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EFFECTS OF CONSERVATION PRACTICES ON STORM RUNOFF IN THE TEXAS BLACKLAND
BAIRD, R W , RICHARDSON, C W , KNISEL, W G , JR 1 OF 1

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EFFECTS OF CONSERVATION PRACTICES ON STORM RUNOFF IN THE TEXAS BLACKLAND PRAIRIE

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE
in cooperation with
Texas Agricultural Experiment Station

Contents

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Effects of Conservation Practices on Storm Runoff in the Texas Blackland Prairie

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INTRODUCTION

As demands for water grow, the effects of land-use changes on amounts of runoff become increasingly important to all water users. Where direct surface runoff is the chief source of water, as in the Texas Blackland Prairie, there is considerable interest in the effect that conservation measures on the agricultural lands have on this source of water supply. The increase of the acreage of grassland and the introduction of terraces or contour tillage were believed to have decreased surface runoff. Therefore, a study to determine the effects of these conservation measures on runoff was conducted at the Blacklands Experimental Watershed near Riesel, Tex.

The study was conducted by instrumenting small watersheds in the Texas Blackland Prairie to measure rainfall and runoff. These measurements were made during an initial period when all watersheds were farmed alike in the then conventional manner. Following this initial period, conservation practices were applied to all watersheds except one, which was maintained in nonconservation farming to serve as a base, and the measurements continued.

Equations were developed from the data obtained from these measurements for predicting runoff from each watershed—first as an area without improved treatment, and second, as an area with conservation practices applied. These equations were used to predict runoff based on the data for the entire period of record. The predicted amounts of runoff for the two treatments were then compared to determine the effect that conservation practices had on runoff.

THE TEXAS BLACKLAND PRAIRIE

The Texas Blackland Prairie extends in a southwesterly direction from near the Red River in northeast Texas to San Antonio in south-central Texas (fig. 1). About 11,500,000 acres are included within this

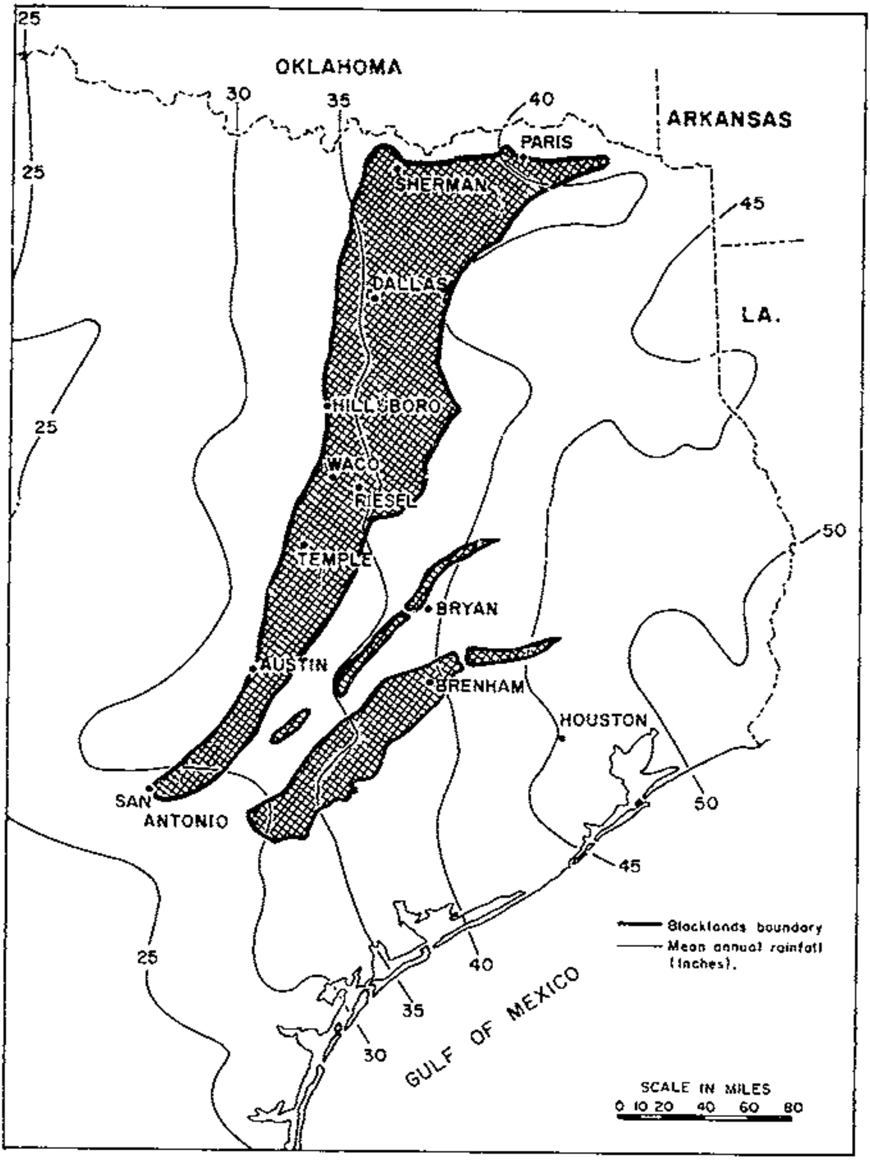

FIGURE 1.—Location of the Texas Blackland Prairie and mean annual rainfall in eastern Texas.

area. The soils of this area are primarily heavy calcareous clays. These deep soils can absorb large amounts of water rapidly when dry, but swell when wet and are very slowly permeable. The major part of the area is gently rolling, with slopes of 3 percent or less. This part now includes much of this cultivated land of the area. Some relatively small areas, frequently along fault zones, have much steeper slopes. Some of these steeper areas had been cultivated but now most of them are grassland. More detailed information of soils and geology of the area can be found elsewhere.[1]

Agriculture

The native vegetation in the Texas Blackland Prairie was largely grasses with scattered patches of small trees and some larger trees along creeks.[2] From the early 1900's into the 1930's, this area was extensively cultivated. Cotton and corn were the primary crops until reductions in cotton acreage started in the 1930's. Much of the area formerly planted to cotton is now in grass and weeds. However, some of it is used for improved pastures and a considerable part for grain sorghum and small grains.

Farming on the cultivated lands has changed. Animal power and small tractors have been replaced with row-crop equipment of four rows or more. Deeper tillage, made possible by large power equipment, and use of herbicides have resulted in more effective weed control with fewer tillage operations.

Climate

The climate of the area is characterized by long, hot summers and relatively mild winters. Mean annual rainfall varies from about 30 inches in the southwestern part of the area to about 40 inches in the northeastern part (fig. 1). Large variations from the mean are common. From 1937 to 1966, annual rainfall at the Blacklands Experimental Watershed ranged from 17.94 inches in 1954 to 57.91 inches in 1957. Long periods of below-average rainfall, without any severe storms, also occur, resulting in periods of more than 12 months without any runoff from the experimental watersheds.

THE BLACKLANDS EXPERIMENTAL WATERSHED

Hydrologic studies at the Blacklands Experimental Watershed are conducted on 841 acres of Government-owned land and on 4,000 additional acres of adjacent privately owned land at the headwaters of Brushy Creek.

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[1] Baird, R. W., and Potter, W. D. RATES AND AMOUNTS OF RUNOFF FOR THE BLACKLANDS OF TEXAS. U.S. Dept. Agr. Tech. Bul. 1022, pp. 4–6, July 1950; Blank, H. R., Stoltenberg, N. L., and Emmerich, H. H. GEOLOGY OF THE BLACKLANDS EXPERIMENTAL WATERSHED, NEAR WACO, TEXAS. Univ. Tex., Bur. Econ. Geol. Invest. Rpt. 12, pp. 8–28, March 1952; and U.S. Department of Agriculture, Soil Conservation Service. THE AGRICULTURE, SOILS, GEOLOGY, AND DESCRIPTION OF THE BLACKLANDS EXPERIMENTAL WATERSHED. U.S. Dept. Agr., Hydrol. Bul. 5, pp. 8–9, 1942.

[2] Carter, W. T. THE SOILS OF TEXAS. Tex. Agr. Expt. Sta. Bul. 431, 189 pp., illus. July 1931.

The experimental watershed is representative of the Texas Blackland Prairie. Its soils are developed from the marls of the Taylor formation, the most extensive formation in the Blackland Prairie. Land uses within the watershed are typical of those for the area and the slopes and drainage comparable to the general area. In addition, this watershed has subwatersheds suitable for measuring runoff and sediment yields.

DESIGN OF THE EXPERIMENT

The data for this study were collected during two treatment periods. During the initial period, hereafter referred to as the uniform treatment period, all watersheds were treated alike. Fields were cultivated with straight rows without regard to slope and with no special conservation treatment. This uniform treatment period permitted the differences in runoff production to be determined among the watersheds

Different treatments were started in 1942 on experimental watersheds Y, Y–2, Y–4, and Y–7, and in 1948 on watershed SW–17. Watershed W–1 was retained without a major change to serve as a basis for comparing the old treatment with the new treatments. The new treatment period will be called the differential treatment period. The treatment periods and the total period recorded on each watershed are shown in table 1.

The major part of all but one of the study watersheds is on Government-owned land where land uses and conservation practices can be controlled. The soils of these watersheds range from 66 to 100 percent Houston Black clay. Physical characteristics of the watersheds are given in table 2. A map of the experimental area is shown in figure 2.

TABLE 1.—*Land treatments on experimental watersheds and periods with runoff records, Texas Blackland Prairie*

Watershed	Treatment			Periods with runoff records
	Nonconservation [1]	Transition [2]	Conservation [3]	
W–1	1939–66	None	None	1939–66.
Y	1939–Aug. 1942	Sept. 1942–48	1949–66	1939–July 1943. May 1946–66.
Y–2	1939–Aug. 1942	Sept. 1942–48	1949–66	1939–66.
Y–4	1939–Aug. 1942	Sept. 1942–48	1949–66	1939–July 1943. 1946–66.
Y–7	1939–Aug. 1942	Sept. 1942–48	1949–66	1939–July 1943. May 1947–66.
SW–17	1939–July 1943	Aug. 1943–48	1949–66	1939–July 1943. 1948–66.

[1] No special conservation treatment.
[2] Conservation practices were being established.
[3] Construction of terraces or change in agronomic treatment or both.

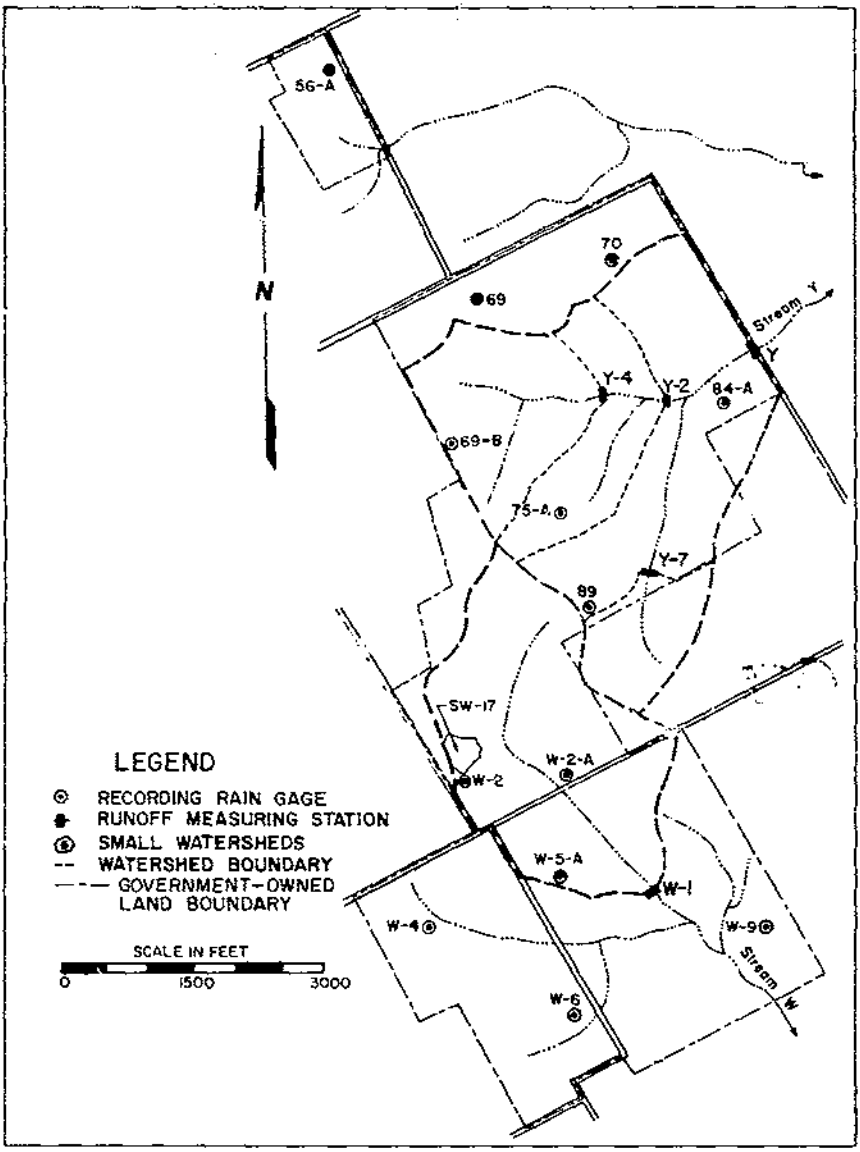

FIGURE 2.—Location of runoff measuring stations and rain gages on the Government land.

Uniform Treatment Period

Under the land use prevailing in 1936 and 1937, farms in this area had approximately 80 percent of their total acreage in cultivation, 16 percent in permanent grass for hay or pasture, and 4 percent in roads and farmsteads. Of the total cultivated land, about 75 percent

TABLE 2.—*Characteristics of the experimental watersheds, Texas Blackland Prairie*

Watershed	Size	Length [1]	Area in slope range of—			Average slope [2]
			Less than 1 percent	1–3 percent	3–6 percent	
	Acres	*Feet*	*Percent*	*Percent*	*Percent*	*Percent*
W-1	176.0	5,400	11	75	14	2.19
Y	309.0	5,040	3	79	18	2.41
Y-2	132.0	3,280	6	67	27	2.57
Y-4	79.9	2,760	3	61	36	2.86
Y-7	40.0	1,970	9	91	0	1.87
SW-17	2.99	380	0	100	0	1.83

[1] Distance from the measuring station to the most distant point of the watershed.
[2] For areas of less than 25 acres, average slope was determined by the contour-length method; for larger areas, from the average slope of each slope class weighted by its area.

was in cotton or corn (both spring-planted crops) and the rest in fall-planted oats and other crops. This land-use practice was applied to all watersheds during the nonconservation period, although some minor changes were made in the acreages of the various crops grown. Actual land uses for 1937, 1939, 1942, 1949, and 1966 are shown in table 3.

Preparation of land for row crops generally started in the fall after harvest, and usually completed in October. The land was bedded and rebedded with beds spaced 36 to 38 inches. If control of winter weeds was necessary, one to three additional bedding operations were made before planting. Corn was planted in early March and cotton, about April 15 or later. Planting on the bed left the field with only a minor ridge. Row crops had frequent shallow cultivation for weed control until about July 1 when corn became too tall to cultivate or until cotton was nearly ready for harvest. Usually stalks and other residue were covered by the fall tillage. No effective stalk shredders were available and stalks and other residues were difficult to incorporate into the soil. In some areas burning the stalks was common, but this was not done on these watersheds.

Oats, usually drilled in cotton land without other tillage soon after cotton harvest, were grazed from December through February and harvested in May or June. Bedding of land to be planted to cotton the following year was usually started soon after harvest of oats or corn. Sometimes, however, this work was delayed because of other workloads or dry soil.

Pastures on the watersheds were usually small and severely overgrazed. Many farms retained small acreages (or areas) of native grass which were cut for hay about July 1. This grass was usually in good condition unless heavily grazed after the hay was cut.

The only major change in tillage operations from 1939 through August 1942 was replacing animal power with small tractors. Little fertilizer, herbicide, or insecticide was used during this period.

TABLE 3.—*Major uses of land in experimental watersheds, Texas Blackland Prairie, specified years 1937–66*

Watershed and year	Fall-	Spring-	Perma-	Farm-	Roads	Other [1]
Watershed and year	planted	planted	nent	steads		
Watershed and year	oats	crops	grass			
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Watershed W-1:						
1937	10.5	76.7	8.1	1.5	2.6	0.6
1939	12.5	73.6	9.3	1.6	2.6	.4
1942	13.6	71.5	10.2	2.1	2.6	
1949	15.8	58.3	16.7	1.9	2.6	4.7
1966	18.1	50.7	21.4	.8	2.6	6.4
Watershed Y-2:						
1937	7.0	46.2	8.6	.5	1.1	36.6
1939	11.2	80.8	6.9	--------	1.1	--------
1942	18.3	71.8	8.8	--------	1.1	--------
1949	25.9	44.2	28.8	--------	1.1	--------
1966	26.1	39.7	33.0	--------	1.2	--------
Watershed Y-7:						
1937	12.0	88.0	--------	--------	--------	--------
1939	15.6	84.4	--------	--------	--------	--------
1942	28.1	71.9	--------	--------	--------	--------
1949	93.1	--------	6.9	--------	--------	--------
1966	35.5	22.8	14.1	--------	--------	27.6
Watershed Y:						
1937	7.4	54.9	18.2	.8	1.1	17.6
1939	10.6	69.3	18.5	.5	1.1	--------
1942	15.6	64.0	18.8	.5	1.1	--------
1949	14.9	37.8	31.1	.2	1.1	14.9
1966	27.8	30.6	37.0	--------	1.1	3.5
Watershed Y-4:						
1937	11.6	57.8	11.8	.07	--------	18.1
1939	12.3	77.6	9.0	--------	1.1	--------
1942	19.0	68.2	11.7	--------	1.1	--------
1949	24.7	46.2	28.0	--------	1.1	--------
1966	29.9	37.7	31.3	--------	1.1	--------

[1] Primarily idle land usually with cover of Johnsongrass or areas without record of crops.

NOTE.—Watershed SW-17 had 100 percent of the area in 1 crop each year. Crops grown were: Cotton, 1939, 1941, 1943, 1945, and 1947; corn, 1938, 1946; oats, 1940, 1942, and 1944. Sprig sodded with bermudagrass, spring 1948, used for pasture through 1966.

Differential Treatment Period

The staff of the Blacklands Experimental Watershed in cooperation with the Operations Division of the Soil Conservation Service and conservation specialists of the Texas Agricultural Experiment Station prepared a conservation plan for watershed Y and its subwatersheds. This plan included terraces, grassed waterways, larger acreages of permanent grasses, and a 3-year rotation of cotton, corn, and oats with Hubam or Madrid clover. Early in 1943, terraces, waterways, and changes in field layouts were completed, but improved agronomic practices were not fully effective until 1949, when the 3-year rotation had completed two cycles.

Watersheds Y, Y–2, Y–4, and Y–7 were terraced and acreages of permanent grasses were increased. The major differences in these areas were the physical differences shown in table 2 and in the crops grown (table 3). A detailed description of the treatment on each area follows.

Base Watershed W–1

In 1942, watershed W–1 was selected as the base area for later comparison with areas on which conservation practices would be established. Tillage and cropping practices had only minor changes (table 2). The acreage of permanent grass was increased and grain sorghum replaced corn, but row crops were grown each year on approximately 75 percent of the cultivated land in a 4-year rotation of cotton, oats, cotton, corn or grain sorghum. Fertilizers were not used until 1963 and then at rates comparable to those used in the conservation areas. Little changes occurred in tillage until 1963, when heavier equipment was used which resulted in deeper tillage and more timely field operations. Throughout the period recorded, the area was cultivated in straight rows, parallel to field boundaries without regard to slope.

Conservation Watershed Y–2

The conservation program on watershed Y–2 started in 1942. The plan included: (1) Increasing the acreage of grassland for additional pasture and for protection of drainageways and terrace outlet channels; (2) terracing all cultivated land with slopes greater than 1 percent; and (3) improving agronomic practices, including deeper tillage and recommended crop rotations. Some small areas with slopes as great as 5 percent were included in cultivated fields, but areas with steeper slopes generally were seeded or sodded to grasses. Construction of terraces started in the fall of 1942 and was completed in 1943. Since then, all tillage operations have been parallel to the terraces.

In 1949, commercial fertilizer applications of 24–30–0 [3] were used with the oats-clover; these rates were gradually increased to 50–38–0 by 1966. Oat fields were moderately grazed from December through February except during wet periods. The principal change in tillage was plowing all oat-clover fields when the clover had made some growth after harvest of oats. Plowing depths were gradually increased from about 5 inches in 1949 to 8 inches or deeper in 1966. Plowing with a two-way plow was parallel to terraces and all dead furrows were in the terrace channels. Except for tillage parallel to terraces, planting, cultivating, and harvesting on conservation-treated watersheds were the same as on the base watershed W–1. Figure 3 shows the improvements in methods and depths of tillage.

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[3] Fertilizer applications are the amounts of total N, available P_2O_5, and water-soluble K_2O.

FIGURE 3.—Typical tillage methods and depths used in 1939 (upper) and 1963 (lower).

Watershed Y-4

Watershed Y-4 is part of watershed Y-2 and has a similar conservation and cropping plan. Land slopes, however, are generally greater on Y-4 than on Y-2. Slopes of 3-6 percent occur on 36 percent of Y-4 and on 27 percent of Y-2. Only 13 percent of the part of Y-2 below Y-4 has slopes within this range.

A smaller proportion of watershed Y–4 has the deep Houston Black clay soil than watershed Y–2. Shallower soils occur on 26 percent of watershed Y–4 and 24 percent of watershed Y–2.

Watershed Y–7

After 1942, watershed Y–7 had the same type of terraces and waterway system as Y–2. The cultivated land of this watershed is privately owned, but the grassed waterway (about 6 percent of the area) is owned and maintained by the Government. Deeper tillage was not used on this watershed as on Y–2. After 1942, cotton acreage was reduced and no special cropping or tillage plan was followed. Quality and timeliness of farming were poorer than those followed on the base watershed W–1. Oat crops frequently were intensively grazed and seldom harvested for grain. After corn or grain sorghum was harvested, the stalks remaining were also heavily grazed. Cultivation was parallel to the terraces and the terraces were maintained in good condition.

Watershed Y

The 309-acre watershed Y includes subwatersheds Y–2, Y–4, and Y–7. Although this watershed had the same type of conservation plan as described for Y–2, an intensive treatment of all the drainage area was impossible. This area has 20 acres of privately owned land, in addition to that in watershed Y–7, with no special conservation treatment or agronomic plan. On the Government-owned land, 59 acres were tenant operated with the Government prescribing the crop plans. The types and timing of farming operations, however, were left to the discretion of the tenant. Until 1953, these two privately owned areas were managed much like watershed Y–7. Since then, the 59-acre area has been managed and operated by the Government. By 1956, one rotation cycle was completed using the same type of farm equipment, fertilizer, and other practices used on watershed Y–2. The remaining 35 acres of cultivated land and 23 acres of pasture on watershed Y had an improved treatment comparable to that used on watershed Y–2 during the entire conservation period.

Watershed SW–17

Watershed SW–17 is a 3-acre area with only one crop any one year. From 1939 to July 1943, tillage and crop practices were the same as for the same crop in the larger areas—cotton and oats in alternate years, beginning with cotton in 1939.

Common bermudagrass was sprig sodded in January 1948, overseeded with Hubam clover in February, and other clovers added in the fall of 1948. By January 1949, a good cover was established. From 1949 to 1962, grazing was moderately heavy, but since then, it has been only moderate.

THE DATA

Rainfall and runoff data were collected from these study areas from 1939 to 1966. Data for this entire period were obtained from only two watersheds (W–1 and Y–2). The other watersheds had no record of runoff for various periods starting in August 1943.

Amounts of rainfall for the various areas were computed by the Thiessen weighting method from a network of rain gages over the area. Areas of 20 acres or less may have one centrally located gage or two gages near the boundary. Larger areas have two or more gages within or near the boundary. The number of rain gages was changed several times during the period recorded. The rain gages shown on the map in figure 2 have been used since October 1960.

Runoff was computed from continuous records of gage height at each measuring station. Watersheds Y–2, Y–4, and Y–7 have Parshall flumes with V-notch Columbus weirs in the recovery section for measuring low-flow rates. The measuring device on watershed W–1 is similar, except a deep-notch Columbus weir is used for measuring low flows. Ratings for these flumes and weirs were obtained from model studies and checked with a few field current meter measurements. The 309-acre watershed Y has an artificial control, which has been rated by current meter measurements. A deep-notch Columbus weir is included for low-flow rates. Watershed SW–17 is equipped with an H–3 flume with a sloping floor that has a standard rating. An example of each type of runoff-measuring installation is shown in figure 4.

The rainfall and runoff data used in this study are summarized by storm periods in the appendix. All storms that had 0.005 inch of runoff or more on both the base watershed, W–1, and the watershed being studied were included. In the Texas Blackland Prairie, most of the total water yield results from storms causing more than 0.005 inch of runoff. On some watersheds, a high ground-water table will cause a sustained low flow for several days after a storm. Runoff from these sustained low-flow periods is not considered storm runoff but is included in total flow. The percentage of total flow occurring as storm runoff is shown as follows for each watershed discussed.

Watershed	*Storm runoff as percentage of total flow*
W–1	96.7
Y	97.0
Y–2	98.1
Y–4	98.0
Y–7	99.5
SW–17	92.1

DATA ANALYSIS

Areal variations in storm rainfall are large, even on small areas. These rainfall differences cause variations in runoff amounts from small areas that cannot be attributed to treatment. Because of these uncontrolled variations, a simple comparison of runoff on the base watershed with runoff on each of the study watersheds is not meaningful. In this report, equations were developed to predict runoff from each watershed being studied, both as an area with nonconservation treatment and as an area with conservation treatment. These equations predict runoff based on data from nearby base watershed W–1. Amounts of runoff could then be predicted for either the nonconserva-

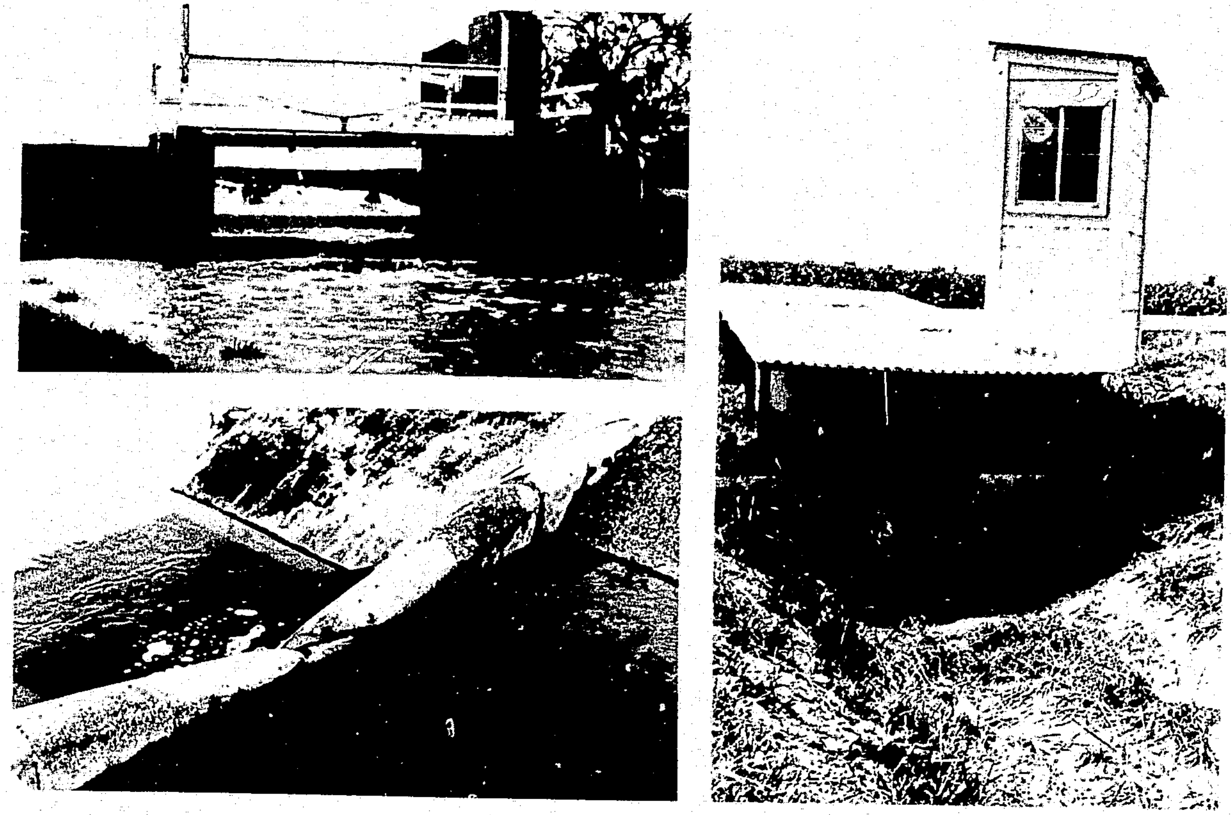

FIGURE 4.—Typical runoff-measuring structures on the watersheds used in this study, 15-foot Parshall flume with a V-notch weir in the recovery section (upper left), Columbus weir with artificial control for overbank flow (lower left), and H–3 flume (right).

tion or conservation condition on a given watershed. When these two equations are applied to the same period of record, variations due to climatic differences between periods are avoided.

Equation Development

Amounts of storm retention (rainfall minus runoff) from two adjacent watersheds are more highly correlated than runoff volumes because of precipitation differences. Equations were derived for each treatment period which related storm retention on W–1 to storm retention on each of the other watersheds.

The equations were developed by a linear regression of the retention data. The basic form of the regression equation is

$$(P-Q)_X = a(P-Q)_{W-1} + b, \qquad (1)$$

where $(P-Q)_x$ is storm retention on the watershed being studied, $(P-Q)_{W-1}$ is storm retention on W–1, and a and b are regression constants. The regression constants for each watershed and each treatment are shown in table 4 along with the number of storms and correlation coefficients. The retention equations for all watersheds are plotted in figure 5. The retention equations were solved for Q_X, to produce an equation of the form

$$Q_X = P_X - a(P-Q)_{W-1} - b. \qquad (2)$$

Runoff was then computed for each treatment using equation (2) for every storm during the period of record (1939–66). The reliability of the runoff computation procedure is shown by the close agreement of computed and measured amounts shown in table 5.

TABLE 4.—*Regression constants for retention equations, experimental watersheds, Texas Blackland Prairie*

Watershed and treatment[1]	Slope (a)	Intercept (b)	n	r
Y:				
NC	1.0744	−0.0646	46	0.9952
C	1.1480	−.0696	151	.9702
Y–2:				
NC	1.0065	−.0496	46	.9924
C	1.1296	−.0346	132	.9819
Y–4:				
NC	1.0435	−.0565	45	.9898
C	1.1328	−.0545	134	.9847
Y–7:				
NC	1.0203	.0807	44	.9870
C	.9324	.0711	140	.9767
SW–17:				
NC	.8219	.1028	52	.9611
C	1.1383	−.1055	135	.9675

[1] NC, nonconservation treatment; C, conservation treatment.

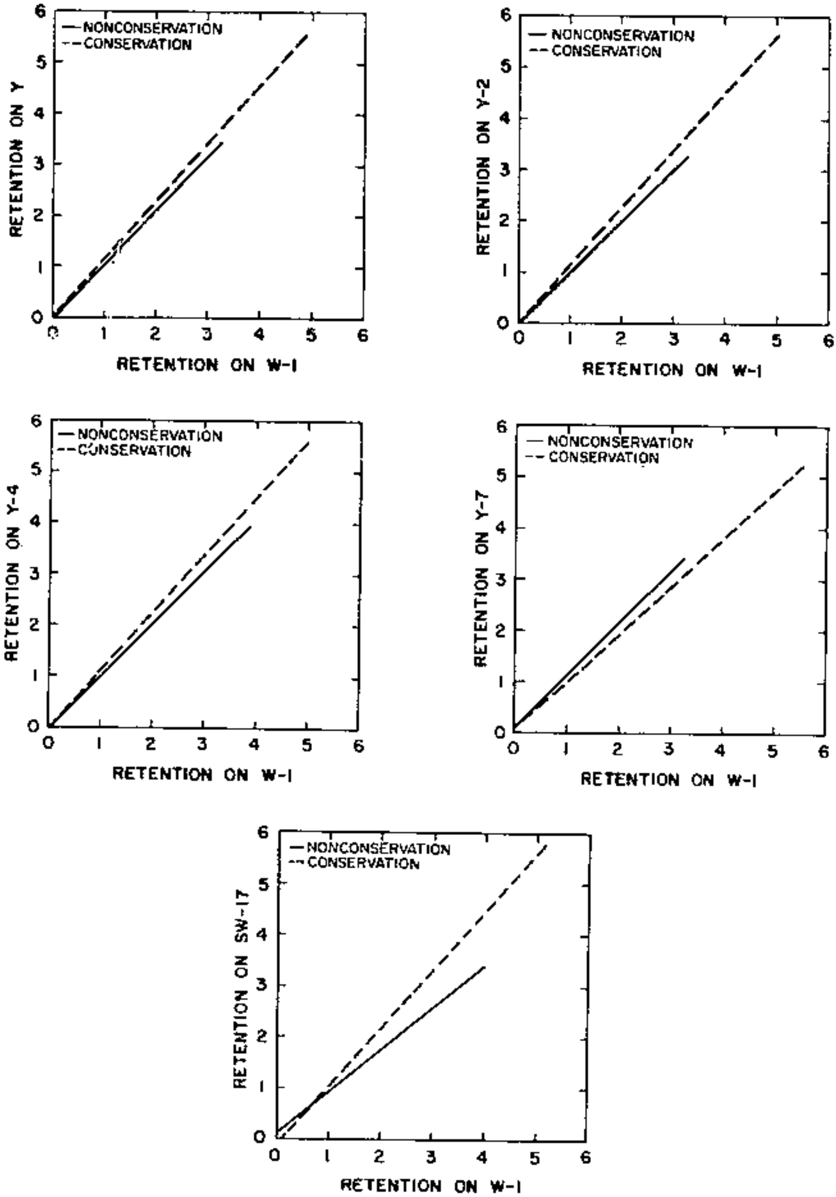

FIGURE 5.—Retention relations for all experimental watersheds.

TABLE 5.—*Measured and computed runoff for each treatment period, experimental watersheds, Texas Blackland Prairie* [1]

Watershed	Runoff			
	Nonconservation		Conservation	
	Measured	Computed	Measured	Computed
	Inches	*Inches*	*Inches*	*Inches*
Y	24.92	24.64	70.21	71.31
Y–2	27.23	27.15	68.68	70.89
Y–4	25.30	25.40	71.45	73.42
Y–7	22.69	22.94	85.71	87.91
SW–17	40.47	40.87	79.96	75.49

[1] See table 1 for treatment periods for each watershed.

Runoff Computation

Using equation (2) with the appropriate constants shown in table 4, amounts of storm runoff were computed for both treatments on each watershed for the entire period (1939–66). For a specific watershed, the difference between the computed runoff amounts for each treatment is the predicted change in storm runoff due to treatment. The sums of the computed amounts for each treatment for the 28-year period are shown in table 6.

Tests were made to determine if significant differences existed between the slopes and intercepts of the two equations for each watershed. The results of these tests are shown in table 6. If either the slopes or intercepts of the regression lines are significantly different at the 5-percent level, a significant effect of treatment on runoff volumes exists.

Runoff was computed for periods of nonconservation and conservation treatments and the transition period during which conservation

TABLE 6.—*Computed runoff for conservation and nonconservation treatments, experimental watersheds, Texas Blackland Prairie, 1939–66*

Watershed	Equation significance tests [1]		Computed 28-year runoff		Percentage change due to treatment
	Slope	Intercept	NC	C	
			Inches	*Inches*	*Percent*
Y	Yes	No	158.23	138.20	−12.7
Y–2	Yes	No	177.23	135.45	−23.6
Y–4	Yes	No	166.53	139.44	−16.3
Y–7	Yes	No	140.22	168.98	20.5
SW–17	Yes	Yes	198.89	151.14	−24.0

[1] *Yes* indicates significant difference at 5 percent level; *no*, no significant difference at 5 percent level.

practices were being established. Runoff computed by both the nonconservation and the conservation equations and measured runoff, when available, can be compared during each period. These comparisons are shown in the form of mass curves for each of the watersheds studied in figures 6 through 10.

DISCUSSION

Terraces in the gently sloping Texas Blackland Prairie were designed primarily to reduce losses from erosion. Studies showed that they were successful as an erosion-control measure.[4] Peak rates of runoff from small agricultural watersheds are also reduced by terraces. Baird and Potter showed that the percentage reduction in peak rates was inversely proportional to both size of watershed and magnitude of storm (see reference listed in footnote 3).

The effects of terraces on amounts of runoff are more difficult to ascertain. Data from individual storms are inconsistent. When runoff-producing storms occurred and the soils were moderately dry, terraces had sometimes reduced amounts of runoff. However, the effect was reversed when large amounts of rainfall occurred and the soils were

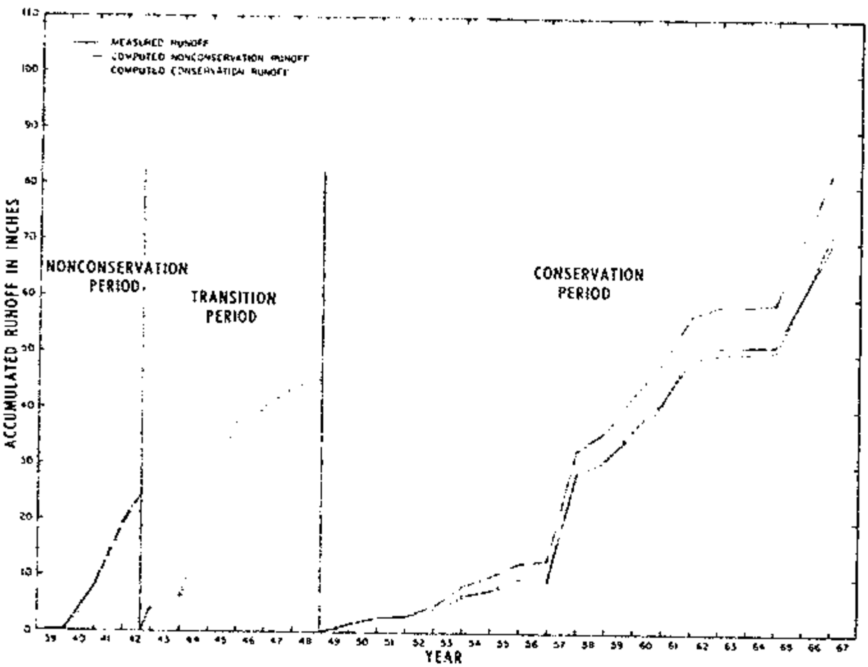

FIGURE 6.—Measured and computed storm runoff for watershed Y.

[4] BAIRD, R. W. SEDIMENT YIELDS FROM BLACKLAND WATERSHEDS. Amer. Soc. Agr. Engin. 7(4): 454–456. 1964.

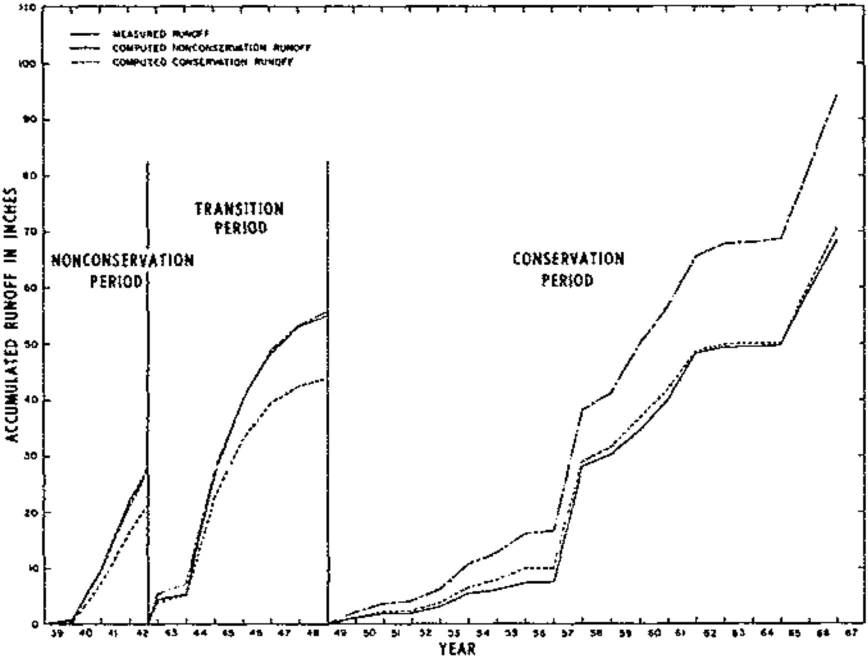

Figure 7.—Measured and computed storm runoff for watershed Y–2.

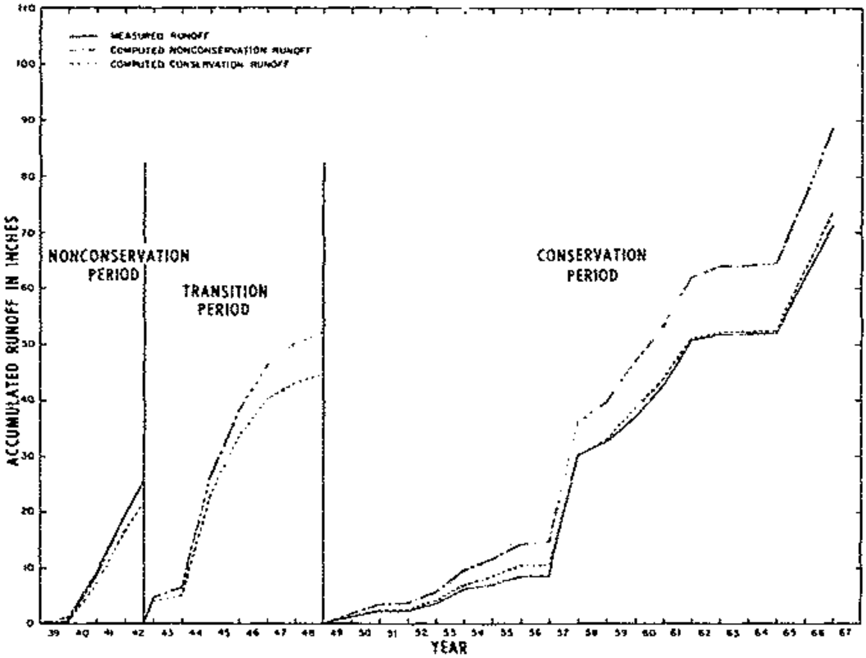

Figure 8.—Measured and computed storm runoff for watershed Y–4.

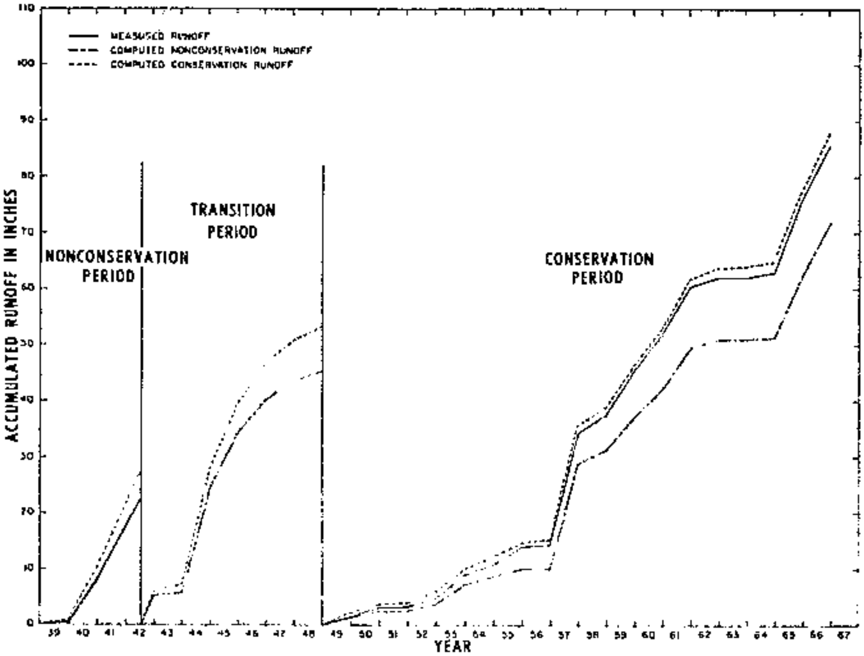

FIGURE 9.—Measured and computed storm runoff for watershed Y–7.

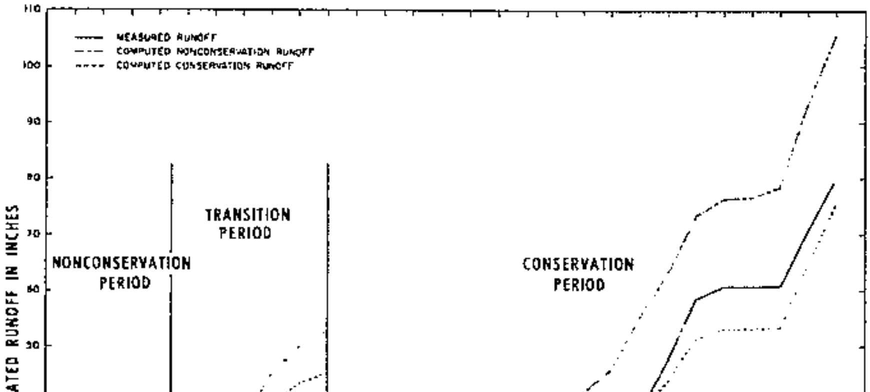

FIGURE 10.—Measured and computed storm runoff for watershed SW–17.

wet.[5] These inconsistencies may be explained by anticipated effects of terraces on amounts of runoff as follows:

1. Terraces reduce the velocity and increase the travel distance of the runoff water, thus allowing more time for the water to enter the soil.

2. Terrace channels are frequently wetter than the interterrace areas. Under these conditions, the volumes of runoff are sometimes greater than that from areas without terraces.

3. Terrace construction increases the average field slope, with the steepest area being near the terrace channel. This may result in increased runoff from high-intensity storms.

Land-use practices may also affect volumes and timing of runoff. Rapidly growing crops can deplete soil moisture quickly. A watershed with several crops in different stages of growth will not contribute runoff equally from all areas during runoff-producing storms unless soils are extremely wet. Plowing crop residues into the soil may increase the water-absorbing capacity of the soil. The increase in crop growth by the use of fertilizers and better tillage practices should deplete soil moisture more rapidly and permit greater water retention from rains after short dry periods. In general, land-use practices alter the rate of moisture intake of the soil. The effect on runoff depends on the type of land-use practice.

Both terraces and land use affect amounts of runoff. When combined, their effects become more complex and difficult to separate.

In this study, watershed Y-2 showed the greatest reduction in runoff due to conservation treatment of any of the mixed land-use watersheds. Figure 7 shows that from 1939 to August 1942 the computed nonconservation runoff for watershed Y-2 agrees closely with the measured runoff. The computed conservation runoff was considerably less than the measured runoff. During the transition period, the measured runoff again is very near the computed nonconservation runoff, except during the fall of 1942 when terraces were being constructed and in 1943 when very little runoff occurred. The terrace system was established on this watershed soon after the beginning of the transition period. Deep plowing was started on oat fields in 1946 but did not cover all field areas of the rotation until the summer of 1948. Evidently, a terrace system, in itself, had little effect on amounts of runoff. By 1948, the planned 3-year rotation was ending the second cycle and the agronomic plan was nearing complete effectiveness. During the conservation period, the computed nonconservation runoff is considerably greater than the measured runoff, whereas the computed conservation runoff is nearly equal to the measured runoff as expected.

On watersheds Y and Y-4 the results are similar to those on Y-2 except that the effect of treatment is not as great as on Y-2. The less intensive agronomic treatment on Y and the greater slopes and shallower soils on Y-4 account for this difference. Measured runoff closely approximated computed amounts during both the nonconservation and conservation periods on these watersheds (figs. 6 and 8).

Runoff measurements on watershed Y-7 were discontinued in July

[5] BAIRD, R. W., HARTMAN, M. A., POPE, J. B., and KNISEL, W. G., Jr. SURFACE RUNOFF AS AFFECTED BY SOIL CONSERVATION PRACTICES. Fourth Annual Conf. on Water for Texas Proc. 1958: 49–53. Sept. 1958.

1943 and not resumed until May 1947; therefore, little data were available during this transition period. The runoff computed on Y-7 for the conservation treatment exceeded the computed nonconservation runoff (fig. 9). Since the terraces on this watershed were not accompanied by the deeper plowing and crop rotation, it can be concluded that this type of treatment results in larger amounts of runoff than the nonconservation treatment.

Treatment on watershed SW-17, which was 100 percent bermudagrass, had the greatest effect on storm runoff. However, large differences were observed between measured and computed runoff (fig. 10). These differences were due to a relatively large amount of seepage flow during and after sustained wet periods. Only 92.1 percent of the total flow on this watershed occurred as storm runoff. More seepage flow occurred on SW-17 than on any other of the watersheds studied. From 1958 to 1961, the total measured runoff was 31.97 inches; however, the measured storm runoff was 27.92 inches compared with computed runoff of 22.07 inches. High seepage flow and, consequently, underestimation of runoff, occurred most often during the winter months on this grassed area. When the grass is dormant, little moisture is dissipated because surface evaporation is suppressed by the dense cover. On the adjacent cultivated areas, the soil is bare and is tilled, resulting in greater evaporation.

CONCLUSIONS

The results of this study indicate that the response of amounts of storm runoff to conservation treatment depends on the combination of land-use practices and terrace construction. Data from the transition period on watershed Y-2 indicate that terraces in themselves probably cause little change in amounts of runoff over time (fig. 7). Terraces accompanied by a change in land use may either increase or decrease runoff, depending on the type of land-use change.

When improved land-use practices were combined with terraces on watershed Y-2, there was an apparent reduction in amounts of storm runoff. These land-use practices were (1) an increase in permanent grasses, (2) deeper tillage, (3) a 3-year crop rotation, and (4) use of legumes in oats. Computations showed that storm runoff from this type of system for the 28-year study period would have been about 24 percent less than from a nonconservation farming system.

Terraces without improved land-use practices have not shown a reduction in runoff amounts. During the transition period on watershed Y-2 (September 1942-48), when terraces were constructed but before deep tillage and improved agronomic practices began, the runoff volumes compared closely with that expected from the area with a nonconservation treatment (fig. 7).

Terraces accompanied by shallow tillage and intensive use of crop residues by livestock may cause runoff to be greater than that expected from the area with a nonconservation treatment. This is illustrated by the apparent 20-percent increase in runoff from Y-7, the privately owned watershed (fig. 9).

Conservation practices were not as intense on watershed Y as on Y-2. Watershed Y contained both Y-2, an area with decreased runoff, and

Y–7, an area with increased runoff. Although all planned terraces were completed, only about 35 acres of the part of watershed Y below Y–2 received the intensive agronomic treatment during the full period that was in effect on watershed Y–2. The net effect of this treatment was an apparent 13-percent decrease in runoff.

Watershed SW–17 was changed from a cultivated area with one crop each year to an area with 100 percent common bermudagrass. Only moderate grazing was permitted. This change decreased storm runoff by about 24 percent.

Findings of the study showed that in the Texas Blackland Prairie the intensity of agronomic treatment had a greater effect on amounts of storm runoff than terraces. A combination of terraces and good management, including deep tillage and other improved farming practices, had the greatest effect upon runoff. On watershed Y–2, a mixed land-use watershed of 132 acres, storm runoff computed during a 28-year period was 24 percent less than that expected without such conservation practices. The effects of land-use treatments upon storm runoff in the Texas Blacklands should seldom exceed these values. A good grass cover also resulted in less storm runoff, although this decrease was partly offset by increases in seepage flow. A combination of terraces and poor agronomic treatment increased amounts of runoff.

Seldom will a watershed of several square miles and with many farm operators have the intensive conservation practices described for watershed Y–2. On almost all the larger watersheds, such as on watershed Y, the farms will be operating under many different levels of management. Under these conditions, it is unlikely that terraces and agronomic treatment will appreciably change total amounts of storm runoff.

SUMMARY

The objective of this study was to determine the effect of various conservation practices on amounts of storm runoff. This was done by studying treated and untreated watersheds in the Texas Blackland Prairie and then developing equations to predict runoff resulting from either of the two conditions on a given watershed. The results of these computations showed that amounts of storm runoff can be significantly affected by conservation and land-use practices.

An intensive conservation program, including a complete terrace system, increased the acreage of grazed grassland. In addition, when conservation was combined with recommended crop rotations and tillage practices, such as used on experimental watershed Y–2 in the study, storm runoff was about 24 percent less in a 28-year period than would have occurred without such treatments.

In the Texas Blackland Prairie, terraces without a change in land-use management apparently had little effect on the amounts of storm runoff. On the other hand, when terraces were accompanied with shallow plowing and heavy stocking of livestock, amounts of runoff were greater than from a comparable area with no conservation treatment.

Usually, drainage areas of several square miles will have a number of farm operators, each using different farming practices. Therefore, storm runoff or water yield will not be greatly affected.

APPENDIX

TABLE 7—*Measured storm rainfall (P) and runoff (Q) 1939–66*

[In inches]

Date	*W–1*		*Y* [1]		*Y–2*		*Y–4* [1]		*Y–7* [1]		*SW–17* [1]	
	P	*Q*	*P*	*Q*	*P*	*Q*	*P*	*Q*	*P*	*Q*	*P*	*Q*
1–11–39	2. 091	0. 045	2. 099	0. 014	2. 075	0. 028	2. 063	0. 015	2. 182	0. 006	2. 200	0
2–17–39	1. 281	. 016	1. 256	. 005	1. 269	. 003	1. 270	. 005	1. 280	0	1. 280	0
2–24–39	1. 166	. 081	1. 109	. 046	1. 075	. 037	1. 065	. 051	1. 145	. 007	1. 180	0
5–16–39	3. 144	. 356	3. 028	. 283	2. 931	. 396	2. 854	. 374	3. 141	. 330	2. 970	. 388
5–20–39	. 930	. 338	. 905	. 258	. 875	. 305	. 864	. 359	. 930	. 326	. 850	. 500
4– 5–40	2. 259	. 289	2. 202	. 170	2. 297	. 315	2. 293	. 280	2. 278	. 266	2. 260	. 001
4–11–40	. 453	. 011	. 315	0	. 291	0	. 291	0	. 383	0	. 480	0
4–28–40	1. 331	. 020	1. 273	. 001	1. 273	0	1. 282	0	1. 280	. 002	1. 350	. 004
5–22–40	1. 395	. 016	1. 420	. 017	1. 396	. 042	1. 376	. 056	1. 524	. 039	1. 390	. 004
6–15–40	1. 478	. 205	1. 377	. 158	1. 368	. 251	1. 348	. 277	1. 480	. 218	1. 310	. 084
6–17–40	. 929	. 101	. 817	. 033	. 825	. 065	. 838	. 085	. 862	. 033	. 950	. 066
6–24–40	2. 135	. 376	2. 107	. 398	2. 116	. 566	2. 139	. 598	2. 166	. 273	2. 140	. 173
7– 3–40	1. 380	. 457	1. 355	. 277	1. 379	. 441	1. 378	. 502	1. 371	. 096	1. 430	. 601
10–30–40	3. 164	. 316	3. 101	. 132	3. 082	. 209	3. 057	. 144	3. 170	. 299	3. 170	1. 021
11–22–40	9. 358	5. 997	8. 918	5. 138	8. 855	5. 522	8. 911	5. 219	9. 197	5. 789	9. 470	6. 757
12–11–40	1. 955	. 493	1. 939	. 497	1. 946	. 630	1. 960	. 517	1. 951	. 436	1. 960	. 464
12–15–40	1. 088	. 736	1. 046	. 714	1. 054	. 803	1. 048	. 667	1. 064	. 374	1. 090	. 783
12–26–40	. 751	. 113	. 708	. 108	. 718	. 100	. 734	. 073	. 733	. 055	. 760	. 011
1–13–41	2. 949	1. 800	2. 814	1. 706	2. 758	1. 595	2. 731	1. 588	2. 917	1. 274	2. 970	1. 806
2– 1–41	2. 668	1. 479	2. 630	1. 448	2. 590	1. 430	2. 580	1. 382	2. 637	1. 165	2. 690	1. 446
2–21–41	2. 590	1. 375	2. 544	1. 448	2. 494	1. 468	2. 475	1. 390	2. 626	1. 423	2. 590	1. 424
3– 5–41	1. 438	. 528	1. 472	. 601	1. 497	. 611	1. 526	. 583	1. 474	. 553	1. 430	. 466
3–17–41	1. 287	. 292	1. 193	. 261	1. 181	. 273	1. 179	. 185	1. 231	. 236	1. 310	. 178
3–23–41	. 869	. 482	. 647	. 287	. 588	. 248	. 558	. 181	. 846	. 355	. 890	. 580
3–26–41	. 433	. 079	. 379	. 051	. 368	. 055	. 363	. 028	. 412	. 056	. 430	0

4- 2-41	.542	.073	.560	.087	.547	.130	.540	.086	.558	.021	.540	.088
4- 6-41	.517	.041	.585	.056	.618	.135	.634	.087	.554	.007	500	.039
4-19-41	.508	.015	.527	.010	.530	.009	.528	.008	.526	.007	.500	0
4-21-41	1.591	.395	1.520	.376	1.513	.398	1.519	.415	1.556	.381	1.610	.213
4-26-41	.533	.114	.575	.107	.575	.108	.579	.073	.564	.075	.520	.054
5- 2-41	1.403	.321	1.357	.343	1.333	.389	1.343	.305	1.342	.295	1.430	.195
5-19-41	3.343	1.199	3.419	1.159	3.370	1.393	3.342	1.127	3.463	1.123	3.290	1.843
5-25-41	.299	.052	.244	.028	.230	.045	.221	.035	.301	.033	.310	.078
6- 2-41	1.401	.393	1.392	.369	1.372	.406	1.368	.348	1.417	.273	1.400	.667
6- 6-41	1.046	.259	.969	.198	.963	.203	.966	.161	1.016	.139	1.060	.265
6- 9-41	2.891	2.090	2.505	1.678	2.510	1.935	2.519	1.866	2.630	1.547	2.780	2.277
6-14-41	.498	.059	.515	.083	.511	.133	.513	.103	.534	.042	.490	.072
6-16-41	.531	.176	.613	.292	.548	.256	.505	.198	.564	.119	.520	.241
7-11-41	2.899	.339	3.220	.429	3.294	.542	3.296	.469	3.075	.186	2.820	.346
11-22-41	1.395	.031	1.366	0	1.313	0	1.267	0	1.442	0	1.380	.063
4- 7-42	2.538	.384	2.487	.204	2.474	.279	2.484	.279	2.565	.106	2.530	.516
4-19-42	1.039	.080	.949	.023	.976	.031	1.006	.043	.855	0	1.110	.225
4-23-42	2.371	1.118	2.424	1.035	2.447	1.192	2.458	1.180	2.395	.832	2.360	1.908
5- 6-42	1.694	.285	1.819	.381	1.811	.392	1.799	.402	1.732	.264	1.680	.608
5-11-42	.741	.082	.717	.072	.717	.070	.721	.057	.740	.034	.740	.132
5-19-42	.600	.025	.658	.013	.673	.008	.676	.002	.591	.001	.600	0
5-23-42	1.402	.427	1.212	.305	1.201	.284	1.171	.234	1.377	.320	1.430	.585
6- 5-42	2.433	.501	2.573	.491	2.446	.343	2.445	.228	2.691	.654	2.330	.793
6-10-42	2.384	1.531	2.498	1.680	2.563	1.832	2.614	1.780	2.431	1.656	2.360	1.651
6-14-42	1.904	1.084	1.952	1.114	1.979	1.192	2.012	1.188	1.901	.964	1.910	1.256
9- 7-42	8.071	2.834	8.073	2.293	8.076	2.340	8.002	2.315	8.123	2.484	8.000	3.897
10-30-42	1.057	.014	.860	.005	.830	0	.810	0	.950	0	1.100	0
11- 4-42	3.150	1.098	3.191	.826	3.124	.793	3.030	.686	3.302	1.056	3.390	1.317
12-21-42	1.135	.058	1.074	.055	1.062	.040	1.055	.016	1.131	.070	1.140	.028
12-26-42	2.524	1.551	2.316	1.323	2.256	1.153	2.195	.946	2.486	1.671	2.530	1.751
1- 6-43	.598	.048	.610	.047	.607	.051	.608	.029	.596	.016	.600	.012
1-12-43	.207	.022	.183	.015	.180	.017	.178	.007	.201	.000	.210	.012
3-24-43	1.960	.183	1.887	.161	1.918	.144	1.963	.106	1.921	.085	1.990	.127
4- 8-43	1.161	.106	1.248	.079	1.273	.084	1.290	.055	1.180	.035	1.150	.189
5-10-43	1.116	.043	1.159	.014	1.168	.009	1.148	.005	1.156	.009	1.100	.065

See footnote at end of table.

TABLE 7—*Measured storm rainfall (P) and runoff (Q) 1939–66*—Continued

Date	*W–1*		*Y* [1]		*Y–2*		*Y–4* [1]		*Y–7* [1]		*SW–17* [1]	
	P	*Q*	*P*	*Q*	*P*	*Q*	*P*	*Q*	*P*	*Q*	*P*	*Q*
5–30–43	1.352	.280	1.501	.195	1.558	.198	1.585	.207	1.409	.205	1.310	.530
6– 5–43	1.558	.523	1.490	.321	1.445	.308	1.436	.307	1.515	.385	1.580	.742
12–23–43	1.324	.020	1.227	--------	1.220	0	1.222	--------	1.290	--------	1.350	--------
1– 1–44	1.860	.547	1.827	--------	1.825	.151	1.826	--------	1.849	--------	1.870	--------
1–12–44	1.402	.349	1.409	--------	1.410	.283	1.410	--------	1.404	--------	1.400	--------
1–24–44	.305	.017	.292	--------	.294	.010	.298	--------	.297	--------	.310	--------
1–27–44	.358	.065	.341	--------	.336	.023	.332	--------	.356	--------	.360	--------
1–29–44	.648	.225	.644	--------	.645	.161	.646	--------	.646	--------	.650	--------
2– 8–44	2.986	2.067	2.839	--------	2.800	1.762	2.765	--------	2.966	--------	3.000	--------
2–13–44	.752	.216	.756	--------	.755	.227	.754	--------	.754	--------	.750	--------
2–16–44	.108	.026	.101	--------	.100	.059	.100	--------	.106	--------	.110	--------
2–19–44	.330	.078	.329	--------	.326	.133	.322	--------	.334	--------	.330	--------
2–22–44	.135	.063	.175	--------	.183	.111	.191	--------	.143	--------	.130	--------
2–25–44	1.514	1.103	1.518	--------	1.505	1.061	1.486	--------	1.530	--------	1.500	--------
2–28–44	.301	.179	.326	--------	.322	.222	.314	--------	.316	--------	.290	--------
3– 9–44	.975	.165	.968	--------	.969	.244	.972	--------	.971	--------	.980	--------
3–18–44	.207	.011	.185	--------	.181	.021	.178	--------	.201	--------	.210	--------
3–21–44	2.133	1.268	2.283	--------	2.306	1.677	2.320	--------	2.480	--------	2.110	--------
4–29–44	13.738	10.778	13.111	--------	13.078	10.225	13.119	--------	13.493	--------	13.910	--------
5– 4–44	.662	.281	.633	--------	.630	.264	.630	--------	.653	--------	.670	--------
5–22–44	1.074	.123	1.169	--------	1.183	.183	1.190	--------	1.103	--------	1.060	--------
5–24–44	2.459	1.047	2.181	--------	2.137	.951	2.112	--------	2.385	--------	2.510	--------
5–27–44	.761	.529	.737	--------	.731	.588	.726	--------	.756	--------	.760	--------
6– 5–44	1.357	.100	1.470	--------	1.491	.205	1.506	--------	1.389	--------	1.350	--------
11–24–44	3.410	.637	3.089	--------	3.046	.658	3.026	--------	3.315	--------	3.470	--------
12– 4–44	2.086	.406	2.033	--------	2.030	.668	2.032	--------	2.066	--------	2.100	--------
12–26–44	1.695	.291	1.558	--------	1.541	.361	1.536	--------	1.651	--------	1.720	--------
12–30–44	.897	.435	.887	--------	.886	.626	.884	--------	.896	--------	.900	--------
1– 5–45	.168	.025	.161	--------	.160	.065	.160	--------	.166	--------	.170	--------

1–17–45	2.002	.802	2.059	---------	2.075	1.041	2.092	---------	2.009	---------	2.000	---------
2–12–45	1.227	.178	1.169	---------	1.165	.214	1.166	---------	1.206	---------	1.240	---------
2–18–45	1.167	.424	1.247	---------	1.258	.562	1.264	---------	1.189	---------	1.150	---------
2–26–45	.410	.042	.328	---------	.320	.085	.320	---------	.383	---------	.430	---------
3– 2–45	3.316	2.445	3.171	---------	3.146	2.819	3.128	---------	3.286	---------	3.350	---------
3–11–45	.408	.040	.455	---------	.477	.107	.504	---------	.401	---------	.410	---------
3–14–45	.471	.085	.509	---------	.511	.173	.508	---------	.486	---------	.460	---------
3–19–45	.428	.036	.424	---------	.414	.010	.410	---------	.437	---------	.420	---------
3–30–45	3.431	2.054	3.727	---------	3.769	2.234	3.790	---------	3.518	---------	3.380	---------
4–20–45	4.037	1.996	4.062	---------	4.058	2.095	4.048	---------	4.056	---------	4.030	---------
5–10–45	1.658	.216	1.877	---------	1.921	.240	1.954	---------	1.707	---------	1.630	---------
5–15–45	.871	.159	.877	---------	.851	.119	.812	---------	.906	---------	.850	---------
6–12–45	1.800	.182	1.874	---------	1.877	.038	1.870	---------	1.832	---------	1.780	---------
7–10–45	1.113	.079	1.134	---------	1.135	0	1.134	---------	1.123	---------	1.110	---------
9–29–45	1.473	.084	1.379	---------	1.384	.002	1.406	---------	1.430	---------	1.420	---------
10– 8–45	2.578	.514	2.331	---------	2.321	.377	2.310	---------	2.481	---------	2.640	---------
12– 1–45	4.940	2.183	4.749	---------	4.752	2.612	4.782	---------	4.844	---------	4.990	---------
1–10–46	.590	.118	.580	---------	.576	.086	.572	.103	.590	---------	.590	---------
1–14–46	.750	.181	.724	---------	.724	.193	.728	.232	.739	---------	.760	---------
2– 9–46	.882	.194	.882	---------	.888	.150	.896	.161	.871	---------	.880	---------
2–12–46	.202	.025	.206	---------	.206	.031	.204	.029	.204	---------	.200	---------
2–17–46	1.607	.788	1.603	---------	1.607	.894	1.616	.814	1.597	---------	1.610	---------
3–13–46	1.599	.587	1.754	---------	1.773	.603	1.780	.557	1.647	---------	1.570	---------
3–25–46	1.847	.598	1.962	---------	1.950	.608	1.916	.537	.875	---------	1.810	---------
4–23–46	.542	.019	.553	---------	.555	.007	.556	.007	.544	---------	.540	---------
4–29–46	1.145	.121	1.161	---------	1.161	.075	1.158	.087	1.153	---------	1.140	---------
5– 6–46	.962	.197	.948	.176	.928	.152	.900	.144	.980	---------	.950	---------
5–10–46	1.083	.351	1.125	.332	1.137	.354	1.148	.332	1.089	---------	1.080	---------
5–12–46	3.845	2.956	3.511	3.033	3.442	2.803	3.384	2.336	3.778	---------	3.890	---------
5–15–46	.960	.497	.969	.643	.970	.596	.970	.502	.964	---------	.960	---------
5–24–46	.501	.019	.562	.032	.573	.030	.558	.029	.516	---------	.490	---------
5–31–46	1.468	.197	1.369	.313	1.331	.217	1.293	.223	1.471	---------	1.480	---------
6– 9–46	1.114	.078	1.299	.123	1.343	.173	1.383	.214	1.147	---------	1.100	---------
11– 3–46	2.283	.432	2.181	.172	2.174	.241	2.178	.219	2.246	---------	2.310	---------
11– 5–46	.727	.093	.649	.073	.637	.074	.630	.098	.706	---------	.740	---------
11–25–46	.823	.015	.761	.008	.727	.001	.710	0	.801	---------	.840	---------

See footnote at end of table.

TABLE 7—*Measured storm rainfall (P) and runoff (Q) 1939–66*—Continued

Date	*W–1*		*Y* [1]		*Y–2*		*Y–4* [1]		*Y–7* [1]		*SW–17* [1]	
	P	*Q*	*P*	*Q*	*P*	*Q*	*P*	*Q*	*P*	*Q*	*P*	*Q*
12–10–46	2.019	.470	2.059	.445	2.075	.444	2.079	.387	2.052	---------	2.010	---------
1–2–47	.646	.041	.637	.052	.642	.044	.651	.029	.632	---------	.650	---------
1–8–47	.549	.063	.554	.113	.554	.086	.557	.064	.546	---------	.550	---------
1–16–47	2.489	1.462	2.455	1.764	2.475	1.757	2.195	1.474	2.470	---------	2.500	---------
3–7–47	1.437	.246	1.350	.325	1.355	.271	1.358	.233	1.416	---------	1.450	---------
3–12–47	1.000	.270	1.011	.426	993	.377	.985	.349	.996	---------	1.000	---------
3–18–47	1.741	.861	1.703	1.083	1.706	1.116	1.713	.899	1.724	---------	1.750	---------
4–19–47	.702	.087	.643	.029	.641	.022	.629	.014	.700	---------	.700	---------
4–25–47	1.307	.135	1.328	.156	1.341	.135	1.344	.120	1.322	---------	1.300	---------
5–9–47	.699	.012	.708	.011	.701	.002	.687	0	.655	---------	.690	---------
5–16–47	2.039	.480	1.972	.419	1.976	.381	1.991	.332	2.016	.494	2.060	---------
5–20–47	1.012	.483	1.139	.590	1.111	.575	1.092	.468	1.166	.650	.990	---------
4–12–48	2.075	.395	2.056	.108	2.076	.097	2.085	.101	2.037	.299	2.090	.753
4–25–48	3.105	1.174	2.946	1.013	2.889	1.082	2.845	.810	3.067	1.181	3.120	2.002
5–5–48	.742	.082	.838	.127	.868	.145	.877	.139	.706	.220	.750	.214
5–11–48	2.213	.532	2.111	.486	2.123	.496	2.109	.457	2.160	.622	2.230	.582
5–27–48	1.226	.049	1.351	.090	1.283	.028	1.303	.009	1.442	.310	1.160	.002
3–21–49	2.034	.261	1.946	.094	1.903	.052	1.852	.044	2.105	.168	2.000	.353
4–27–49	1.351	.381	1.159	.226	1.174	.206	1.175	.255	1.369	.214	1.360	.335
6–14–49	1.227	.041	1.347	.002	1.384	0	1.413	0	1.288	0	1.200	0
6–24–49	2.018	.238	1.925	.077	1.895	.029	1.881	.076	1.962	.256	2.050	.051
7–4–49	2.864	1.072	2.884	.911	3.002	.783	3.035	.879	2.852	.901	2.870	.672
10–24–49	1.561	.013	1.516	0	1.553	0	1.579	0	1.578	0	1.580	0
1–12–50	.299	.028	.289	.003	.285	.003	.285	0	.300	0	.300	0
2–12–50	1.984	1.102	1.919	1.452	1.958	.863	1.989	.927	1.947	1.331	2.000	1.291
4–16–50	1.670	.218	1.672	.122	1.672	.055	1.682	.100	1.645	.260	1.680	.067
5–13–50	.782	.014	.815	.007	.812	0	.801	0	.848	0	.760	0
6–5–50	1.301	.036	1.355	.013	1.373	0	1.374	0	1.300	0	1.300	0
4–25–51	1.330	.059	1.301	0	1.302	0	1.303	0	1.348	0	1.330	.002

5–10–51	.757	.019	.739	0	.733	0	.723	0	.759	0	.750	.002
5–15–51	1.221	.068	1.113	0	1.102	0	1.097	0	1.162	0	1.250	0
6–16–51	1.638	.187	1.607	.020	1.641	.004	1.661	.001	1.631	.152	1.640	.062
3–10–52	1.098	.008	1.118	.010	1.125	.010	1.126	.024	1.142	0	1.080	0
4–12–52	1.031	.035	1.009	.050	.999	.044	.998	.070	1.064	.011	1.020	.105
4–20–52	.825	.013	.806	.001	.799	0	.793	.001	.804	0	.830	.007
4–22–52	1.048	.126	1.086	.090	1.120	.065	1.145	.130	1.083	.071	1.080	.238
5–23–52	2.321	.541	2.355	.388	2.402	.328	2.473	.377	2.355	.485	2.320	.460
11–25–52	1.504	.041	1.449	.000	1.434	0	1.427	0	1.543	0	1.490	.016
12–19–52	1.132	.230	1.291	.094	1.309	.093	1.239	.107	1.196	.207	1.090	.234
12–30–52	2.221	.798	2.116	.595	2.124	.589	2.126	.568	2.144	.684	2.250	.986
2–10–53	1.445	.084	1.162	.004	1.105	.000	1.056	.001	1.357	.027	1.480	.068
3– 9–53	3.016	1.065	3.104	.842	3.093	.836	3.069	.889	3.029	1.167	3.020	1.091
4–23–53	2.114	.294	2.118	.059	2.084	.026	2.066	.050	2.153	.225	2.100	.007
5–11–53	4.263	1.386	4.047	.844	4.029	.845	4.031	.871	4.115	1.651	4.080	.462
5–14–53	1.855	1.106	1.870	.925	1.842	.700	1.833	.910	1.977	1.287	1.810	.638
9– 3–53	1.697	.016	1.557	0	1.531	0	1.522	0	1.658	0	1.720	0
10–25–53	2.360	.203	2.395	0	2.427	.003	2.469	0	2.302	0	2.390	0
12– 2–53	.946	.116	.954	.019	.974	0	.988	0	.957	.036	.940	.042
12–19–53	1.061	.057	1.083	.020	1.073	.003	1.076	.011	1.052	.016	1.070	.033
1–14–54	.496	.029	.458	.009	.452	0	.450	0	466	0	.510	0
4–30–54	1.835	.220	1.909	.033	1.978	0	1.986	.008	1.838	.224	1.820	.010
5– 2–54	.301	.015	.271	0	.258	0	.256	0	.284	0	.310	0
5–10–54	3.558	1.311	3.435	.596	3.413	.519	3.417	.712	3.579	1.469	3.570	.546
6– 2–54	.949	.012	1.189	.007	1.251	0	1.289	0	1.017	.055	.920	0
2– 4–55	1.772	.105	1.746	0	1.753	0	1.736	.003	1.753	.053	1.780	.046
2–19–55	1.652	.134	1.569	.018	1.611	0	1.628	0	1.574	.081	1.680	.043
3–20–55	3.260	1.174	3.450	1.018	3.407	.865	3.371	.846	3.354	1.401	3.230	.993
3–31–55	.382	.016	.412	0	.413	0	.406	0	.405	.029	.370	.004
4– 9–55	2.310	.397	2.302	.219	2.327	.117	2.341	.197	2.344	.575	2.300	.219
5– 6–55	1.205	.063	1.468	.078	1.492	.084	1.494	.089	1.244	.220	1.200	.002
5–16–55	1.340	.059	1.294	.031	1.264	.004	1.257	.019	1.331	.140	1.340	0
5–19–55	1.547	.216	1.211	.151	1.546	.126	1.209	.153	1.205	.362	1.170	0
6– 5–55	1.243	.102	1.660	.108	1.686	.102	1.678	.125	1.451	.251	1.160	.002
6– 8–55	.955	.078	.859	.034	.873	.015	.876	.035	.950	.099	.950	.001
5– 1–56	2.940	.028	3.070	0	3.154	0	3.222	0	2.949	.062	2.940	0

See footnote at end of table.

TABLE 7—*Measured storm rainfall (P) and runoff (Q) 1939–66*—Continued

Date	*W–1*		*Y* [1]		*Y–2*		*Y–4* [1]		*Y–7* [1]		*SW–17* [1]	
	P	*Q*	*P*	*Q*	*P*	*Q*	*P*	*Q*	*P*	*Q*	*P*	*Q*
11– 4–56	3.323	.375	3.163	.069	3.130	.109	3.109	.157	3.238	.241	3.370	.025
2–23–57	.944	.018	1.004	.018	.993	.017	1.002	.024	1.017	.007	.920	0
3–11–57	.990	.011	.931	.001	.920	0	.909	0	.965	0	1.000	.002
3–20–57	1.911	.295	1.875	.199	1.844	.144	1.821	.157	1.919	.453	1.910	.080
3–27–57	.894	.097	.973	.033	1.017	.021	1.058	.039	.933	.101	.880	.001
3–31–57	1.341	.313	1.271	.255	1.298	.240	1.316	.318	1.315	.262	1.350	.239
4–19–57	5.260	2.954	5.538	3.713	5.702	3.245	5.867	3.366	5.461	2.958	5.170	3.114
4–22–57	6.138	5.218	5.954	4.728	5.999	4.991	6.040	5.198	6.216	4.913	6.110	5.151
4–26–57	2.883	1.772	2.846	1.730	2.851	1.744	2.872	1.710	2.922	1.711	2.860	1.043
5– 1–57	.352	.078	.265	.058	.233	.022	.223	.038	.326	.103	.370	0
5– 3–57	.932	.587	1.446	.983	1.570	1.218	1.640	1.352	1.175	.640	.840	.498
5– 9–57	.914	.213	.974	.249	.978	.262	.969	.261	.969	.253	.890	.025
5–11–57	3.893	3.295	3.718	2.827	3.681	3.092	3.659	3.213	.832	3.135	3.920	3.173
5–13–57	1.661	1.398	1.638	1.318	1.632	1.389	1.620	1.446	1.669	1.445	1.660	1.377
6– 1–57	1.150	.016	.976	.007	.912	.005	.871	.007	1.084	0	1.190	.016
6– 3–57	1.798	.740	2.530	1.082	2.552	1.294	2.484	1.346	2.174	.892	1.620	.216
6–19–57	.816	.032	.962	.006	.922	.001	.857	.002	.884	.015	.770	.016
10–13–57	7.216	1.780	7.036	1.240	7.139	1.659	7.230	1.712	6.942	1.941	7.330	.855
10–22–57	.542	.046	.532	.057	.531	.051	.533	.079	.550	.030	.540	.001
11– 5–57	.829	.039	.788	.072	.784	.076	.808	.107	.840	.017	.850	.004
11– 7–57	.520	.096	.416	.097	.403	.089	.398	.127	.453	.121	.530	.042
11–13–57	.523	.114	.547	.173	.549	.188	.554	.200	.530	.198	.520	.075
11–18–57	.628	.111	.606	.148	.599	.168	.591	.174	.649	.167	.620	.093
11–22–57	1.119	.424	1.045	.506	1.059	.547	1.065	.589	1.044	.634	1.150	.463
1–19–58	.939	.062	.951	.079	.954	.067	.971	.074	.940	.022	.940	.041
2–21–58	2.404	1.019	2.269	1.007	2.298	1.029	2.325	1.033	2.266	1.183	2.460	1.305
2–26–58	.093	.015	.109	.017	.115	.014	.116	.018	.100	.006	.090	.008
3–12–58	.575	.028	.572	.044	.573	.043	.573	.036	.589	.007	.570	.057
4–13–58	.888	.025	.903	.015	.914	.007	.916	.010	.880	.013	.890	.006

5- 2-58	1.628	.618	1.655	.517	1.642	.544	1.606	.657	1.640	.883	1.620	.455
8-24-58	2.399	.364	2.801	.046	2.802	.008	2.826	.034	2.639	.337	2.300	.063
9-19-58	3.348	.568	3.298	.174	3.355	.167	3.434	.225	3.206	.476	3.410	.250
10-21-58	1.870	.258	2.098	.110	2.158	.130	2.208	.188	1.985	.188	1.820	.084
2-14-59	1.582	.620	1.508	.410	1.474	.409	1.440	.452	1.590	.583	1.580	.980
4-11-59	1.285	.481	1.255	.251	1.274	.212	1.304	.246	1.280	.635	1.290	.220
4-16-59	1.046	.211	1.034	.138	1.123	.090	1.131	.104	1.108	.180	1.020	.124
5- 2-59	.703	.025	.765	.006	.712	0	.692	0	.738	.002	.690	.028
5- 9-59	1.421	.119	1.473	.053	1.474	.028	1.504	.029	1.382	.181	1.440	.221
5-22-59	1.796	.226	1.764	.126	1.706	.064	1.755	.032	1.839	.333	1.820	.156
6- 4-59	1.940	.309	2.067	.184	2.083	.126	2.098	.106	2.035	.413	1.900	.191
6-23-59	3.534	1.766	3.695	.909	3.637	1.116	3.652	1.000	3.550	1.564	3.530	1.556
7-27-59	1.654	.203	1.482	.053	1.494	.006	1.518	.008	1.526	.313	1.710	.203
8-31-59	1.857	.022	1.607	.000	1.652	0	1.685	0	1.812	.010	1.880	.009
10- 4-59	3.787	1.422	3.860	.699	3.837	.956	3.829	1.065	3.780	1.357	3.790	1.395
10-13-59	2.079	.488	1.784	.258	1.680	.168	1.627	.144	2.004	.595	2.120	.633
11- 3-59	1.641	.604	1.719	.506	1.752	.578	1.783	.533	1.640	.732	1.640	.789
12-10-59	.756	.029	.702	.026	.675	.014	.657	.009	.751	.004	.760	0
12-15-59	1.457	.420	1.465	.356	1.466	.266	1.482	.340	1.479	.524	1.450	.620
12-27-59	.163	.013	.164	.011	.164	.005	.167	.007	.170	.004	.160	.008
12-31-59	1.257	.475	1.119	.441	1.233	.469	1.287	.510	1.261	.550	1.300	.814
1- 5-60	.702	.324	.700	.315	.708	.336	.719	.405	.710	.369	.700	.434
1-13-60	.780	.406	.772	.368	.782	.417	.789	.450	.780	.480	.780	.561
1-16-60	.585	.253	.502	.208	.490	.212	.476	.230	.552	.249	.600	.379
2- 3-60	.835	.175	.848	.181	.841	.182	.847	.183	.878	.135	.820	.335
2-20-60	.369	.014	.351	.013	.344	.010	.345	.013	.370	.003	.370	.028
2-23-60	.535	.084	.544	.084	.543	.066	.549	.084	.578	.024	.520	.228
3- 1-60	.589	.181	.594	.183	.617	.164	.627	.183	.542	.190	.610	.335
3-14-60	.156	.010	.163	.007	.167	.004	.165	.008	.150	.001	.150	.080
3-25-60	.796	.051	.474	.081	.824	.069	.789	.068	.840	.016	.640	.138
4-29-60	1.067	.033	.983	.025	.947	.007	.918	.002	1.061	.064	1.050	.012
6-24-60	3.814	.388	3.704	.150	3.770	.157	3.835	.226	3.639	.557	3.760	.325
10-18-60	2.487	.323	2.330	.041	2.296	0	2.282	0	2.441	.362	2.580	.119
10-28-60	1.267	.434	1.218	.003	1.236	0	1.278	0	1.222	.011	1.300	.042
11-20-60	1.937	.101	1.961	.059	1.957	.035	1.962	.030	1.977	.160	1.990	.422
12- 6-60	6.322	3.642	6.073	3.231	6.075	3.351	6.115	3.202	6.332	3.874	6.170	4.220

See footnote at end of table.

TABLE 7—*Measured storm rainfall (P) and runoff (Q) 1939–66*—Continued

Date	*W*–1		*Y* [1]		*Y*–2		*Y*–4 [1]		*Y*–7 [1]		*SW*–17 [1]	
	P	*Q*	*P*	*Q*	*P*	*Q*	*P*	*Q*	*P*	*Q*	*P*	*Q*
12–30–60	. 666	. 037	. 660	. 070	. 669	. 059	. 670	. 065	. 641	. 009	. 680	. 098
1– 6–61	4. 641	2. 995	4. 620	3. 864	4. 658	3. 480	4. 723	2. 994	4. 559	3. 109	4. 560	3. 372
2– 5–61	3. 108	1. 737	2. 890	2. 152	3. 057	1. 947	2. 923	1. 842	2. 941	1. 670	2. 920	2. 260
2–15–61	1. 474	. 556	1. 418	. 720	1. 400	. 647	1. 390	. 543	1. 451	. 499	1. 480	. 834
3–16–61	1. 098	. 044	1. 152	. 053	1. 155	. 049	1. 145	. 054	1. 109	. 024	1. 100	. 075
3–30–61	. 492	. 013	. 356	. 004	. 318	. 001	. 289	. 002	. 443	. 000	. 410	. 005
5–22–61	1. 816	. 121	1. 602	. 001	1. 629	0	1. 649	0	1. 703	. 089	. 190	0
6–15–61	5. 283	2. 032	5. 141	1. 333	5. 186	1. 247	5. 242	1. 470	5. 263	1. 882	5. 350	1. 972
6–25–61	1. 381	. 329	1. 470	. 320	1. 506	. 316	1. 524	. 341	1. 446	. 232	1. 380	. 351
7– 9–61	. 985	. 007	1. 112	. 010	1. 150	. 010	1. 156	. 006	1. 191	0	. 980	. 003
7–12–61	. 590	. 021	. 370	. 001	. 322	. 001	. 299	. 001	. 570	. 006	. 650	. 007
7–16–61	1. 207	. 177	1. 277	. 141	1. 294	. 142	1. 285	. 119	1. 277	. 134	1. 200	. 309
9–12–61	3. 851	. 460	4. 590	. 163	3. 961	. 140	4. 063	. 179	3. 699	. 571	3. 930	. 244
12–16–61	1. 262	. 159	1. 144	. 093	1. 079	. 080	1. 049	. 065	1. 242	. 078	1. 190	. 517
1–26–62	. 459	. 015	. 462	. 016	. 471	. 009	. 481	. 007	. 470	0	. 470	. 044
2–23–62	. 846	. 021	. 786	. 025	. 790	. 019	. 784	. 018	. 802	. 001	. 840	. 012
3–10–62	. 728	. 012	. 751	. 025	. 771	. 016	. 782	. 015	. 740	. 001	. 710	. 010
4–27–62	2. 083	. 432	2. 101	. 285	2. 050	. 194	1. 995	. 241	2. 110	. 378	1. 980	. 120
5–28–62	2. 233	. 095	2. 289	. 020	2. 335	. 025	2. 386	. 005	2. 288	0	2. 300	. 005
6– 1–62	1. 136	. 139	1. 072	. 021	1. 055	. 017	1. 039	. 008	1. 091	. 016	1. 180	. 029
6– 9–62	2. 065	1. 199	1. 853	. 704	1. 796	. 730	1. 726	. 723	2. 109	. 871	2. 070	1. 670
6–13–62	. 671	. 072	. 595	. 022	. 640	. 015	. 678	. 022	. 554	. 006	. 800	. 187
11–26–62	2. 368	. 169	2. 347	. 025	2. 333	0	2. 358	0	2. 305	. 117	2. 280	. 018
4– 5–63	1. 150	. 006	1. 110	. 001	1. 110	0	1. 110	0	1. 220	0	1. 160	. 005
3–18–64	1. 255	. 008	1. 235	. 001	1. 235	0	1. 232	0	1. 260	0	1. 250	0
4–25–64	2. 542	. 538	2. 462	. 185	2. 477	. 294	2. 486	. 226	2. 444	. 490	2. 520	. 029
8–22–64	1. 925	. 029	1. 618	0	1. 520	0	1. 504	0	1. 840	. 301	1. 974	0
9–16–64	1. 797	. 007	1. 796	0	1. 806	0	1. 827	0	1. 793	. 002	1. 719	0
9–24–64	1. 528	. 012	1. 507	0	1. 568	0	1. 525	0	1. 522	. 012	1. 526	. 004

11-4-64	1.929	.013	1.921	0	1.939	0	1.953	0	1.853	0	1.949	0
11-19-64	1.315	.046	1.387	.020	1.357	.003	1.329	.002	1.455	.165	1.232	0
1-21-65	2.863	.645	2.886	.411	2.919	.344	2.942	.422	2.781	.972	2.949	.369
2-9-65	1.327	.285	1.304	.194	1.308	.152	1.299	.184	1.294	.492	1.276	.075
2-11-65	.330	.020	.285	.010	.260	0	.248	.001	.330	.030	.310	.001
2-16-65	1.067	.160	.994	.101	.985	.050	.982	.078	1.034	.223	1.060	.042
2-23-65	.892	.152	.873	.130	.881	.085	.875	.124	.890	.233	.889	.066
3-29-65	6.256	4.523	6.163	4.061	6.115	3.875	6.115	4.025	6.529	4.702	6.103	4.301
4-5-65	.524	.111	.370	.037	.336	.009	.323	.015	.406	.079	.530	.006
5-9-65	3.455	.969	3.706	.767	3.789	.958	3.823	.914	3.536	.830	3.540	.080
5-14-65	.675	.131	.707	.095	.694	.101	.684	.093	.738	.080	.600	.011
5-16-65	3.981	2.950	3.755	1.975	3.700	2.160	3.690	2.218	3.838	2.655	3.861	2.363
5-28-65	2.154	1.163	2.137	.789	2.139	1.013	2.147	.999	2.198	1.032	2.149	.981
6-5-65	1.539	.406	1.538	.371	1.478	.355	1.443	.328	1.588	.558	1.510	.450
11-3-65	3.606	.487	3.509	.183	3.513	.181	3.537	.182	2.536	.501	3.598	.187
11-8-65	1.176	.512	1.493	.328	1.484	.401	1.490	.331	1.550	.618	1.679	.449
12-18-65	1.067	.062	1.120	.062	1.140	.069	1.161	.056	1.099	.023	1.054	0
1-24-66	.325	.012	.350	.022	.350	.023	.350	.015	.329	.002	.330	0
1-28-66	.466	.065	.461	.038	.466	.041	.460	.050	.413	.017	.460	.008
2-9-66	2.244	1.087	2.560	1.343	2.615	1.429	2.624	1.498	2.366	1.232	2.406	1.425
2-12-66	.153	.013	.150	.086	.142	.032	.139	.032	.160	.005	.150	.026
2-15-66	.408	.058	.407	.161	.410	.070	.413	.067	.401	.031	.400	.082
2-26-66	.723	.278	.717	.340	.710	.325	.708	.336	.712	.317	.720	.368
3-12-66	.604	.034	.600	.055	.600	.051	.599	.057	.580	.006	.640	.066
3-28-66	1.076	.052	1.039	.054	1.122	.066	1.169	.078	.975	.006	1.030	.054
4-17-66	1.072	.021	1.043	.008	1.038	.002	1.021	.004	1.060	0	1.050	0
4-22-66	1.214	.052	1.276	.041	1.289	.050	1.306	.044	1.212	.003	1.221	0
4-24-66	5.405	4.258	5.062	3.045	4.928	3.356	4.846	3.305	5.271	3.937	5.369	3.140
4-28-66	.940	.398	1.142	.361	1.290	.450	1.155	.441	.891	.293	.950	.387
4-30-66	.889	.464	.809	.425	.820	.438	.841	.506	.833	.386	.870	.474
5-12-66	1.970	1.215	1.696	.455	1.656	.460	1.637	.449	1.846	.602	1.881	.726
5-20-66	.656	.023	.872	.056	.876	.060	.847	.054	.745	0	.710	.023
6-18-66	1.998	.029	2.300	.018	2.377	.016	2.377	.016	1.988	0	1.940	.022
8-12-66	6.477	2.359	6.616	1.314	6.677	1.559	6.608	1.699	6.397	2.183	6.610	1.697
9-16-66	2.211	.563	2.390	.314	2.411	.380	2.421	.367	2.255	.553	2.167	.126
12-15-66	1.149	.005	1.286	.006	1.345	0	1.388	0	1.187	0	1.210	0

[1] No entry in runoff columns indicates that measuring station was not operating.

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END