Effects of Juniper and Pinyon Eradication on Streamflow from Corduroy Creek Basin, Arizona

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Prepared in cooperation with the U.S. Bureau of Indian Affairs and the White River Apache Tribe

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By M. R. COLLINGS *and* R. M. MYRICK

STUDIES OF EVAPOTRANSPIRATION

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EFFECTS OF JUNIPER AND PINYON ERADICATION ON STREAMFLOW FROM CORDUROY CREEK BASIN, ARIZONA

By M. R. Collings and R. M. Myrick

ABSTRACT

An investigation to determine the effect of juniper and pinyon removal and of controlled burning on runoff was made on the adjacent Carrizo Creek and Corduroy Creek basins, Fort Apache Indian Reservation, Ariz. The watersheds encompass areas of 237 and 213 square miles, respectively. The study was begun in 1957 with 5 years of streamflow records already existing. Thirty-eight percent of Corduroy basin was modified; Carrizo basin was left undisturbed. There were 7 years of premodification data (1952–1958) and 5 years of postmodification data (1959–1963). Comparisons were made on the runoff relations from adjacent basins and precipitation-runoff relations over each basin for water-year periods, summer storm periods, and winter storm periods. No statistically significant difference in runoff relations could be detected; however, a significant difference between precipitation-runoff relations was indicated for the winter storm period on both the modified basin and the control basin. A test of precipitation relations of the control versus the treated basin for the before- and after-modification periods indicated no detectable difference in precipitation between basins. A test of precipitation for the period before versus the period after modification over each basin showed a statistically significant change in both basins; therefore, the change in the precipitation-runoff relations for the before- and after-modification periods was concluded to be the effect of a climatic change. The statistically significant change in the precipitation-runoff relations for the control basin was no different than would be expected by chance than the change in the precipitation-runoff relation for the modified basin. If a change does exist because of vegetation modification, the change is masked by the variance of the data.

Prior to this study the theory had been advanced that if undesirable species of vegetation were eradicated from a basin, such as the one studied in this investigation, runoff would be increased and measurable and additional discrete quantities of water would be made available for appropriation. From the results of this study, however, it cannot be demonstrated that the partial clearing of Corduroy Creek basin resulted in either an increase or a decrease in water yield.

INTRODUCTION

Juniper and pinyon plant communities occur between altitudes of 4,000 and 6,500 feet above sea level and occupy extensive areas in the Southwest. These trees cover about 74 million acres if the juniper types that extend northward in the Rocky Mountains into Canada are excluded. The trees have increased in number in the last 30 years, possibly because of increased livestock grazing—seeds germinate more readily after passing through the alimentary tract of animals (Arnold and Schroeder, 1955)—and because of the reduced number of forest fires.

In 1955 Arnold and Schroeder stated that the encroachment of juniper is believed to have reduced grazing capacities, increased erosion, increased livestock-handling costs, and possibly decreased water yields. The next year Barr and others (1956) estimated the probable increase in water yield that would result from the removal of pinyon and juniper if the land were reseeded with grasses.

In 1957 the Carrizo Creek and Corduroy Creek watersheds on the Fort Apache Indian Reservation were selected as investigation sites for a study of the hydrologic effects and the probable water-yield change produced by the Bureau of Indian Affairs vegetation-modification program.

The criteria used to select the basins were that they be adjacent, about the same size, relatively unmodified by man, and representative of the juniper and pinyon woodlands. It was possible to start basin modification early in the investigation because streamflow and precipitation stations having 5 years of record already existed.

This report is based on work done by the U.S. Geological Survey in cooperation with the U.S. Bureau of Indian Affairs and the White River Apache Tribe, Fort Apache Indian Reservation, Ariz. The description of vegetation was aided by suggestions from R. M. Turner, botanist, U. S. Geological Survey.

DESCRIPTION OF AREAS

The Carrizo Creek-Corduroy Creek area is entirely within the Fort Apache Indian Reservation (fig. 1). The northern boundary of these watersheds is the Sit-

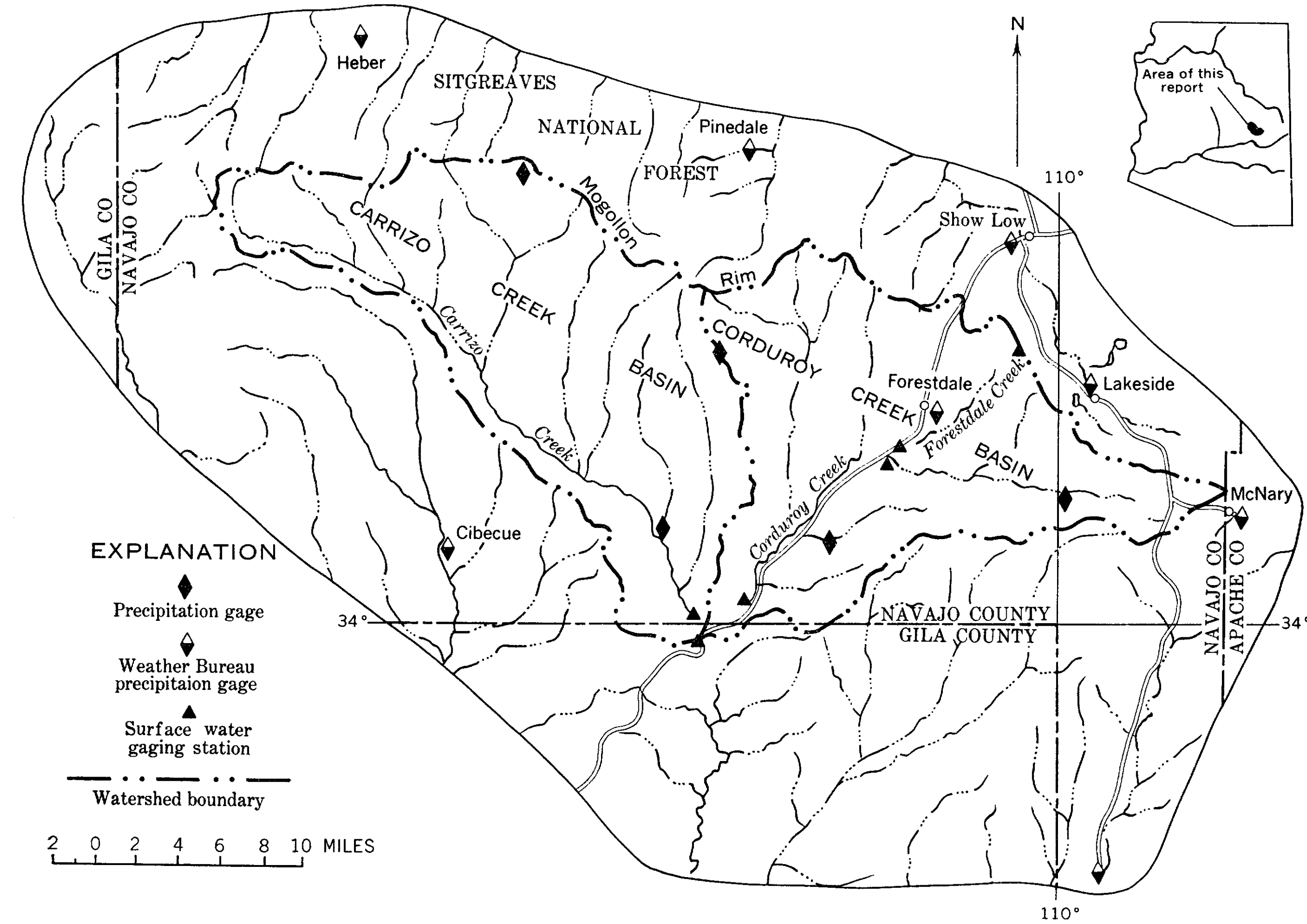


FIGURE 1.—Index map of Carrizo Creek-Corduroy Creek area, showing location of instruments.

greaves National Forest, which borders the Mogollon Rim, and the southern boundary is just north of the mouth of Corduroy Creek on the Navajo-Gila County line. Both drainage areas are in Navajo County and are adjacent—Corduroy Creek lies to the east and Carrizo Creek to the west.

In summer, almost all the precipitation is produced by windborne moisture from the Gulf of Mexico. Winter storms generally originate along the Pacific coast and are carried to Arizona by frontal action. The mean annual precipitation is about 20 inches, although local topographic features may cause significant variations from this average. Summer precipitation occurs during thunderstorms in the late afternoon; it is frequently intense and of short duration and is very localized. Winter precipitation occurs as rain and snow; it is usually of low intensity and long duration and is widespread. Drought conditions are common from late April through early July.

A distinctive plant-community pattern is recognizable in the area. Chaparral grows at 5,200 feet—the lowest altitude in the basins. Above the chaparral, the lower reaches of the watersheds are sufficiently elevated to support the stands of juniper and pinyon pine species which characterize the next vegetation zone. Open low forests dominated by these plants occur where soil or topography compensate for the relative aridity to produce habitats with adequate moisture for the growth of these plants. The juniper-pinyon woodlands occur as high as 6,500 feet on the southern slopes of the Mogollon Rim. Utah juniper (*Juniperus osteosperma*), alligator bark juniper (*J. deppeana*), and pinyon pine (*Pinus edulis*) are the dominant conifers; Arizona white oak (*Quercus arizonica*) and emory oak (*Q. emoryi*) are the most important live oaks in this vegetation zone.

The third and highest (above 6,000 ft) vegetation zone in the watersheds is dominated by ponderosa pine (*Pinus ponderosa*)—a tall long-leafed pine that contrasts sharply with the low short-leafed pinyon pine of the zone below.

CORDUROY CREEK BASIN

Corduroy Creek drains an area of 213 square miles. The main stream is 30 miles long, and the average channel slope is 68 feet per mile. The slope of the major tributaries to the stream is 101 feet per mile. Stream density, the length of channel per unit area, in the basin is 1.25 miles per square mile.

The drainage area is somewhat triangular in shape, the hypotenuse being the southeast side. Altitudes range from 5,350 to 7,300 feet. Basalt crops out in the eastern part of the basin along the main stem, and lava-capped cuestas and sedimentary rocks crop out in the rest of the area. The soil is derived from the Supai Formation, Kaibab Limestone, Cretaceous units, Coconino Sandstone, rim gravels, and Quaternary lava.

CARRIZO CREEK BASIN

Carrizo Creek basin drains an area of 237 square miles. The main stream flows in a southeasterly direction and is 35 miles long. The drainage density is 1.66 miles per square mile. The slope of the major tributaries of the main stem is 155 feet per mile.

The basin is triangular in shape, the hypotenuse being the southwest side. Altitudes range from 5,200 to 7,400 feet. The bedrock geology and soils are similar to those of Corduroy Creek, except that the Quaternary lava is present only near the mouth of Corduroy Creek.

STREAMFLOW

The streamflow pattern in the basins shows the integrated effect of the climatological and physical characteristics of the area. Except for the transbasin diversion from Show Low Lake into the Corduroy basin during the spring and midsummer, the streams rise during the winter, reflect the heavy precipitation of summer storms, and are very low to dry from early summer through fall.

The Carrizo Creek flood plain is ¼–½ mile wide in the lower reach and is covered with riparian vegetation which includes many phreatophytes. Perennial flow from the upper reach is lost as ground-water recharge upstream from the Carrizo Creek gaging station. The Corduroy Creek flood plain is very narrow and has little or no riparian vegetation. Corduroy Creek is a perennial stream.

MODIFICATION PROGRAM

To modify the pinyon and juniper vegetation on the Corduroy watershed, the following criteria were used in selecting the areas to be treated: The slope of the land was not to exceed 20 percent; undesirable vegetation was removed only where treatment would cause no damage to the commercial timber stand; excessively rocky or inaccessible areas were not included in order to keep the eradication program as economically feasible as possible. These criteria are in agreement with those recommended by Wilm (1956, p. 210–212).

Data on the modification program was compiled from the Corduroy watershed progress report, Bureau of Indian Affairs (1959). Clearing of the watershed was started in 1957 and completed in 1959. Bulldozers and crawler tractors dragging chains were used to clear most of the area, but some hand cutting, girdling, and grubbing was done. Areas having less than 10 percent native sod were reseeded from the air. Prescribed burning, which is controlled burning of dense underbrush and duff in areas of ponderosa pine, a common practice on the Fort Apache Indian Reservation, was restricted to the Corduroy basin. Prescribed burning was discontinued on the study areas after 1959.

Vegetation modification in the Corduroy Creek basin (fig. 2) consists of the steps shown in the unnumbered table.

Corduroy Creek basin modification

	Acres	Percent of basin
Eradication of juniper, pinyon, and manzanita	34, 500	25
Prescribed burning	18, 000	13
Total	52, 500	38
Reseeded to grass	9, 400	7

HYDROLOGIC ANALYSIS

All analytical methods used herein are subject to the basic assumptions that the data suitably describe the variables and that the relations among the variables is described properly. The validity of the interpretations and conclusions derived from any analysis are related directly to the reliability of these assumptions.

Correlations between monthly runoff from adjacent areas and between precipitation and monthly runoff are poor. In the following analysis of runoff and precipitation, it was necessary to use periods greater than one month. Monthly data cannot be considered as independent events because of serial correlations.

In the analysis, two periods based on storm type were defined. The first period, November through June, is dominated by widespread frontal-type storms; during the second period, July through October, localized thunderstorms prevail. The water year, beginning October 1, was also tested in the analysis so that all chronological periods could be examined and compared. The data (1952 through 1963) were divided into two periods: before vegetation modification (1952–58) and after basin modification (1959–63). The area was modified in 1957, 1958, and 1959. The total area of

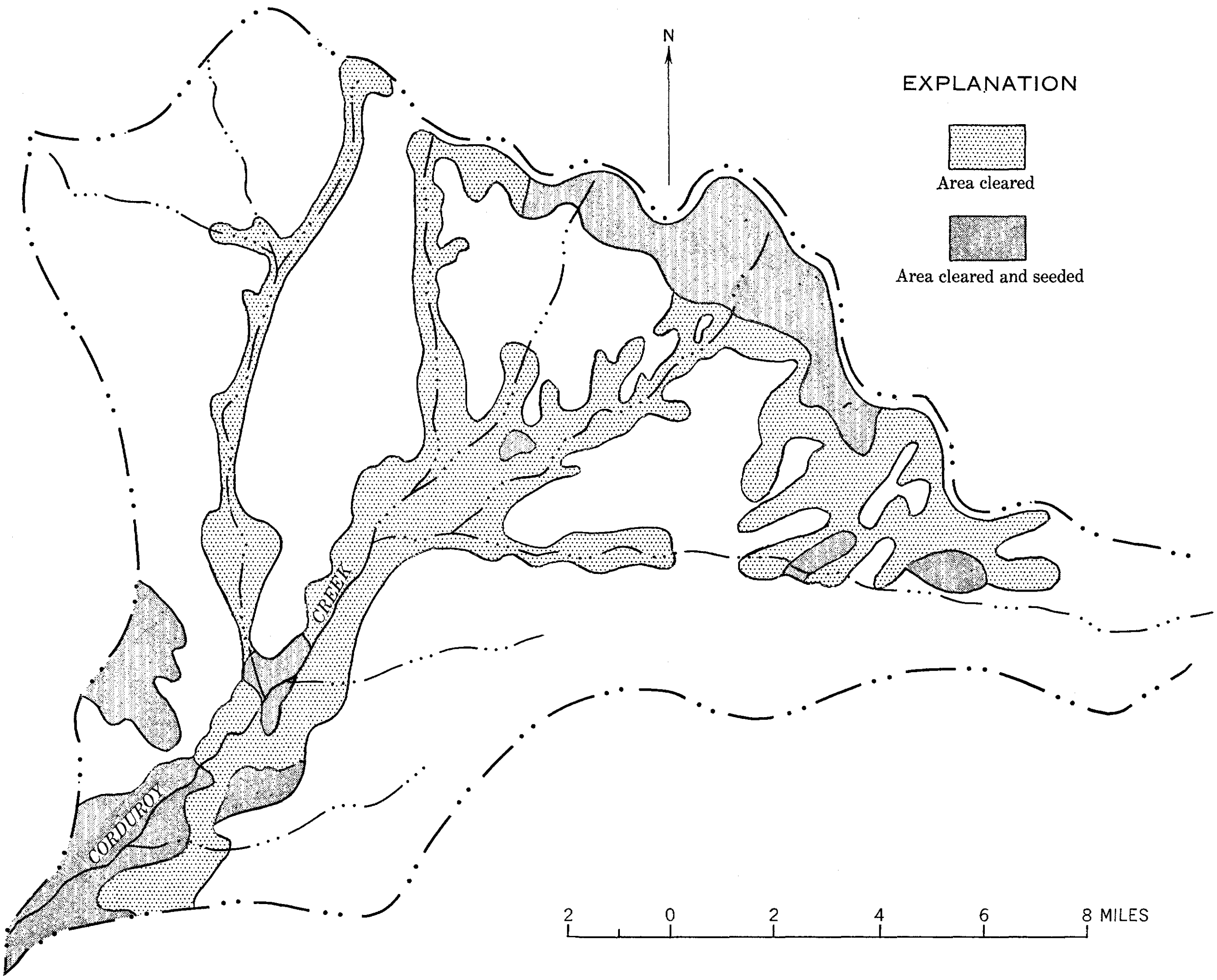
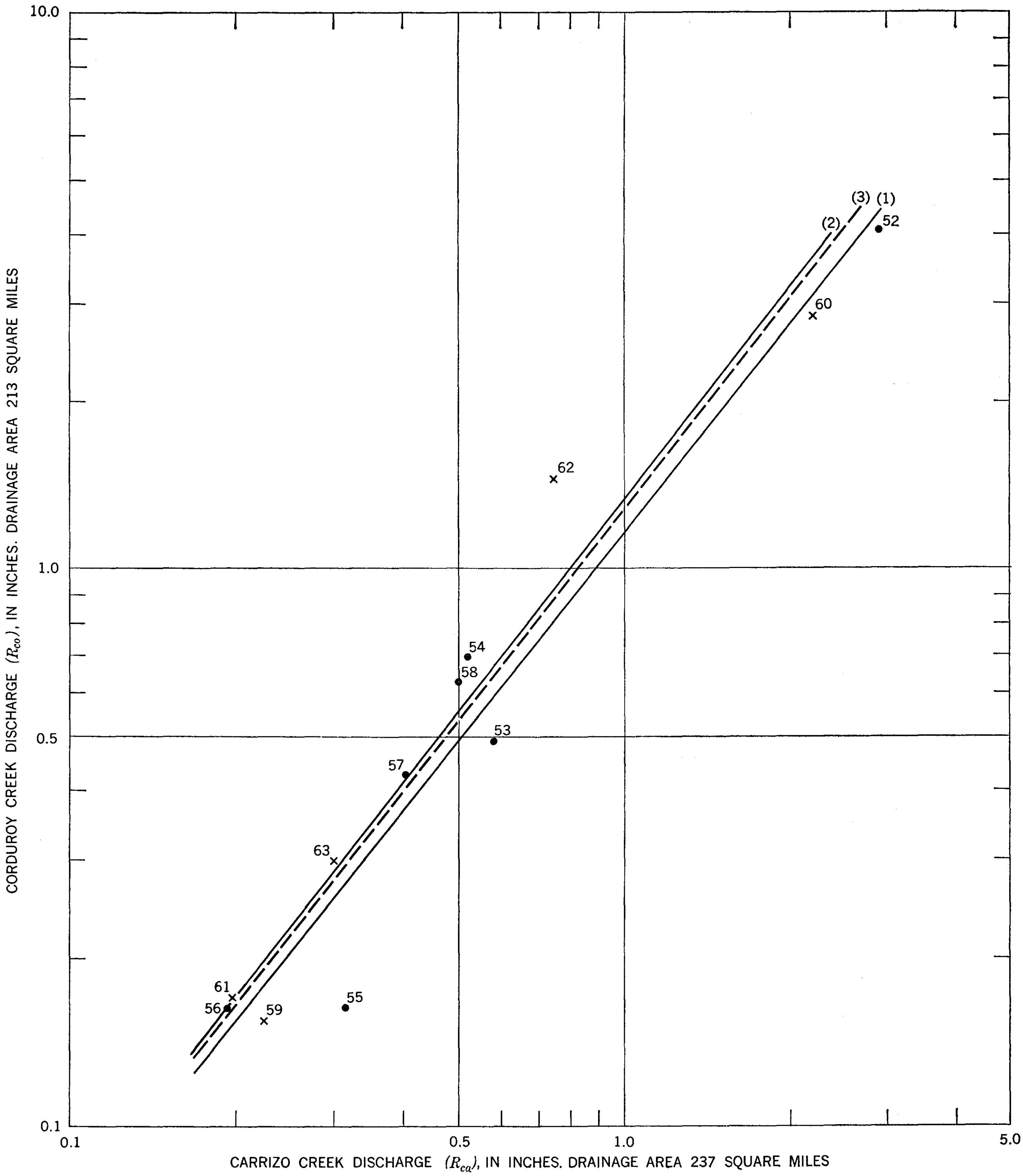


FIGURE 2.—Areas cleared and seeded in the Corduroy Creek basin.

modification on Corduroy basin amounted to 38 percent; 6.2 percent was treated in 1957, 11.8 percent in 1958, and 20 percent in 1959. The assumption is made that prescribed burning would have the same effect as juniper and pinyon removal. In 1957 and 1958, 47.4 percent of the total 38 percent had been modified or less than half the total modification had been accomplished. During 1959 the remainder, or 52.6 percent, of the modification was accomplished. On this basis the 1957 through 1958 period was considered premodification and the 1959 period postmodification.

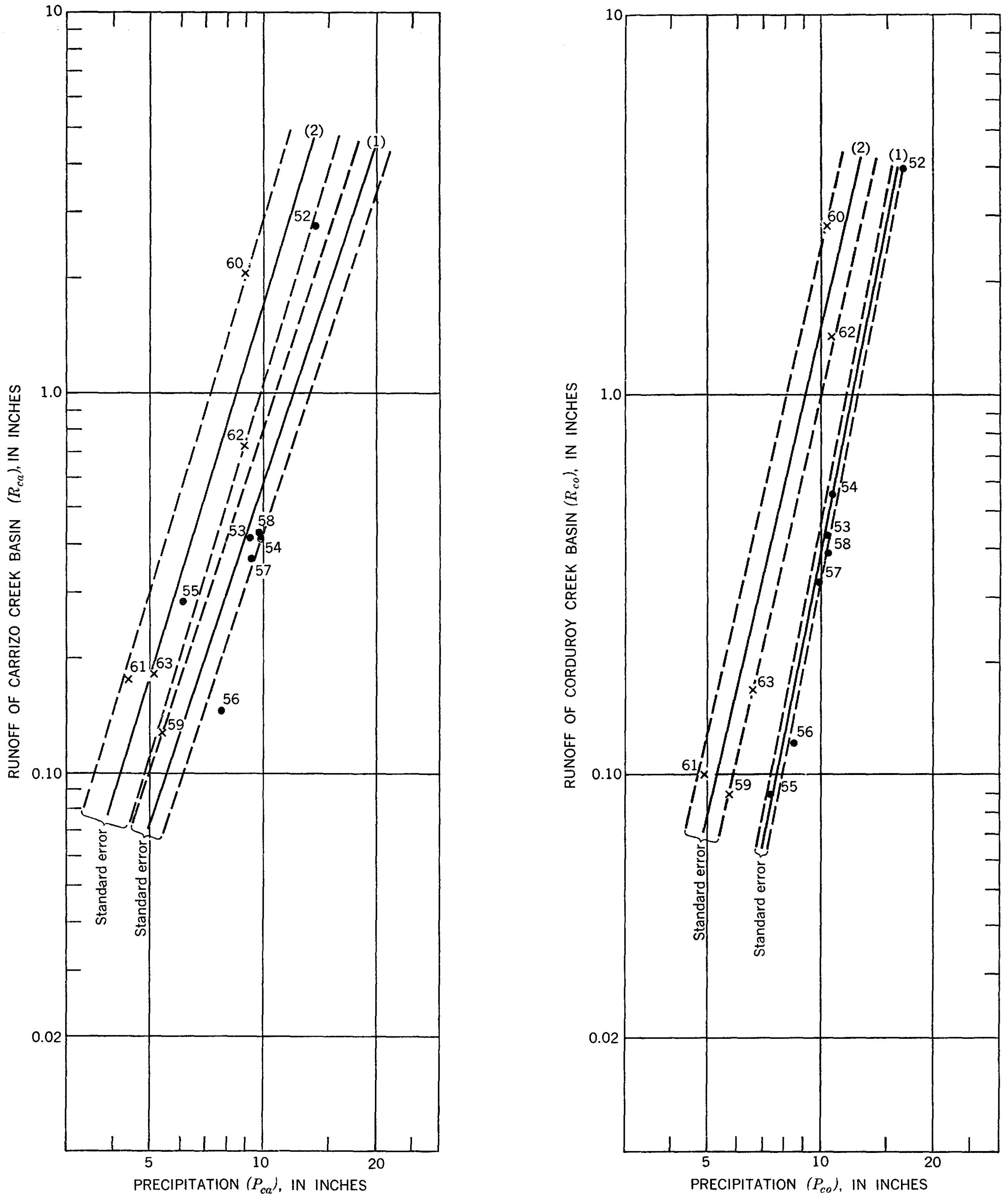
The first step in the analysis was to relate the runoff from Carrizo basin to the runoff from Corduroy basin by means of a regression analysis. The November through June, the July through October, and the water-year periods for before and after Corduroy basin modification did not vary more than would be expected by chance. Therefore, the runoff relations are not significantly different (tested at the 1 percent level of significance). All the plotted runoff observations (fig. 3) may be best fitted by one line. If one curve were fitted to all observations, 1952 through 1963, its error band (90 percent confidence limits) would overlap both curves (1) and (2) in figure 3. Thus curves (1) and (2) are not farther apart than might occur by chance, considering the variance of the data, even though the 1959 through 1963 line (curve 2) visually indicates an increase in the runoff relations. An increase in water yield on Corduroy basin after removal of vegetation is not indicated by the runoff data.

In their report, Barr and others (1956, p. 218) estimated that the probable increase in water yield due to juniper and pinyon removal would be 0.46 inch (weighted average per unit of area treated), the initial yield being 1.2 inches. Because 38 percent of Corduroy Creek basin was modified, the increase in water yield



Curve (1), 1952 through 1958. ●, before treatment of Corduroy Creek basin. $R_{co}=1.15\,R_{ca}^{1.24}$. Standard error=0.136 log units, +37 percent, −27 percent.
Curve (2), 1959 through 1963. X, after treatment of Corduroy Creek basin. $R_{co}=1.32\,R_{ca}^{1.27}$. Standard error=0.147 log units, +41 percent, −29 percent.
Curve (3), Barr and others (1956). Dashed line indicates suggested probable water-yield increase.

FIGURE 3.—Relation between Carrizo Creek and Corduroy Creek runoff before and after treatment.



Carrizo Creek basin, November through June data:

Curve (1), ● 1952 through 1958. Log R_{ca}=−3.23+3.00 log P_{ca}. Standard error=0.232 log units, +37 percent, −27 percent.

Curve (2), X 1959 through 1963. Log R_{ca}=−3.07+3.31 log P. Standard error=0.2561 log units, +64 percent, −39 percent.

Corduroy Creek basin, November through June data:

Curve (1), ● 1952 through 1958. Log R_{co}=−5.47+5.03 log P_{co}. Standard error=0.075 log units, +11 percent, − 10 percent.

Curve (2), X 1959 through 1963. Log R_{co}=−4.12+4.27 log P_{co}. Standard error=0.224 log units, +54 percent, −35 percent.

FIGURE 4.—Relation between precipitation and runoff.

TABLE 1.—*Runoff, in inches, of Corduroy and Carrizo Creeks*

Water year	Annual		November-June	
	Carrizo	Corduroy	Carrizo	Corduroy
1952	2.918	4.043	2.780	3.984
1953	.585	[1] .489	.420	[1] .432
1954	.526	[1] .698	.418	.558
1955	.314	[1] .162	.281	.090
1956	.195	[1] .162	.144	[1] .121
1957	.402	[1] .425	.362	.330
1958	.501	[1] .624	.432	.593
1959	.224	.153	.127	.088
1960	2.233	[1] 2.848	2.185	2.776
1961	.198	.166	.175	.101
1962	.747	[1] 1.447	.724	1.417
1963	.297	.296	.180	.169

[1] Corduroy Creek minus Forestdale Creek diversion.

would be 38 percent of 0.46 inches, or 0.18 inches. In figure 3, curve (3) is the increase in water yield suggested by Barr and others. This projected increase in water yield, if it exists, could not be detected from the records examined in this report. Curve (3) assumes no significant difference in slopes for the three lines.

Next, the precipitation-runoff relations of the control and modified basins were compared. The water-year period, the period July through October, and the period November through June were tested. The water-year and the July through October precipitation-runoff relations show no significant difference in means for either basin—that is, the before- and after-modification data are not significantly different; however, Corduroy Creek basin (the modified basin) and Carrizo Creek basin (the control basin) show precipitation-runoff relations that are significantly different (at the 90 percent confidence level) during November through June (fig. 4). The change in precipitation-runoff relations of Corduroy basin from before to after modification, is not different (statistically not significant) from the change between these relations in the Carrizo basin before and after the modification.

The precipitation relations over the basins was analyzed by comparing the Corduroy Creek basin precipitation for before- and after-treatment periods with the Carrizo basin precipitation for the same periods. No change in precipitation relations between basins could be detected, but the precipitation over each individual basin for before and after periods was tested and found to vary significantly on both the control and the modified basins. The precipitation was substantially less during the period following treatment. If the precipitation is the independent variable (fig. 4), the significant change in the precipitation-runoff relations for both basins could be accounted for by the difference (decrease) in precipitation over the same periods on each basin. In summary, the change indicated by precipitation-runoff relations over the control and the modified basins probably resulted from climatic change. If a change exists because of vegetation modification, it is masked by the variance of the data. (See table 2.)

TABLE 2.—*Analyses of covariance*

[F ratio: * denotes a significant difference at the 10 percent level; ** denotes a significant difference at the 1 percent level. Logarithmic transformations were used in parts 1-5 to obtain linearity and normalization of the data (Cramer, 1946)]

DISCHARGE

CARRIZO CREEK BASIN (R_{ca}) VERSUS CORDUROY CREEK BASIN (R_{co})

Source of variance	Degrees of freedom	Sum of squares			About regression	Test	F ratio (No significant difference at 90 percent level unless otherwise indicated)
		R^2_{ca}	$R_{ca}R_{co}$	R^2_{co}			
Water-year period [See fig. 3]							
Within each group:							
1952–58	6	0.80583	1.00184	1.33728	0.09176	Total means	0.45
1959–63	4	.78274	.99490	1.32950	.06494	Regression	.20
						Slopes	.01
Within groups	10	1.58857	1.99674	2.66678	.15700		
Among means	1	.00796	.00206	.00053	.00001		
Total	11	1.59653	1.99880	2.66731	.16489		
November through June period							
Within each group:							
1952–58	6	0.92231	1.17929	1.74274	0.23492	Total means	2.59
1959–63	4	1.09971	1.42443	1.92793	.08290	Regression	1.15
Within groups	10	2.02202	2.60372	3.67067	.31796		
Among means	1	.01909	.01453	.09733	.08628		
Total	11	2.04111	2.61825	3.76800	.40948		

TABLE 2.—*Analyses of covariance*—Continued

PRECIPITATION-DISCHARGE RELATIONS

CORDUROY CREEK BASIN PRECIPITATION (P_{co}) VERSUS RUNOFF (R_{co})

Source of variance	Degrees of freedom	Sum of squares			About regression	Test	F ratio
		P^2_{co}	$P_{co}R_{co}$	R^2_{co}			
Water-year period							
Within each group:							
1952–58	6	0.06618	0.26291	1.33728	0.29284	Total means	0.09
1959–63	4	.00726	.08996	1.32949	.21478		
Within groups	10	.07344	.35287	2.66677	.97128		
Among means	1	.00028	−.00039	.00054	.00001		
Total	11	.07372	.35248	2.66731	.98199		
November through June period [See fig. 4]							
Within each group:							
1952–58	6	0.06768	0.34065	1.74274	0.02817	Total means	**35.31
1959–63	4	.09681	.41371	1.92793	.15998	R_{co} means	.03
						Regression	**8.65
Within groups	10	.16449	.75436	3.67067	.21114	P_{co} means	*4.06
Among means	1	.06666	.02715	.01105	.00001	Slopes	.98
Total	11	.23115	.78115	3.68172	1.03947		

CARRIZO CREEK BASIN PRECIPITATION (P_{ca}) VERSUS RUNOFF (R_{ca})

[See fig. 4]

Source of variance	Degrees of freedom	Sum of squares			About regression	Test	F ratio
		P^2_{ca}	$P_{ca}R_{ca}$	R^2_{ca}			
Within each group:							
1952–58	6	0.07257	0.21754	0.92230	0.27019	Total means	*7.10
1959–63	4	.08212	.27220	1.09882	.19657	R_{ca} means	.09
						Regression	*3.22
Within groups	10	.15469	.48974	2.02112	.47064	P_{ca} means	*5.06
Among means	1	.07842	.03881	.01920	.00001	Slopes	.07
Total	11	.23311	.52855	2.04032	.84190		

CARRIZO CREEK BASIN PRECIPITATION (P_{ca}) VERSUS CORDUROY CREEK BASIN PRECIPITATION (P_{co})

[Logarithm transformations were not used]

Source of variance	Degrees of freedom	Sum of squares			About regression	Test	F ratio
		P^2_{ca}	$P_{ca}P_{co}$	P^2_{co}			
Within each group:							
1952–58	6	34.48620	39.81910	46.91840	0.91505	Total means	1.68
1959–63	4	18.92948	23.26434	29.61092	1.01904	Regression	.91
Within groups	10	53.39568	63.08344	76.52932	2.00044		
Among means	1	23.22742	23.91881	24.63078	.00001		
Total	11	76.62310	87.00225	101.16010	2.37277		

DISCUSSION

The curve relations of runoff from Carrizo basin versus runoff from Corduroy basin (fig. 3) indicate an increase in runoff after basin treatment; however, the scatter of the data, or the poorness of the relations, is such that it would be correct, 90 times in 100, to draw one line through all the data (1952–63). It is concluded that an increase cannot be detected from the runoff relations. If the variance of the before- and after-treatment runoff data were constant, that is, if everything were to remain static, the visually suggested change in water yield shown over Corduroy basin would be statistically significant after about 38 years of post-modification data.

A statistically significant change in the precipitation-runoff relations is indicated over both basins for the before- and after-modification periods for the winter months. The tests show that there is 90 percent confidence in this change; however, the change over Corduroy basin is not different from that over Carrizo basin. If precipitation were 10 inches and if one standard error were used for the variance of the data, Carrizo basin would have a change in runoff of 1.17 inches which could range from 0.25 to 2.49 inches, and Corduroy basin, a change of 1.08 inches which could range from 0.48 to 1.92 inches. Thus, a change on Corduroy (the treated basin), if it exists, is completely masked by the change on the control basin.

The precipitation was shown to vary significantly over each basin between the before- and after-modification periods. The precipitation data over the basins was weighted by the Thiessen method. A multiple-regression method (Linsley, Kohler, and Paulhus, 1949, p. 436) was also used to weight the precipitation data, and the results of the analysis were not changed except that the scatter of the data was slightly increased.

During the winter period (November–June) transbasin diversions were made into Corduroy basin in the 1953 and 1956 water years. These diversions were subtracted from the data in this report. The total diversion amounted to about 0.047 inches of runoff. No diversions were made in the 1959 through 1963 winter periods. If the diversions were appropriately added to the Corduroy basin runoff, none of the results of the analyses in this paper would be changed.

The question arose as to whether the years of clearing (1957–59) should be included in the analyses. The total analyses were made using data from 1952–56 for premodification and 1960–63 as the postmodification. The conclusions are not different from those already made in the report.

CONCLUSIONS

The removal of pinyon and juniper from approximately 38 percent of the drainage basin of Corduroy Creek produced no significant change in runoff. If clearing had been complete, a significant increase might have resulted; however, as much of the basin was cleared as was considered economically practicable, and this restriction presumably would also prevent complete clearing of other basins.

This data is not to be interpreted to mean that no increase in runoff can result from the eradication of undesirable vegetation. In the two basins studied here, however, the relation between rainfall and runoff is poorly defined, as is common in arid and semiarid regions, and this natural variability masks any small-scale effects of man's endeavors. In other words, an increase in runoff may result from vegetation modification, but its magnitude is small and is so masked by other factors as to be indistinguishable. The most important fact is that in the Corduroy Creek basin neither an increase nor a decrease in flow could be proved from the available data and, therefore, no discrete or measurable quantity of water was made available for appropriation.

RECORDS AVAILABLE

STREAMFLOW

Stream-gaging stations (fig. 1) were established on Carrizo Creek in June 1951; on Corduroy Creek near its mouth in September 1951; on Forestdale Creek diversion from Show Low Creek in May 1953; and on Carrizo Creek above Corduroy Creek in October 1953. Carrizo Creek gaging station was discontinued in June 1961. Data-collecting facilities on Carrizo Creek above Corduroy Creek and on Corduroy Creek near its mouth consist of continuous water-stage recorders and concrete controls; on Carrizo Creek a continuous water-stage recorder and a natural rock control; and on Forestdale Creek diversion from Show Low Creek a continuous water-stage recorder and a V-notch sharp-crested weir. Records of discharge and runoff have been published as part 9 of the annual water-supply papers of the U.S. Geological Survey.

PRECIPITATION

The U.S. Weather Bureau operates six precipitation stations in or near the study area. In 1958, the U.S. Geological Survey project personnel established five recording gages at less accessible interior sites to supplement the Weather Bureau data. All the precipitation stations are shown in figure 1. Data from the five project stations were not used in the analysis, as no record is available for the pretreatment period. The supplemental record shows that a vast network of stations would be required to accurately measure the mean precipitation from convective-type storms.

In the Southwest, convective-type storms usually do not produce rain of a general nature or greatly influence peak discharges from larger watersheds. The storms are, however, of utmost importance in the production of maximum runoff from watersheds of 10 square miles or less or for parts of large watersheds (Dorroh, 1946).

Precipitation measurements in the area were based on records from Cibecue, 5,300 feet above sea level; Heber, 6,400 feet; Pinedale, 6,500 feet; Lakeside, 6,800 feet; McNary, 7,250 feet; and Forestdale, 6,200 feet (tables 3, 4). Data for the stations are published by the U.S. Weather Bureau as part of the annual climatological data summary.

TABLE 3.—*November through June precipitation, in inches*

Year	Heber	Pinedale	Lakeside	McNary	Cibecue	Forestdale
1952	14.34	12.31	19.12	24.03	14.46	15.78
1953	8.13	8.45	10.68	14.95	9.88	10.14
1954	8.47	9.94	11.73	15.20	10.22	10.48
1955	4.61	5.28	7.29	9.59	4.50	7.53
1956	7.23	7.13	8.28	13.38	5.30	8.43
1957	9.75	7.57	11.04	17.12	9.32	9.66
1958	8.22	10.60	11.58	16.63	10.78	10.10
1959	5.60	4.77	6.11	6.77	3.90	5.64
1960	8.64	8.04	12.93	14.72	12.07	9.84
1961	4.88	3.88	6.97	8.36	6.72	4.41
1962	7.33	7.00	12.44	12.61	12.92	10.81
1963	4.39	4.02	8.22	9.95	8.34	6.35

TABLE 4.—*Annual precipitation, in inches*

Year	Heber	Pinedale	Lakeside	McNary	Cibecue	Forestdale
1952	22.37	23.14	30.46	35.45	21.33	26.17
1953	15.75	18.08	15.37	22.30	16.37	14.25
1954	16.12	16.51	22.39	27.47	17.25	19.72
1955	11.91	13.25	17.49	21.07	10.98	14.47
1956	13.05	10.31	18.05	20.58	10.82	13.18
1957	15.01	18.27	20.50	26.92	15.91	20.00
1958	19.01	20.87	24.18	29.98	22.00	21.09
1959	16.03	15.63	15.44	18.05	17.09	16.69
1960	18.09	18.89	22.81	24.18	21.71	20.48
1961	17.17	15.81	19.74	21.14	17.09	17.70
1962	16.42	14.57	22.68	25.83	20.25	20.80
1963	18.88	12.57	20.46	23.00	16.92	19.30

RELIABILITY OF DATA

STREAMFLOW

Daily discharge was computed for the six stream-gaging stations using stage-discharge relations established for each station. Because the stage-discharge relations were stable, the records are considered accurate streamflow measurements, except for brief periods of recorder malfunction. Estimates of flow during these periods of lost record are generally less than 3 percent of the annual streamflow and, therefore, represent a negligible amount of error.

The transbasin diversion from Show Low Creek, which was started in May 1953, is pumped from Lake Show Low in the Little Colorado River basin into headwaters of Forestdale Creek in the Salt River basin (Corduroy Creek basin). The volume of water and periods of diversion depend on the storage in Lake Show Low. Records on Corduroy Creek near its mouth were adjusted for the transbasin diversion by subtracting the measured inflow into Forestdale Creek.

PRECIPITATION

The precipitation data were thoroughly analyzed for consistency as an index of the actual basin precipitation. Each station record was analyzed for any trend or abrupt change in the measured precipitation. The method used to detect these changes was the double-mass-curve technique. The double-mass curves were constructed by plotting the cumulative precipitation for each gage against the average for a group of gages for the same period of record. An abrupt change in the slope of the double-mass relation indicates some inconsistency in the record of one of the gages. The precipitation stations have given consistent records (figs. 5, 6).

The average precipitation in the basins was determined by constructing a Thiessen network, which is weighted in respect to the areal distribution of the measuring stations. The results, as the percentage of precipitation given to each gage, are shown in table 5.

TABLE 5.—*Results of Thiessen method for weighting precipitation records*

Gage	Altitude (feet above sea level)	Weighted percentage
Carrizo Creek Basin		
Forestdale	6,200	7.92
Pinedale	6,500	30.20
Heber	6,400	26.28
Cibecue	5,300	35.60
Corduroy Creek Basin		
Pinedale	6,500	8.6
McNary	7,250	3.7
Lakeside	6,800	12.5
Forestdale	6,200	75.2

SELECTED REFERENCES

Arnold, J. F., and Schroeder, W. L., 1955, Juniper control increases forage production on the Fort Apache Indian Reservation: Rocky Mountain Forest and Range Expt. Station, Paper no. 18, p. 1–35.

Barr, G. W., and others, 1956, Recovering rainfall: Report of Arizona Watershed Program, Univ. Arizona, Tucson, pt. 1, 33 p., pt. 2, 218 p.

Bureau of Indian Affairs, 1959, Corduroy watershed progress report: Whiteriver, Fort Apache Indian Agency, 24 p.

Cramer, Harald, 1946, Mathematical methods of statistics: Princeton, N.J., Princeton Univ. Press, 575 p.

Dixon, W. J. and Massey, F. J., Jr., 1957, Introduction to statistical analysis [2d ed.]: New York, McGraw-Hill Book Co., p. 112–138.

Dorroh, J. H., Jr., 1946, Certain hydrologic and climatic characteristics of the Southwest: Univ. New Mexico Press, 64 p.

Ezekial, Mordecai, 1941, Methods of correlation analysis: New York, John Wiley & Sons, 535 p.

Linsley, R. K., Jr., Kohler, M. A., and Paulhus, J. L. H., 1949, Applied hydrology: New York, McGraw-Hill Book Co., 689 p.

Schneider, W. J., and Ayer, G. R., 1961, Effect of reforestation on streamflow in central New York: U.S. Geol. Survey Water-Supply Paper 1602, 61 p.

Sellers, W. D., ed, 1960, Arizona climate: Univ. Arizona Press, 60 p.

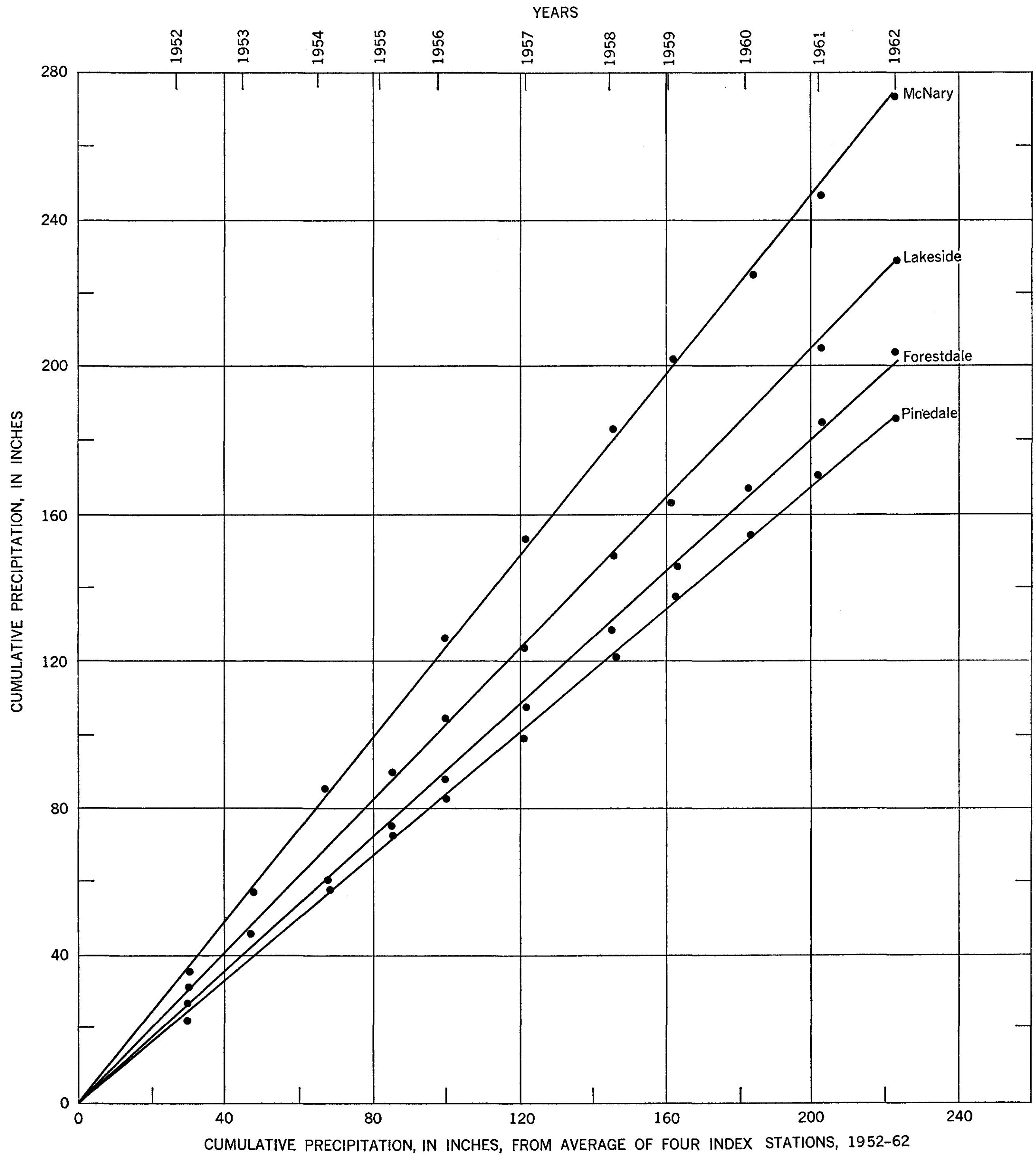


FIGURE 5.—Double-mass curves of precipitation data, Corduroy Creek basin.

Stoyanow, A. A., 1936, Correlation of Arizona Paleozoic formations: Geol. Soc. America Bull., v. 47, no. 4, p. 533–536.

Wilm, H. G., 1949, How long should experimental watersheds be calibrated?: Am. Geophys. Union Trans., v. 30, no. 2, p. 272–278.

——— 1956, Treatment of vegetation on the Salt River watershed to increase water yield, *in* Recovering rainfall: Report of the Arizona watershed program, Univ. Arizona, Tucson, pt. 1, 33 p., pt. 2, 218 p.

Wilson, E. D., Moore, R. T., and O'Haire, R. T., 1960, Geologic map of Navajo and Apache Counties, Arizona: Arizona Bur. Mines, Tucson, Ariz.

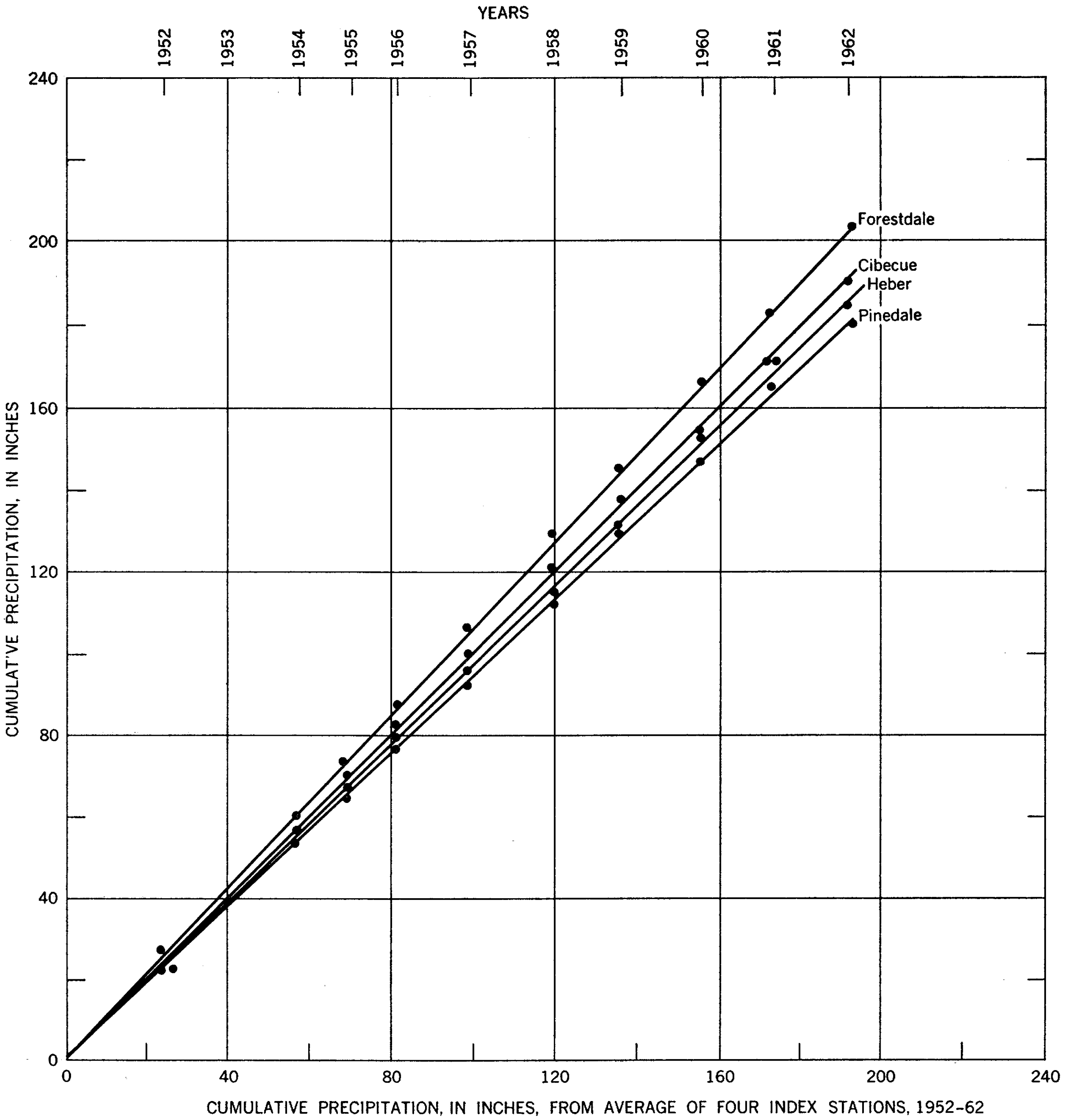


FIGURE 6.—Double-mass curves of precipitation data, Carrizo Creek basin.