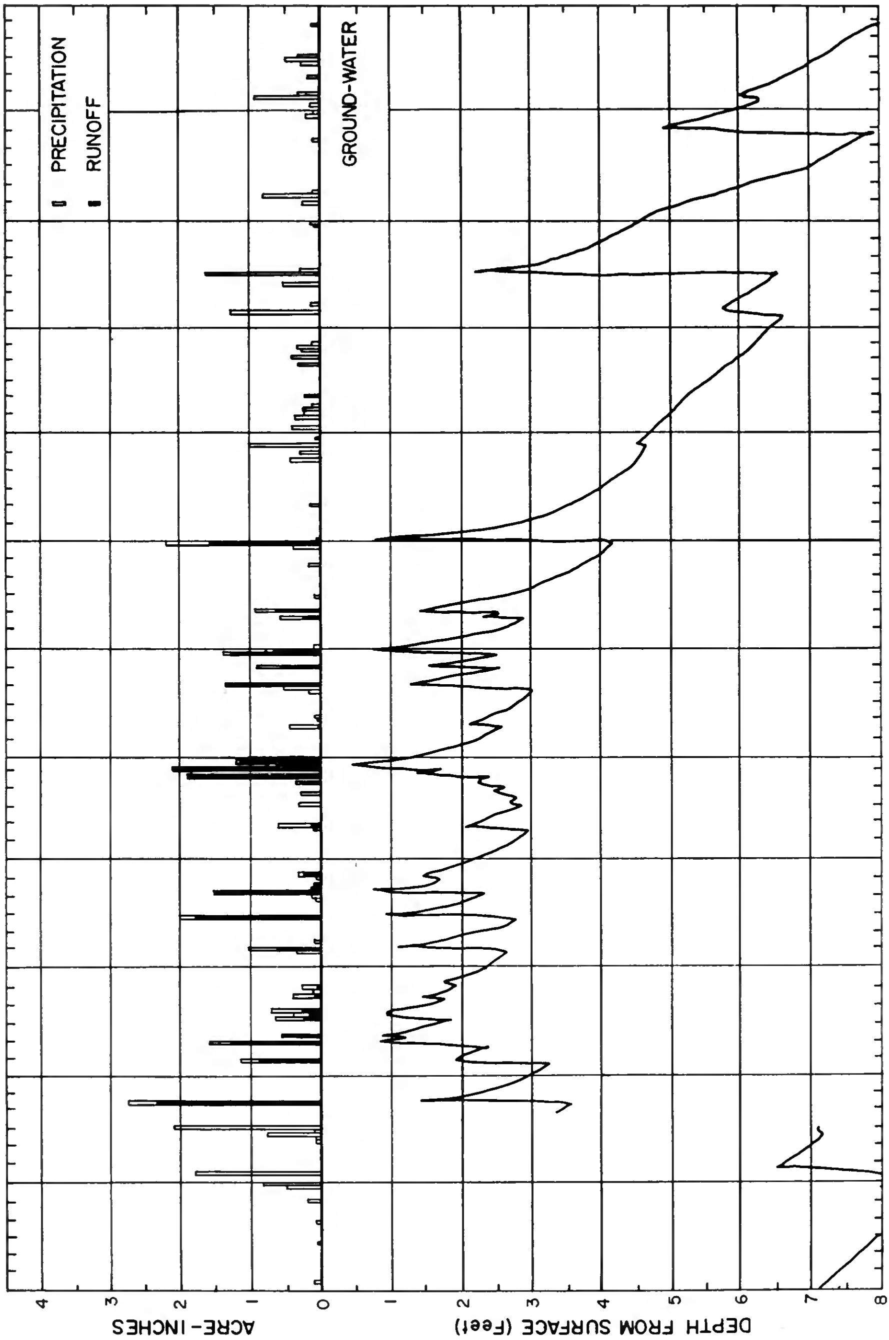
Precipitation, runoff (water yield), and ground-water levels for the water year 1958-59. (Fig. 13)



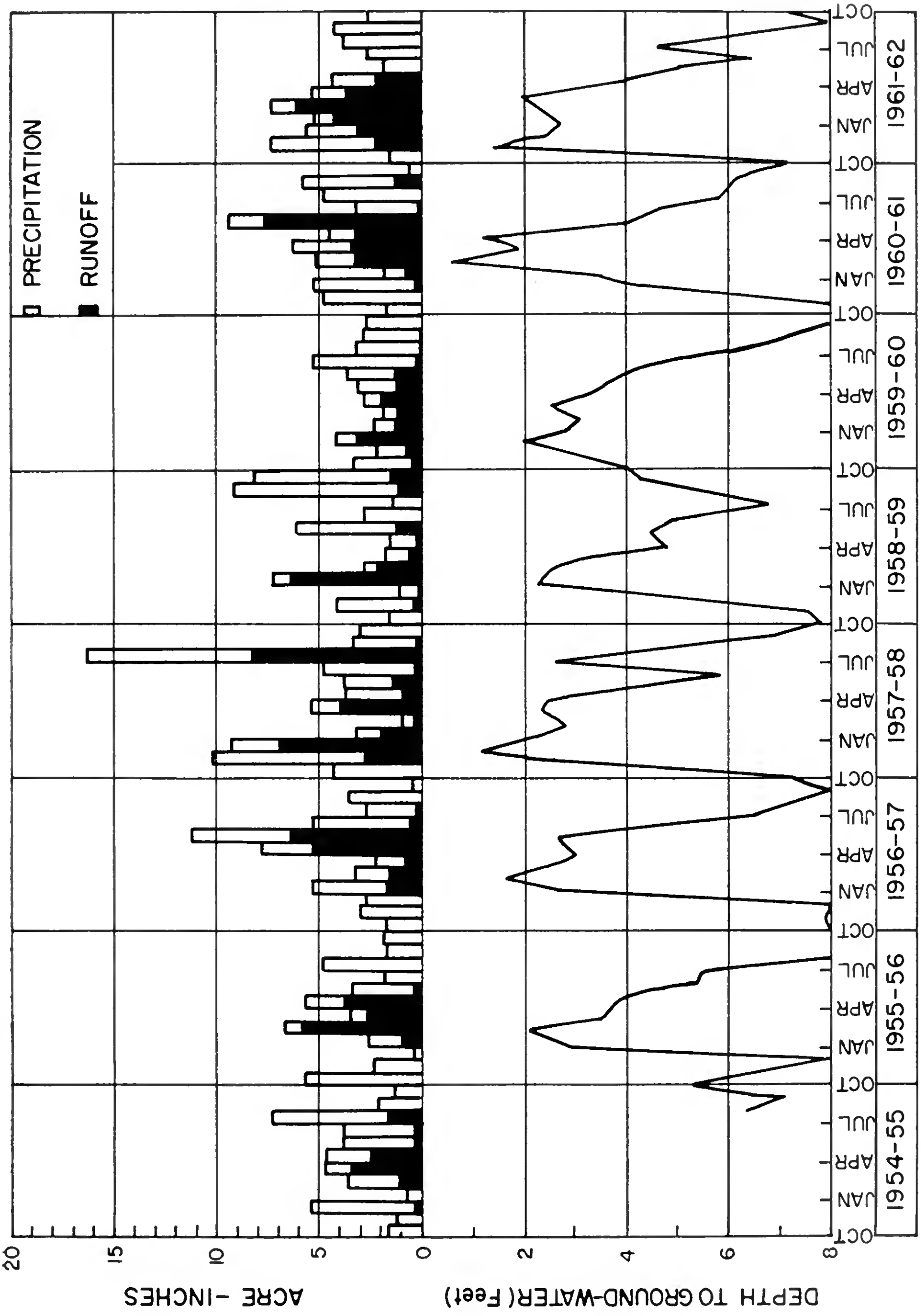
Precipitation, runoff (water yield), and ground-water levels for the water year 1959-60. (Fig. 14)



Precipitation, runoff (water yield), and ground-water levels for the water year 1960-61. (Fig. 15)



Precipitation, runoff (water yield), and ground-water levels for the water year 1961-62. (Fig. 16)



Precipitation, runoff (water yield), and ground-water levels for eight years.

(Fig. 17)

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