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THE RELATIONSHIP OF STREAM FLOW TO PRECIPITATION ON THE SALT RIVER WATERSHED ABOVE ROOSEVELT DAM

By

Charles K. Cooperrider, Senior Range Examiner,

and

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Southwestern Forest and Range Experiment Station
Forest Service

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FOREWORD

This bulletin is published by the Agricultural Experiment Station of the University of Arizona in co-operation with the Southwestern Forest and Range Experiment Station in order that the important information it contains may be made available at once to the people of Arizona to whom such facts are vital in their management of land resources. I have read the manuscript with intense interest and feel that it will prove of great value to water users, farmers, stockmen, and many others in this state where water may be regarded as the "life blood" of the social and economic structure.

PAUL S. BURGESS, *Director*
Arizona Agricultural Experiment Station,
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Errata

Page	
14	Table 2, heading first column should be "Calendar year"; last column, "Average monthly rate."
16	In sentence beginning in last line, change 62 to 61 and 38 to 39.
24	Second paragraph, first line, Figure 1 should read Figure 2.
42	Figure 7. Description should read " . . . ratio of cumulated flow to fall, from same data plotted in Figure 8, . . ."
58	Last sentence, first paragraph, change "second-feet" to "acre-feet" in three places.

The Authors,
Southwestern Forest and Range Experiment Station

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THE RELATIONSHIP OF STREAM FLOW TO PRECIPITATION ON THE SALT RIVER WATERSHED ABOVE ROOSEVELT DAM

By Charles K. Cooperrider, Senior Range Examiner,
and Glenton G. Sykes, Assistant Conservationist,
Southwestern Forest and Range Experiment Station[1]

INTRODUCTION

Climate and water supply have exerted tremendous influence in the settlement and development of the Southwest. High in the mountains the rainfall is favorable for agriculture, but low temperature, stony, shallow soils, and steep slopes usually make the mountain areas unsuited to farming. Below the mountains are vast plainlike valleys with alluvial soils. Here rainfall is low and temperature high and permanent water is available only in places. Prehistoric people, village Indians, and early white settlers dwelt where arable lands and water were found. Nowadays, as well, the amount and dependability of water supply governs the extent of human endeavors and the future of social and economic development.

The dependable water supplies come from the cool, green hills where rainfall is absorbed and given off in streams which carry "life" into the desert valleys below. However, variations in both seasonal and annual precipitation exert so much influence that the natural delivery of water is too uncertain to be relied upon for extensive developments, which, in turn, accounts for the artificial regulation of rivers, as through storage systems. Furthermore, the vital need for every bit of stream flow accounts for the extraordinary size of southwestern storage

[1] Maintained at Tucson, Ariz., by the Forest Service, U. S. Department of Agriculture, in cooperation with the University of Arizona, and covering the States of Arizona, New Mexico, and the western third of Texas.

dams and reservoirs—Coolidge, Roosevelt, Elephant Butte, and Boulder—for during periods of high yield, water must be saved for the lean precipitation years.

With the improvement of water supplies has come a better understanding of the limitations of agricultural and urban growth and of the dangers of over-development. No reservoir can supply more water than it stores, nor can any underground basin be pumped very long in excess of its rate of recharge without decline and ultimate ruin of dependent values. In order to make the most of the available supply, more and more has been done to conserve water and to use it more effectively. Much thought has been given to determining the irrigation requirement of arable lands and to the conservative use of municipal water supplies, and now even the reclamation of used water is receiving attention.

Until faced with the reality, it is often not fully realized that the size to which any desert city, as well as irrigation district, can grow depends on the water supply and not alone on man's creative ability. In southern Arizona the time may come when agriculture, valuable as it is, may be greatly restricted because of the urgent demand for water by climate-seeking urban population. Any intense demand for water eventually results in a search for new supplies and for an answer to the old question of how more water may be obtained from existing sources.

IMPORTANCE OF WATERED AREAS

Attention was first focused on the available water and, following that, to developing the supply, because the demand tends to become more acute with the growth of dependent agriculture industry and population. The natural tendency in a region where there are extensive desert plains that need only water to convert them into fertile gardens is to over-develop, but water supply must always limit highly productive areas to spots, as it were, in comparison with the vast whole. Nevertheless, these garden spots bear a peculiar relationship to the whole. Their importance cannot be judged alone by population, wealth, or products. For roundabout each spot revolves the economic and social life of a much larger, less productive, and sparsely populated area. Thus the irrigated spots may be considered the nerve centers which radiate human-betterment influences, and from which also may spread social paralysis wherever man fails in this modern conquest of the desert.

With the building of large storage dams for irrigation, the generation of hydroelectric power has become an important although secondary industry. On Salt River in Arizona, three supplemental dams have been built below the main storage structure, Roosevelt Dam, not so much for impounding water as for adapting the release of it to the fluctuating demands of irrigation and to sustained power production.

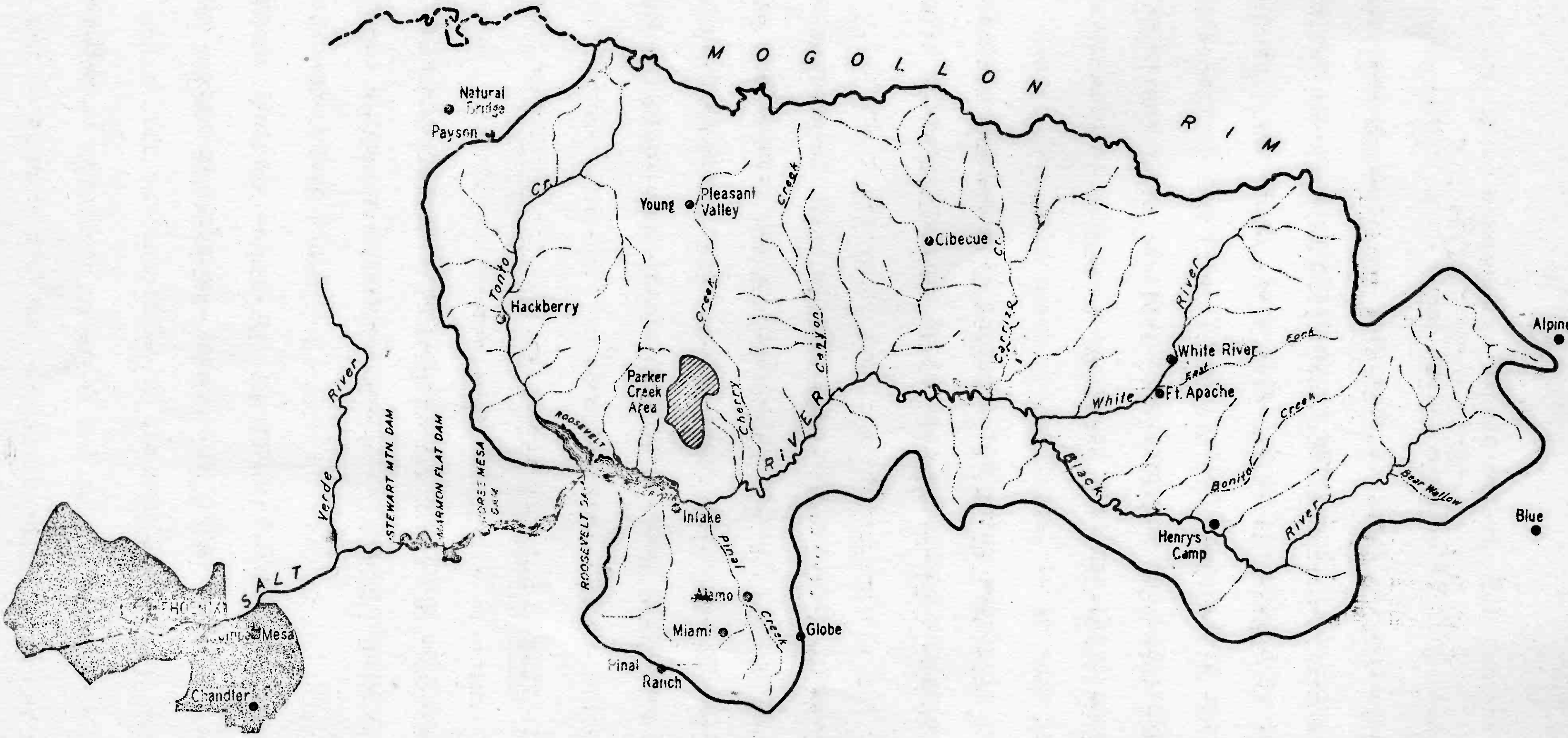
NEED FOR KNOWLEDGE ABOUT FACTORS THAT AFFECT WATER YIELD

All that we call modern reclamation improvements are developments of land and water resources in the lower part of drainage basins. The importance of the watershed, which yields the water, has not always been fully appreciated. In fact, in almost any particular instance, it has been given but secondary consideration until abuse of the protective ground cover of vegetation has resulted in some serious water, silt, or flood problem.

Past misuse of land has been responsible for the recent growth of interest in better land management. With this Nation-wide stimulus of appreciation for the perpetuation of our renewable resources, the inseparable relation of the vast areas of wild lands composing western watersheds and the garden spots made through the waters they yield are more generally realized than ever before. This interest in areas above the irrigated valleys and storage dams is also making it possible to better realize the administrative aims of land-management agencies, as the Forest Service, including investigations for the determination of the facts on which to base protective watershed-management practices.

Preliminary watershed investigations, including studies of vegetation, vegetation influences on run-off and soil erosion, and precipitation, were begun on the Salt River drainage about 1926. On the basis of the findings, intensive long-time investigations were initiated at intervals since 1931. The field set-up includes the Parker Creek forest and range influences station (Fig. 1).

Such systematic search for facts is necessary to satisfactorily answer even the more common questions, as What becomes of the rainfall and



IRRIGATION DISTRICT
SALT RIVER VALLEY WATER USERS ASSOCIATION

SALT RIVER DRAINAGE BASIN
ABOVE ROOSEVELT RESERVOIR
1938

Scale Miles

Figure 1

PS

how much of it may be obtained as usable water? For want of specific facts, the answers to such vital questions usually have been left to speculation through which the deduction is sometimes made that the protective forest and range vegetation on watersheds is robbing water users of much needed river flow. Such thinking is encouraged by the fact that only a small part of the total precipitation on semiarid watersheds is returned in stream flow. Furthermore, everyone who has irrigated field crops or even watered a lawn is impressed with the large amount of water required. Hence, from only these meager facts, it is easy to conclude that all that is necessary to increase the water supply is to decrease the number of thirsty plants. Would that watershed management were so simple!

The purpose of this publication is to present, insofar as is known at present, the circumstances surrounding run-off from its origin in precipitation on Salt River basin to the flow discharged by Salt River, one of the most important and highly developed water resources in the Southwest.

WATERSHED AND PRECIPITATION CHARACTERISTICS AFFECT WATER YIELD

In this analysis of precipitation-stream flow relationships, consideration was given the watershed peculiarities or characteristics which tend to influence water yield.

Typical drainage basins of the semiarid Southwest may be considered to have two parts—an upper and lower—not alone because of differences in elevation and relief but according to the amount of water the different areas contribute.

Upper Part

Most permanent streams rise in higher mountain masses. The higher part of Salt River drainage is small in comparison to the vast area of low but extremely rugged mountains, however precipitation is relatively high on both areas. Temperature varies more or less directly with elevation, but is, in average, relatively low as compared with the high temperature of the desert lowlands. This combination of circumstances allows for a rather large amount of the total fall being returned in stream flow.

Still other characteristics afford particular advantages for study. Among the most important of these is the common occurrence of bedrock in the channel of Salt River. Such rock outcrops raise subflow to the surface, hence the results of river gauging may be considered indicative of the total water yield.

Lower Part

In the lower part of most watersheds, including extensive low plain and valley areas, conditions are entirely different. Here the total run-off is small; rivers shrink and flow usually becomes intermittent, because the water contributed by the lower part may be less than the natural losses in the flow from the upper part. Moreover, the measurable stream flow through valley areas may not be indicative of the total run-off from above, because the subflow in deep deposits beneath and bordering the channel may greatly exceed the surface flow. In addition to these natural conditions, the diversion and impounding of water for irrigation has greatly changed the flow through the lower courses of most rivers.

RECORDS AND ANALYSES

All available data on precipitation and stream flow on the Salt River basin were considered. After a preliminary study, the period having the most usable records on stream flow, namely from 1902 to 1936, was selected for the analyses. Stream-flow measurements that were taken at a point near the location of Roosevelt Dam are available from 1902 to about 1910, when the dam was completed. Since then the flow has been measured immediately above the reservoir, hence the measurements before and after 1910 may be regarded as one continuous record.

Although desirable from the standpoint of length of records, use of the measurements at Granite Reef, a point on the edge of the desert below the confluence of the Verde and Salt Rivers (Fig. 1), would have necessitated confusing adjustments, as for the discharge of the Verde River. Furthermore, precipitation and flow data are compared and a number of representative weather records are no older than the stream-flow data considered.

Precipitation Records

The data on precipitation are from U. S. Weather Bureau records. Any measure of total rainfall on areas with such complex climate as Salt River drainage presents a problem. In comparison with most other mountainous areas, the Salt River drainage has a goodly number of stations which study indicates are fairly representative of the principal parts of the watershed.

The relationship between climate and elevation is fairly well recognized. In connection with the study of vegetation relationships, an analysis of southwestern weather records had previously been made, in which it was found that relief as well as elevation may have a profound influence on the amount of rainfall. To illustrate, precipitation may vary more or less directly with elevation on the slopes of large mountains and gradually rising plateaus. However, extensive areas with extremely rugged relief but rather low average elevation have a comparatively high rainfall. Here the precipitation on the roughs may be greater than that on the intermingled or adjacent areas of regular relief (mesas, basins, and flats) but much higher average elevation.

These relationships between precipitation and relief are distinctly reflected by the vegetation. Thus plant life may be considered a good indicator of climate, and was employed to determine the location and extent of the different areas with similar climatic conditions where measurements, even for extensive areas, are available at only a few points. Through appreciation of this fact, the broad vegetation types in which the weather stations are located were considered in analyzing the data. The locations of the stations employed are shown in Figure 1, and the precipitation data are grouped in Table 1 according to the condition the stations represent — that is, low, medium, and high rainfall.

It should be stated that no continuous long-time records are available for the higher parts of the basin, within the saw-timber belt. However, comparison of the vegetation and short-time records with the vegetation and long-time records from places outside the borders of the drainage but within the same timber belt showed the precipitation at the high-fall stations in Table 1 to be reasonably representative of the fall on the higher areas also.

Any incomplete parts of records were supplied through substitution of data from other stations within the same vegetation types.

Table 1.—Precipitation on the upper Salt River watershed, 35-year average, 1902 to 1936, inclusive

Group	Station	Summer				Winter								Average annual
		June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	
		Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
High[1/] rainfall	Natural Bridge	0.43	3.24	3.50	2.01	1.63	2.08	2.64	2.53	3.32	2.58	1.63	0.59	26.18
	Pinal Ranch	0.49	2.94	3.50	2.13	1.29	2.06	3.19	3.06	3.35	2.62	1.14	0.48	26.25
	Payson	0.63	2.96	3.19	2.08	1.61	1.85	2.07	2.27	2.57	1.97	1.35	0.41	22.96
	Average	0.52	3.05	3.40	2.07	1.51	2.00	2.63	2.62	3.08	2.39	1.37	0.49	25.13
Medium[2/] rainfall	Blue	0.58	3.78	3.39	1.92	1.49	1.52	1.65	1.43	1.79	1.38	0.88	0.81	20.62
	Fort Apache	0.48	3.03	2.91	1.73	1.09	1.26	1.37	1.52	1.50	1.61	1.10	0.50	18.10
	Average	0.53	3.40	3.15	1.82	1.29	1.39	1.51	1.48	1.64	1.50	0.99	0.66	19.36
Low[3/] rainfall	Intake	0.30	2.26	2.17	1.00	0.72	1.02	1.54	1.23	1.50	1.06	0.67	0.31	13.80
	Globe	0.43	2.86	2.54	1.32	0.96	1.30	1.79	1.54	1.52	1.24	0.75	0.41	16.66
	Roosevelt	0.44	1.74	2.22	1.13	1.05	1.42	2.06	2.04	2.35	1.77	1.02	0.33	17.57
	Average	0.39	2.29	2.31	1.15	0.91	1.25	1.80	1.60	1.79	1.36	0.81	0.35	16.01
	Grand average	0.47	2.85	2.93	1.66	1.23	1.56	2.04	1.95	2.24	1.78	1.07	0.48	20.26
	Percentage of average annual	2.32	14.07	14.46	8.19	6.07	7.70	10.07	9.62	11.06	8.78	5.28	2.37	-------

1/ Substitute stations: Henry's Camp, Young, Alpine.
2/ Substitute stations: Miami.
3/ Substitute stations: Hackberry, Alamo.

Stream-flow Records

Stream-flow data are given in Table 2. They were obtained from the records of the Salt River Valley Water Users Association. All values not already in such denominations were reduced to common terms, either second-feet or acre-feet, as shown in the tables and figures.

CLOSE RELATIONSHIP BETWEEN PRECIPITATION AND STREAM FLOW ON THE UPPER PART OF THE WATERSHED

The great differences in the amount of precipitation and flow of streams during different years and also during different periods of the same year are well known. However, the stream flow for any interval of time depends on many circumstances and factors and not alone on the amount of rainfall during the corresponding interval. Hence the extent to which any group of storms or the fall for some period contributes to stream flow is only vaguely revealed through general observations; neither is it definitely established through comparison of annual fall and flow records. For this reason, the comparative distribution trends of both fall and flow were investigated.

Annual Distribution of Fall and Flow

In the Southwest rainfall occurs principally during two rainy periods—one in summer, the other in winter—which are separated by a spring-early summer and a fall-dry period. The typical character of both rainfall and flow is different during the two rainy periods. Local thunderstorms and flash-flood flows are characteristic of summer, whereas widespread, protracted storms and prolonged high flows occur in winter. The period of protracted high winter flow is extended well into the spring dry months through the melting of any accumulated winter snow in the high mountains. Violent rain storms and flash floods of summer may be so

See errata sheet

Table 2.—Flow of Salt River above Roosevelt Dam, 1902 to 1936, inclusive

Year	Summer				Winter								Average monthly total
	June	July	August	September	October	November	December	January	February	March	April	May	
	Sec.-ft.	Sec.-ft.	Sec.-ft.	Sec.-ft.	Sec.-ft.	Sec.-ft.	Sec.-ft.	Sec.-ft.	Sec.-ft.	Sec.-ft.	Sec.-ft.	Sec.-ft.	Sec.-ft.
1902	106	78	478	1,057	131	189	441	189	207	201	268	167	293
1903	285	142	411	316	253	211	208	207	318	600	909	352	351
1904	80	356	1,513	460	281	164	172	221	223	217	148	133	331
1905	1,405	529	600	722	342	6,391	1,685	1,611	8,207	15,301	12,550	4,604	4,496
1906	667	514	868	466	299	276	4,944	1,470	1,430	7,774	5,080	1,691	2,123
1907	514	428	1,279	1,129	1,321	881	527	2,862	2,557	3,708	1,933	748	1,492
1908	424	777	2,086	1,001	367	356	365	370	3,917	3,708	1,537	908	1,325
1909	608	525	1,316	2,433	357	325	431	1,083	3,441	2,902	3,630	740	1,482
1910	136	155	294	211	170	294	274	1,606	604	1,196	997	491	536
1911	310	793	355	324	1,204	627	294	1,997	2,454	4,349	1,404	547	1,222
1912	394	358	541	466	407	285	294	229	241	2,702	2,766	1,165	821
1913	228	231	270	279	230	352	449	264	556	1,379	1,860	592	558
1914	261	620	1,101	759	670	530	2,959	543	1,969	1,189	1,106	446	1,013
1915	1,311	1,556	650	416	327	401	456	3,118	4,908	4,352	6,257	4,000	2,313
1916	874	492	831	1,090	1,491	499	366	17,006	5,547	8,813	4,515	1,873	3,616
1917	529	565	547	349	248	281	309	1,905	1,866	1,330	3,395	1,303	1,056
1918	303	425	495	213	185	291	452	344	612	2,424	754	379	573
1919	390	3,652	1,917	874	516	2,645	5,989	331	1,752	2,027	3,934	1,278	2,109
1920	676	332	712	332	322	602	392	3,306	11,459	3,415	2,550	1,731	2,152
1921	227	966	3,985	1,109	350	267	509	343	409	429	342	299	770
1922	418	398	553	260	195	257	862	1,202	2,058	3,379	2,204	1,086	1,073
1923	253	436	1,134	1,975	410	1,191	5,099	309	874	2,248	1,334	669	1,328
1924	391	257	306	206	183	201	396	1,685	1,040	1,115	3,362	1,142	857
1925	205	284	642	1,320	499	342	291	245	457	1,133	662	271	529
1926	478	347	376	405	276	259	649	257	284	1,453	6,301	2,337	1,118
1927	777	390	521	980	230	229	276	371	6,702	2,617	2,323	1,371	1,399
1928	258	327	465	268	270	307	273	258	959	854	663	522	452
1929	216	312	1,196	1,043	420	268	227	311	422	863	2,270	465	660
1930	285	675	1,075	273	166	428	292	340	589	2,030	1,755	627	711
1931	271	331	1,143	1,249	1,117	1,082	1,731	201	3,398	887	1,521	1,093	1,169
1932	447	518	887	519	356	237	341	1,040	8,388	3,883	3,295	1,237	1,762
1933	529	500	474	445	520	282	319	396	661	1,735	1,203	1,079	678
1934	126	183	814	486	186	238	225	257	303	429	326	202	314
1935	670	233	648	576	224	252	255	1,157	2,638	3,035	3,340	1,136	1,180
1936	357	248	435	535	263	309	321	232	2,309	2,156	3,419	1,153	978
Average	440	541	884	704	422	621	945	1,350	2,393	2,738	2,569	1,081	14,688
Percentage of average annual flow	3.00	3.68	6.02	4.79	2.87	4.23	6.43	9.19	16.29	18.64	17.49	7.40	---------

P.S.

See errata sheet

spectacular and destructive that an erroneous impression of their contribution to annual river flow is apt to be gained.

The significance of such facts as those just given, which were gleaned through long-time observations and preliminary study of fall and flow data, were taken into account in analyzing the Salt River records. The data are presented by months, this being a convenient form by which to show the distribution of values throughout the year.

Rainfall

The precipitation data, summarized in Table 1, include monthly averages and the percentage of the mean annual fall by months. These records show the dry period during April, May, and June, the high fall of July and August, the fall-season low in October, and the gradual building up to and then the decline from the winter high in February.

Some facts which the average monthly data fail to show are:

1. The April and September falls usually occur early in these months, whereas the June average would be almost nothing were it not for the few years having good rains in late June when summer rains begin early.

2. Years of little or no rain in May, June, and October are common.

3. The beginning and ending dates of the annual rainy periods vary greatly.

4. Wide departures from most monthly averages commonly occur, the least variation being in the months of highest fall, particularly in summer.

Seasonal Precipitation

Local, short-duration thunderstorms with rainfall of high intensity are typical of the period from June to September, whereas main storms are general and protracted and the fall is of low intensity during the period from November to March. The character of the April, May, and October falls varies, but is most nearly like that of winter. The fall for these three months is comprised principally of showers that are preceded and followed by dry weather. Hence such precipitation waters usually are absorbed by dry ground and over a period of years contribute but little to the total stream flow.

Seasonal Stream Flow

The different character of precipitation during the two annual rainfall periods has a marked effect on how rain water reaches the streams. In summer any run-off from slopes is from the surface of the ground. In contrast, most of the winter rain or snow water sinks where it falls or, except in drainageways, runs over the surface for only short distances before it sinks. Hence winter rain water usually sinks into and drains from the ground mantle between the time of falling and the time of becoming stream flow.

Summer and Winter Periods

The previously summarized findings furnished a clear-cut basis for the consideration of both fall and flow according to the character of the precipitation and run-off, namely:

1. June 1 to September 30, hereinafter called summer; the period of local, short-time thunderstorms and direct surface run-off.

2. October 1 to May 31, hereinafter called winter; the period of general, protracted storms with low-intensity rainfall or snow and indirect or ground run-off.

The data in Tables 1 and 2 indicate: (1) a rather close relationship between rainfall and stream flow, the agreement being closer in winter than in summer, and (2) the large part of the annual flow that occurs in winter. As regards the last, 62 percent of the annual fall and

See errata sheet

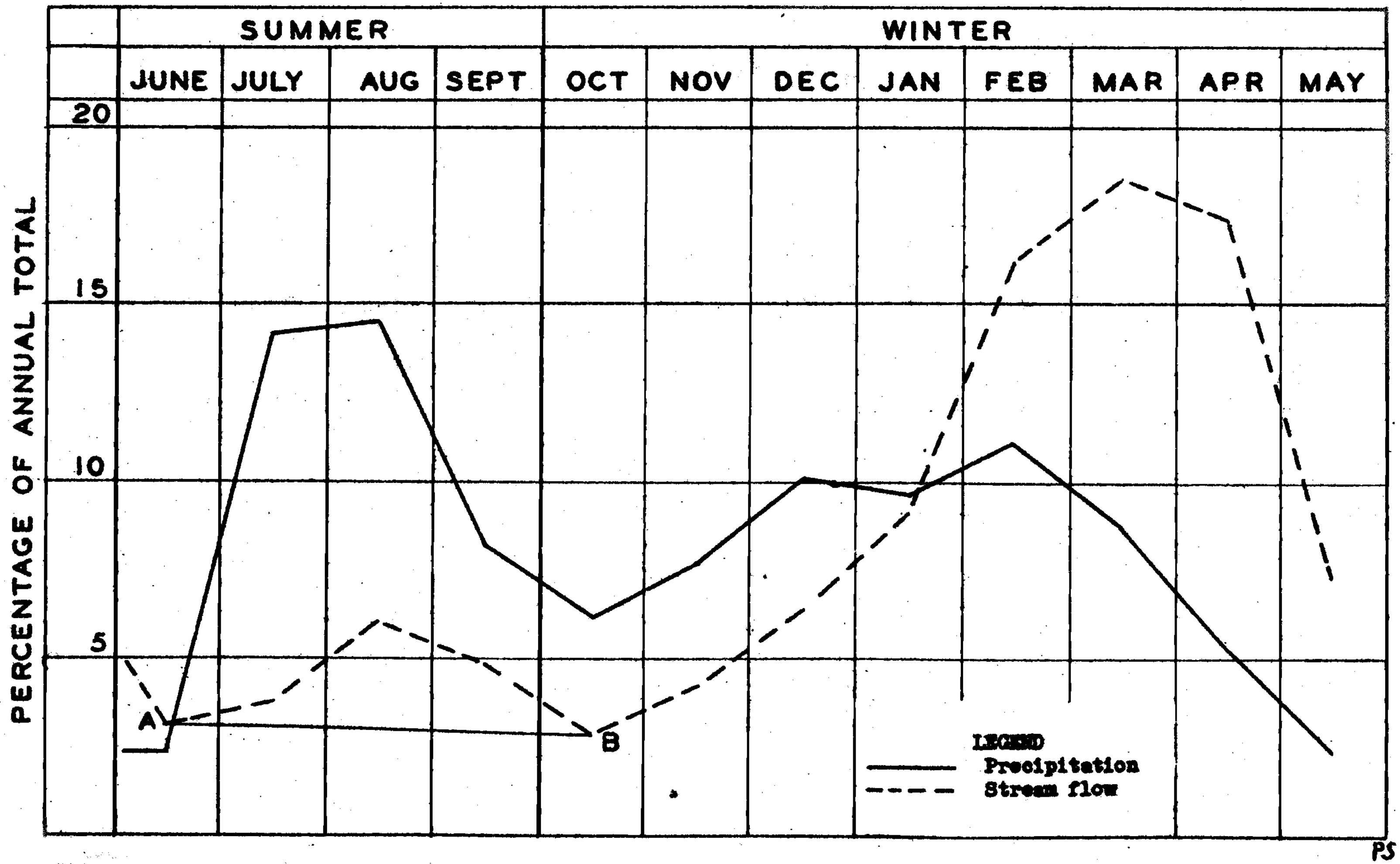


Figure 2.—Distribution of precipitation and stream flow on the upper Salt River watershed for 35 years, 1902 to 1936, inclusive.

82.5 percent of the annual flow are in winter, whereas summer includes
See errata sheet
38 percent of the fall but only 17.5 percent of the flow.

Annual Distribution Curves

Figure 2 graphically presents the data in Tables 1 and 2, each point in the curves being the percent of the average total for the 35 years. In comparing rainfall and flow, allowance should be made for lapsed time—the interval between the fall of precipitation and the arrival of run-off at some distant point in the main stream.

From October to January the upward trends of both curves are similar. The reason for this is shown by our investigations at low and medium elevations. Here the fall during these months is rain and snow, but the snow soon melts. The soil becomes wet; evaporation is low and percolation or gravity water soon reaches rock or unconsolidated layers of drained slopes and is shunted to the surface in draws and canyons throughout the low mountains.

Ground Run-off

During periods of active infiltration, rain and snow waters drain through the ground readily and as readily add to the flow of streams. The process may be compared to water being turned into innumerable supply pipes already carrying some water. However, the way down through the soil and then over bedrock to stream channels is an indirect, intricate route. Hence underground run-off occurs slowly as compared with surface run-off.

This may be illustrated by a typical record of winter rain, run-off, and percolation from small experimental areas at Parker Creek Station (Fig. 1).

Table 3.—Run-off from the ground surface and percolation at 22 inches in terms of rainfall

Rainfall			Run-off			Percolation		
Began	Ended	Amount in in.	Began	Ended	Amount in in.	Began	Ended	Amount in in.
8:08 a.m. Feb. 6	2:55 p.m. Feb. 7	3.24	12 noon Feb. 7	2:40 p.m. Feb. 7	.09	5:30 a.m. Feb. 7	3:00 p.m. Feb. 9	3.05

Although any delivery of percolation water had ceased when the storm began, the soil moisture content was high, which accounts for the high yield of 3.05 inches from 3.24 inches of rain. As regards the rain, the average fall was slow and intermittent. All surface run-off occurred during periods of highest fall intensity (.08 inch per 5 minutes for short periods on February 7), whereas infiltration continued for over 57 hours. The amount of surface run-off is small as compared with that resulting from the high-intensity falls of summer, as may be illustrated by the typical summer storm of August 1, 1935, when rain fell on the areas considered in Table 3 between 2:39 and 3:13 p.m. Of the total fall of 1.36 inches, 0.57 inch ran off between 2:45 and 3:18 p.m.

The conditions during the storm of February 1937 resulted in an exceptionally high flow of Salt River; such a flow was measured from Parker Creek drainage, an experimental area of about 700 acres having very rugged relief, steep slopes, and an elevation range of from 5,450 to 7,500 feet. At 8 a.m. February 6, when the storm began, the flow in Parker Creek was about 5 second-feet (Fig. 3). The peak of discharge, about 120 second-feet, was reached at 11 a.m. on February 7, which flow receded to about 2 second-feet by noon on February 8. Practically all this large flow of over 80 acre-feet in 52 hours was from percolation water, which same is also indicated by the record in Table 3.

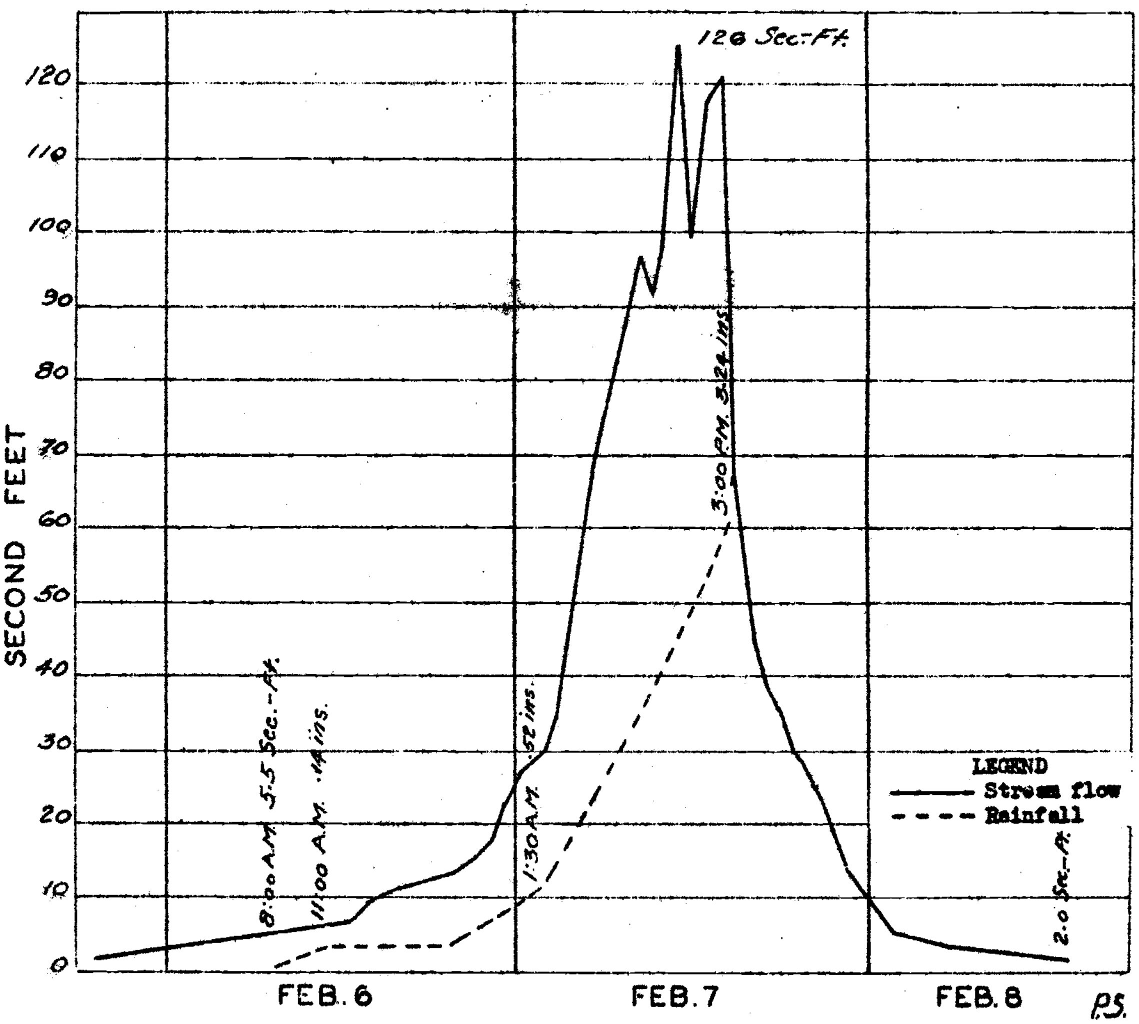


Figure 3.—Rainfall on the watershed and discharge of Parker Creek on February 6, 7, and 8, 1937.

The rapidity of percolation is accounted for mainly by the circumstances when the storm began and the natural features of the area. The soil mantle must have been practically saturated and the percolation chain well established, for a good percolation flow was being given off. Steep slopes with rather shallow soils and dense unshattered quartzite bedrock are characteristic of the area. The ground was covered with snow, however little of it seemed to melt during the rain; but, rather, most of the total rainfall of 3.24 inches filtered through the snow, which observation was confirmed through water-content determinations on snow before and after the storm. A hard freeze, which followed the storm period, accounts for the sudden drop in stream flow.

In Figure 2 we see, as percolation becomes established generally, how the effect on flow becomes cumulative; one area after another comes into production until practically the whole watershed yields water. Hence the flow curve rises rapidly in January and February, reaching its highest point in March. By April, slopes at medium elevations have about drained out, but the melting of snow on the higher mountain areas speeds up percolation there and accounts for the high flows of March and April.

Summer Period

The two months of highest rainfall—July and August—follow the spring-summer dry period; but the stream flow rises only slightly. This is explained by results from experimental watersheds where most of the July fall is dissipated on the dry, hot ground where it falls, or when surface run-off forms and most of it is absorbed in the temporary-flow drainageways connecting the land area with permanent streams. The August fall is but slightly more effective.

Surface Run-off

During the summer months any increase in stream flow results almost entirely from direct surface run-off rather than from the slower process of indirect, ground-water run-off, as during winter. Temperature is too high and evaporation too great for rain water to accumulate in and drain through the ground, except in wet spots and possibly to some extent on high, cool mountain tops. For this reason, stream flow during the fall-dry season usually shows no carry-over influence of summer rains.

Sustained Flow is From Winter Precipitation

The abundant contribution of winter precipitation to stream flow and the evident carry-over of its influence throughout the driest months of the year—April, May, and June—have been pointed out. Just how far this influence extends into the summer and thus how much of the summer flow is from winter precipitation becomes an important consideration in any analysis of the seasonal relationship of rainfall and flow.

Base Flow is Indicated by the June and October Values

In any study of Figure 2, the two lowest points in the stream-flow curve attract attention. Is it a coincidence that these values are almost identical? Or, do they indicate the carry-over influence of winter precipitation waters?

These low flows occur during the driest periods of the year. They precede and follow the summer rains which contribute to flow almost entirely through surface run-off. Hence the June value may be considered the stage to which flow commonly drops when drained slopes have given up the gravity water that accumulates in them during winter. Similarly, the October value is the slightly lower stage to which flow declines when the influence of surface run-off from summer rains is spent. This being the case, both of these low flows must be sustained by depth seepage that accumulates in and slowly drains from the terrain. The line AB in Figure 2 may then be drawn to form the approximate division between the average sustained or base flow and the contribution of summer rain which, on this basis, is only about one-third of the total flow for the summer period, or about 6 percent of the annual flow.

The same reasoning which led to the connecting of these sustained flow points has been applied by Sherman[2/] and Hoyt and others[3/] in segregating surface run-off from ground-water run-off. Here recognition is made of the fact that these values are averages and hence need some further consideration.

June and October Values Include Some Summer Run-off

The 35-year averages in Figure 2 are slightly influenced by the different conditions during different years. The values include any years when surface and shallow ground run-off contributed to the June and October flows and also some years when the minimum flow occurred in other than those months.

Study of the records in Tables 1 and 2 shows that the higher flows in June are preceded by high winter flows, and those in October are either preceded by high flows or occur with high rainfall. In 1905 and 1915 the high June values are evidently the result of large flows during the preceding winter months; there was no exceptional June rainfall which might

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[2/] Sherman, L. K. Stream flow from rainfall by unit-graph method. Eng. News-Record, Vol. 108, pp. 501-505. 1932.

[3/] Hoyt, W. G., and others. Studies of relation of rainfall and run-off in the United States. Water-Supply Paper 772, 301 pp. 1936.

account for any above-average flow. The October flows for 1907 and 1916 were preceded by high flows, and the October rainfall was also far above the average. In 1911, August and September flows were low, but the October rainfall was about three times the average, whereas in 1931 the October rainfall was about average and the August and September flows were high. These facts are mentioned because of their relation to the average values in Figure 2 and not because of any indication that the averages tend to minimize the influence of summer precipitation on stream flow.

Constancy of Base Flow

See errata sheet

In Figure 1 the constancy of the base flow is obscured by the averaging of monthly values that differ widely because of such variables as the beginning and ending of dry and wet seasons. Figure 4 is presented to illustrate the nature of the base flow during a typical year. The year 1935 was selected because 1934 was very dry, and any gravity water resulting from winter precipitation in 1934 must have drained from the watershed before 1935.

The flow gradually declines from mid-April to mid-July, an almost rainless period of 3 months; or it took that long for shallow ground-water run-off to drain from the watershed. Of particular interest is the almost constant flow (base flow) through October, November, and December, and how closely it agrees with the July record.

The flow from October on certainly must have been from precipitation water that fell prior to the summer of 1935. For, any influence from summer run-off had apparently ended; there is almost no relation between rain and flow after September.

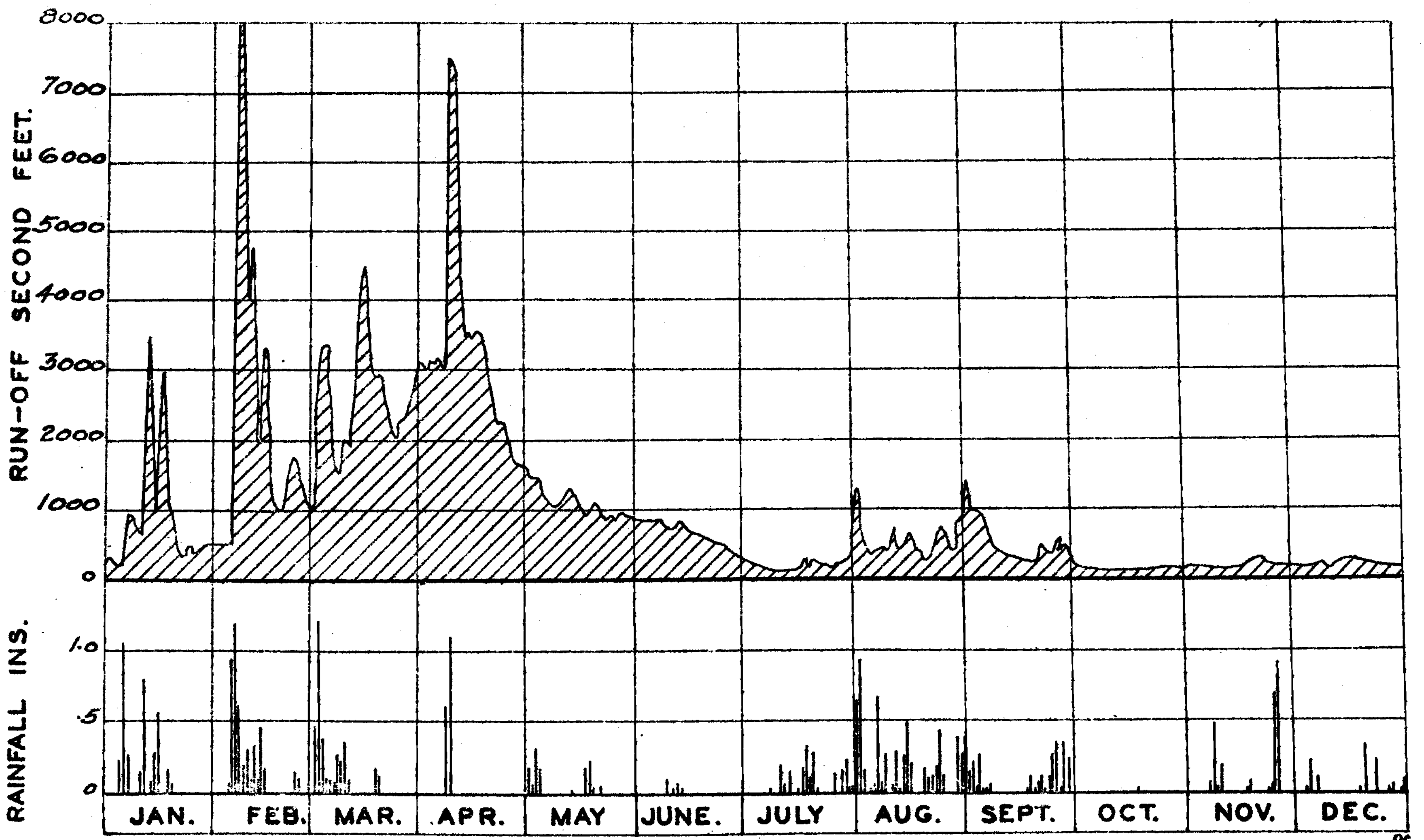

FIGURE 4.—DISTRIBUTION OF PRECIPITATION AND STREAM FLOW FOR UPPER SALT RIVER WATERSHED, 1935

The findings from small experimental drainages were similar. Here the November and December rainfalls were absorbed by the dry soils but were too small to establish percolation. In Figure 4 the slight but gradual increase and also most of the fluctuations in flow after September are accounted for through changes in temperature. We have found on experimental drainages that periods of cool weather or even cool nights during the fall season tend to lessen water losses, as evaporation, and result in some rise in flow without any rain.

Source of Base Flow

General study of the watershed indicates that the base flow of Salt River has its main source in certain areas—the high White Mountain mass where White and Black Rivers rise, a part of the Coconino Plateau (although topographically within the Colorado River drainage), and similar but small areas here and there throughout the drainage. On the White Mountains some snow usually lies until late in spring. Here the amount of shallow seepage from drained slopes is similar in spring to that at medium elevations during winter; it keeps the creeks booming.

On the Plateau topsoils usually dry out early and summer rains penetrate only to shallow depths. But some winter moisture must seep deep into the rock formations, because many almost constant flowing large springs, the heads of Salt River tributaries from White River westward, rise near the foot of the high Mogollon Rim (Fig. 1). Other springs indicate deep seepage within the topographic boundaries of the drainage. All of these sources may be compared with underground reservoirs where seepage water accumulates, perhaps to some degree over long periods of time, and is given off in more or less constant amounts.

Some Conditions Affecting Behavior of Flow

Figure 4 also illustrates the relation of flow to conditions that affect run-off. The cumulative build-up of flow from January to April is indicative of the effectiveness of winter precipitation; the rainfall is only about 2.50 inches greater than that of summer, when the rise in flow is small.

The short-time peaks in flow during both the summer and winter periods are similar to the results obtained on the Parker Creek experimental drainages. Here only hard rains produce summer flows, which are of short duration because of the brief period of surface run-off during typical, short-time thunderstorms. In winter, peaklike flows may result at the higher elevations from rain and also melting snow, particularly when periods of rapid percolation are followed by freezing weather. Freezing curtails infiltration. Hence the fall of peak flows may be as sudden as the rise, as is shown in connection with Figure 3 where the flow resulted from rain, and in Figure 4 where the peak flows of late February and mid-March must have been caused by the melting of snow.

FURTHER TESTS OF RELATIONSHIPS OF FALL AND FLOW

In order to subject fall and flow relationships to still other critical tests, the data were considered by annual and also winter and summer periods. The resulting values are given in Table 4. Analyses of them show that annual differences in precipitation are followed closely by annual differences in stream flow.

Table 4.—Mean annual, winter, and summer precipitation and stream flow, Salt River watershed above Roosevelt Reservoir

Year	Annual		Summer		Winter	
	Total precipitation in inches	Mean discharge in second-feet	Total precipitation in inches	Mean discharge in second-feet	Total precipitation in inches	Mean discharge in second-feet
	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
1902	14.15	293	5.11	430	9.04	224
1903	11.29	351	6.68	288	4.61	382
1904	12.37	331	7.55	602	4.82	195
1905	40.76	4,496	7.93	814	32.83	6,336
1906	23.31	2,123	7.51	629	15.80	2,870
1907	20.61	1,492	7.89	842	12.72	1,817
1908	23.63	1,325	9.09	1,092	14.54	1,441
1909	17.24	1,482	7.23	1,220	10.01	1,614
1910	12.26	536	4.98	199	7.28	704
1911	25.12	1,222	11.07	446	14.05	1,610
1912	19.39	821	8.29	440	11.10	1,011
1913	17.48	558	5.90	252	11.58	710
1914	23.68	1,013	9.02	685	14.66	1,176
1915	24.86	2,313	8.24	983	16.62	2,977
1916	26.78	3,616	10.13	822	16.65	5,014
1917	16.75	1,056	5.63	498	11.12	1,330
1918	22.52	573	7.00	359	15.52	680
1919	26.76	2,109	12.76	1,708	14.00	2,309
1920	20.46	2,152	6.56	513	13.90	2,972
1921	18.51	770	11.13	1,572	7.38	368
1922	18.78	1,073	5.83	407	12.95	1,405
1923	22.67	1,328	9.24	950	13.43	1,517
1924	12.32	857	3.99	290	8.33	1,140
1925	16.28	529	8.80	613	7.48	488
1926	21.51	1,118	5.91	402	15.60	1,477
1927	22.79	1,399	10.61	667	12.18	1,765
1928	15.20	452	6.46	330	8.74	513
1929	16.56	668	9.92	692	6.64	656
1930	21.98	711	8.29	577	13.69	778
1931	28.68	1,169	10.70	748	17.98	1,379
1932	19.94	1,762	7.21	593	12.73	2,347
1933	17.08	678	7.74	487	9.34	774
1934	12.31	314	5.28	402	7.03	271
1935	23.06	1,180	8.53	532	14.53	1,505
1936	24.09	978	9.14	394	14.95	1,270
Means:	20.32	1,224	7.92	642	12.40	1,515

Correlation Analysis

The relation of stream flow to rainfall is directly proportional; hence the correlation coefficients for the values in Table 4 may be used in calculating the measure of agreement between flow and fall. Such an analysis indicates a similar and close association of both the annual and winter values.

Annual agreement of flow and fall (columns 1 and 2) - - .79

Summer agreement of flow and fall (columns 3 and 4) - - .67

Winter agreement of flow and fall (columns 5 and 6) - - .81

The total flow was considered in calculating the summer agreement; that is, no reduction was made for base flow. Even then the flow-fall correlation value in summer is only .67, as compared with .81 in winter.

Analysis of Agreement in Annual Trends

The results of the correlation analysis were obtained from a study of average values. They indicate nothing of the flow-fall agreement year by year or the association of trends during different periods of the year. In order to obtain such information, accumulated deviations were computed from the data in Table 4 and were then compared through plotting of them, as is shown in Figure 5. The curves portray the relationship between precipitation and stream-flow values for each year.

The use of accumulated deviations from average values offers particular advantages in comparing the relationship of stream flow to precipitation. When the slope of both curves is in the same direction, flow and fall are in agreement or each one is increasing or decreasing in relation to the average value of all its points. Furthermore, when the slope of these curves is upward or positive between only two points, it indicates above-average value of the quantities plotted, and when it

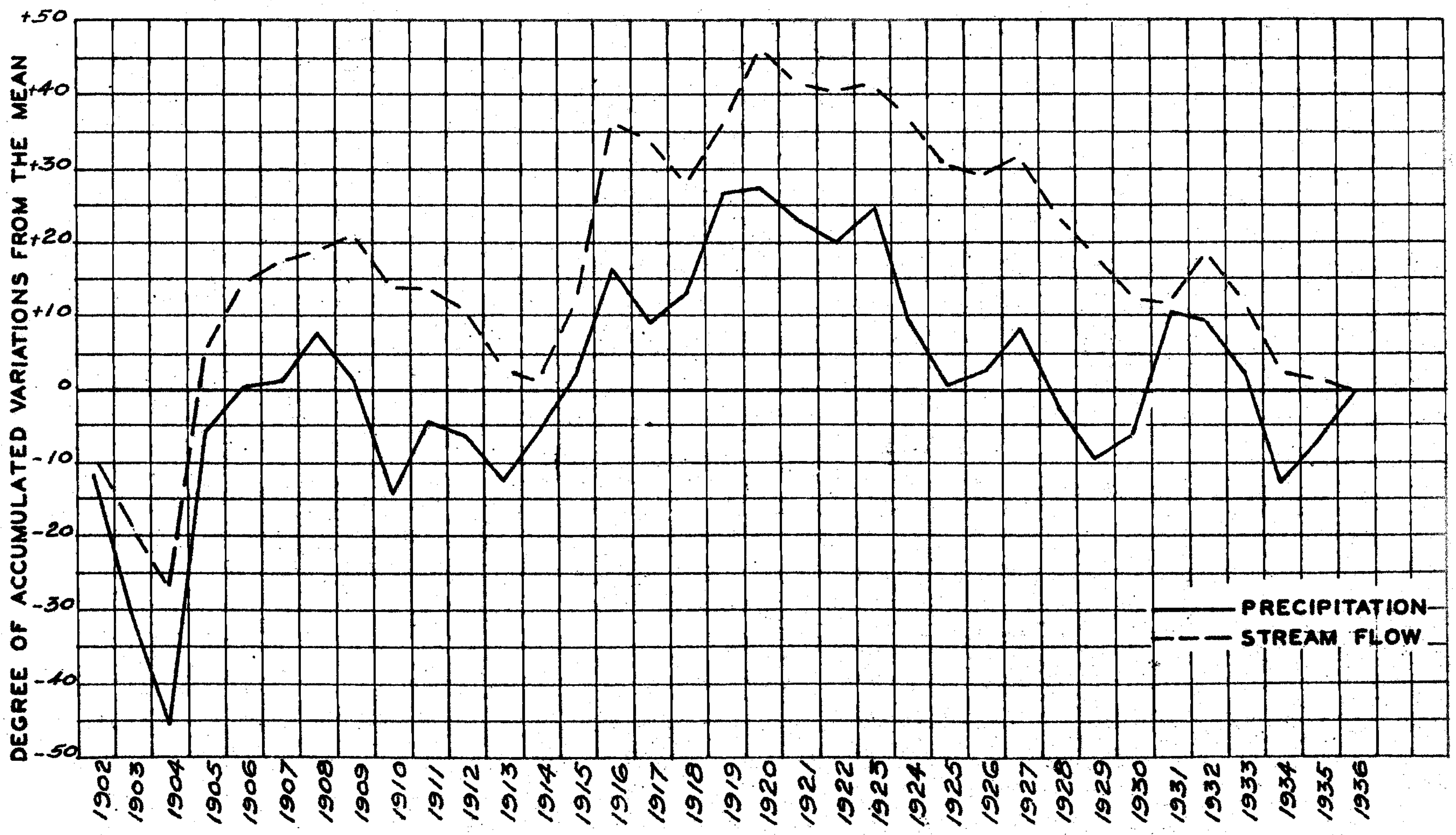

FIGURE 5—DEGREE OF ACCUMULATED EXCESS AND DEFICIENCY OF PRECIPITATION AND STREAM FLOW, UPPER SALT RIVER WATERSHED.

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is downward or negative the quantities plotted are below average. For example, the behavior of flow and fall are similar for the period 1902 to 1908, but the values are below average or minus before 1905 and above average or plus thereafter.

In general, the trend of annual stream flow may be said to follow closely the trend of annual rainfall. In fact the relationship is close when one considers factors like seasonal fall, flow lag, and fall distribution, which may determine how large or small a part of a given annual fall is returned in flow during the same year.

Seasonal Fall

The greater effectiveness of winter rainfall, as compared with summer rains, is one of the important factors that influences the yield of precipitation water. The close relationship between average annual flow and winter fall during the 35-year period has been pointed out. In like manner, the annual flow is more apt to agree with the winter than the average annual rainfall.

This is borne out forcefully by the data in Table 4. For 35 years, 19 of the winter falls were above and 16 below the average. About half, or 10, of those above the average were accompanied by above-average annual flows, whereas 14 of the 16 below-average falls resulted in below-average flows. This indicates that 7 out of 8 of the years with below-average winter rainfall are years of below-average flow and that it is about an even break that above-average winter rainfall means above-average annual flow. There is agreement also between winter fall and annual flow in 24 of the 35 cases.

In studying the fall and flow agreement in Figure 5, we find that the ineffective nature of summer fall must be the principal reason for the disagreement in some years, as in 1911. Both the winter fall and flow are above average, but the summer fall, which is one of the highest on record, being about 40 percent above the average, produced 30 percent below-average flow. The reasons for the uncertainty of contributions to flow by summer storms is discussed later.

Flow Lag

Flow usually disagrees with fall when the precipitation for the last few months of the calendar year, particularly November and December, is so high or low as to determine whether the annual fall is above or below normal. In the high country these early winter storms usually result in snow, which may not melt and add to flow until the next calendar year. Where the fall is rain, all or nearly all of it may be absorbed by the ground which has become dry during the almost rainless fall period. This wetting of the ground prepares the way for future run-off; but here, too, as in the case of snow in the high mountains, actual contribution to flow occurs during the next rather than the current year. Hence the lag, or interval of time between the fall of precipitation and the effect of it on stream flow, may result in the disagreement of annual flow and fall when these values are compiled on a calendar-year basis. Disagreement may also occur in years having little or no fall in November and December. In such an instance, there is little or no storing of moisture or even wetting of the ground and hence no contribution to the flow of the next year.

Flow lag is illustrated by the year 1909 (Fig. 5), when the below-average fall was accompanied by a slight rise in flow. On the basis of the monthly weather records, we offer this explanation of the disagreement. The fall for December 1908 is several times the average. Thus there must have been some contribution of 1908 fall to 1909 flow.

The annual precipitation for 1909 is below average, but only because of the low fall during those months from April on, or the period of the year when fall usually contributes little to flow. Before April, or during January, February, and March, precipitation was above normal. Hence the period from December 1908 to April 1909 had above-average precipitation and also well-distributed rainfall. This last introduces the important influence of the distribution of fall on the amount of water given off in stream flow.

Distribution of Rainfall

Our intensive investigations show that the amount of any winter rain that becomes ground-water run-off is most during periods when the soil is saturated. On the other hand, when storms are preceded and followed by dry-out periods, all or nearly all of the rainfall may be absorbed by the soil and, in turn, lost to the air. Fall distribution suggests one reason for the consecutive disagreements in the flow-fall curves (Fig. 5) for 1930, 1931, and 1932.

In 1931 was recorded the second highest winter fall in 35 years, and yet the annual flow was below average. This high fall represents the far-above-average precipitation for the months of February, April, November, and December. January and March had almost no fall. Thus both February and April were preceded and followed by long dry periods which tended to dissipate the fall. Furthermore, the November and December precipitation undoubtedly contributed mostly to the 1932 flow. A similar combination of conditions affected the relationship in 1930 and also in 1936. The opposite condition prevailed in 1932 when a well-distributed winter fall was preceded by high November and December falls in 1931. The result was an above-average flow during a year of below-average fall.

Other years in which fall distribution and flow lag seem to exert so strong an influence as to cause disagreement between the curves are 1914 and 1918. In 1914 about one-third the annual precipitation fell during the last 3 months of the year, and must have contributed principally to the 1915 flow. The sharp disagreement in 1918 is explained by similar circumstances. There was almost no precipitation during the last 3 months of 1917, whereas in 1918 the precipitation for the same 3 months was high. Hence the 1918 flow could not have included the normal carryover, whereas the 1918 fall must have contributed to the 1919 flow.

LONG-TIME TRENDS

There is always a deal of speculation regarding climate, particularly in semiarid countries. The Southwest is no exception. Here one commonly hears of lack of effective rain and of drought conditions at present, as compared with the past. In contrast, the terms "cloudburst" and "flood" have come into such common usage in describing summer thunderstorms that they no longer signify anything exceptional.

It is true that beliefs regarding climate that are unsubstantiated by weather records are readily gained in any country such as the Southwest. However, no natural peculiarities can reconcile any belief that the climate is rapidly becoming drier while cloudbursts and flash floods are increasing in number and severity. The influence of different conditions of land and vegetation aid in explaining this seeming conflict.

Induced Drought

Some areas are noted for cloudbursts and destructive floods; others are seldom visited by such disasters. Measurements of rainfall and run-off show that like storms exert vastly different influences on country otherwise similar except for conditions of vegetation and soil. On vegetation-depleted, eroded areas even small thunderstorms produce flash floods, and hard storms are always destructive. Hence cloudbursts may seem to be common occurrences in places, because the rain is usually judged by its effect rather than by the amount and intensity of the fall.

Conditions that swell flood flows also make for droughty lands. The soils of deteriorated areas become drier and dry out more frequently than similar lands having good vegetation and soil conditions. The effect becomes particularly serious on drought years, but critical conditions also arise at intervals throughout all but the most favorable rainfall years.

There are many reasons for the induced drought conditions of eroded lands; among the most important of which is the loss of soil moisture through increased surface run-off and evaporation, particularly in summer. The natural ground cover (including vegetation and litter), together with topsoil, operates as a whole to retard surface run-off, promote penetration of water into the soil, and to minimize evaporation losses.

Under normal conditions vegetation grows through rainy periods having temperature favorable for growth, and barely survives critical dry periods. On badly eroded areas so much of the summer rain water is lost that falls of 1 inch commonly penetrate less than 3 inches into the soils of bare spots, whereas penetration may reach 6 to 8 inches or more in plant-covered areas on the same slope. Furthermore, bare spots may dry out in a few hours following a storm, but the soils of plant-protected spots usually retain considerable moisture for days. This abnormal loss of moisture has such a profound influence on the growth and survival of plants that droughty conditions may prevail during periods with normal rainfall.

The facts regarding induced drought, such as have just been related, were revealed by researches on the Salt River watershed. The same investigations have shown how deterioration of vegetation and erosion operate to cause drought. To illustrate: Let us suppose an area of grassland in good condition, with an average summer rainfall of 10 inches. If 6 inches of the rain water penetrate the soils and half of that becomes available to plants, the equivalent of 3 inches of water is required during summer by that kind and state of vegetation. When vegetation declines through injury until the loss of rain water through increased run-off and evaporation is so great that only 2 inches of water are available to plants, the effect is disastrous. It is the same as might be expected from a sudden change in climate.

This explains why grasslands near the borders of desert areas are readily changed to shrub deserts, and also why deteriorated eroded areas having either low rainfall or high temperature are so difficult to revegetate. It also indicates that the individuals who conclude from observations of the condition of vegetation and land that drier conditions prevail now than 20 or 40 years ago may be correct; this depends on the areas concerned. When compared with lands in good condition, deteriorated lands are drier and more desertlike, but not because of any recent and sudden change in climate.

Climatic Cycles

Most investigators agree that over a period of time the annual precipitation tends to increase and then decrease, forming cycles, each of which, in turn, may consist of lesser cycles. This incident of precipitation and the tremendous variation in annual fall so influence short-time records that they may have but little significance as indicators of long-time trends.

The changes in climate here considered are not the gradual swings through ages of time, for which there is proof. They are changes that are supposed to have taken place within the experience of those now living and thus within the period of record taking. Nevertheless, there are no long-time values with which to compare any existing short-time records. Thus when considering data for some period, such as the 35 years of this analysis, we have no assurance that we are doing any more than measuring a part or parts of one or more cycles.

Tests for Trends

The Salt River data were tested in a number of ways to determine whether there is any indication of increase or decrease in rainfall and stream flow.

Least-squares Line

The first is the least-squares trend line determination (Fig. 6) in which flow and precipitation values are plotted in comparable terms, that is in depth of water in inches on the watershed. A indicates a downward trend in precipitation of .006 inch per year and B, a decline in stream flow of .0463 inch. Neither is statistically significant. B, for example, to be significant would need be 1.7 times greater than the slope found. The difference in slope of the two lines is to be expected. The ratio of stream flow to precipitation is never a constant, the amount of precipitation being only one of the factors affecting annual stream flow. (See seasonal fall, flow lag, and fall distribution, pp. 31-33.) Only in case the decline in flow were unaccounted for by such factors would it be assumed that more of the rainfall was being consumed on the watershed.

May we consider this assumption briefly before testing further the significance of the flow line in Figure 6. Our researches indicate that destruction of plant cover results in acceleration of the rate of surface run-off, and on some areas in some increase in the amount of surface run-off. However, the decline of vegetation also stimulates the action of other natural factors affecting total water yield and not surface run-off only. The effect of increasing evaporation by decreasing ground cover, of increasing surface run-off at the expense of ground-water run-off, and the like, may offset any increase in surface run-off. Hence, the decreasing of vegetation may fail to increase the total water delivered by such streams as Salt River.

Surface run-off must reach some live stream in order to contribute to the flow of any main river. But the same water in run-off that becomes so accelerated as to gully slopes may spread out later and evaporate from the ground surface and the soil of lesser slopes and depressions. Then, too, it may reach dry drainageways and eventually be absorbed, particularly in deep deposits of recently eroded material. Many are the losses to which surface run-off is subjected.

Any conclusion that decline in flow is the result of plant growth would have weight only when substantiated by evidence of an increase in the amount of vegetation and/or a change in vegetation to plants of higher water requirement. Vegetation cover over a large part of the Salt River watershed undoubtedly has undergone some changes. The character and condition of plants and land furnish abundant proof of change, but some of it must have taken place before 1902—how much, there is no way of knowing. There is considerable evidence of injury to both vegetation and land, such as verbal history of floods following drought and

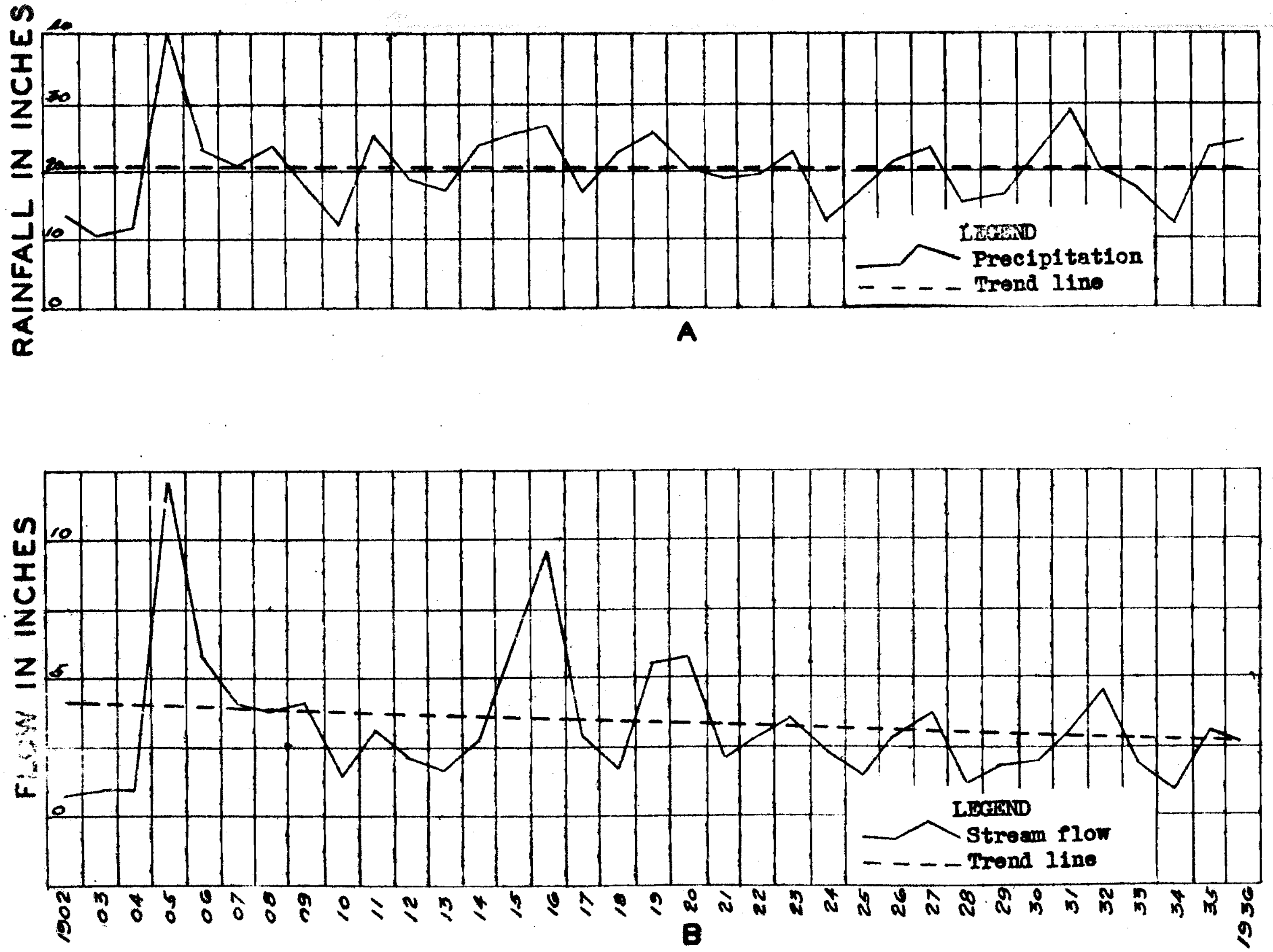

Figure 6.—Trend lines of fall and flow, upper Salt River watershed, 1902 to 1936; A, precipitation; B, stream flow. For discussion, see page 37.

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tremendous cattle die-offs as early as 1891 and 1892, and particularly by the early 1900's.

Neither is there any way of knowing how much of the present accelerated run-off and erosion is traceable to circumstances during the period before 1902 or what the decline has been in some places, and the recovery in others, since then. Without some definite proof as to average gain or loss in vegetation cover on the whole watershed and particularly the higher water-yielding parts, it cannot be assumed that a good stand of plants on some particular areas is sufficient evidence to establish cause for any decline in water yield.

The trend lines in Figure 6 are for only a few of the many years that undoubtedly are involved in any long-time trends of climate and stream flow. The amount of precipitation in the year 1905 is so exceptionally great that it is a strong influence on such calculations. Had this one included a longer period prior to 1905, the results undoubtedly would be very different. It is evident that the number of years with high stream flow between 1902 and 1920 and the lack of similar flows since 1920 greatly influence the trend line B, Figure 6. Here the effect of 1905 is so marked that even a trend line for the period up to 1920 has a slope of -.0500, as compared with only a -.0048 slope after that year. The downswing of the precipitation and streamflow cycle since 1920 is evident (also see Fig. 5). The trough in the cycle may have been reached, or probably was near at hand, in 1934. With an upward swing in the cycle in the next 15 to 20 years that would correspond in degree of rise to the decline since 1920, the trend lines may be expected to flatten out or even reverse.

Ratio of Flow to Fall

In order to test further for any evidence of decrease in the quantity of flow at the expense of the quantity of fall, the ratio of the two values was plotted and a trend line determined. The result is shown in Figure 7.

The outstanding feature in this figure is the disagreement of the values for the first 3 years as compared with the almost horizontal line formed by the other 32 points. The flows for the years 1902 to 1904 are lower than any others in the record. They are also much the lowest in proportion to the precipitation. These years were the last of a series with very low fall, the cumulative effects of which resulted in exceptionally low annual flows.

On the basis of the full 35 years, this calculation gives an increase in the ratio of stream flow to rainfall. But the first 3 years are so out-of-line that they probably should be disregarded. When only those years after 1904 are considered, the ratio trend line indicates a decrease in flow of about .0269 inch per year, which is similar to the relationships obtained by plotting the least-squares line in Figure 6.

Flow, Fall, and Retention Compared

Still another test was made to determine any change in the relation of fall to flow that would indicate an increase in the retention of rainfall on the watershed. The accumulated values were plotted by years after the manner shown in Figure 8, in which the retention curve is obtained by subtracting flow from fall.

In such diagrams any gain is indicated by an upward curvature and loss by a downward curvature of the plotted lines. In this case the almost straight lines indicate the lack of any material change. Had flow declined without a change in fall, the fall line would be straight and the

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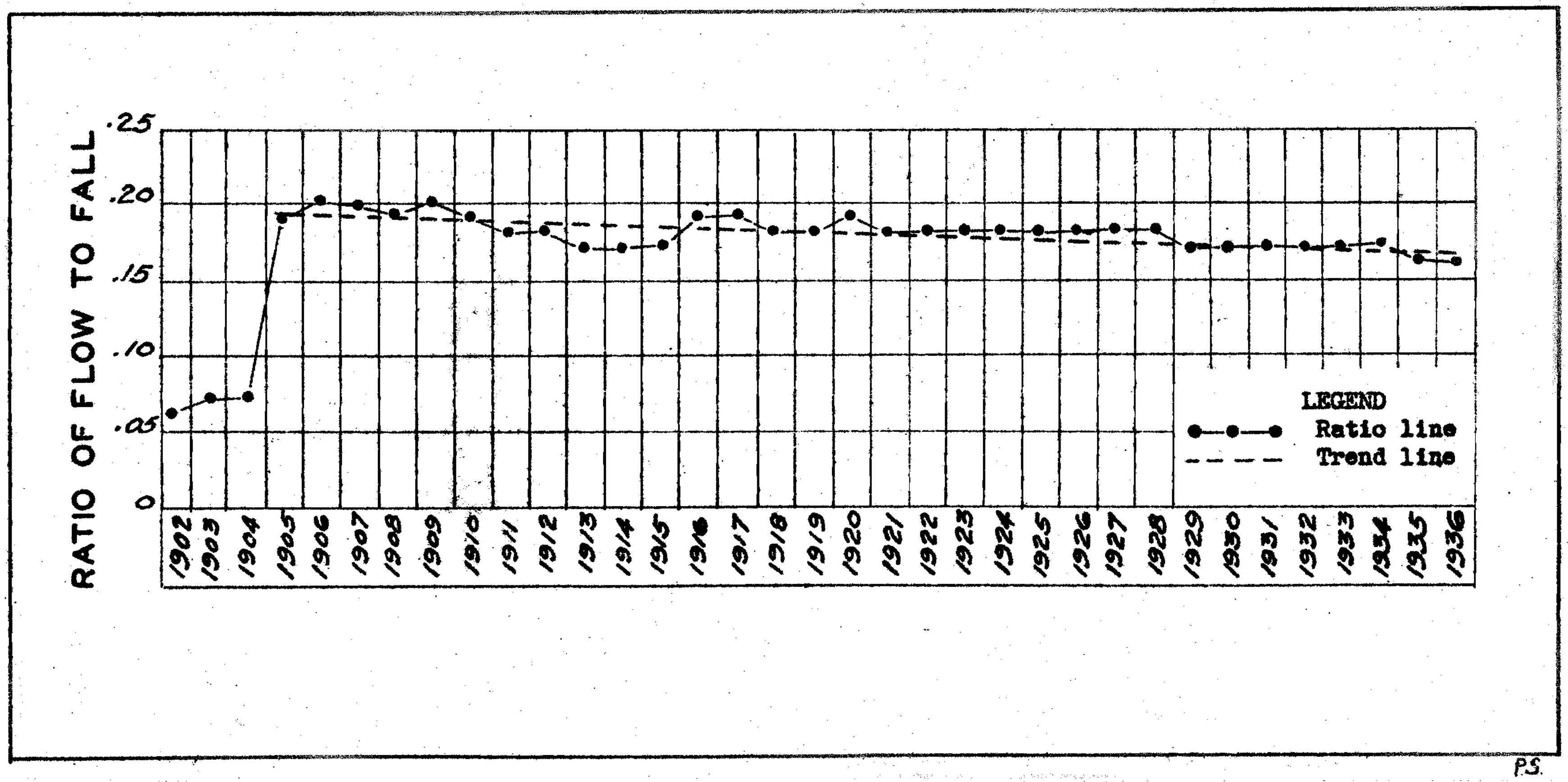
Figure 7.—Trend line of ratio of flow to fall, Salt River watershed.



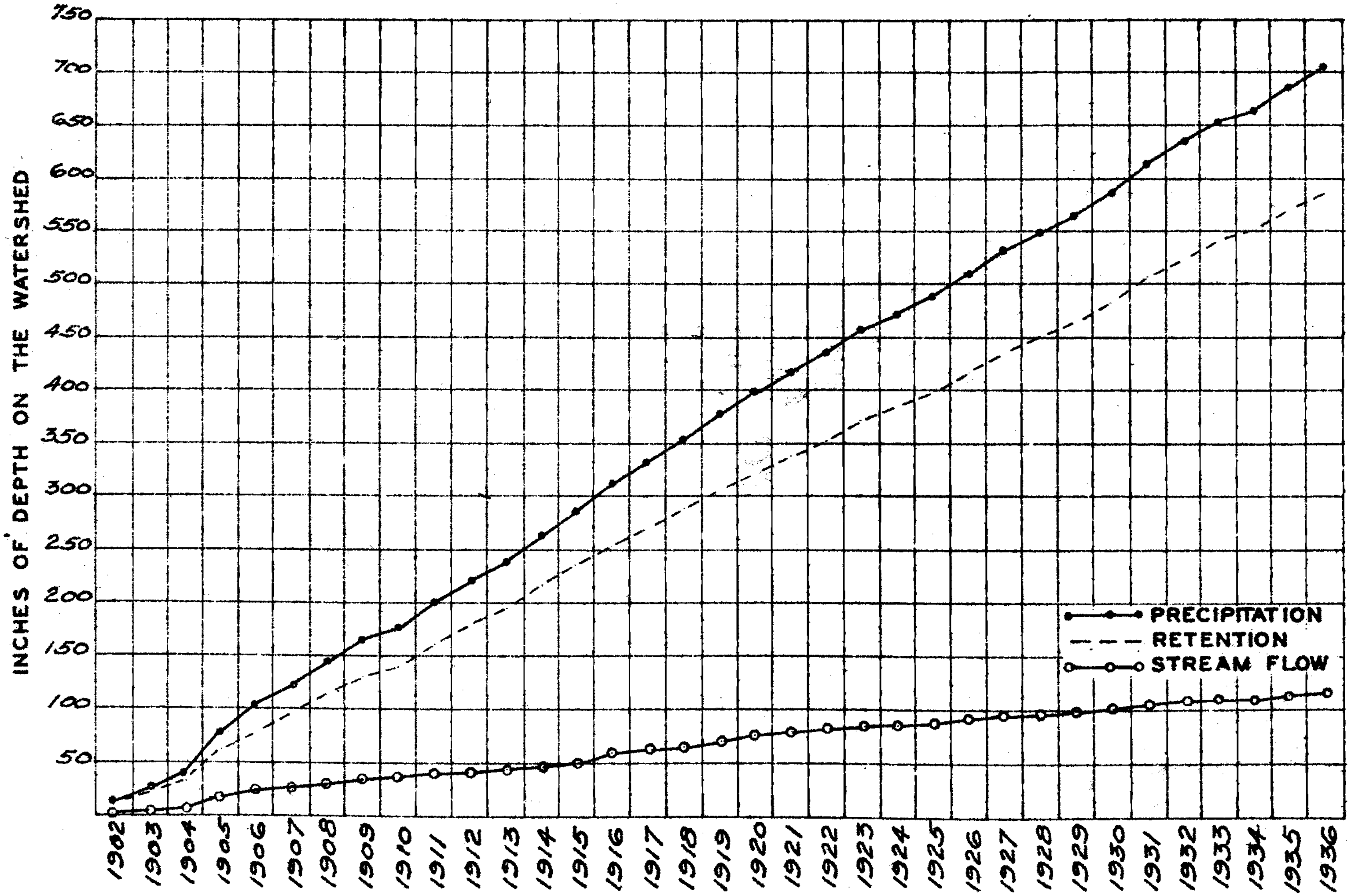


FIGURE 8—SUMMATION CURVES OF PRECIPITATION AND STREAM FLOW, FOR UPPER SALT RIVER WATERSHED.

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flow line a convex curve. As it is, each line is made up of a series of slight convex and concave curves, as may be seen by placing a ruler so as to connect such points as 1904 and 1910, and 1923 and 1927.

Also, the variations in the flow and fall curves are in close agreement. This could be interpreted to mean that there have been only slight changes in the conditions which affect the amount of rain water delivered as stream flow or that any changes that may have occurred have not affected, in the aggregate, the relation of flow to fall.

The results of the three tests are similar; they show minus trends in both fall and flow that are statistically nonsignificant. Hence, whether the trend for so short a period is a plus or minus quantity may not have meaning. Even the older precipitation records in the Southwest confirm this conclusion. For example, a trend-line determination on the precipitation at Tucson during the same period as the Salt River study, 1902-36, gives a decline of .0366 inch per year, whereas the first 25 years of the full 69-year record show an increase of .0279 inch per year.

Amount of the Precipitation Returned in Stream Flow

How much of the precipitation is returned in stream flow? is a question commonly asked. The lack of adequate precipitation data for the many different climatic conditions on any large semiarid drainage makes it difficult to give any positive answer. On the Salt River this is still further complicated by peculiar local conditions. We know from the large springs previously mentioned as arising immediately below the almost perpendicular Mogollon Rim (Fig. 1) that the drainage area of Salt River differs considerably from that defined by its topographic boundaries. The source of this deep seepage from the Coconino Plateau is unknown. Perhaps it comes mainly from the more recently active of the volcanic areas where peculiar formations cause surface waters to sink; if so, as much as 500,000 acres of the drainage basin may lie beyond the Mogollon Rim.

The total rainfall and stream flow from 1902 to 1936 amounted to 711 and 116 inches, respectively, in depth over the drainage, an area of about 3,500,000 acres (Fig. 8). On this basis, 16.3 percent of the precipitation was returned in stream flow. When 500,000 acres are added to cover the probable sources of water outside the relief-defined boundaries of the drainage, stream flow amounts to about 14¼ percent of the precipitation.

WHY SUMMER PRECIPITATION CONTRIBUTES SO LITTLE TO STREAM FLOW

The summer rains contribute more than one-third of the total annual fall. They usually occur within a period of only 2 to 2½ months and as thunderstorms that may cause flash floods.

Raging torrents in stream courses that have been dry only a short time before are impressive, but the slight rise they usually cause in the water level of large reservoirs is equally impressive. Although summer storms occasionally deliver important quantities of water, any seasonal comparison of the flow data in Table 2 shows how little summer floods contribute to the average annual yield of Salt River.

Why only a small amount of the annual precipitation, particularly the summer part of it, is returned in stream flow has been the cause of much speculation. The present results of investigations on the Salt River watershed indicate that certain interactive influences, principally <u>character of storms</u>, <u>consumptive use</u> (including loss from evaporation), and <u>watershed peculiarities</u> determine the amount of precipitation water that is returned in stream flow.

Character of Storms

The amount of the precipitation that becomes surface run-off is greatest in summer and least in winter, largely because of the difference in character and intensity of rainfall during the two periods. However, a large percentage of the summer rainfall may run off the surface of small areas, particularly steep slopes, and yet the yield from the whole watershed be small. This diminishing return of rainfall from large drainage basins as compared with plots is shown by the results from experimental areas.

In our detailed investigations a battery of 10 paired installations, representing small areas with five degrees of ground cover, are employed to measure run-off where the rain falls. Here surface run-off amounted to nearly one-third of all the summer rain. But most of this run-off was lost before it reached the drainageway of the experimental watershed on which the plots are located.

On the head of this watershed, an area comprising 700 acres, rain in summer has totaled about 30 percent of the annual fall, but less than 1 percent of the annual run-off or flow has occurred during the same period. Such a small yield is explained by the stream becoming temporary in summer or as soon as the ground-water run-off from winter precipitation has drained from the shed. Hence the summer flow of such temporary streams is affected less by the carry-over of percolation water from winter precipitation than are permanent streams.

The data in Table 2 and Figure 5 are for the whole upper drainage of Salt River. They also show that only a small part of the summer precipitation is given off in stream flow. The data from the small drainage where the progress of surface run-off is measured go one step further.

They indicate that although a large part of the summer rainfall may run off small areas, only a little of it contributes to stream flow. These facts, however, must be considered with other related influences, in order to determine what becomes of the summer run-off in its journey from distant parts of the watershed to the reservoir.

Consumptive Use

The losses through evaporation and transpiration account for most of the difference between precipitation and water yield.

On the Salt River watershed evaporation from a free water surface is high. The annual average must be at least 3 times the average precipitation, and exceeds 80 inches at lower elevations. It is least for the period from November to March, about 2 or 3 inches monthly at lower elevations, and highest from May to August, 10 to 12 inches monthly. At Roosevelt Dam, from where standard Weather Bureau measurements are available for over 20 years, more than one-half the annual total evaporation occurs during summer. Comparable results have been obtained at medium elevations (Parker Creek Station). Such high evaporation exacts a tremendous toll from precipitation water before it becomes run-off or stream flow.

From what has been said concerning surface run-off and infiltration, it is apparent that most of the summer rainfall is returned to the air. The ground is dry when the summer rains begin, and water absorbed by the soil mantle is lost rapidly between storms. Thus there is no accumulation and percolation of water through deep soil layers as occur in winter, and surface run-off originating on one area is commonly absorbed and dissipated on others.

Evaporation and transpiration are so closely associated that they have been considered together in what has been said. Both may greatly exceed precipitation where moisture is available. This alone shows how necessary it is to consider the circumstances under which stream flow is affected by consumptive use of water.

Evaporation approaching anything like that measured from a free water surface may take place only during periods when the uppermost soil layers are saturated. Before maximum or even appreciable transpiration can occur, water must be available for the plants and temperature must also be favorable for growth. Under natural conditions the amount of transpiration during the principal growing period is governed by the amount of available moisture.

The findings at Parker Creek Station shed considerable light on the relation of vegetation to water losses. Both evaporation and transpiration are least during the cooler winter months, when percolation becomes established and water readily sinks and reappears as stream flow. In the spring, when most shrubs and trees begin to function and grow, rainfall declines, temperature rises, and the percolation chain through drained slopes is broken or disappears from soil layers in which the root systems of plants abound; and, except in some drainageways, the gravity water soon drains out. Thus during this period vegetation must function principally on water that is retained by the soils.

The late-spring, early-summer period is very dry. Ground water that might otherwise reach main streams is available to plants only along some drainage lines and depressions. The vegetation of drained slopes (more than 95 percent of that on the watershed) is adapted to conserve when it must. In the mountains vegetation fails to indicate any extensive underground reservoirs on which plants may draw, as there sometimes are in low valleys with water tables at shallow depths.

Perennial grasses make their growth, flower, and seed during the summer rainy period. Summer rains also revive most of the other kinds of plants; trees and shrubs have some roots near the ground surface and moist air conditions are favorable for growth. But the part of the rainfall that vegetation uses must first be absorbed by the soils. Shallow-sinking summer moisture, even if not used by plants, reaches ground water in a few wet places only, and for the most part is evaporated.

Evaporation is closely related to transpiration and varies in amount with the condition of the ground surface or the amount of vegetation cover. It represents a loss in water for which there is no return, as the forage, timber, and ground protection afforded through the transpiration of plants; it is an inorganic process that operates independently of the functioning of plants or other life; it goes on to a greater or lesser degree at all times and is not governed by state of growth and rest of living things; it is influenced less by seasons and circumstances than is transpiration; it may take place from all surfaces, including the ground, flowing water, and water impounded in reservoirs; and it even reaches beneath the surface of the soil to consume moisture there.

Our researches indicate at present that the control of evaporation is the most important consideration in any watershed planning for conservation of soil moisture. Other things being equal, evaporation from soils is least on plant-covered areas having the natural litter or duff that normal vegetation affords, and greatest on bare areas. When plant cover declines, transpiration, or at least the rate of transpiration, may be reduced, but more of the ground surface is exposed and water losses through the subtle influences of evaporation increase. Such changes in ground cover are particularly important in semiarid countries where evaporation is high and vegetation covers only a part of the ground surface.

In winter, when precipitation contributes most to stream flow, the evaporation from bare areas was found to be nearly equal to the evaporation and transpiration on normally vegetated areas. During summer, areas with plants lost more water (evaporation and transpiration) than was evaporated from similar areas bare of vegetation. This means that some additional soil moisture would be stored and carried over from one winter to the next if it were not extracted by plants during the summer.

However, such storage is small in amount and may take place only in areas without any plants. Under field conditions the normal number and character of plants may be changed, but any common means of bringing this about, as overgrazing and fire, does not entirely eliminate the old or keep out some new vegetation. It was also found that even a few plants consumed any available soil moisture. No more moisture was conserved through the summer in ground with scant, deteriorated vegetation than in ground having a good protective cover, the beginning of percolation in winter being about the same for both conditions.

These conclusions on percolation are based on detailed measurements at medium high and lower elevations on the watershed. Conditions affecting loss of precipitation water are somewhat different on the high-mountain mass at the extreme headwaters of Salt River. Precipitation is probably similar to that where some of the percolation measurements were made, but the temperature of the high-elevation area is lower. Thus because of snow and low temperature the period of draining away of winter moisture is retarded and the summer rains may reestablish percolation in damper locations. However, until measurements are made in the high country, we may assume that here also the amount of percolation water from summer rains is small, for the total high-mountain area is less than one-fifth of the Salt River drainage and the data show that substantial increases in stream flow seldom occur during the summer rainy period.

Watershed Peculiarities

Many of the conditions peculiar to southwestern watersheds have been previously mentioned. Here they are considered collectively in order to point out their interactive influence on water losses.

Summer Thunderstorms

Winter moisture comes in general and protracted falls as cyclonic storm areas move inland from the Pacific Coast region, whereas summer storms originate through penetrative convection of high-level anticyclone areas. Such penetration is local. It occurs here and there where convection is perfected through high ground-surface temperature. The result is local showers at the beginning, more nearly general thunderstorms at the height of the season, and in scattered falls as the summer wanes. In his excellent discussion of the North American anticyclone, Reed[4/] states,

> The anticyclone, being distinctly a warm-season phenomenon, makes its first appearance in the spring, but it does not become fully established until mid-summer. It reaches its maximum development in July and August, and disappears, except for sporadic recurrences in October. It appears first over Mexico and moves northward as the season advances, retreating to Mexico as the warm season wanes.

4/Reed, Thomas R. The north american high level anticyclone, Monthly Weather Review, Vol. 61, No. 11, W. B. No. 1117, Nov. 1933.

This period of anticyclonic storms includes the "summer rainy period" of this analysis, which was determined on the basis of the distinctive characteristics of the rainfall.

The amount of precipitation water returned in stream flow is tremendously influenced by the widely different circumstances during the two rainy periods—general storms, low-intensity rainfall and snow, and low temperature in winter, as compared with local storms, high-intensity rainfall, and high temperature in summer. Winter storms result in depth penetration of water, seepage into stream courses, and the like, simultaneously over large areas, whereas scattered summer storms make for local surface run-off only.

Local Rains and Run-off on Areas Without Permanent Streams

The lack of permanent streams makes the local surface run-off from summer storms an ineffective source of stream flow on most of the Salt River area. Run-off may attain considerable volume on storm areas, but on leaving them must roll down long dry canyons and washes and is commonly lost where there are no permanent streams. Even where streams are fed by deep effluent seepage but become temporary in places through channel losses, any increase in flow from surface run-off may be absorbed in part or whole through the dry sections. In comparison, such streams run for long periods in winter; even the more temporary of them usually carry water during the same intervals. Hence, in winter, surface water originating almost anywhere on the drainage stands a good chance of reaching the main river through the myriads of drainageways having flow during that season.

The local character of summer rainfall results in tremendous loss of surface run-off. It may rain somewhere almost every day during the summer rainy period. It sometimes rains at numerous points on the same day but these rains usually are widely scattered and consequently most of the run-off must pass long distances through dry areas en route to living waters. Such routes commonly traverse deep geologic deposits where flash flows may be absorbed and later consumed before some succeeding flow.

Comparative Distribution of Summer Rainfall

In order to obtain a measure of the comparative daily distribution of rainfall during the summer and winter rainy periods, data from 7 of the Weather Bureau stations listed in Table 1, namely those for which complete daily records were available over an extended period, 1926-36, inclusive, were analyzed. The results are shown in Figure 9, in which August, the month with most nearly general summer rains, and January, a month having typical winter storms, are compared. Each point plotted is the percent of the total precipitation for all stations that fell at one or more of them on the same day. To illustrate, 13 percent of the August rain fell at no more than 1 station on the same day, although it included several rains which occurred on different areas.

The greatest differences in the distribution of summer and winter fall are found where more than four stations are involved. The sum of the rain that occurred at only one and up to as many as four stations equals 75 percent of the August total, but only 40 percent of the January total. These values have greater significance when it is known that four of the seven stations lie within a radius of less than 15 miles, while the greatest distance between any two of the other three is about 100 miles. When station location is given full consideration,

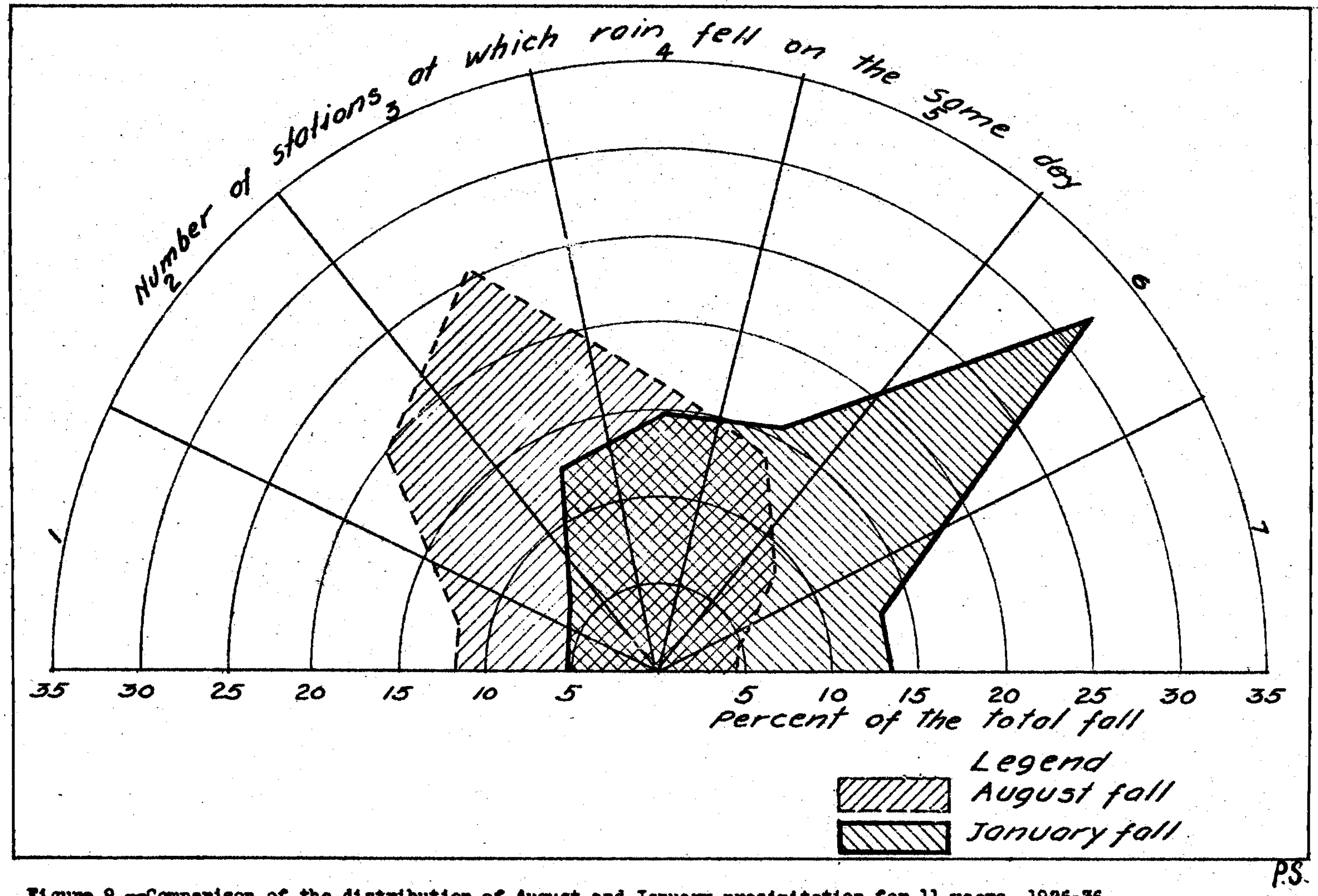

Figure 9.—Comparison of the distribution of August and January precipitation for 11 years, 1926-36.

the local nature of most of the summer storms is quite apparent. More than half of the August rain was so local in occurrence that the fall spread to no more than three of the seven stations, whereas only 13 percent extended to more than five stations. In contrast, 45 percent of the January fall is spread far and wide over the drainage.

Summer rains sometimes occur at a number of widely spaced stations on the same day. However, our observations during several years show that even within a radius of 20 miles, rain at a number of points on the same day is commonly the result of fall on more than one distinct rain area or several local rains with dry areas between their margins. Time-gage records show the usual lack of simultaneous occurrence of rains that has become so noticeable with modern travel. That is, during the same 24 hours it may rain at one point in the morning, at others in the afternoon, and still others at night. This scattered character of the fall and the failure of the run-off from one area to synchronize with that on others tends to make for dissipation of surface waters before they become a part of permanent streams.

Unproved Practices for Increasing Run-off may Result in Permanent Injury to the Watershed

Of the many factors affecting run-off, only one—vegetation—is controllable to any degree by man. The lack of appreciation of the tremendous influence of other factors has sometimes resulted in vegetation being held responsible for the small part of the total precipitation that is delivered in stream flow. Just how much widespread control of vegetation through different systems of watershed management may affect the total yield of water is unknown. Until the results of commonly effected changes are better known and understood, any attempt to increase water yield through wholesale destruction of the protective ground cover of natural vegetation may be regarded as extremely dangerous.

We know that vegetation greatly aids infiltration and checks the rate of run-off from the ground surface. Percolation, the principal means by which rain water that sinks into the ground reaches streams under natural conditions, may be easily diminished and hindered through the removal of protective ground cover, because the surface of bared ground tends to seal, and the spaces between the soil particles and even the seams in underlying rock tend to clog. Thus through the destruction of protective ground cover, winter precipitation water may be diverted from age-old underground courses and retained on or near the ground surface where it is subjected to excessive losses, as from evaporation.

The rate of flow from slopes where run-off originates may be increased tremendously by decreasing the protection afforded by vegetation, so much so that destructive soil erosion becomes a menace in a short time. However, as we have already seen, there is as yet no factual evidence or assurance that increases in annual river flow may be had through acceleration of the summer run-off which causes most of this erosion.

It is accelerated erosion, which results from the destruction of vegetation, to which we wish to call attention here. Silt will eventually ruin the storage capacity of any retention reservoir. Hence, in the economic planning of reclamation projects the life expectancy of such works is taken into account. But silt becomes a menace whenever the rate of silting which takes place under the natural cover of protective vegetation becomes accelerated through deterioration of that cover. Moreover, the injury that may result through trial-and-error methods of increasing water yield today may not be readily controllable or even controllable tomorrow. Once accelerated erosion of semiarid mountainous lands attains an advanced stage, the control of it becomes very difficult. This may be illustrated by the measurements on 7 experimental drainages where the grasses of an original mixed grass-and-shrub cover were grazed out. Here, after 10 years of virtual protection, vegetation has improved but not sufficiently to control erosion. During the last half of this period (5 years), an average total of about one-third inch of soil was washed from all drainages—6 acres—and as much as one-half inch from some of them.

PRECIPITATION-STREAM FLOW RELATIONSHIPS IN THE LOWER PART OF SOUTHWESTERN WATERSHEDS

Because of artificial regulation of flow, as through storage dams, it is impossible to make any analysis of precipitation-stream flow relationships in the lower part of the Salt River drainage. The Santa Cruz River above Tucson, Ariz., may be used to illustrate the peculiarities of flow through the lower courses of main streams, although circumstances make for some differences in precipitation on the Santa Cruz, as compared with Salt River watershed. Santa Cruz has no large high mountain masses; the higher parts of the drainage are narrow ranges without extensive areas of rugged relief and corresponding high rainfall. Consequently, average precipitation for low-elevation areas and for the drainage as a whole is less than for Salt River.

In the study of the Santa Cruz, available data for the 21-year period 1916-36 were grouped in a manner similar to that shown in Table 1, records from the Weather Bureau stations Helvetia, Nogales, and Tucson being employed for high, medium, and low rainfall, respectively. On this basis, the average summer fall, June to September, inclusive, equals 9.17 inches, and the winter, 6.57 inches, or an average total annual of 15.74 inches, of which 58 percent occurs in summer and 42 percent in winter. The stream-flow records at Tucson show an average Santa Cruz flow of 13,312 second-feet in summer and 2,402 second-feet in winter, or 85 percent and 15 percent, respectively, of the average annual total of 15,714 second-feet.

See errata sheet

Any comparison of Figures 10 and 2 shows that these data for Santa Cruz differ widely from those of upper Salt River, but principally as to the large percent of the total annual precipitation and stream flow on the Santa Cruz that occurs in summer. However, the flow of Santa Cruz is influenced by circumstances other than the amount of fall. Practically all the regular surface flow of the stream is diverted above the gaging point at Tucson. Here the channel becomes dry for intervals, and flash surface run-off from torrential summer thunderstorms is the principal measured flow.

But the measured flow is only the surface flow, and the unmeasured subflow in the deep deposits through the broad Santa Cruz valley must be taken into account in any consideration of total water yield. Ground-water run-off here, as on Salt River drainage, must be largely from winter precipitation. Summer flows usually are short-lived flash floods, whereas in winter the discharge of the mountain tributaries of Santa Cruz is continuous for months. Winter flow comes to the surface in the mountains but sinks where stream channels become sand washes in the valleys. That sub-surface flow greatly exceeds the small surface flow

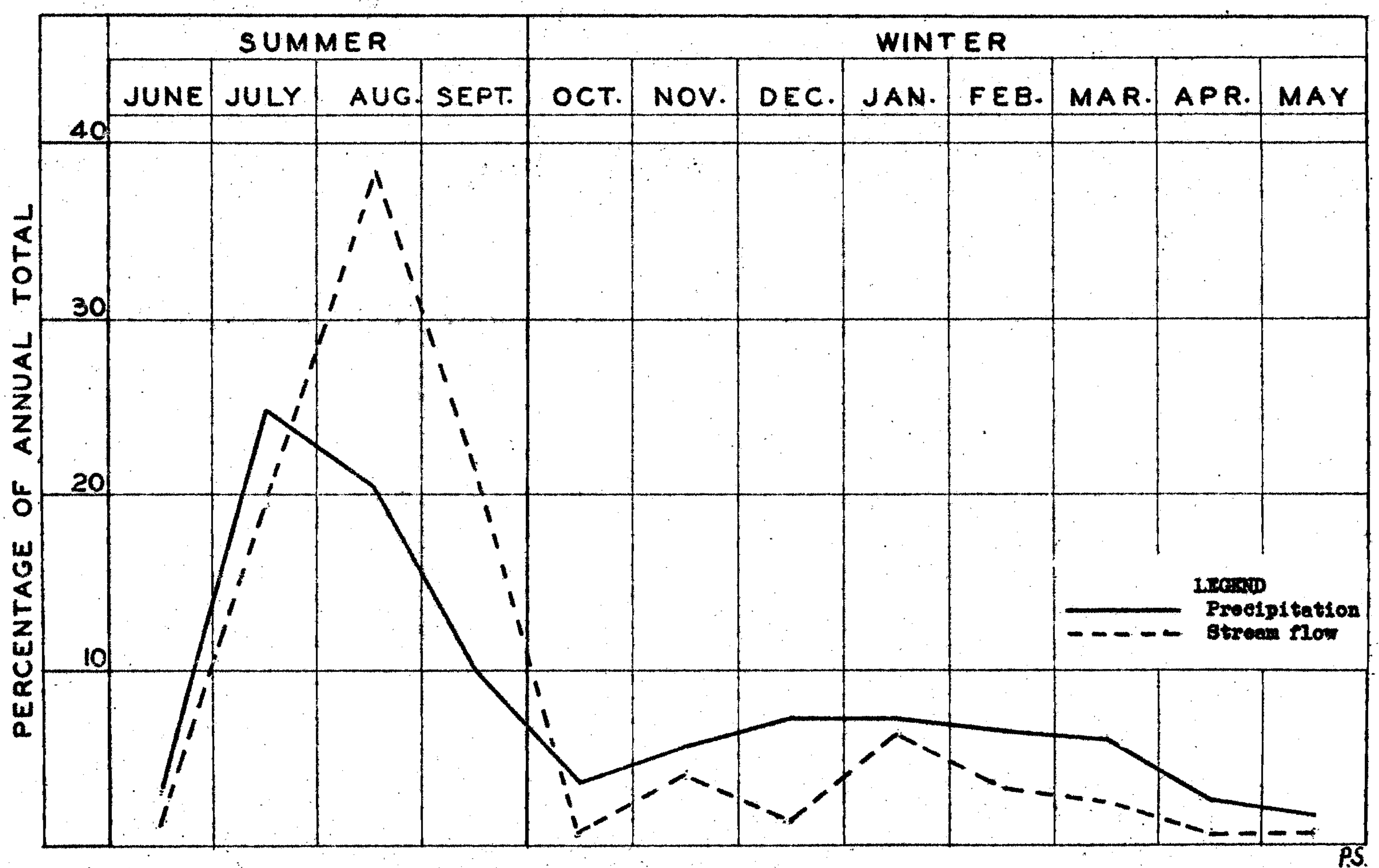

Figure 10.—Distribution of precipitation and stream flow on the Santa Cruz watershed above Tucson, Ariz., for 21 years, 1916-36.

is indicated by the extensive areas that are irrigated through water pumped from the valley above and below the gaging station.

In any event, the total flow per unit area of the Santa Cruz watershed must be small, as compared with Salt River. This is to be expected. The winter rainfall is also small, being only about 6½ inches, whereas on Salt River it is 12 inches. Furthermore, relief, soil mantle, and other circumstances that affect yield through ground-water run-off are considerably different on the two watersheds. The Santa Cruz has large outwash plains and valleys with rolling or regular relief and deep soils and geologic deposits, whereas rugged relief, shallow soils, and a lack of large valleys with deep deposits are typical of the Salt River drainage.

When due credit is given the unmeasured subflow and also the fact that it must result principally from winter precipitation, the seasonal relationship of water yield to precipitation in Santa Cruz must be similar to that of Salt River drainage.

APPLICATION OF FINDINGS IN WATERSHED MANAGEMENT

In this analysis the principal circumstances surrounding the water yield of Salt River basin have been considered, insofar as present information permits.

Salt River Compared With Other Drainage Basins

Work enough has been done to indicate that the findings on Salt River drainage are applicable to a greater or lesser degree to other southwestern watersheds. The upper Rio Grande and Colorado drainages have large mountainous areas, where precipitation is high and much of the fall occurs as snow, and correspondingly low-plains areas having only low rainfall. Hence, in comparison with Salt River, the total water yield per unit of watershed area is lower, probably very low from the parts below 7,500 feet in elevation, and the build-up of flow in winter reaches a maximum later. On Gila drainage the water yield on rugged mountainous parts is similar to that on Salt River, but the total flow of the Gila River tends to be limited by the large low-elevation, low water-yielding areas below the mountains. A preliminary analysis of data from the Verde River drainage below Del Rio, or the part exclusive of the Chino Valley, gives similar results to those obtained on Salt River watershed.

The Problem of Local Water Supplies and Total Water Yield

The discharge of any main river is the result of different conditions and circumstances on the watershed. Consequently, the relationships between fall and flow on parts of a drainage, as compared with the whole, may differ widely. To illustrate, this analysis indicates the importance of winter precipitation to the annual flow of main rivers. However, it is common knowledge that surface run-off from summer rains ordinarily supplies the only water of importance in the filling of stock tanks and in flood-water irrigation. But here no provision is made for collecting the underground flow. The usable supply is from local areas, and ditching and control of vegetation are commonly practiced to increase surface run-off.

The surface run-off from some local areas may affect the yield of the whole watershed but little; and should the methods of increasing it be practiced generally, losses of valuable watershed vegetation and soils, destructive silting of streams and water systems, and increased flood damage would undoubtedly be the result. Hence the procuring of local water supplies and the obtaining of maximum amounts of usable water from entire drainage basins are distinct problems in watershed management. Nevertheless they are problems to be considered jointly, for what is of benefit locally may be detrimental at large, and where conflicts arise there is the necessity for the consideration of the greatest lasting public good.

The Importance of Seasonal Rainfall Relationships in Watershed Management

Summer rains contribute only a small part of the average flow of Salt River. However, some large and important flows have occurred in summer. It is the usual small flow and the infrequency of large flows in summer and not the importance of some given amount of water to which we wish to call attention. The real significance of seasonal fall-flow relationships lies in the importance of such knowledge in watershed management. An understanding of the relationship of seasonal precipitation to the yield of water, the growth of protective ground cover, and the behavior of run-off and soil erosion is essential in any comprehensive watershed-management planning in the Southwest.

Winter precipitation may be considered to give us our dependable water supply for irrigation, industry, and town, whereas summer rains bring forth the herbaceous growth that completes the natural ground cover, which cover regulates run-off, keeps streams cool and clean, aids in the age-old process of soil building and retention, provides forage for livestock and game animals, and makes wild lands desirable for pleasure as well as for financial profit.

Winter Period

In winter, water reaches the streams largely through ground run-off. During this period the fall is of low intensity or occurs as snow, hence the degree of soil erosion is less than from the torrential rains and surface run-off of summer. The protracted flows of winter do carry on the debris discharged into stream channels by summer torrents and may cause stream-bank erosion. Also, in draining through the ground, winter rain water leaves behind the moisture that fosters the watershed protection afforded by deep-rooted vegetation—trees and shrubs.

Summer Period

In comparison, summer precipitation seldom sinks so deeply into the ground as to escape, being rapidly returned to the air. Hence it contributes to streams almost entirely through surface run-off which, although it may result in destructive and rapid erosion, usually is dissipated in large part before reaching any permanent stream.

Summer rain, however, does play a most important part, indirectly, in watershed protection. Grasses make their main growth during the summer, and grasses constitute an indispensable part of the natural protective ground cover on every southwestern drainage basin. On about 75 to 95 percent of these areas climate and other factors prevent forest and brush field growth so dense that the canopy above and the litter on the ground may afford all the protection that nature usually provides. Here grasses are the well-distributed, close-to-the-ground growth that fill in the spaces between and below the crowns of trees and shrubs, that aid in protecting the soils from the destructive action of sun, wind, rain, and surface run-off, that are necessary in most forests to hold tree litter in place, and that complete and make fully effective the protection afforded by other vegetation. Decline of grass is also the most common cause of land deterioration, for the only general watershed use is grazing, and grasses are the most desired and most closely eaten forage plants.

Vegetation an Indicator of Water Yield

The amount and seasonal distribution of the precipitation on different areas, and hence the degree to which they may be expected to contribute to stream flow, is usually indicated by natural characteristics. Lands of rugged relief, when of large area, commonly receive a high winter as well as high annual fall. Saw-timber forest areas, including high mountain parks, receive more than twice as much precipitation as falls on the pinon-juniper woodlands. Mountain brush lands indicate a high winter fall and a good return of it in stream flow, whereas grasslands have more summer than winter precipitation and a comparatively low water yield. In the comparison of the Salt River basin, a typical brush-and-forest drainage, with the Santa Cruz basin, which has large areas with semidesert grassland vegetation, the respective precipitation data are, average annual fall 20.26 and 15.74 inches, summer fall 7.91 and 9.17 inches, or 39 and 58 percent of the annual totals.

Control of Surface Run-off in Relation to Water Yield

Management is concerned with both watershed protection and water yield. The natural, most effective, and most economically maintained protection is through vegetation. Mechanical works, such as storage dams, are necessary to control water supply and provide flood protection beyond that afforded by natural vegetation, but they should not be expected to take the place of it. Before dams are built, provision must be made for adequately protecting watershed vegetation or it means not only rapid siltation and consequent rapid decline in the efficacy of such artificial structures but also loss of sites, of which there may be no others on the watershed.

Where watershed deterioration has occurred, still other works and practices that hasten revegetation or which counteract the effects of cultural activities and the disturbances brought about by modern improvements, such as roads, may be needed. Some mechanical works may impound or divert surface run-off. Much investigation remains to be done before knowledge of their effect on water yield may be considered adequate to meet even the more urgent of existing demands. The results of this investigation show the very large amount of the total water yield that is from ground-water run-off. <u>They do not support any belief that material losses in stream flow must result from the control of accelerated surface run-off</u>.

Let us now examine some typical examples of control of surface run-off in the light of their effect on water delivery.

Effect on Ground-water Run-off

Where ground water is the usable supply, the recharging of underground basins is necessary for the perpetuation of dependent developments. Here the sinking of flood waters that would otherwise flow beyond the point of water storage undoubtedly is beneficial.

In the treatment of eroded wild lands, the usual purpose in detaining surface run-off, as through retards, furrows, and checks, and even in spreading water, is to restore, or at least to provide a substitute for, some former and natural condition. In general, practices patterned after what occurs in nature may be expected to interfere least with the natural processes of water delivery. To illustrate: Structures that aid in the sinking of surface run-off in locations where rain water did or does sink would not be expected to result in any decrease in stream flow. On the contrary, when rain water that now produces abnormal amounts of surface run-off is returned to long-established underground passages, where it is protected from evaporation, the total yield may be larger than otherwise. However, diversion of water from productive channels onto non-water-yielding lands can be justified only where the attending benefits compensate for the water used. This also applies to the impounding of water in dams in locations where it may not sink and contribute to ground-water run-off.

Silt Control a Prime Necessity

The benefits of controlling silt on lands where surface run-off has become accelerated through deterioration of vegetation may far more than offset any possible loss of water. In this connection, it is well to keep in mind that the problems arising from abnormal silting are the result of only the beginning of general break-down after 50 to 75 years of our use of land. Unless deterioration is checked and eventually controlled, it may be expected to overwhelm all efforts to cope with destruction, as has been the case in some long-used but similar semiarid parts of the old world. In fact, we need look no farther than to the worse spots of destruction and consider the far-reaching effects they have in this country for ample proof of the necessity of controlling floods, land break-down, and siltation.

Floods—the eminent and direct forces of destruction—have been the most appreciated of any of the damaging effects of accelerated run-off. The menace of silt is becoming better realized as serious depositions in reservoirs and water systems become realities and not just possibilities for future consideration. There has been the tendency to think in terms of the number of years that may be required to fill large reservoirs with silt rather than of the serious water shortage that may be suffered during years of low stream flow and of the cost of providing additional storage when the capacity of most reservoirs is only in part replaced by silt.

Low Water-yielding Areas May Have High Protection Values

On low mesas and plains the total precipitation is low and the water yield under any circumstances must be small. Here the value of forage and the protection that forage plants afford to improvements as roads, railroads, and irrigation systems, as well as irrigable valley lands, must be far greater than the value of any water that might be lost because of such lands having protective vegetation or artificial works where they are needed to restore deteriorated vegetation and land to good condition. Similar conditions prevail in low alluvial valleys. Many of them have become channeled and are now the source of tremendous quantities of silt.

Vegetation in Relation to Water Yield

Where watershed vegetation is in good condition, the question commonly arises whether such growth is maintained at the expense of stream flow. Likewise, any consideration of practices for bettering deteriorated vegetation and lands usually raises the issue of whether such action may not result in the decline of some existing water supply. There is nothing to indicate that water supplies have increased in amount during recent years, whereas there is abundant evidence that vegetation has deteriorated on parts of most watersheds.

The Salt River basin data show no material gain nor loss in the amount of stream flow during the 35 years between 1902 and 1936 that may not be satisfactorily explained by corresponding differences in the amount, character, and distribution of the precipitation. Insofar as watershed vegetation is concerned, this result may be explained through one of three possibilities: (1) There may have been no important changes in ground cover during the period; (2) perhaps the effects of decreases in vegetation in some places were compensated by increases in others; or (3) decreases and increases of vegetation, within the limits of those that must have taken place, had no material effect on the total amount of stream flow. It is difficult to reconcile the first of these with any knowledge of past and present conditions on Salt River basin; the second, although possible, is very improbable; but the third has support in the results of investigations on the Salt River watershed. The data shows that in winter, the period of greatest water yield, vegetation aided ground-water run-off; that in summer the smaller and lighter falls were consumed whether vegetation cover was good or poor, these losses being mainly evaporation on poorly vegetated areas and transpiration on well-covered ground; that only large and intense falls produce appreciable run-off in summer and that for the most part such run-off is dissipated before it reaches any permanent stream; and that the part of the annual flow from summer rains is naturally so small that even material increases or decreases in it would result in only slight changes in the amount of water yield.

Control of Vegetation in Watershed Management

From what has been presented, it is apparent that methods for obtaining increases in water yield through destroying and even thinning and changing vegetation must be proved before they may be practiced with any degree of safety. Deterioration of vegetation is accompanied by deterioration of soils, and vegetation and soils cannot be replaced at will. In semiarid regions particularly, it takes only a short time to decrease the amount and change the character and protective qualities of the natural vegetation, whereas nature required ages for the development of both vegetation and soils. Although some increase of surface run-off may be obtained through general destruction of watershed vegetation, the possibility of increasing the total water yield through such means is very limited and is fraught with great dangers. By general destruction of vegetation is meant lessening of the amount, change of character and decline in protection afforded by vegetation throughout a watershed and through known destructive means, as fire and overgrazing.

The results of this study do not permit of any discussion of unproved but probable means of increasing water supply, as through robbing the water-loving vegetation of canyon-bottom forests in the mountains and riverside growth in the valleys, through leading run-off over places where it ordinarily is dissipated, and through possible control of evaporation. However, the proving of methods before applying them holds here wherever vegetation is concerned; otherwise, destructive forces may be set in motion, which may result in damages that would far outweigh the value of any additional water obtained and even destroy the very water systems and lands for which water was sought. How to obtain the most water from any watershed is something that must still be determined. But it is well known now that indiscriminate destruction of the vegetation always results in the loss of forage, timber, wildlife, and recreation resources and, above all, in the destruction of the protection that prevents soil wastage and the choking of streams and water systems with silt.