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ARIZONA
STREAM FLOW SUMMARY

Colorado River Commission of Arizona
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COLORADO RIVER COMMISSION
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Capitol Building
PHOENIX, ARIZONA

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March - 1940

INTRODUCTION

The topographical features of the Colorado River basin naturally divide the whole basin into two sub-basins, which have been popularly called the upper and lower basin. A short distance below Lee's Ferry, Arizona, which is about 720 miles about the mouth of the main stream, the Colorado River enters the canyon section and traverses this section for nearly 300 miles through the deep canyons and gorges of the Grand Canyon, from which it emerges into Lake Mead, formed by the construction of Boulder Dam, some 355 miles below Lee's Ferry. Lee's Ferry thus becomes a natural point of division between the "upper basin" and the "lower basin".

The drainage area of the entire River system comprises approximatel 262,500 square miles, or about 1/13th the area of continental United States. This area is about equally divided between the upper division, namely, Colorado, New Mexico, Utah and Wyoming; and the states of the lower division Arizona, California and Nevada. Prior to 1922 the lower basin had been growing more rapidly in population than the upper, and the reclamation development was progressing rapidly. Each year saw a larger diversion and beneficial consumptive use made of the Colorado River water. The Imperial valley, lying below sea level and waging a losing battle against the rising bed of the River, was reaching a point where the continued increase in the height of the levees was nearing an end, and the erection of a flood control dam and an All-American water supply was vigorously advocated. In April, 1922, a bill was introduced

in Congress asking for Federal assistance in building a storage dam upon the River in the vicinity of Black Canyon, and asking for the construction of the All-American Canal. Arizona was formulating plans for projects in the area adjacent to the Gila River in the vicinity of Yuma, Arizona, and had plans for the development of a large area in the vicinity of Parker, and had listed many other projects for investigation, all of which would require a large amount of water for their full development. The development below the International Boundary line in Mexico was also progressing rapidly, and more and more water was being diverted to these lands.

It was evident that the normal flow of the Colorado River would not be sufficient to meet the demands of the established irrigation projects and the planned projects in both the upper and the lower basin. The States of the upper basin urged, and insisted, that a Compact dividing the water between the Basin States should be negotiated before further development resulted in probable litigation. This resulted in the formulation of the Santa Fe Compact, which was signed on November 24, 1922, by the delegates from the states of Arizona, California, Colorado, Nevada New Mexico, Utah and Wyoming.

The negotiations which preceeded the signing of the Compact by the representatives of the compacting States were long and arduous. Originally, the delegates had hoped to divide the water among the seven individual States, but after much negotiation it was found that no agreement could be reached on this basis, and the plan was abandoned. The water was then divided between the two basins, leaving to the future the allocation and division of water between each of the States in the two basins Lee's Ferry being a natural point of division, it was selected as the point of division between the two basins, the upper basin consisting of

drainage area above Lee's Ferry and the lower basin comprising the drainage areas below that point. Colorado, New Mexico, Utah and Wyoming thus formed the upper division, and California, Arizona and Nevada the lower division.

It is necessary to draw a find distinction between the words "basin" and "divisions". Each includes small areas of States assigned to the opposite division, and this fact has been taken into account in the accompanying report.

The principal reason why it was impossible during the compact negotiations to divide the water among each of these seven basin States was due to the fact that the problem required knowledge of the stream flows in each of the States, and the relation of the present flow, present and anticipated consumptive use, and a knowledge of the virgin contribution from each State.

The subsequent hearing before Congressional committees indicated that the reconstructed flow for the entire River system had been estimated by the various delegates to be from 19,000,000 to 22,000,000 acre feet. A summary of the reconstructed flow prepared by Mr. R. I. Meeker, who assisted Mr. Delph E. Carpenter, the representative from Colorado, and who is recognized as one of the leading authorities on the subject in the early compact negotiations, will be found printed in Mr. Carpenter's statement in the hearing on Sen. Res. 320, pp 691 to 693, December 1925. In this summary, the flow from the upper basin is given as 17,000,000 acre feet, and that from the lower basin as 4,600,000 acre feet. The Arizona contribution to the lower basin is 3,852,000 acre feet, that of Utah and Nevada, 300,000 acre feet, and that of New Mexico, 443,000 acre feet. These figures, apparently, represent the natural contribution from the catchment areas and are not reduced by evaporation and other River

losses.

In Senate Document No. 186, 70th Congress, 2nd Session December 1928, is a summary of Colorado River investigations, reports, and hearings prepared by Mr. George W. Malone, a former State Engineer of Nevada, who was active in Colorado River matters for several years, and who had made many investigations and studies pertaining to the matter. On pages 79-81 of this Report, Mr. Malone presents figures on reconstructed flow. The upper basin is credited with 16,600,000 acre feet and the lower basin with 4,600,000 acre feet. For the lower basin, Mr. Malone evidently used Mr. Meeker's figures for details, but charged off 1,000,000 acre feet for evaporation and River losses between the Black Canyon and Yuma, and 500,000 acre feet for evaporation and River losses on the Gila. Net figures for the lower basin are, therefore, 3,100,000.

If Mr. Meeker's estimate of the contributions of Utah and Nevada (300,000 acre feet) is deducted, the balance, or 2,800,000 acre feet, should be comparable to the contributions of 2,151,300 acre feet by Arizona and New Mexico as given in the accompanying report. Meeker gives 443,000 acre feet as New Mexico's contribution to the Gila Basin. He gives none for the Little Colorado River. The accompanying report gives New Mexico's contribution to both Rivers at the State line as 186,300 acre feet.

For the upper basin, Malone obtained his figures from tables in LaRue's Water Service Paper 556. La Rue did not present figures on "reconstructed" flow at Lee's Ferry, but such figures can readily be derived from his tables. In 1934, LaRue's tables were brought up to date and from the extended tables a reconstructed flow of 16,100,000 acre feet was derived for the upper basin. The reduction of 500,000

acre feet was due, no doubt, to the presence of several low years in the period between 1922 and 1935. This condition is shown to exist in the stream flow records in the accompanying report.

In 1938, Mr. Royce J. Tipton, Consulting Engineer, of Denver, Colorado, prepared a report entitled "Water Supply of the Colorado River and Allied Matters" for the upper Colorado River basin committee. In Mr. Tipton's report, he has summarized and compared the estimated flow of the Colorado River at Lee's Ferry as found by various authorities, and has added to these various estimates the record flow for the missing years and has brought the records to the date of 1937. By taking LaRue's 1922 figures, which he terms "LaRue's Estimates" and adding the records from 1922 to 1937, he gets a mean annual discharge of 14,217,000 acre feet for the 1902 to 1937 record. Taking the record between 1897 and 1937 the mean annual discharge was found to be 14,351,000 acre feet.

By taking Mr. Debler's 1930 estimate and adding the record to bring it to the date of 1937, then Mr. Debler's figures would show between the years of 1902 and 1937, the mean annual discharge at Lee's Ferry to be 14,528,000 acre feet. By bringing Mr. Debler's 1934 estimate to the date of 1937, which includes the record for the years 1897 ato 1937, the resulting discharge was found to be 14,648,000 acre feet. By taking the 1902 to 1937 year records, the mean annual discharge was found to be 14,543,000 acre feet. Taking Mr. Tipton's estimate for the years 1902 to 1937, the discharge was found to be 14,484,000 acre feet. Taking the years 1897 to 1937, the mean annual discharge at Lee's Ferry, as found by Mr. Tipton, was 14,401,000 acre feet.

Mr. Tipton concludes from his studies of the water supply at various points in the basin under virgin, present and estimated ultimate conditions, for such periods as 1897 to 1937 to be as follows:

For the entire basin, including the Gila River, under virgin conditions, the water supply amounted to 18,000,000 acre feet. At present, the available supply is 11,600,000 acre feet. It is estimated that the water flowing into Lake Mead, under virgin conditions, would have been 17,400,000 acre feet,-under present conditions, 14,800,000 acre feet, and ultimately, 9,000,000 acre feet. The water passing Lee's Ferry, under virgin conditions, would have been 16,400,000 acre feet, under present conditions, is 14,200,000 acre feet, and ultimately, 8,900,000 acre feet will pass this point. This indicates the present consumptive use of 2,200,000 acre feet in the upper basin and 4,200,000 acre feet in the lower basin, and the ultimate consumption of 7,500,000 acre feet in the upper basin and from 8,500,000 to 9,300,000 acre feet in the lower basin.

Mr. Tipton in analyzing the ultimate upper basin's consumptive use and surpluses and deficiencies in deliveries based on 10 year progressive mean, as measured at Lee's Ferry to be as follows:

Taking the mean for the total record between the years 1897 and 1937, the estimated mean upper basin consumption as allowed under the Compact will be 7,500,000 acre feet. The estimated mean flow at Lee's Ferry for the same period is 8,975,000 acre feet. The estimated surplus for the same period is 1,475,000 acre feet.

Another interesting point in the study of this data as presented by Mr. Tipton, is the marked effect of the last few years upon the mean as compared to the long time records. This condition is pointed out in the accompanying report.

In December, 1937, a joint report to the Secretary of Interior was prepared by Joseph Jacobs and J. C. Stevens, Consulting Engineers, of Denver, Colorado, on the surplus waters of the Colorado River system.

This is a very comprehensive report and includes much factual data of very great value. In their analysis they have reached certain conclusions with respect to the water supplies of the basin. In the report by Messrs. Jacobs and Stevens, they have estimated the mean annual flow of the Colorado River for various conditions. Five stages of development were selected for consideration, as follows:

1: Historical, representing conditions in the sequence of development as actually made to date.

2: Virgin, representing conditions prior to any development by man.

3: Present, representing conditions as of 1937.

4: Early, representing conditions when all projects for water utilization now under construction and those definitely authorized have been completed. Under this heading, the provision is made for a moderate expansion of existing projects. No specific date was set for this consummation, but about 1950 was the date selected as adequate.

5: Ultimate, representing conditions when all feasible projects for water utilization have been completed and the basin shall have reached its highest practical state of development with regard to water resources. No definite date can be fixed for the attainment of the ultimate development, but it is believed it should be realized within the next 50 years, or about the end of the century.

In the studies made by Messrs. Jacobs and Stevens, the entire basin was broken down into sub-basins. The estimated mean annual discharge of the Colorado River above Lee's Ferry, Arizona, for the period 1897 to 1937 under virgin conditions, was estimated to be 16,270,000 acre feet. Under historical conditions, the discharge was estimated

to be 14,650,000 acre feet, under present conditions, 14,284,000 acre feet, and ultimately, 9,922,000 acre feet. Considering the Little Colorado River above Grand Falls, Arizona, including Moenkopi Wash, for the period 1926 to 1937, under virgin conditions, the discharge would have been 298,000 acre feet, historically, 258,000 acre feet, at present, 255,000 acre feet, and ultimately, 87,000 acre feet annually.

Considering the Colorado River between Lee's Ferry, Arizona, and Boulder Dam, excepting therefrom the Little Colorado River, for the period of 1879 to 1937, under virgin conditions, the mean annual discharge would have been 17,285,000 acre feet, under historical conditions, 15,523,000 acre feet, under present conditions, 15,145,000 acre feet, and ultimately, 10,292,000 acre feet.

The Gila River, above the mouth, for the period 1897 to 1937, the mean annual discharge under virgin conditions would have been 1,434,000 acre feet.

For the entire Colorado River system within the United States as measured at the upper boundary between the United States and Mexico for the period between the years of 1902 and 1937, the mean annual discharge under virgin conditions would have been 17,850,000 acre feet. Under historical conditions, the mean annual discharge would have been 12,699,000 acre feet. At present, the discharge is 11,401,000 acre feet.

It can be readily seen from the foregoing that there has been a great divergence of opinion regarding the water supply of the Colorado River and its tributaries. Obviously, there may be difference in opinion regarding the water supply of the streams in Arizona tributary to the Colorado River. Therefore, in the preparation of the following report, every effort has been made to place this data in such a form that it may

be readily interpreted by others, and the methods by which conclusions have been reached are given in detail.

In reducing a stream flow to virgin conditions, there must be taken into consideration the relation of the water beneficially used to the water formerly naturally lost. Under virgin, or natural, conditions, the stream losses were very extensive, due to great growths of natural vegetation in the river channels, making the channels broad and the overflow areas extensive. This led to great losses, due to evaporation and transpiration from the native vegetation.

The use of water by cultural activities of man, within certain limits, has decreased materially the natural losses of water, by diverting the water from river channels and, thereby, decreasing the size of the channel and the area of overflow. In many instances, also, the lands which formerly were covered with natural vegetation and, in some instances, subject to overflow, have been put under cultivation by man, therefore, actually, not reducing the virgin flow. There are reliable records which show that during the historical period, large areas of land have been brought under cultivation with little increase in the total loss of stream flow.

RUN-OFF CONTRIBUTION OF ARIZONA TO THE UPPER AND LOWER COLORADO RIVER BASINS AND OF NEW MEXICO TO THE LOWER COLORADO RIVER BASIN.

For convenience, the study was made in seven parts as listed below. The colored sheets indicate the beginning of each new section.

1. SUMMARY OF STREAM FLOW OF COLORADO RIVER UPPER BASIN IN ARIZONA (2 sheets of computations, 2 sheets of notes).

2. SUMMARY OF INFLOW TO COLORADO RIVER BASIN FROM ARIZONA BETWEEN LEES FERRY AND BOULDER DAM EXCEPT THAT FROM PARIA AND LITTLE COLORADO RIVERS (2 sheets of computations, 8 sheets of notes, 1 chart).

3. LITTLE COLORADO RIVER BASIN STREAM FLOW SUMMARY (3 sheets of computations, 6 sheets of notes).

4. LITTLE COLORADO RIVER BASIN IN NEW MEXICO STREAM FLOW SUMMARY (5 sheets of computations, 9 sheets of notes, 1 chart).

5. WILLIAMS RIVER BASIN STREAM FLOW SUMMARY (1 sheet of computations, 1 sheet of notes).

6. GILA RIVER BASIN STREAM FLOW SUMMARY (11 sheets of computations, 21 sheets of notes, 8 charts).

7. GILA RIVER BASIN IN NEW MEXICO STREAM FLOW SUMMARY (7 sheets of computations, 8 sheets of notes, 2 charts).

GENERAL STATEMENT AND SUMMARY

This study was made July 1939 to March 1940. It is based on stream-flow and diversion data gathered from many sources, but principally from the published Water-Supply Papers of the United States Geological Survey. The notes accompanying the computation sheets explain the source and give credit for each figure used. In the case of many of the diversions for which no record were in existence, field

trips were made by Mr. Davis and the writer who interviewed persons most familiar with the facts in the areas concerned.

Purpose of the study is to make available virgin stream flow data for use of the Arizona Colorado River Commission and others, and to ascertain the virgin flow contribution of Arizona streams to the upper and lower Colorado River basins and of New Mexico to the lower. The terms "upper" and "lower" basin, as used herein, conform to the definition given in the Santa Fe Compact which sets the dividing point one mile below the mouth of the Paria River. Virgin flow as used in this study is that flow which would occur if no water were stored or diverted and the stream were allowed to flow unobstructed by man.

Studies on each stream and catchment area have been carried through so that the final figures of each of the seven parts of this report show the theoretical virgin flow contribution to the main Colorado River from that stream or drainage basin. In other words, all probable losses which would occur in transit to the main river are accounted for. In comparing figures from this study with those from other studies, this should be kept in mind.

In considering the main stream of the Colorado River, all losses in Arizona above Boulder Dam are accounted for. Losses from Lake Mead are ignored, as it did not exist under virgin flow conditions. Losses in Arizona above Lee's Ferry are negligible. Inspection of the seven parts of this report will show that all run-off from Arizona is accounted for except that part of the main stream of the Colorado below Boulder Dam. This area of 6,400 square miles is made up almost entirely of low-lying desert, with precipitation little greater than that at Yuma which has a long-time annual mean of 3.5 inches. Run-off from this area into Colorado River is erratic, occurring only occasionally during

heavy storms. The average annual contribution of this 6,400 square miles would be less than the Williams River drainage area (5,140 square miles contribution of 105,000 acre-feet) and has not been included in this investigation.

It should also be noted that losses from Colorado River below Boulder Dam have not been accounted for. This was not studied because it is amply covered by Bureau of Reclamation studies and the Jacobs-Stevens Report.

From the above, it will be seen that the reference in this report to "contribution of Arizona to the Colorado River basin", or "to lower Colorado River basin" does not take into account the run-off from 6,400 square miles of desert below Boulder Dam, and does not take into account channel losses from this section of the Colorado River. However, channel losses from the Colorado River above Boulder Dam are taken into account.

All figures on the computation sheets are annual run-off in acre-feet for the water year ending September 30, unless otherwise mentioned in the notes or column heading.

Results of the seven parts of the study have been combined in the accompanying table which summarizes all these data. The column " Part No. and Column No." shows where the supporting evidence for these data will be found in the computation sheets following. Part numbers are as given above where the parts are listed by number. For example, "1-9" means that these data are from Part 1, run-off from Arizona, in upper basin, column 9.

Virgin flow contributions from Arizona to the upper and lower Colorado River basins and from New Mexico to the lower Colorado River basin.

Point on stream or area contributing	No. of years record	Period	Mean Annual run-off in acre-feet	Part No. and Column No.
Contribution to Colorado River upper basin from Arizona	13	1926-38	59,800	1-9
	8	1929-33 and 1936-38	71,800	1-9
Contribution to Colorado River from Arizona between Lees Ferry and Boulder Dam excepting Paria and Little Colorado Rivers	15	1924-38	308,000	2-12
	13	1926-38	317,700	2-12
	8	1929-33 and 1936-38	326,700	2-12
Little Colorado River at mouth, from both Arizona and New Mexico.	13	1926-38	402,700	3-17
	8	1929-33 and 1936-38	436,500	3-17
Little Colorado River at mouth, from Arizona	8	1929-33 and 1936-38	410,200	4-26
Little Colorado River at mouth, from New Mexico	8	1929-33 and 1936-38	36,400	4-25
Contribution to Little Colorado River from New Mexico at New Mexico-Arizona line	8	1929-33 and 1936-38	38,500	4-15
Williams River at mouth	10	1929-38	105,500	5-3
	8	1929-33 and 1936-38	115,600	5-3

Point on Stream or area contributing	No. of years record	Period	Mean annual run-off in acre-feet	Part No. and Column No.
Gila River at mouth, from both New Mexico and Arizona	22	1905,1915 and 1919-38	1,501,000	6-63
	20	1919-38	1,316,000	6-63
	13	1926-38	1,252,000	6-63
	11	1928-38	1,194,000	6-63
	8	1929-33 and 1936-38	1,272,000	6-63
Gila River at mouth, from Arizona	11	1928-38	1,071,000	7-37
	8	1929-33 and 1936-38	1,139,000	7-37
Gila River at mouth, from New Mexico	11	1928-38	122,800	7-36
	8	1929-33 and 1936-38	133,400	7-36
Gila River from New Mexico at Arizona New Mexico line	11	1928-38	134,400	7-17
	8	1929-33 and 1936-38	147,800	7-17
Gila River at Ashurst-Hayden Dam	23	1905,1913, 1916, and 1919-38	691,100	6-19
	20	1919-38	513,700	6-19
	11	1928-38	476,600	6-19
	8	1929-33 and 1936-38	508,700	6-19
*Total contribution of Arizona to Colorado River Basin	8	1929-33 and 1936-38	2,063,000	Totalled from above data
Total contribution of New Mexico to Colorado River Basin below Lees Ferry	8	1929-33 and 1936-38	159,800	Totalled from above data

*Limited by the exact definition of "contribution of Arizona" as described above under General Statement.

Run-off records for several different periods are given for the same area in order to make comparisons or additions possible. The division of the Little Colorado River flow between Arizona and New Mexico was computed for only eight years due to lack of records. Since the Little Colorado River flow forms an important part of the total contribution from Arizona to the Colorado River, a total could not be obtained for a period longer than eight years. The eight year period was for 1929-33 and 1936-38, thus omitting the low year of 1934. For this reason, the 8-year mean in nearly cases shows a greater flow than the 11 or 13 year mean, which included 1934. However, by inspecting the data for Gila River at its mouth, it is seen that the 8, 11 and 13 year means are all less than the 20-year mean. Therefore, the 8-year mean for Arizona as a whole, computed as 2,063,000 acre-feet, is undoubtedly lower than a 20-year mean would be.

The comparison was carried further, using the Verde River near McDowell because of its 36 year record, its central location in the state, and the size of the stream, which supplies almost a fourth of Arizona's virgin flow run-off. Actual flow records were used, as diversions were relatively small and did not vary greatly over the period. Results showed mean annual run-off as follows:

For 35 years, 1903-38, 810 second-feet.
20 years, 1919-38, 708 " "
8 years, 1929-33
and
1936-38, 635 " "

From this, no other deduction is possible, but that both the 8-year and 20-year means are far lower than the longer 35-year mean.

The run-off figures derived from this study are not as accurate as run-off actually measured at a gaging station. The basic data used were actual gaging station records but these were modified by and combined with other less accurate records. Few of the diversion figures are actual record. Flow and loss records were extended by curves of relation and drainage area ratios. Diversion by pumping was not included in the study. Considerable judgment entered into the interpretation of many quantities. However, many of the possible errors are compensating and are so small that the final results are not greatly affected.

Caging station records in or near Arizona used in, or having a bearing on, this compilation are as follows (numbers correspond to numbers on map, dash after a date indicates record is being continued):

1. Paria River at Lees Ferry. 1923-
2. Colorado River at Lees Ferry. 1921-
3. Colorado River at Bright Angel Creek, near Grand Canyon. 1922-
4. Bright Angel Creek near Grand Canyon. 1923-
5. Lake Mead at Boulder Dam, Ariz.-Nev. 1935-
6. Colorado River near Willow Beach. 1934-1939.
7. Colorado River near Topock. 1917-
8. Lake Havasu near Parker Dam. 1938-
9. Williams River at Planet. 1910-15, 1928-
10. Colorado River below Parker Dam. 1934-
11. Colorado River near Picacho. 1934-
12. Colorado River at Yuma. 1878-
13. Little Colorado River at St. Johns. 1906-09;1929-33;1935-
14. Little Colorado River near Hunt. 1929-33.
15. Silver Creek near Woodruff. 1929-33; 1935-
16. Little Colorado River near Woodruff. 1905-08;1915-19;1929-33;1935-
17. Chevelon Fork near Winslow. 1905-08;1915-19;1929-34;1935-
18. Clear Creek near Winslow. 1906-09;1929-34;1935-
19. Little Colorado River at Grand Falls. 1925-
20. Moenkopi Wash near Tuba. 1926-
21. Gila River at Fullers ranch, (and at Virden Bridge) near Duncan,1923
22. Gila River at state line, Ariz.-N.Mex. 1939-
23. Gila River near Clifton. 1928-33; 1935-
24. San Francisco River at Clifton. 1910-18; 1927-33; 1935-
25. Gila River below Bonita Creek, (and near Solomonsville).1914-33;1935
26. San Simon Creek near San Simon. 1919-25; 1931-33; 1935-
27. San Simon Creek near Solomonsville. 1931-32; 1935-
28. Gila River at Calva. 1929-
29. San Carlos River near Peridot. 1929-
30. San Carlos Reservoir at Coolidge Dam. 1928-
31. Gila River below Coolidge Dam (near San Carlos). 1914-

32. Gila River at Kelvin. 1911--
33. Gila River at Ashurst-Hayden Dam, near Florence. 1923-
34. Salt River near Chrysotile. 1924-
35. Salt River near Roosevelt. 1913-
36. Tonto Creek near Roosevelt. 1901-04; 1913-
37. Salt River at Stewart Mountain Dam. 1934-
38. Granite Creek near Prescott. 1932-
39. Verde River near Camp Verde. 1934-
40. Verde River below East Verde River, near Pine. 1934-
41. Verde River above Bartlett Reservoir, near Cave Creek. 1938-
42. Bartlett Reservoir at Bartlett Dam. 1939-
43. Verde River above Camp Creek, near McDowell. 1889;1895-99; 1901-
44. San Pedro River at Palominas. 1930-33; 1935-
45. San Pedro River at Charleston. 1904-06;1910-11;1928-33; 1935-
46. San Pedro River near Mammoth. 1931-
47. Aravaipa Creek near Feldman. 1919-21; 1931-
48. Santa Cruz River near Nogales. 1907; 1909-22; 1930-33; 1935-
49. Sonoita Creek near Patagonia. 1930-33; 1935-
50. Santa Cruz River at Tucson. 1905-
51. Sabino Creek near Tucson. 1932-
52. Rillito Creek near Tucson. 1911-
53. Agua Fria River at Lake Pleasant Dam (near Glendale). 1910-
54. Hassayampa River at Box dam site near Wickenburg.1910-12;1922-36; 1938.
55. Hassayampa River near Morristown. 1938-
56. Gila River below Gillespie Dam. 1921-
57. Gillespie Canal at Gillespie Dam. 1935-
58. Enterprise Canal at Gillespie Dam. 1935-
59. Gila River near Dome. 1903-
60. Virgin River at Littlefield. 1929-

Of the above 60 stations, all were in operation on July 1, 1939, except Nos. 14 and 54. All had two years or more of record except Nos. 8, 22, 41, 42 and 55. All records were obtained by the U. S.

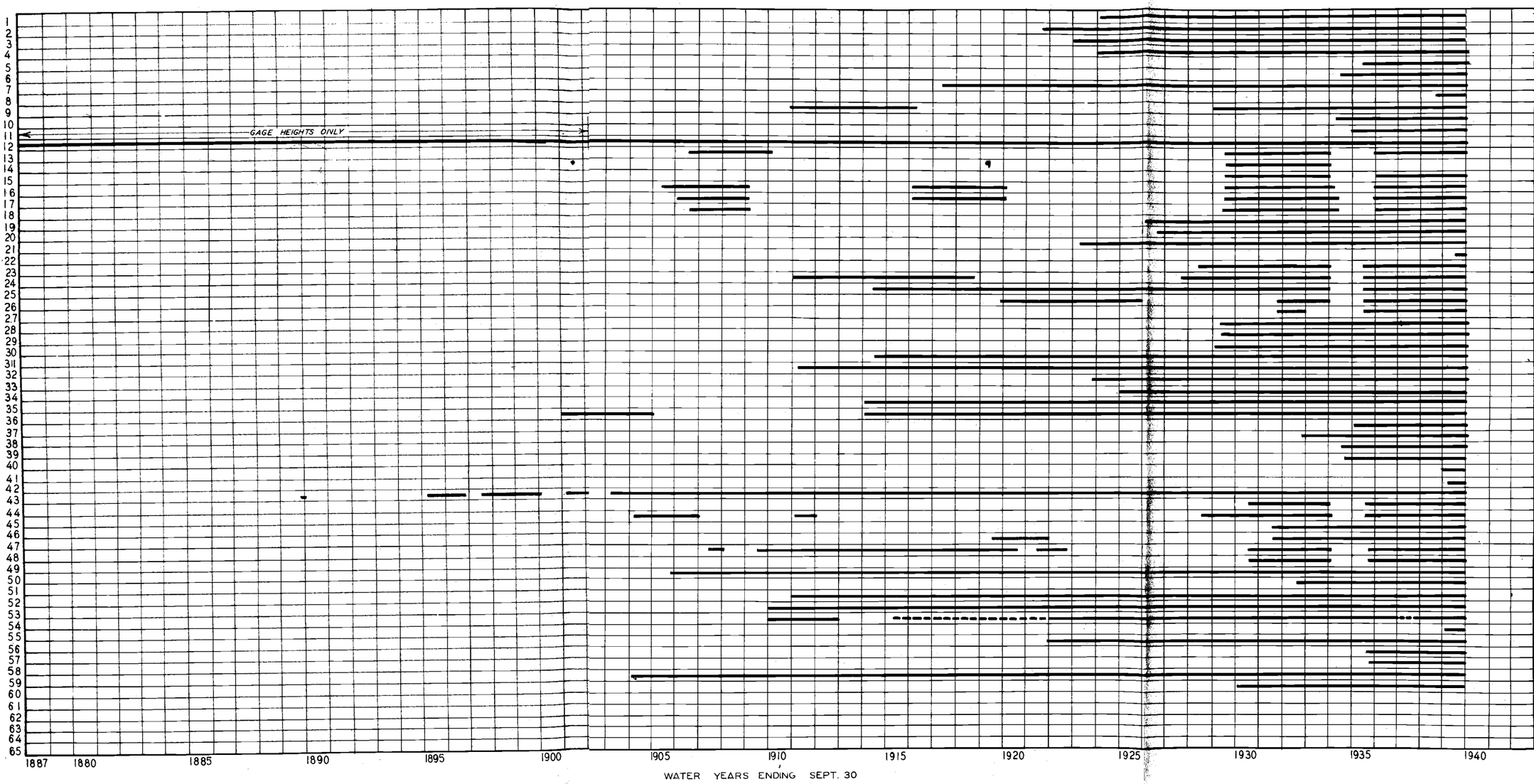
Geological Survey except Nos. 5, 53, and 54 and the early records for 12, 35, 36, 43, and 59. All are records of stream flow except the following, which are records of stage only: 5, 7 (since April 1939), 8, 30, 33, 42, and 58 (discharge measurements only).

AVAILABLE STREAM DISCHARGE RECORDS.

OF

ARIZONA STREAMS

USED IN OR BEARING ON THIS REPORT



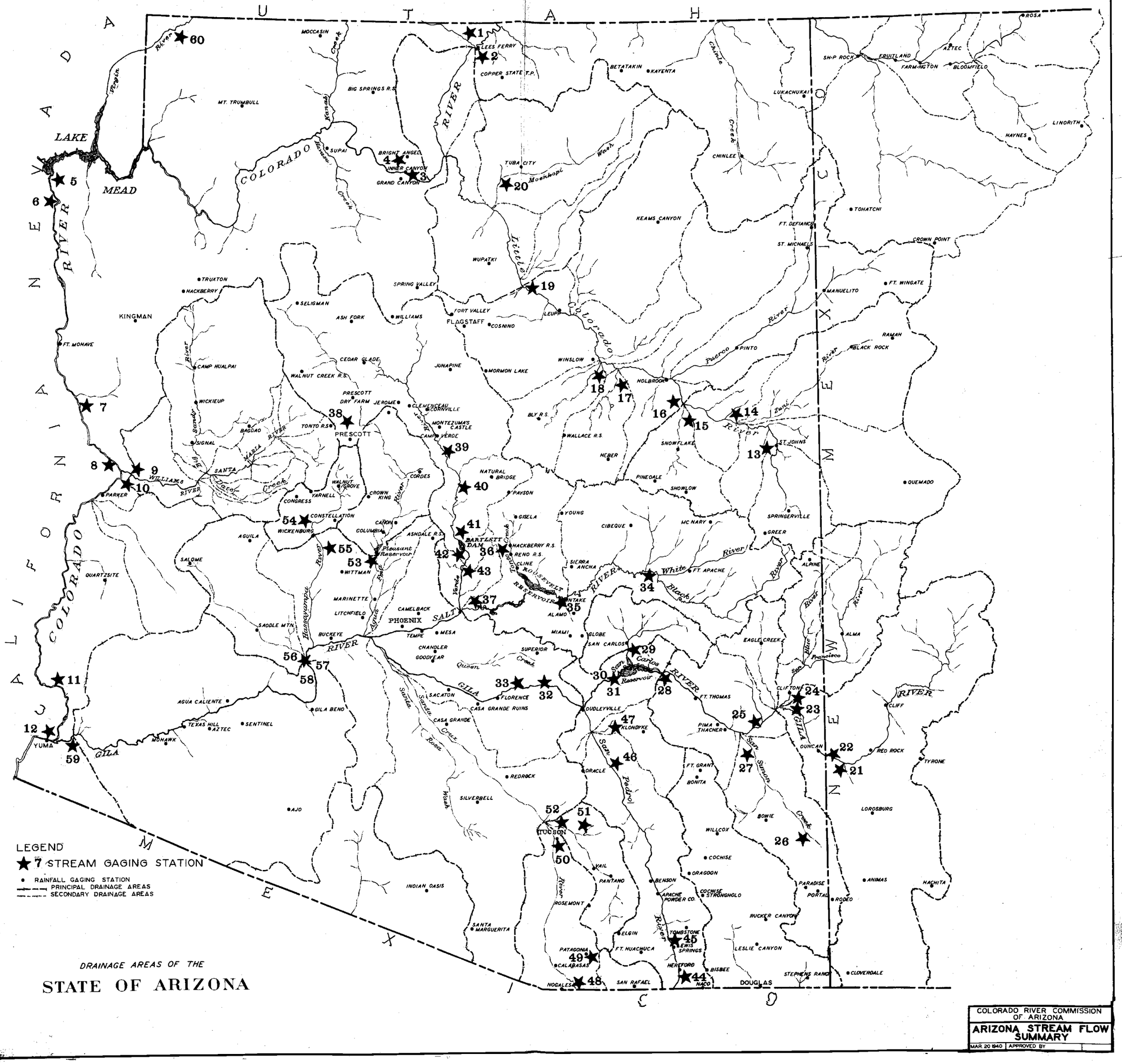
1 Paria River at Lees Ferry
2 Colorado River at Lees Ferry
3 Colorado River at Bright Angel Creek.
4 Bright Angel Creek
5 Lake Mead at Boulder Dam
6 Colorado River near Willow Beach
7 Colorado River near Topock
8 Lake Havasu near Parker Dam
9 Williams River at Planet
10 Colorado River below Parker
11 Colorado River near Picacho
12 Colorado at Yuma
13 Little Colorado River at St. Johns
14 Little Colorado River near Hunt.
15 Silver Creek near Woodruff
16 Little Colorado River near Woodruff
17 Chevelon Fork near Winslow
18 Clear Creek near Winslow
19 Little Colorado at Grand Falls
20 Moenkopi Wash near Tuba
21 Gila River at Fullers ranch-Virden bridge-Duncan
22 Gila River at Ariz.- New Mex. State line
23 Gila River near Clifton
24 San Francisco River at Clifton
25 Gila River below Bonita Creek
26 San Simon Creek near San Simon
27 San Simon Creek near Solomonsville
28 Gila River at Calva
29 San Carlos River near Peridot
30 San Carlos Reservoir at Coolidge Dam
31 Gila River below Coolidge Dam
32 Gila River at Kelvin
33 Gila River at Ashurst-Hayden Dam
34 Salt River near Chrysotile
35 Salt River near Roosevelt
36 Tonto Creek near Roosevelt.
37 Salt River at Stewart Mt. Dam
38 Granite Creek near Prescott.
39 Verde River near Camp Verde
40 Verde River near Pine
41 Verde River above Bartlett Reservoir
42 Bartlett Reservoir at Dam
43 Verde River near McDowell
44 San Pedro River at Palomas
45 San Pedro River at Charleston
46 San Pedro River near Mammoth
47 Ardvaipa Creek near Feldman
48 Santa Cruz River near Nogales
49 Sonoita Creek near Patagonia
50 Santa Cruz River at Tucson
51 Sabino Creek near Tucson
52 Rillito Creek " "
53 Agua Fria River at Lake Pleasant.
54 Hassayampa River at Box Damsite
55 Hassayampa River near Morristown
56 Gila River below Gillespie Dam
57 Gillespie Canal at the Dam
58 Enterprise Canal at Gillespie Dam
59 Gila River near Dome
60 Virgin River at Littlefield
61
62
63
64

Note:- Gaging station numbers correspond to numbers on map

COLORADO RIVER COMMISSION OF ARIZONA

ARIZONA STREAM FLOW SUMMARY

FEB 10 1940 | APPROVED BY.....


UTAH
NEVADA
ARIZONA
NEW MEXICO
COLORADO
LAKE MEAD
COLORADO RIVER
Virgin River
Muddy Creek
Kanab Creek
Navajo Creek
Moenkopi Wash
Little Colorado River
Chinle Creek
Puerco River
Zuni River
Black River
White River
San Carlos Reservoir
Roosevelt Reservoir
Salt River
Verde River
Agua Fria River
Hassayampa River
Bill Williams River
Santa Maria River
Big Sandy River
Santa Cruz River
San Pedro River
San Simon Creek
Gila River
Queen Creek
Queen Valley Wash
Pleasant Reservoir
Bartlett Dam
Coolidge Dam
MOCCASIN
LEES FERRY
COPPER STATE T.P.
BETATAKIN
KAYENTA
SHIP ROCK
FRUITLAND
AZTEC
FARMINGTON
BLOOMFIELD
ROSA
LUKACHUKAI
LINORITH
HAYNES
MT. TRUMBULL
BIG SPRINGS R.S.
SUPAI
BRIGHT ANGEL
INNER CANYON
GRAND CANYON
TUBA CITY
CHINLEE
TOHATCHI
KEAMS CANYON
FT. DEFIANCE
ST. MICHAELS
CROWN POINT
MANUELITO
FT. WINGATE
WUPATKI
SPRING VALLEY
TRUXTON
HACKBERRY
SELIGMAN
KINGMAN
FT. MOHAVE
ASH FORK
WILLIAMS
FORT VALLEY
FLAGSTAFF
COSNINO
LEUPP
WINSLOW
PINTO
RAMAH
BLACK ROCK
CAMP HUALPAI
CEDAR GLADE
WALNUT CREEK R.S.
JUNAPINE
MORMON LAKE
HOLBROOK
WICKIEUP
PRESCOTT
DRY FARM
JEROME
CLEMENCEAU
CORNVILLE
MONTEZUMA'S CASTLE
CAMP VERDE
TONTO R.S.
PRESCOTT
BAGDAD
SIGNAL
BLY R.S.
WALLACE R.S.
SNOWFLAKE
ST. JOHNS
HEBER
PINEDALE
SHOWLOW
QUEMADO
SPRINGERVILLE
GREER
ALPINE
MC NARY
CIBEQUE
NATURAL BRIDGE
PAYSON
GISELA
YOUNG
CORDES
WALNUT GROVE
YARNELL
CROWN KING
CONGRESS
PARKER
WILLIAMS
CONSTELLATION
WICKENBURG
CANON
COLUMBIA
ASHDALE R.S.
AGUILA
SALOME
QUARTZSITE
WITTMAN
MARINETTE
LITCHFIELD
SADDLE MTN.
BUCKEYE
PHOENIX
TEMPE
MESA
CHANDLER
GOODYEAR
CAMELBACK
ALAMO
INTAKE
MIAMI
GLOBE
SAN CARLOS
SUPERIOR
EAGLE CREEK
CLIFTON
CLIFF
DUNCAN
RED ROCK
TYRONE
ALMA
AGUA CALIENTE
GILA BEND
SACATON
FLORENCE
CASA GRANDE RUINS
CASA GRANDE
OUDLEYVILLE
KLONDYKE
PIMA
THACHER
FT. THOMAS
FT. GRANT
BONITA
ORACLE
REDROCK
SILVERBELL
AJO
TEXAS HILL
AZTEC
SENTINEL
MOHAWK
YUMA
TUCSON
WILLCOX
BOWIE
COCHISE
ORAGOON
PANTANO
BENSON
APACHE POWDER CO.
COCHISE STRONGHOLD
PARADISE
PORTAL
RODEO
ANIMAS
HACHITA
LOROSBURG
RUCKER CANYON
LESLIE CANYON
TOMBSTONE
LEWIS SPRINGS
HEREFORD
BISBEE
NACO
DOUGLAS
STEPHENS RANCH
CLOVERDALE
ROSEMONT
VAIL
ELGIN
FT. HUACHUCA
PATAGONIA
CALABASAS
NOGALES
SAN RAFAEL
SANTA MARGUERITA
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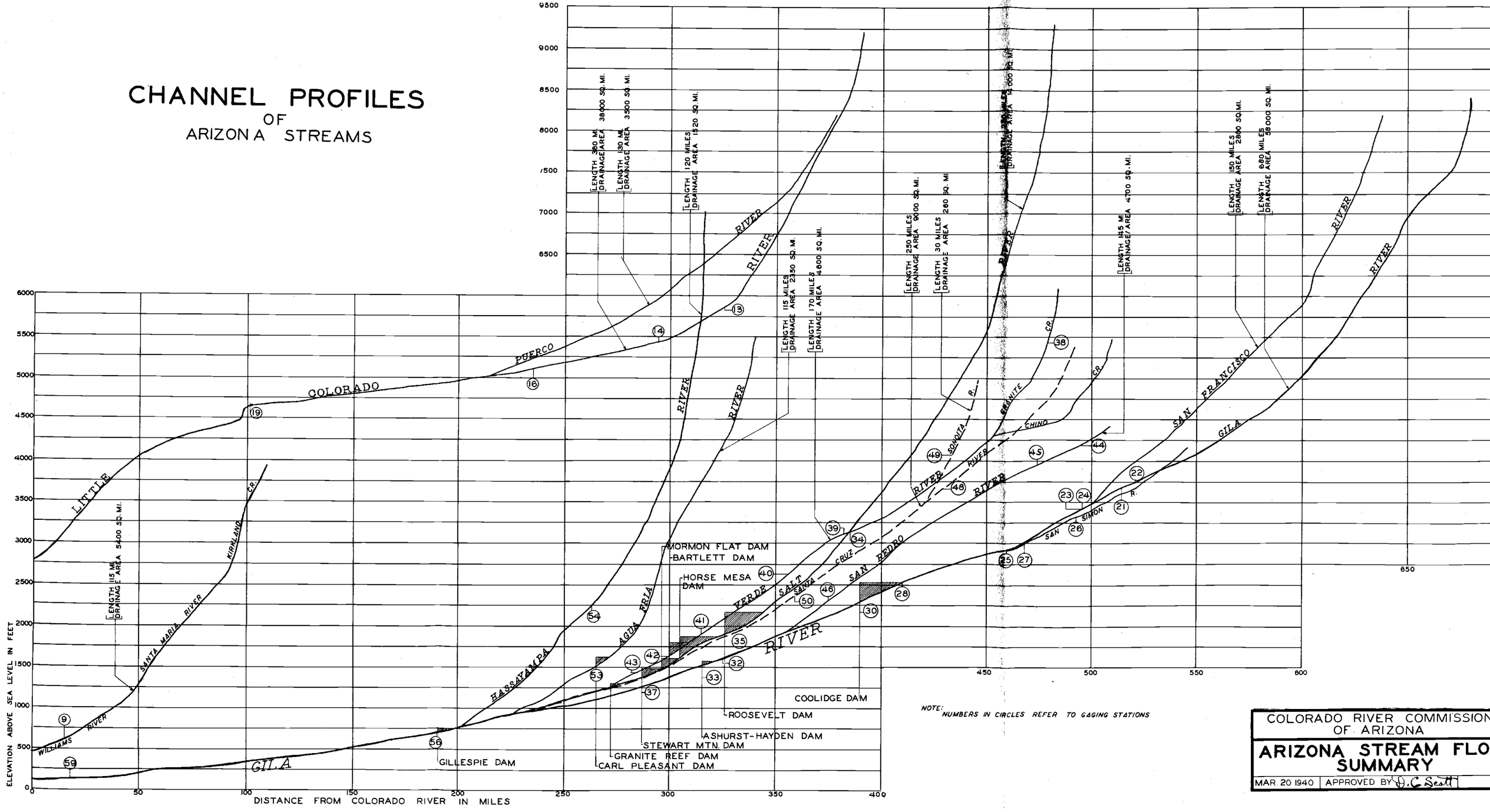
LEGEND
7 STREAM GAGING STATION
RAINFALL GAGING STATION
PRINCIPAL DRAINAGE AREAS
SECONDARY DRAINAGE AREAS
DRAINAGE AREAS OF THE
STATE OF ARIZONA
COLORADO RIVER COMMISSION OF ARIZONA
ARIZONA STREAM FLOW SUMMARY
MAR 20 1940
APPROVED BY

CHANNEL PROFILES
OF
ARIZONA STREAMS



COLORADO RIVER COMMISSION
OF ARIZONA

ARIZONA STREAM FLOW SUMMARY

MAR 20 1940 | APPROVED BY W. C. Scott

S E C T I O N I

SUMMARY OF STREAM FLOW

OF COLORADO RIVER

UPPER BASIN IN ARIZONA

* * *

SUMMARY OF STREAM FLOW OF COLORADO RIVER UPPER BASIN IN ARIZONA.

	Moenkopi near Tuba	Diversions from Moenkopi above Tuba	Virgin flow Moenkopi-Tuba	Virgin flow to Colorado River in Arizona above Lees Ferry	Paria at Lees Ferry	Diversions from Paria
	(1)	(2)	(3)	(4)	(5)	(6)
1940						
1939						
1938	7,810	2,500	10,310	29,600	25,720	1,000
1937	18,230	2,500	20,730	59,516	26,980	1,000
1936	20,710	2,500	23,210	66,636	35,280	1,000
1935	7,360	2,500	9,860	28,308	17,130	1,000
1934	16,590	2,500	19,090	54,807	19,440	1,000
1933	10,200	2,500	12,700	36,462	16,700	1,000
1932	7,890	2,500	10,390	29,830	37,900	1,000
1931	5,500	2,500	8,000	22,968	11,400	1,000
1930	46,000	2,500	48,500	139,244	19,000	1,000
1929	41,200	2,500	43,700	125,463	34,800	1,000
1928	4,510	2,500	7,010	20,126	16,000	1,000
1927	9,750	2,500	12,250	35,170	45,900	1,000
1926	6,000	2,500	8,500	24,404	32,100	1,000
1925					29,500	1,000
1924					18,800	1,000

SUMMARY OF STREAM FLOW OF COLORADO RIVER UPPER BASIN IN ARIZONA.

	Virgin flow of Paria River	Arizona Contribution to Paria	Total Ariz. virgin flow contribution to Upper Basin
	(7)	(8)	(9)
1940			
1939			
1938	26,820	8,016	37,620
1937	27,980	8,394	67,910
1936	36,280	10,884	77,520
1935	18,130	5,439	33,750
1934	20,440	6,132	60,940
1933	17,700	5,310	41,770
1932	38,900	11,670	41,500
1931	12,400	3,720	26,690
1930	20,000	6,000	145,240
1929	35,800	10,740	136,200
1928	17,000	5,100	25,230
1927	46,900	14,070	49,240
1926	33,100	9,930	34,330
1925	30,500	9,150	
1924	19,800	5,940	
			59,840 mean for 13 years.

SUMMARY OF FLOW OF COLORADO RIVER UPPER BASIN IN ARIZONA

Notes on Computations.

All quantities are total acre-feet for water year ending September 30 unless otherwise noted.

Where the term diversions are used in the computations, they have been considered as consumptive use except where otherwise noted.

Column (1). Records from U.S.G.S. Water-Supply Papers. Year 1926 estimated in part.

Column (2). Diversions average 2,500 acre-feet per year. See sheet 2 of notes on computations of "Little Colorado Stream-Flow Summary".

Column (3) is columns (1) plus (2).

Column (4). Total area in Arizona contributing to Colorado River above Lees Ferry and not including Paria River is 6,506 sq. miles. This is mostly Chinle and Navajo Creek drainage. The ratio of this area to that at Moenkopi-Tuba is $\frac{6,506}{2,266} = 2.871$. It is assumed that the area in Arizona above Lees Ferry produces at the same rate as Moenkopi on a drainage area basis or 2.871 times as much. This method gives a figure representing run-off from the area under consideration into Colorado River because the length of stream above Moenkopi gage is about the same as average length of stream in the area; Chinle Creek runs a greater distance, but all other tributaries in the area, notably Navajo Creek, run lesser distances.

Column (5). From U.S.G.S. Water-Supply Papers. Figure for full year 1924 from an estimate.

Column (6). From Bureau of Reclamation figures, the area irrigated is 600 acres and assuming 2½ acre-feet per acre gives 1,500 acre-feet of consumptive use allowing 500 acre-feet imported from the Sevier River basin we have a net Paria use of 1,000 acre-feet.

Column (7) = columns (5) plus (6).

Column (8). Arizona's contribution to the Paria was made on a straight drainage area ratio basis. Area in Arizona is 456 sq. mi. Ratio $\frac{456}{1,523}$ = .30 of column (7) to get column (8).

Column (9). The total virgin flow contribution of Arizona to the Upper Basin, which division point is defined in the Santa Fe Compact as just below the Paria River at Lees Ferry, is the sum of columns (4) and (8).

S E C T I O N II

SUMMARY OF INFLOW TO
TO COLORADO RIVER BASIN FROM ARIZONA
BETWEEN
LEES FERRY AND BOULDER DAM
EXCEPT THAT
FROM PARIA AND LITTLE COLORADO RIVER

* * *

SUMMARY OF INFLOW TO COLORADO RIVER BASIN FROM ARIZONA BETWEEN LEES FERRY AND BOULDER DAM EXCEPT THAT FROM PARIA AND LITTLE COLORADO RIVER.

	Net gain Lees Ferry to Grand Canyon below Paria & Little Colorado Rivers	Bright Angel Creek	Virgin flow of Paria River	Utah's share of virgin flow of Kanab Creek	Grand Canyon to Boulder Dam except Bright Angel Creek and Virgin above Littlefield from Paria	Virgin River at Littlefield
	(1)	(2)	(3)	(4)	(5)	(6)
1940						
1939						
1938	15,000	44,340	26,720	11,760	368,970	278,600
1937	15,000	41,920	27,980	12,310	348,830	251,900
1936	15,000	25,310	36,280	15,960	210,610	131,000
1935	15,000	31,610	18,130	7,980	263,040	164,200
1934	15,000	13,510	20,440	8,990	112,420	85,670
1933	15,000	17,100	17,700	7,790	142,290	131,000
1932	15,000	42,400	38,900	17,120	352,820	401,000
1931	15,000	16,900	12,400	5,460	140,630	119,000
1930	15,000	20,500	20,000	8,800	170,590	190,000
1929	15,000	22,400	35,800	15,750	186,400	
1928	15,000	29,500	17,000	7,480	245,480	
1927	15,000	33,800	46,900	20,640	281,260	
1926	15,000	31,400	33,100	14,560	261,290	
1925	15,000	19,800	30,500	13,420	164,760	
1924	15,000	24,100	19,800	8,710	200,540	
15-year average	27,640			11,780	230,000	
				-* 5,000		
15-year average				6,780 = actual flow from Utah		

*Kanab Creek irrigation in Utah 2,000 acres at 2½ acre-feet=5,000 acre-feet

SUMMARY OF INFLOW TO COLORADO RIVER BASIN FROM ARIZONA BETWEEN LEES FERRY AND BOULDER DAM EXCEPT THAT FROM PARIA AND LITTLE COLORADO RIVER.

	Virgin R. at Virgin, Utah	Inflow between Virgin & Littlefield	Diversions between Virgin & Littlefield	Virgin R. virgin inflow between Virgin & Littlefield	Ariz. virgin contribution to Virgin R. above Littlefield	Total net virgin contribution from Ariz. between Lees Ferry & Boulder Dam except for Paria & Little Col. Rivers.
	(7)	(8)	(9)	(10)	(11)	(12)
1940						
1939						
1938	202,900	75,700	50,000	125,700	50,280	478,590
1937	212,200	39,700	50,000	89,700	35,880	441,630
1936	118,700	12,300	50,000	62,300	24,920	275,840
1935	141,500	22,700	50,000	72,700	29,080	338,730
1934	70,470	7,200	50,000	57,200	22,880	163,810
1933	114,000	17,000	50,000	67,000	26,800	201,190
1932	225,000	176,000	50,000	226,000	90,400	500,620
1931	85,200	33,800	50,000	83,800	33,520	206,050
1930	112,000	78,000	50,000	128,000	51,200	257,290
1929	134,000				28,800	252,600
1928	114,000				26,800	316,700
1927	160,000				31,200	361,200
1926	120,000				27,700	335,390
1925	108,000				26,200	225,760
1924	100,000				25,300	264,940
				15-year average		308,030

SUMMARY OF INFLOW TO COLORADO RIVER BASIN FROM ARIZONA BETWEEN LEES FERRY AND BOULDER DAM EXCEPT THAT FROM PARIA AND LITTLE COLORADO RIVERS

Notes on Computations.

Figures are run-off in acre-feet for the water year ending September 30 unless otherwise noted.

Where the term diversions are used in the computations, they have been considered as consumptive use except where otherwise noted.

Column (1). See top of page 4 of notes on computations of "Little Colorado River basin stream-flow summary" where the figure 15,000 acre-feet is derived as the net gain between Lees Ferry and Grand Canyon except for Paria and Little Colorado Rivers. This is an average figure and will vary from year to year but as nothing is known as to the extent of the variation, it is used as 15,000 for each year.

Column (2). From U.S.G.S. Water-Supply Papers.

Column (3). From column (7) of "Summary of stream flow from Arizona in Upper Basin".

Column (4). Kanab Creek drainage area in Utah is 673 square miles. Total drainage area of Paria is 1,523 square miles. Using a drainage area ratio, virgin flow of Kanab Creek from Utah = $\frac{673}{1,523}$ = 44% of that of Paria or 44% of column (3).

An average of 2,000 acres is irrigated in Utah at a consumpuse of 2.5 feet, or 5,000 acre-feet used annually. Therefore, actual flow of Kanab Creek from Utah can be found for any year by subtracting 5,000 acre-feet from figures in column (4).

Column (5). This column shows contribution from Arizona or net gain between Grand Canyon and Boulder Dam, excluding Bright Angel Creek and Virgin River above Littlefield. Actual flow and virgin flow from this area are the same except for about 500 acres irrigated on Kanab Creek in Arizona

in Arizona and possibly a very small scattered irrigated acreage. This acreage is so small and the results of this part of the study so rough, that actual and virgin flow are considered the same.

Figures for this column have been computed by four different methods as given below. Computation could not be individual years because data were not available. No gaging stations exist in the area under consideration except those at the edges, on the Colorado River at Grand Canyon and Boulder Dam and on Bright Angel Creek and Virgin River at Littlefield.

Method 1. A 10-month's record of natural flow exists at Grand Canyon and Willow Beach stations from April 1934 to January 1935. Before that there was no station at Willow Beach and after that, Boulder Dam regulated the flow. The following computation is based on these records:

Monthly run-off in acre-feet

Month 1934	Colorado-Willow Beach (1)	Colorado-Grand Canyon (2)	Bright Angel Creek (3)	Virgin-Littlefield (4)	(1) minus (2) minus (3) minus (4) (5)
April	439,600	452,400	1,240	3,790	-17,630
May	1,111,000	1,103,000	1,170	2,990	3,840
June	631,300	545,600	1,040	3,190	81,470
July	171,100	146,400	976	4,010	19,714
Aug.	161,800	166,000	1,150	3,310	- 8,660
Sept.	197,100	166,500	1,070	3,250	26,280
Oct.	191,100	171,900	1,120	5,040	13,040
Nov.	209,400	195,800	1,170	6,810	5,620
Dec.	273,200	243,300	1,270	12,960	15,670
1935					
Jan.	326,200	288,100	1,230	14,270	22,600
				Ten months total =	161,944

Flow in February and March of 1935 at Grand Canyon was almost exactly the mean of the other 10 months. Therefore, the annual run-off is $\frac{12}{10}$ of 161,944, or 194,000 acre-feet.

April 1934 to January 1935 is a period of low run-off. On Bright Angel Creek, flow in period Feb. 1, 1934, to Jan. 31, 1935, was 0.50 of

the long-time yearly average. On the Virgin River (using virgin flow), flow at Littlefield less that at Virgin for the same period was 0.45 of the average. Using 0.50 as a mean the 194,000 acre-feet run-off should be doubled, giving 388,000 acre-feet for average run-off.

The figure 388,000 acre-feet is from an area differing from that defined at the start of this write-up under column (5), in that all contribution is not "from Arizona". We should deduct for actual flow of Kanab Creek in Utah which is 6,780 acre-feet, according to column (4), and we should deduct for Nevada's contribution through the Muddy and lower Virgin Rivers, which is worked out below as 22,000 acre-feet average.

Then, 388,000 - 7,000 - 22,000 = 358,000 acre-feet, mean annual run-off from Arizona between Grand Canyon and Boulder Dam excluding Bright Angel Creek and Virgin River above Littlefield.

The Bureau of Reclamation has obtained a record at Boulder Dam beginning in January,1931. Using the three full years December 1931 to November 1934, the computation as above was:

Colorado-Willow Beach	Colorado-Grand Canyon	Bright Angel Creek	Virgin-Littlefield	(1) minus (2) minus (3) minus (4)
30,881,000	30,098,700	72,890	607,130	102,280

This gives an average per year of $\frac{102,280}{3}$ or only 34,090. After deducting 22,000 for Nevada's share and 6,800 for Utah's share as above, Arizona's share would be 5,290 acre-feet per year, which is so small as to be ridiculous. The records at either Grand Canyon or Boulder Dam are not accurate enough to permit the use of this method on the three-year record.

Nevada's contribution of 22,000 acre-feet annual average, used above, was computed as follows:

Principal drainage in Nevada to Virgin River below Littlefield is Muddy River. From U.S.G.S. Water-Supply Papers, station at St. Thomas at mouth of Muddy River showed the following run-off in acre-feet:

1916	Dec. 16 to Sept. 30	12,500 acre-feet
1915	Oct. 1 to Aug. 26 except June 11 to July 8	13,490
1914	Oct. 1 to Sept. 30	13,900
1913	May 23 to Sept. 30	284

The period 1913 to 1916 was one of the wettest known in Arizona and probably was well above average in Nevada. From inspection of above, it appears that 15,000 acre-feet a year would be an ample allowance per year for the Muddy River at mouth.

Drainage areas concerned are:

In Nevada above Colorado River at Boulder Dam	12,980 sq. mi.
Muddy River at mouth, in Nevada, about	-9,200
	3,780

Other area in Nevada above Boulder Dam, excluding Muddy River, Say 3,000.

Assume the run-off from this 3,000 sq. mi. is at same rate as from the Muddy. Then $\frac{3,000}{9,200} \times 15,000 = 6,200$ acre-feet.

	15,000 acre-feet from Muddy
	21,200

Use 22,000 acre-feet as average annual contribution of Nevada to Colorado River above Boulder Dam.

Method 2. On Page 1, notes on column (14), of notes on computations of little Colorado stream-flow summary and also on page 3, it is shown that 4,910 square miles of area between Lees Ferry and Grand Canyon, excluding Paria, Moenkopi above Tuba, and Little Colorado River above

Grand Falls, contributes an average of 110,000 acre-feet a year which is 22.40 acre-feet per square mile. This figure should be applicable to the area between Grand Canyon and Boulder Dam.

Total area contributing to Colorado River between Grand Canyon and Boulder Dam, excluding Bright Angel Creek and Virgin River above Littlefield is 26,145 square miles. To get area in Arizona, deduct 12,986 square miles in Nevada and 1,146 sq. mi. in Utah (about half in upper Muddy and half in upper Kanab Creek). We should also deduct area tributary to Red Lake Playa as it is an interior basin included in total above, but actually contributes no inflow. The area is 1,334 sq. mi. This leaves (26,145 - 12,986 - 1,146 - 1,334 =) 10,679 sq. mi. in Arizona contributing. Then 10,679 times 22.40 gives 239,200 acre-feet contributed from Arizona between Grand Canyon and Boulder Dam excluding Bright Angel Creek and Virgin River above Littlefield.

Method 3. Williams River basin adjoins the area under consideration. Mean virgin run-off from 5,140 sq. mi. of Williams River at Planet is 105,500 acre-feet annually; see Williams River stream-flow summary. At same unit run-off, Arizona's contribution from the 10,679 sq. mi. above is $\frac{10,679}{5,140}$ x 105,500 or 219,000 acre-feet annually.

Method 4. In W.S.P. 556, p. 117, the total of actually measured inflow in the reach Grand Canyon to Boulder Dam (leaving out Bright Angel Creek and Virgin River) in August and September 1923 was 240 second-feet or 174,000 acre-feet a year, at same rate. This figure is almost certainly low as it does not take into account the spring run-off, which is high from the area under consideration.

Recapitulation of the four methods:

Mean annual run-off in acre-feet from Arizona between Grand Canyon and Boulder Dam, excluding Bright Angel Creek and Virgin River above Littlefield	
358,000	From comparison of 10 month's record on Colorado River.
239,000	From unit run-off comparison with area between Lees Ferry and Grand Canyon.
219,000	From unit run-off comparison with Williams River basin.
174,000	From actually measured inflow in Aug. and September 1923.
247,500	Mean

Results by the first and last methods are radically different and are most subject to error. Disregarding them the mean is 229,000 acre-feet. Cultivated areas on Kanab Creek and Virgin River in Arizona below Littlefield amount to about 900 acres. Assuming the mean annual consumptive use to be 2 feet acre-feet per acre or 1,800 acre-feet per year. No other uses in the area under consideration are known. Adding this to 229,000 acre-feet gives, in round numbers, 230,000 acre-feet as Arizona's average contribution of virgin flow run-off to Colorado River between Grand Canyon and Boulder Dam.

This is an average figure, and is assumed to vary from year to year, as Bright Angel Creek varies. Mean flow of Bright Angel Creek is 27,640 acre-feet; see column (2). Figures in column (5) are equal to $\frac{\text{Bright Angel flow for that year}}{27,640} \times 230,000$.

Columns (6) and (7). From U.S.G.S. Water-Supply Papers. Record for Virgin at Virgin for 1935 completed by estimating several months. Column (8) is column (6) less (7) and shows inflow from area between Virgin and Littlefield.

Column(9) is based on an estimated acreage of 9,000 acres in the Dixie project and 8,000 acres in other parts of the basin, less 600 acres above Virgin. This is from government report on irrigated acreage. This nets 17,000 acres. Using 3 feet as consumptive use in this warm area, average annual use would be 51,000 acre-feet. 50,000 acre-feet has been used in the computations.

Column (10) is the sum of (8) and (9) and shows virgin flow to Virgin River from area between Virgin and Littlefield.

Column (11). It is assumed that Arizona would contribute to the Virgin River on a drainage area ratio or slightly less. Areas are as follows:

Virgin River at Littlefield	4,905 sq. miles
Virgin River at Virgin	990
Difference	3,915 " "

Area in Ariz. of Virgin River at Littlefield is 1,713 sq. mi.

Ratio of Arizona to total difference is $\frac{1,713}{3,915} = .438$ Use 0.40

Column (11) was computed by taking 0.4 of column (10) for 1930 to 1938. To obtain the year 1924 to 1929 chart 4 was plotted. It shows the relation between the virgin flow of the Virgin River at Virgin, Utah, and Arizona's contribution to the Virgin River. The years 1933-37 define a very good curve which was used. The curve was entered with the Virgin River flow for the years 1924-29 and Arizona's contribution picked directly from the curve for each year.

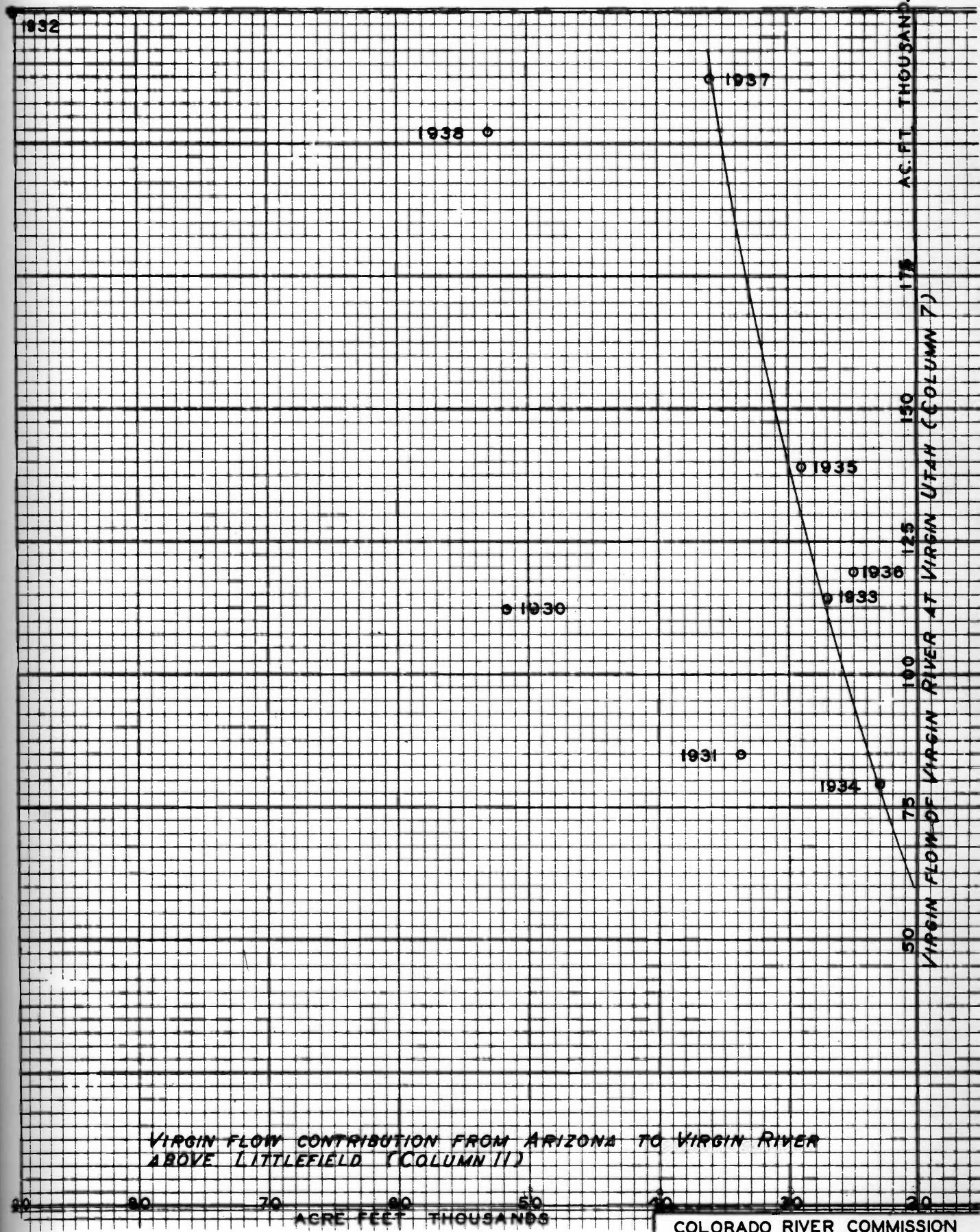
Column (12) is the sum of columns (1), (2), (5), and (11) and is the total net virgin flow contribution from Arizona to the Colorado River between Lees Ferry and Boulder Dam, excluding Paria and Little Colorado Rivers. Paria is excluded because it is part of the summary of flow from the upper basin, the division point between upper and lower basin.

being immediately below the mouth of Paria, under the Santa Fe Compact. Little Colorado River is excluded because it is covered in a separate Little Colorado Summary.

Note that the figures in column (12) are virgin, not actual flow, and also that they are net gains. That is, the inflow to the Colorado River was greater than these figures show, but losses in the stream channels, including the Colorado River channel, reduce them to their value as given in column (12). That these are net, not gross, gains follows from the method of computation used.

The accuracy of figures in column (12) is not high but they are the best obtainable until further stream gaging stations are established, and until changes in Lake Mead are more accurately known through better information on evaporation, transpiration, deep seepage losses, capacity table accuracy and unmeasured inflow.

SUMMARY OF INFLOW TO COLORADO RIVER FROM ARIZONA BETWEEN LEES FERRY AND BOULDER DAM EXCEPT FROM PARIA AND LITTLE COLORADO RIVERS



COLORADO RIVER COMMISSION OF ARIZONA

ARIZONA STREAM FLOW SUMMARY

3/7/40 Approved Donald C Scott

CHART 1

S E C T I O N III

LITTLE COLORADO RIVER BASIN

STREAM FLOW SUMMARY

* * *

LITTLE COLORADO RIVER BASIN STREAM FLOW SUMMARY.

	Little Colorado-St. Johns	Little Colorado-Hunt	Silver Creek-Woodruff	Little Colorado-Woodruff	Chevelon Fork-Winslow	Clear Creek-Winslow
	(1)	(2)	(3)	(4)	(5)	(6)
1940						
1939						
1938	4,110		7,560	15,110	34,550	64,670
1937	3,540		23,040	46,100	69,630	117,300
1936	4,350		15,940	42,710	33,490	46,830
1935						
1934						
1933	5,050	15,900	23,900	51,600	24,500	37,600
1932	15,600	48,700	59,500	117,000	78,400	149,000
1931	3,120	27,600	19,000	64,200	27,300	44,600
1930	5,280	14,000	21,700	42,700	22,200	28,900
1929						
1928						
1927						
1926						
1925						
1924						
1923						
1922						
1921						
1920						
1919				**165,800	31,600	
1918					19,800	
1917					57,800	

**Calendar year; water year estimated the same.

LITTLE COLORADO RIVER BASIN STREAM FLOW SUMMARY.

	Little Colorado Grand Falls	Moenkopi-Tuba City	Zuni River-Black Rock, New Mexico	Colorado River-Grand Canyon	Colorado River-Lees Ferry	Paria-Lees Ferry
	(7)	(8)	(9)	(10)	(11)	(12)
1940						
1939						
1938	170,200	7,810		15,630,000	15,410,000	25,720
1937	330,500	18,230		12,410,000	11,870,000	26,980
1936	165,100	20,710		12,322,000	11,935,000	35,290
1935	215,400	7,360		10,216,000	9,894,000	17,130
1934	70,980	16,590		4,656,000	4,377,000	19,440
1933	129,000	10,200		10,000,000	9,730,000	16,700
1932	466,000	7,890		16,000,000	15,300,000	37,900
1931	165,000	5,500		6,720,000	6,380,000	11,400
1930	189,000	46,000	15,400	13,400,000	13,100,000	19,000
1929	511,000	41,200	6,970	19,400,000	19,200,000	34,800
1928	87,600	4,510	55,600	15,600,000	15,300,000	16,000
1927	394,000	8,750	16,100	17,300,000	16,500,000	45,000
1926	181,000	6,000	5,000	14,400,000	14,000,000	32,100
1925			5,140	11,800,000	11,300,000	29,500
1924			11,900	13,000,000	12,500,000	18,780
1923			17,700	17,000,000	16,240,000	
1922			2,320		16,280,000	
1921			6,790			
1920			11,000			
1919			45,700			

LITTLE COLORADO RIVER BASIN STREAM-FLOW SUMMARY

Notes on computation sheets.

Where the term diversions are used in the computations, they have been considered as consumptive use except where otherwise noted.

Columns (1) to (6) from U.S. G. S. Water-Supply Papers. Some years lacking because there are no complete records.

Column (7) from U.S.G.S. Water-Supply Papers. Water year 1926 was completed from estimates.

Column (8) from U.S.G.S. Water-Supply Papers. 1926 was entirely estimated by inspection.

Columns (9), (10), (11), and (12) from U.S.G.S. Water-Supply Papers. Year 1924 for Paria completed from estimates.

Column (13) is sum of known inflow to Colorado River above Grand Canyon station and is sum of columns (7), (8), (11), and (12).

Column (14) is column (10) less (13) and gives inflow above Grand Canyon station and below the four stations added under column (13). This column was not computed for individual years because at least one negative figure would result. The difference of (10) - (13) is a small percent of the total and an error of 1% in the total would affect the difference greatly. However, the errors from year to year should be compensating so the average difference of 110,317 per year for the 13 years 1926-1938 is reasonably accurate, even though the difference for individual years would be quite inaccurate.

Column (15) represents that part of column (14) contributed by the Little Colorado River basin below Little Colorado River at Grand Falls and Moenkopi Wash near Tuba, and is an average figure only.

Drainage areas concerned:

968 sq. mi. below Lees Ferry and Paria, above Grand Canyon station, and north of Colorado River, and also includes area south of Colorado River, below Little Colorado mouth.

480 sq. mi. north of Little Colorado basin and east of Colorado River.

1,448 sq. mi. below Lees Ferry and above Grand Canyon, except Little Colorado basin.

3,462 sq. mi. in Little Colorado basin below Grand Falls and Tuba but above mouth.

4,910 sq. mi. total area between Lees Ferry and Grand Canyon excluding that above stations on Paria, Moenkopi and at Grand Falls.

Run-off rates concerned, based on 1938 record and all previous years for which there are complete records (virgin flow run-off):

Bright Angel Creek $\frac{27,600 \text{ acre-feet}}{100 \text{ sq. mi.}} = 276$ acre feet per year per sq. mi.

Moenkopi Wash $\frac{18,019}{2,270} = 7.9$ acre-feet per year per sq. mi.

(The above includes 1,000 acres at 2.5 acre-feet per acre per year, or 2,500 acre-feet use added to the 15,510 acre-foot actual average).

Paria $\frac{26,800}{1,520} = 17.7$ acre-feet per year per sq. mi.

(The above includes 600 acres at 2.5 acre-feet per acre per year, or 1,500 acre-feet, less 500 acre-feet (500 acre-feet are imported to Colorado basin from Sevier River drainage), or 1,000 acre-feet net consumptive use added to the 25,800 acre-foot actual average).

The area of 1,448 sq. mi. above (Lees Ferry to Grand Canyon, except Little Colorado basin) was estimated to contribute as follows:

	Acre-feet
100 sq. mi. at Bright Angel rate of 276	= 27,600
868 sq. mi. at Paria rate of 17.7	= 15,400
480 sq. mi. at Moenkopi rate of 7.9	= 3,800
	46,800

The estimated mean annual contributions is 47,000 acre-feet.

Assume all inflow to Little Colorado basin below Grand Falls and Tuba is represented by Blue Springs which are estimated to average about 200 second-feet. This is 145,000 acre-feet per year average.

	Mean run-off in acre feet per year
From Colorado River basin Lees Ferry to Grand Canyon except Little Colorado and Paria	47,000
From Little Colorado basin except that above Grand Falls and Tuba	+ 145,000
Total inflow from 4,910 sq. mi. between Lees Ferry and Grand Canyon excluding Paria, Moenkopi near Tuba and Little Colorado above Grand Falls	192,000
Inflow actually gaged from same area (see above under column (14)	- 110,000
Computed losses in channels of the Little Colorado below Grand Falls and in Colorado River between Lees Ferry and Grand Canyon	82,000
Estimated evaporative loss in main river (87 miles long,400 feet wide, 93 inches per year from Lees Ferry land pan average and pan coefficient 0.7)	- 23,000
Estimated other main river losses (transpiration, deep seepage)	- 9,000
Losses occurring in Little Colorado basin below Grand Falls and Tuba	50,000
Less loss in Moenkopi Wash, estimated as about one half the annual run-off	- 8,000
Losses in 96-mile channel of Little Colorado River below Grand Falls	42,000

Summary of gains and losses

Little Colorado basin below Grand Falls and Tuba:

Inflow	145,000	acre-feet per year
Losses	50,000	" " " "
Net gain	95,000	" " " "

Colorado River between Lees Ferry and Grand Canyon exclusive of Paria and Little Colorado Rivers:

Inflow	47,000	acre-feet per year
Losses	32,000	" " " "
Net gain	15,000	" " " "

Colorado River between Lees Ferry and Grand Canyon exclusive of Paria, Moenkopi, and Grand Falls:

Little Colorado basin, net gain	95,000
Other area, net gain	15,000
Total	110,000

Actual net gain by stream gaging from the above area is 110,000 acre-feet; see column (14). Therefore use "Other area net gain" as 15,000 acre-feet, and Little Colorado area as 95,000 acre-feet. The only use for the above estimate is in the division of the 110,000 acre-foot gain between Little Colorado basin and other area between Lees Ferry and Grand Canyon. Whether the diversion as used is correct or not, in the final summary for Arizona is not effected. The total of 110,000 acre-feet is used as contributed by the area below Lees Ferry, Paria, Tuba, and Grand Falls but above Grand Canyon, and this 110,000 acre-foot figure is based on actual gaging records.

Column (16). Irrigated acreage was derived from three sources:

1. From U. S. Bureau of Reclamation data:

	Cultivated area
Silver Creek	4,000 acres
Other Little Colorado in Arizona	11,740
Little Colorado in New Mexico	6,540
	22,280 acres

Meadow area

Silver Creek	290 acres
Other Little Colorado in Arizona	4,440
Little Colorado in New Mexico	260
	4,990 acres

Assuming meadow land to have consumptive use of ½ of cultivated land, total effective acreage = 22,280 + 2,495 = 24,775 acres.

2/ From Government report of 1938 on Colorado River basin, Appendix A, p. 138:

Zuni in New Mexico	4,500 acres
Other in New Mexico	500
Winslow	1,000
Showlow	0
Tuba	1,000
Other Little Colorado	11,000
	18,000 acres

3. From Navajo County Agent, map of Navajo Reservation by Indian Service, and Walkup of Flagstaff:

(From map) In Arizona on Navajo Reservation	4,989 acres
(U.S.B.R.) In New Mexico	6,500
(From Navajo County Agent) In Navajo County off reservation	7,854
(From Walkup) Near St. Johns	4,000
	23,343 acres

24,775
18,000
23,343
3/ 5,118
22,039 acres average

Using 2½ acre-feet per acre on 22,000 acres, the consumptive use equals 55,000 acre-feet.

There is some question regarding the channel losses in this section of the river and it is felt that a part of this water would have been lost from natural causes had it not been diverted. This discrepancy probably does not exceed 20,000 acre feet. The exact amount is a debatable question, however, the amount negligible with respect to the total virgin flow.

Column (17) is virgin flow at mouth and is sum of columns (7), (8), (15), and (16).

S E C T I O N IV

LITTLE COLORADO RIVER BASIN

IN

NEW MEXICO STREAM-FLOW SUMMARY

* * *

LITTLE COLORADO RIVER BASIN IN NEW MEXICO STREAM-FLOW SUMMARY.

	Little Colorado-Hunt	Little Colorado-St. Johns	Flow at Hunt less that at St. Johns	Little Colorado-Woodruff	Silver Creek-Woodruff	Flow at Woodruff less that at St. Johns & Silver
	(1)	(2)	(3)	(4)	(5)	(6)
1940						
1939						
1938		4,110		15,110	7,560	3,440
1937		3,540		46,100	23,040	19,520
1936		4,350		42,710	15,940	22,420
1935						
1934						
1933	15,900	5,050	10,850	51,600	23,900	22,650
1932	48,700	15,600	33,100	117,000	59,500	41,900
1931	27,600	3,120	24,480	64,200	19,000	42,080
1930	14,000	5,280	8,720	42,700	21,700	15,720
*1929	*63,000	*2,820	60,180	*106,000	*23,600	79,580
†1929	†70,000	†4,000	66,000	†115,600	†26,000	85,600

*Period July 1 to Sept. 30, 1929, only.
†Full water year 1929; part of each year estimated.

LITTLE COLORADO RIVER BASIN IN NEW MEXICO STREAM-FLOW SUMMARY.

	Diversions in New Mexico	Virgin flow at Hunt less that at St. Johns	Virgin flow at Woodruff less that at Silver & St. Johns	New Mex. part of virgin at Hunt less that at St. Johns	N. Mex. part of virgin flow at Woodruff less Silver & St. Johns	N. Mex. virgin flow to Little Colorado except for Puerco
	(7)	(8)	(9)	(10)	(11)	(12)
1940						
1939						
1938	9,750	9,000	13,190	6,760	8,710	7,740
1937	16,250	26,300	35,770	19,750	23,610	21,680
1936	16,250	28,700	33,670	21,550	25,520	23,540
1935	16,250					
1934	16,250					
1933	16,250	27,100	38,900	20,350	25,670	23,010
1932	16,250	49,350	58,150	37,060	38,380	37,720
1931	16,250	40,750	58,330	30,590	38,500	34,540
1930	16,250	24,370	31,970	18,750	21,100	19,920
*1929	*8,000	68,180	87,580	51,200	57,800	54,500
†1929	†16,250	82,250	101,850	61,770	67,220	67,220

*Period July 1 to Sept. 30, 1929, only.
†Full water year 1929; part of each year estimated.

LITTLE COLORADO RIVER BASIN IN NEW MEXICO STREAM-FLOW SUMMARY.

	Virgin run-off per sq. mi. New Mex. excluding Puerco River	Puerco virgin flow from New Mexico	Total virgin flow from New Mexico	Total actual flow from New Mexico	Virgin flow of L. Colo. at Holbrook	Virgin flow of L. Colo. at Grand Falls
	(13)	(14)	(15)	(16)	(17)	(18)
1940						
1939						
1938	1,634	2,380	10,120	370	77,320	322,200
1937	4,577	6,670	28,350	12,100	119,280	391,500
1936	4,909	7,240	30,780	14,530	114,690	217,100
1935						267,400
1934						122,980
1933	4,858	7,080	30,090	13,940	126,720	181,000
1932	7,963	11,610	49,330	33,080	215,270	518,000
1931	7,292	10,630	45,170	28,920	143,780	217,000
1930	4,205	6,130	26,050	9,800	114,670	241,000
*1929	11,305	16,770	71,270	63,270		
+1929	14,190	20,690	87,910	71,600	213,370	563,000

*Period July 1 to Sept. 30, 1929, only.
+Full water year 1929; part of each year estimated.

LITTLE COLORADO RIVER BASIN IN NEW MEXICO STREAM-FLOW SUMMARY

	Total loss N. Mex. to Holbrook	N. Mex. share of losses N. Mex. to Holbrook	Total losses Holbrook to Grand Falls	N. Mex share of losses Holbrook to Grand Falls	N. Mex. virgin flow at Grand Falls	N. Mex. share of losses below G. Falls
	(19)	(20)	(21)	(22)	(23)	(24)
1940						
1939						
1938	8,490	1,000	18,510	1,130	7,990	1,050
1937	13,100	2,810	31,560	3,150	22,390	2,950
1936	12,600	3,050	20,500	3,430	24,300	3,200
1935						
1934						
1933	13,920	2,980	19,020	3,350	23,760	3,130
1932	23,650	4,380	45,310	5,490	38,960	5,130
1931	15,800	4,470	22,300	5,030	35,670	4,700
1930	12,600	2,580	21,980	2,900	20,570	2,710
1929	23,440	8,700	47,980	9,790	69,420	9,150

LITTLE COLORADO RIVER BASIN IN NEW MEXICO STREAM-FLOW SUMMARY

	New Mex. share of virgin flow of L. Colo. at mouth	Ariz. share of virgin flow of L. Colo. at mouth	Total virgin flow losses charged to New. Mex.
	(25)	(26)	(27)
1940			
1939			
1938	6,940	321,070	3,180
1937	19,440	488,290	8,910
1936	21,100	314,710	9,680
1935			
1934			
1933	20,630	268,570	9,460
1932	33,830	590,060	15,500
1931	30,970	289,530	14,200
1930	17,860	367,140	8,190.
1929	60,270	641,930	27,640
8 year average	26,380	410,170	12,100

LITTLE COLORADO RIVER BASIN IN NEW MEXICO STREAM-FLOW SUMMARY

Notes on computation sheets.

All figures on computation sheets are annual run-off in acre-feet for water year ending September 30, unless otherwise noted.

Where the term diversions are used in the computations, they have been considered as consumptive use except where otherwise noted.

Columns (1) and (2) from U.S.G.S. Water-Supply Papers;

Records for water year 1929 are not complete for most of the gaging stations. Because 1929 is the year of highest run-off, flow July 1 to September 30 being greater for most stations than flow for entire year, 1929 was carried through on two bases: (1) Using period July 1 to September 30, all of which is actual record, and (2) completing the 1929 water year by estimation. The estimates are based largely on comparison with flow at Grand Falls and weather records.

Column (3) is difference between column (1) and (2) and represents actual flow contributed below St. Johns and above Hunt. The area from which this is contributed is:

Hunt	7,243 sq. mi.
St. Johns	-938
	6,305 sq. mi.

Of this difference, New Mexico contains:

Hunt	4,781 sq. mi.
St. Johns	-44
	4,737 sq. mi.

Therefore, New Mexico contributes, on a drainage area basis, $\frac{4,737}{6,305}$ of the difference in flow.

Columns (4) and (5) from U.S.G.S. Water - Supply Papers.

Column (6) is (4) - (5) - (2) and represents actual flow below St. Johns, but above Woodruff, excluding Silver Creek. The area contributing this is:

Little Colorado -	Woodruff	9,062
	Silver	-943
	St. Johns	-938
		7,181 sq. mi.

Of this difference New Mexico contributes:

Little Colorado-	Woodruff	4,781 sq. mi.
	Silver	0
	St. Johns	-44
		4,737 sq. mi.

Therefore, New Mexico contributes $\frac{4,737}{7,181}$ of the difference in flow.

Column (7) is consumptive use in New Mexico consisting of 6,500 acres at 2.5 acre-feet per acre, or 16,250 acre-feet except for 1938, which is a very low year and for which 1.5 acre-feet per acre was used. This is all on the Zuni and therefore in the area for which flow has been computed in columns (3) and (6). There are no known irrigated areas on the Puerco. The figure 6,500 acres was furnished by U.S.B.R. from a report of Bureau of Reclamation land classifiers.

Column (8) for 1929-1933 is sum of columns (3) and (7) and is virgin flow at Hunt with area above St. Johns excluded. Column (3) contains no figures for 1936-1938. To get these years for column (8), chart 11 was made by plotting column (9) against column (8) for 1929-1933. For column (9) derivation, see below. A mean curve was drawn on chart 11, and values for column (8) for 1936-1938 picked from it.

entering the cart with values from column (9).

Column (9) is sum of columns (6) and (7) and is virgin flow at Woodruff with area above St. Johns and all of Silver Creek excluded. There are no diversions in Arizona in the areas represented by flow in either column (8) or (9).

Column (10). As shown under column (3) discussion, on a drainage area basis New Mexico contributes $\frac{4,737}{6,305}$ or 75.1% of the flow above Hunt but below St. Johns. Column (8) represents the virgin flow from the area above Hunt but below St. Johns. Column (10) is 75.1% of column (8) and represents New Mexico's contribution to the virgin flow coming from the area above Hunt but below St. Johns.

Column (11). If everything were correctly known, Column (11) would give identical figures with column (10) as it is a different method of arriving at the same thing. Under column (6) it is shown that on a drainage area basis New Mexico contributes $\frac{4,737}{7,181}$ or 66.0% of the flow above Woodruff, excluding St. Johns and Silver Creek. Column (9) represents the virgin flow from that area. Column (11) is 66.0% of Column (9) and represents New Mexico's contribution to the virgin flow coming from the area above Woodruff excluding St. Johns and Silver. This is virgin flow from the same area as column (10) represents, and the figures should be the same. They differ roughly uniformly by about 4,000 acre-feet; the significance of this is not known. At any rate, the two columns constitute a fair check of one another.

It is to be noted that columns (10) and (11) represent all of virgin flow coming from New Mexico except that from the Puerco River drainage.

Column (12) is the mean of columns (10) and (11) and is the best figure obtainable for New Mexico's contribution to the virgin flow of the Little Colorado excluding Puerco River. For 1929 full water year figure in column (11) used.

Column (13) is the per square mile virgin run-off from New Mexico, excluding Puerco River, and is equal to column (12) divided by 4,737 square miles which is the area contributing the flow in column (12).

Column (14) is column (13) multiplied by 1,458, and gives Puerco River virgin run-off from New Mexico. This is on the assumption that the run-off per square mile of the area contributing run-off in column (12) (mostly Zuni) is the same as on the Puerco. The area of the Puerco in New Mexico is 1,458 square miles.

Column (15) is sum of columns (12) and (14).

Column (16) is columns (15) less (7) and is total actual flow from New Mexico to Little Colorado River basin.

Column (17) is column (4) plus 42,000 acre-feet plus $\frac{3207}{9062}$ of the foregoing sum. Column (4) is actual flow at Woodruff. As shown in column (16) of main Little Colorado River study, total consumptive use from Little Colorado River average 55,000 acre-feet a year from 22,000 acres. From item 3 at bottom of sheet 5 of notes on computations for column (16) of main Little Colorado River study, it is estimated that the following irrigated acreage is above Woodruff:

In Arizona on Navajo Reservation	1,000 acres
In New Mexico	6,500
In Navajo County off reservation	5,500
Near St. Johns	4,000
	17,000 acres.

At 2.5 acre-feet consumptive use, gives 42,000 acre-feet the mean annual usage.

The sum of column (4) and 42,000 acre-feet gives virgin flow at Little Colorado - Woodruff gaging station, from an area of 9,062 square miles. Additional area above Holbrook is 3,107 sq. mi. for Puerco River at mouth and 100 sq. mi. for other intervening area. Assuming run-off from this area the same per unit area as at Woodruff, additional virgin run-off at Holbrook is $\frac{3,207}{9,062}$ of that at Woodruff. There are no diversions in the Puerco River basin, nor in the other 100 sq. miles of additional area.

Column (18) is sum of column (7) of main Little Colorado study and 52,000 acre-feet. As shown in column (16) of main study, entire diversions in Little Colorado basin are 55,000 acre-feet. Of this, 3,000 acre-feet are estimated to be below Grand Falls. See Page 2 of notes on computation sheets for Little Colorado main study where 2,500 acre-feet is estimated as diversion above Moenkopi gaging station. An additional 500 acre-feet diversion is estimated below Grand Falls and Moenkopi gaging stations.

Column (19) is losses from Little Colorado River channels between New Mexico line and Holbrook. Above Holbrook the river may be considered to have three channels, the main stem Little Colorado (which does not reach into New Mexico), the Zuni and the Puerco. The assumption was made that these channels would act as one, chosen as the Little Colorado from Holbrook to the Zuni, then up the Zuni to the New Mexico line. The length of this channel, Holbrook to New Mexico is 80 miles.

On page 3 of notes on computations for Little Colorado main study, near bottom of sheet, it is computed that 42,000 acre-feet are lost in channel of Little Colorado in the 96 miles from Grand Falls to mouth. This is a canyon section. It was assumed that the loss Holbrook to New Mexico line would be as great per mile, per unit discharge. Considering that the channel above Holbrook is actually in three parts and that none is in canyon, this assumption would appear to make losses low above Holbrook, if anything. Mean virgin flow at Grand Falls 1929-33 and 1936-38 is 318,850 acre-feet (see column (18). Then losses below Grand Falls, for the average in the 8-year period per mile per acre-foot are $\frac{42,000}{96 \times 318,850}$ = 0.001372 acre-feet. Applying this figure to the stretch New Mexico to Holbrook, we multiply by 80 miles, and by virgin flow at Holbrook (col. (17)) to get column (19) figures.

Column (20), New Mexico's share of losses above Holbrook is solved for as follows:

Let NM = total virgin flow out of New Mexico. = col. (15)

L = New Mexico part of loss from N.M. line to Holbrook.

X = New Mexico part of total virgin flow at Holbrook.

T = Total virgin flow at Holbrook.

Col. (19) = Total loss from New Mexico line to Holbrook.

$\frac{X}{T}$ x col. (19) = L

X + L = N.M.

L = N.M. - X

Then,

$$\frac{X}{T} = \frac{\text{N.M.} - X}{\text{col. 919)}}$$

and

$$\text{Col. (19)}\ X = TNM - TX$$

$$\text{Col. (19)}\ X + TX = TNM$$

$$X\ (\text{col. (19)} + T) = TNM$$

$$X = \frac{TNM}{\text{col. (19)} + T}$$

$$\text{col. (20)} = \text{col. (15)} - X$$

or

$$\text{col. (20)} = \text{col. (15)} - \frac{\text{col. (17)} \times \text{col. (15)}}{\text{col. (17)} + \text{col. (19)}}$$

Column (21) was computed on same basis as column (19), using a distance of 90 miles instead of 80, as it is 90 miles from Holbrook to Grand Falls. Also, instead of using virgin flow at Holbrook as a measure of the flow, the mean of virgin flow at Holbrook and Grand Falls was used. Therefore col. (21) = $\frac{\text{col. (17)} + \text{col. (18)}}{2}$ x 90 x 0.001372. Loss per mile per second-foot in the stretch Holbrook to Grand Falls were considered at least equal to losses below Grand Falls becuase the channel above Grand Falls is, in general, wide and sandy.

Column (22) is $\frac{\text{col. (15)} - \text{col. (20)}}{\frac{\text{col. (17)} + \text{col (19)}}{2}}$ x col. (21).

The factor col. (15) - col. (20) gives New Mexico virgin flow at Holbrook. The factor below the line gives the mean virgin flow in the stretch Holbrook to Grand Falls, and the division of the first factor by the second gives the ratio of New Mexico's virgin

flow to the total virgin flow in the stretch. This ratio times col. (21), the total losses, gives New Mexico's share of the losses Holbrook to Grand Falls.

Column (23) = col. (15) - (20) - (22) and is new Mexico's virgin flow at Grand Falls.

Column (24) is computed on same principle as col. (19). In notes on col. (19) it is shown that average loss from Grand Falls to mouth of Little Colorado is 0.001372 acre-feet per year per mile per acre-foot. Multiplying this by 96 miles and by New Mexico's virgin flow figures in col. (23) gives col. (24), New Mexico's share of losses below Grand Falls.

Column (25) = col. (23) - (24) and is New Mexico's contribution to virgin flow of Little Colorado River at the mouth.

Column (26) = column (17) of main Little Colorado summary, less col. (25) of this summary and is Arizona's contribution to the virgin flow of Little Colorado River at the mouth.

Column (27) is sum of columns (20), (22), and (24) and is the losses charged to New Mexico's virgin flow due to transit between New Mexico border and the mouth of the river.

Review of summary of Little Colorado River flow from New Mexico.

The longest usable stream-flow record in the Little Colorado River basin is available for only 13 years and most records run only 7 or 8 years. No records at all exist on the important tributaries Zuni and Puerco Rivers. Because of this, the study in the Little Colorado basin has been compared to the Gila River basin. These

comparisons have been made to test the accuracy of Little Colorado basin results as against results in the Gila basin.

Loss per mile

The average loss used in Little Colorado study above was 0.001372 acre-feet per year per mile per second-foot. This is based largely but not entirely on the records for the 13 years 1926-1938. The comparable figure for the Gila River basin derived from "Gila River basin stream flow summary", sheet 11, col. (61)-(63) for 1936-1938, allowing an estimated 65,000 acre-feet per year as inflow to the stretch Gillespie to Dome, using 140 miles as the distance, and 1,691,000 acre-feet as mean virgin run-off at Gillespie (from col. (61), is 0.002128 acre-feet loss per year per mile per acre-foot. This is a loss of 1.5 times as much on the lower Gila as on the Little Colorado, under virgin flow conditions. This seems reasonable.

Loss of New Mexico water in transit across Arizona.

On the Gila, New Mexico is charged with losses of 76,300 acre-feet out of the 199,130 acre-feet of virgin flow leaving New Mexico. This is a loss of 38.3%

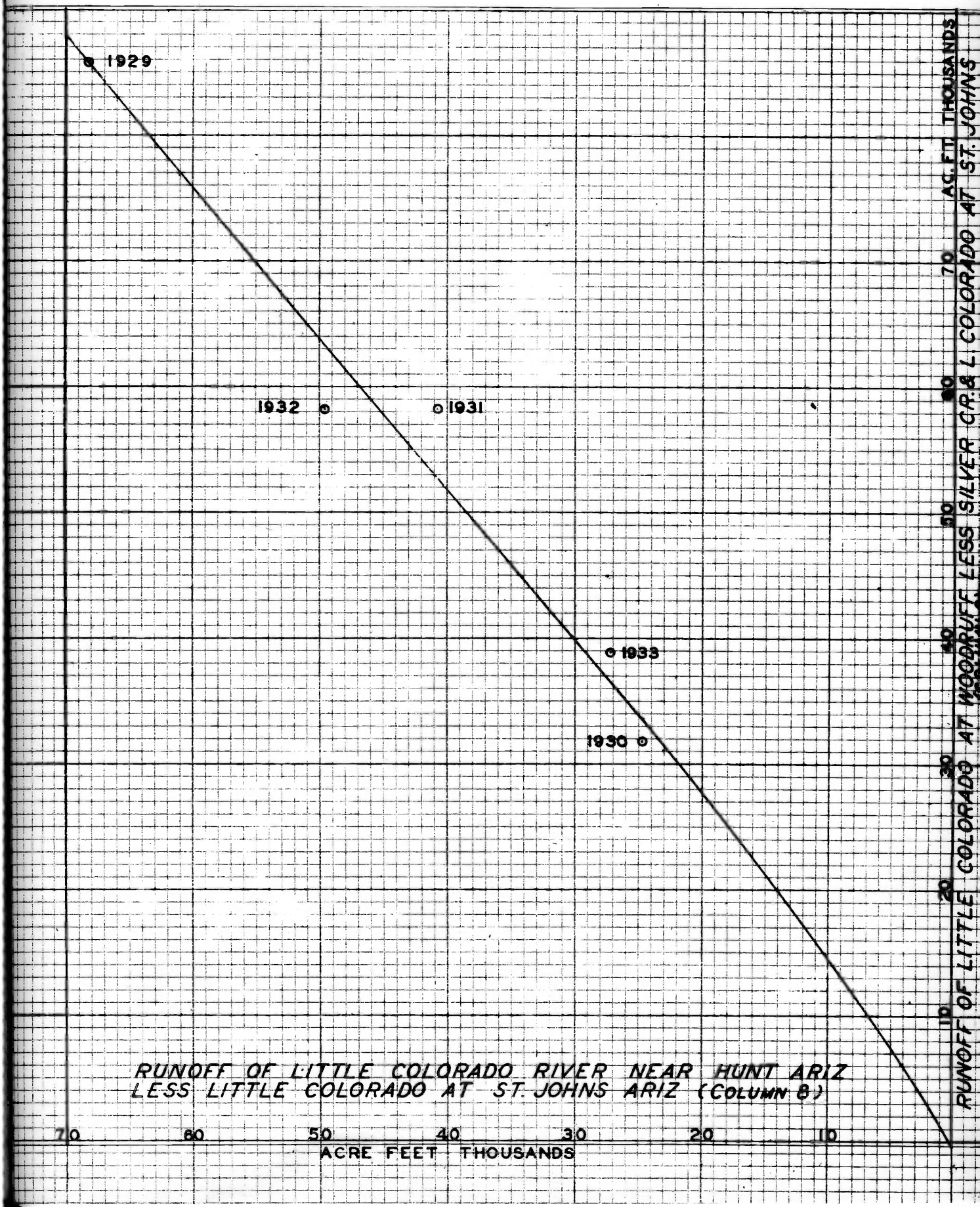
On the Little Colorado, loss is 12,100 out of 38,480 acre-feet or 31.4%.

Considering that the length of the Gila in Arizona is about 460 miles and of the Little Colorado 270 miles, the Little Colorado loss should be $\frac{270}{460}$ of 38.3% or 22.5%, on a mileage comparison basis, instead of the 31.4% it is. The difference is probably due to the fact that the Little Colorado carries only 1/3 to 1/4 the quantity of water which the Gila carries. Losses per second-foot are higher on low flows. A rough estimate based on Gila River

studies indicated that loss per unit run-off increased from 1.3 to 2 times as much for a decrease in total flow of the order of 6 to 1. An increase of 1.4 applied to the 22.5% above, would check the actual figure on the Little Colorado of 31.4%. Therefore the percent loss in transit on the two streams seems reasonable.

CHART 1

LITTLE COLORADO RIVER BASIN IN NEW MEXICO STREAM FLOW SUMMARY



S E C T I O N V

WILLIAMS RIVER BASIN

STREAM FLOW SUMMARY

* * *

WILLIAMS RIVER BASIN STREAM FLOW SUMMARY.

	Williams-Planet	Diversions	Virgin Flow	
	(1)	(2)	(3)	
1940				
1939				
1938	113,000	4,000	117,000	
1937	252,900	4,000	256,900	
1936	21,800	4,000	25,800	
1935	110,200	4,000	114,200	
1934	11,650	4,000	15,650	
1933	13,300	4,000	17,300	
1932	319,000	4,000	323,000	
1931	109,000	4,000	113,000	
1930	33,000	4,000	37,000	
1929	31,200	4,000	35,200	
1928			105,500	= 10-year average
1927				
1926				
1925				
1924				
1923				
1922				
1921				
1920				
1919				
1915	116,000	4,000	120,000	
1914	78,100	4,000	82,100	
1913	*29,400	4,000	33,400	

*Calendar year; estimated same for water year.

WILLIAMS RIVER BASIN STREAM FLOW SUMMARY

Notes on computation sheets.

Where the term diversions are used in the computations, they have been considered as consumptive use except where otherwise noted.

Column (1) From U.S.G.S. Water-Supply Papers. The record for 1913-1915 was published as "Williams River near Swansea, Arizona." The figure for 1913 is calendar year figure, but published gage heights show that flow in October, November, December, 1912, was very nearly the same as in October, November, December, 1913.

Column (2) Acreage irrigated was 1,860 acres, including much meadow land, according to Major Simons of U. S. Bureau of Reclamation who has made extensive studies on the Williams River basin. Allowing a consumptive use of 2½ acre-feet per acre, per year, 4,180 acre-feet were used. Use 4,000 acre-feet. Variation in use from year to year would be small.

Column (3) is sum of columns (1) and (2). The gaging station is 12 miles above the river mouth but only a few miles above water in Lake Havasu when it is at operating level. Flow at the gage is therefore assumed the same as flow at the mouth.

S E C T I O N VI

GILA RIVER BASIN
STREAM FLOW SUMMARY

* * *

GILA RIVER BASIN STREAM FLOW SUMMARY.

	Duncan Valley Diversions			Safford Valley Diversion		
	U.S.G.S. records	On basis of 1936-38	River loss	U.S.G.S. records	On basis of 1936-38	River loss
	(1)	(2)	(3)	(4)	(5)	(6)
1940						
1939						
1938		29,769	20,000		114,720	76,000
1937		37,273	25,000		159,840	107,000
1936		38,620	26,000		131,830	88,000
1935		36,000	24,000		135,000	91,000
1934		22,000	15,000		92,000	61,000
1933		47,000	31,000		165,000	110,000
1932		33,000	22,000		124,000	83,000
1931	70,650	46,000	31,000	230,210	163,000	109,000
1930	66,160	33,000	22,000	206,230	126,000	84,000
1929	61,530	29,000	19,000	185,920	110,000	73,000
1928	75,410	29,000	19,000	236,050	112,000	75,000
1927	75,780	37,000	25,000	251,140	137,000	91,000
1926	65,380	46,000	30,000	233,800	160,000	106,000
1925	54,100	25,000	17,000	147,540	95,000	78,000
1924	62,150	33,000	22,000	214,460	124,000	83,000
1923		34,000	23,000	169,620	126,000	87,000
1922		24,000	16,000	180,650	99,000	66,000
1921		32,000	21,000	183,700	120,000	80,000
1920		52,000	30,000		130,000	110,000
1919		52,000	30,000		180,000	110,000
1918						
1917						
1916			30,000			110,000
1915	36,530		30,000	197,440	175,000	110,000
1905			20,000			75,000

GILA RIVER BASIN STREAM FLOW SUMMARY

	Gila-Calva plus San Carlos-Peridot	Diversions in New Mexico except Duncan Valley	20% of Peridot	Gila-Kelvin	Gila-Coolidge Dam	Gain 10 minus 11
	(7)	(8)	(9)	(10)	(11)	(12)
1940						
1939						
1938	121,910	20,000	3,142	234,000	189,700	44,300
1937	364,540	20,000	9,328	365,200	279,600	85,600
1936	194,770	20,000	8,914	301,700	228,100	73,600
1935	237,180	20,000	17,536	334,300	184,600	149,700
1934	173,830	20,000	2,746	220,000	184,700	35,300
1933	165,800	20,000	3,360	373,000	335,000	38,000
1932	494,000	20,000	10,400	366,000	257,000	109,000
1931	326,700	20,000	7,340	363,000	224,000	139,000
1930	247,000	20,000	7,400	343,000	220,000	123,000
1929	*200,000	20,000		97,700	16,700	81,000
1928	*100,000	20,000		151,000	100,000	51,000
1927	*231,000	20,000		324,000	231,000	93,000
1926	*268,000	20,000		405,000	268,000	137,000
1925	*148,000	20,000		177,000	148,000	29,000
1924	*342,000	20,000		378,000	342,000	36,000
1923	*237,000	20,000		350,000	237,000	113,000
1922	* 65,900	20,000		120,000	65,900	54,100
1921	*285,000	20,000		461,000	285,000	176,000
1920	*528,000	20,000		694,000	528,000	166,000
1919	*518,000	20,000		736,000	518,000	218,000
1918						
1917						
1916				1,410,000		
1915				2,260,000		
1905	*1,334,000			1,400,000	1,334,000	

* Flow at Coolidge Dam, which is equivalent to the sum of Gila-Calva, San Carlos-Peridot, and 20% of Peridot.

GILA RIVER BASIN STREAM FLOW SUMMARY.

	San Pedro-Mammoth	Aravaipa	San Pedro valley Diversions	Winkelman Valley Diversions	12 minus 13 and 14	25% of 17
	(13)	(14)	(15)	(16)	(17)	(18)
1940						
1939						
1938	31,080	12,370	12,000	676	850	212
1937	62,950	19,150	11,700	1,290	3,500	875
1936	38,030	19,390	11,400	1,166	16,180	4,045
1935	45,020	37,280	11,100	1,200	67,400	16,850
1934	24,860	10,750	10,800	650	- 130	None
1933	15,000	13,700	10,500	1,300	9,300	2,325
1932	65,800	29,100	10,050	1,300	14,100	3,525
1931	*94,000		9,600	1,300	45,000	11,250
1930	*80,000		9,150	1,250	43,000	10,750
1929	*80,000		8,700	1,000	1,000	250
1928	* 9,000		8,250	1,000	42,000	10,500
1927	*74,000		7,800	1,300	19,000	4,750
1926	*140,000		12,000	1,300	-3,000	None
1925	* 48,000		12,000	1,000	-19,000	None
1924	* 22,000		12,000	1,200	14,000	3,500
1923	* 57,000		12,000	1,200	56,000	14,000
1922	* 47,000		12,000	1,100	7,100	1,725
1921	*150,000	24,900	12,000	1,200	26,000	6,500
1920	* 85,000	15,400	12,000	1,300	81,000	20,250
1919	*138,000	17,700	12,000	1,300	80,000	20,000
1918						
1917						
1916			12,000	1,000		20,000
1915			12,000	1,000		20,000
1905			10,000	1,000		20,000

*Figures represent Mammoth plus Aravaipa and are all estimates

GILA RIVER BASIN STREAM FLOW SUMMARY

	Virgin flow at Ashurst-Hayden Dam	Ashurst-Hayden Dam Diversions	19 minus all Diversions	Actual flow below Ashurst Hayden Dam	Salt Roosevelt	Tonto
	(19)	(20)	(21)	(22)	(23)	(24)
1940						
1939						
1938	298,240	191,610	-22,046	42,620	354,000	40,000
1937	625,333	287,909	172,434	78,166	377,730	160,000
1936	427,895	245,388	35,941	60,357	637,000	54,220
1935	568,566	240,000	181,266	111,150	747,900	92,650
1934	319,326	210,839	1,037	9,161	236,300	19,500
1933	382,285	326,394	-116,909	48,931	426,000	47,200
1932	753,275	208,920	348,005	100,605	1,170,000	225,000
1931	655,190	239,292	244,998	134,958	547,000	92,100
1930	524,550	220,183	167,967	133,567	471,000	37,600
1929	402,950	60,000	221,250	37,950	408,000	64,100
1928	284,750	101,000	60,500	60,500	282,000	35,500
1927	473,750	120,000	208,750	208,750	794,000	166,000
1926	574,300	119,000	286,000	286,000	632,000	161,000
1925	305,000	62,000	115,000	115,000	291,000	36,900
1924	515,700	110,000	267,500	271,500	770,000	134,000
1923	507,200	80,000	284,000	284,000	494,000	120,000
1922	236,875	78,000	43,775	43,775	529,000	162,000
1921	601,700	71,000	396,500	396,500	511,000	35,400
1920	887,550	88,000	626,250	626,250	1,620,000	269,000
1919	929,300	62,000	694,000	694,000	881,000	112,000
1918						
1917						
1916	1,613,000	52,000	1,388,000	1,378,000	2,200,000	213,000
1915	2,483,000	50,000	2,260,000	2,230,000	1,590,000	189,000
1905	1,526,000	25,000	1,375,000	1,395,000	*3,001,320	

*Measured on Salt just above Verde and includes columns (24) and (25).

Numbers heading columns should be

25, 26, 27, 28, 29, 30.

instead of

23, 24, 25, 26, 27, 28.

GILA RIVER BASIN STREAM FLOW SUMMARY

	Unmeasured inflow to Salt River above Granite Reef	Verde-McDowell	Verde Diversions above McDowell	City of Phoenix Verde diversions	McDowell Indian Diversions	Virgin flow of salt at Granite Reef
	(23)	(24)	(25)	(26)	(27)	(28)
1940						
1939						
1938	40,620	436,050	31,000	14,173	3,937	920,360
1937	160,000	819,200	31,000	6,783	2,790	2,059,500
1936	54,220	287,400	31,000	6,136	3,449	1,075,425
1935	92,650	505,500	31,000	5,999	3,681	1,479,380
1934	19,500	164,200	31,000	14,900	5,113	490,513
1933	47,200	320,000	31,000	12,800	3,842	788,042
1932	225,000	835,000	31,000	14,400	3,639	2,504,039
1931	92,100	404,000	31,000	13,600	3,988	1,183,788
1930	37,600	287,000	31,000	13,500	3,774	881,474
1929	64,100	387,000	31,000	13,000	1,614	968,814
1928	35,500	314,000	31,000	11,100	1,462	710,562
1927	186,000	827,000	31,000	9,850	2,117	1,905,967
1926	161,000	509,000	31,000	8,530	4,335	1,506,865
1925	36,900	253,000	31,000	7,330	4,404	660,534
1924	134,000	548,000	31,000	8,200	2,555	1,627,755
1923	120,000	538,000	31,000	7,590	2,000	1,312,590
1922	162,000	784,000	31,000	5,170	2,000	1,675,170
1921	35,400	309,000	31,000	0	2,000	923,800
1920	269,000	1,270,000	31,000	0	2,000	3,461,000
1919	112,000	542,000	31,000	0	2,000	1,680,000
1918						
1917						
1916	213,000	933,000	30,000	0	2,000	3,591,000
1915	189,000	705,000	30,000	0	2,000	2,705,000
1905	200,000	1,569,430	25,000	0	2,000	4,555,430

GILA RIVER BASIN STREAM FLOW SUMMARY.

	Hassayampa at the box	Hassayampa Diversions	Virgin flow of Hassayampa	Agua Fria at Lake Pleasant	Agua Fria Diversions	Virgin flow of Agua Fria
	(31)	(32)	(33)	(34)	(35)	(36)
1940						
1939		1,000				
1938	17,000	1,000	18,000	28,924	26,639	29,924
1937	86,000	1,000	87,000	111,924	109,951	112,924
1936	51,345	1,000	52,300	23,809	28,810	24,809
1935	99,507	1,000	100,500	79,459	56,910	80,459
1934	4,097	1,000	5,100	13,578	11,852	14,578
1933	12,376	1,000	13,400	32,497	46,577	33,497
1932	47,756	1,000	48,800	84,193	82,015	85,193
1931	31,101	1,000	32,100	103,047	58,158	104,047
1930	3,615	1,000	4,600	34,460	30,175	35,460
1929	3,871	1,000	4,900	23,257	1,649	24,257
1923	22,836	1,000	23,800	39,781	64,800	40,781
1927	155,875	1,000	156,900	327,000	1,000	328,000
1926	36,321	1,000	37,300	164,200	1,000	165,000
1925	30,738	1,000	31,700	43,000	1,000	44,000
1924	34,355	1,000	35,400	142,500	1,000	143,500
1923	28,100	1,000	29,100	143,000	1,000	144,000
1922	85,561	1,000	86,600	306,000	1,000	307,000
1921	22,511	1,000	23,500	66,000	1,000	67,000
1920	219,309	1,000	220,300	466,000	1,000	467,000
1919	28,147	1,000	29,100	74,500	1,000	75,500
1918						
1917						
1916	100,000	2,000	102,000	395,500	1,000	396,500
1915	54,600	2,000	56,600	230,000	1,000	231,000
1905	60,000	1,000	61,000	250,000	1,000	251,000

GILA RIVER BASIN STREAM FLOW SUMMARY.

	Actual flow of Agua Fria below Pleasant	Salt Stewart Mountain Dam	Diversion At Granite Reef Dam	Total Diversion at and above Granite Reef	Actual flow of Salt River below Granite Reef	Santa Cruz-Tucson
	(37)	(38)	(39)	(40)	(41)	(42)
1940						
1939						
1938	None	837,900	1,039,432	1,088,542	211,157	7,619
1937	None	886,400	1,266,929	1,307,502	407,707	8,260
1936	None	795,900	1,048,520	1,088,105	7,427	8,760
1935	None	572,000	971,731	1,012,411	88,977	20,440
1934	None		862,000	913,013	563	7,570
1933	None		888,000	935,642	105	7,300
1932	24,715		1,140,000	1,189,039	380,000	14,700
1931	7,196		776,000	824,583	117,000	37,300
1930	None		748,000	796,274	12,800	8,080
1929	None		851,000	896,614	78,000	24,300
1928	None		1,120,000	1,163,562	26,500	2,920
1927	300,050		1,040,000	1,082,967	454,000	3,140
1926	164,000		842,000	885,865	200,000	20,200
1925	43,000		875,000	917,734	23,900	6,940
1924	142,500		1,260,000	1,301,755	276,000	3,700
1923	143,000		1,160,000	1,200,590	122,000	15,700
1922	306,000		1,240,000	1,278,170	392,000	10,900
1921	66,000		1,080,000	1,113,000	61,500	32,100
1920	460,000		1,380,000	1,413,000	1,330,000	7,920
1919	74,500		1,100,000	1,133,000	235,000	27,500
1918						
1917						
1916	395,500		1,227,000	1,259,000	2,191,000	37,300
1915	230,000		1,004,900	1,036,900	648,000	80,200
1905	250,000		455,000	482,000	4,100,430	50,000

GILA RIVER BASIN STREAM FLOW SUMMARY

	Santa Cruz Diversions	Rillito	Virgin flow from Mountain area	Actual flow from Mountain area	Sacaton Dam Diversion	Buckeye Diversion
	(43)	(44)	(45)	(46)	(47)	(48)
1940						
1939						
1938	10,500	2,500	1,287,000	281,000	1,493	98,148
1937	10,500	4,450	2,908,000	585,000	2,452	106,408
1936	10,500	3,600	1,601,000	131,500	4,606	69,983
1935	10,500	18,270	2,278,000	338,500	8,016	97,415
1934	10,500	2,100	850,000	23,500	8,315	90,567
1933	10,500	1,650	1,237,000	70,500		103,161
1932	10,500	14,800	3,431,000	582,500		124,056
1931	10,500	12,100	2,035,000	339,500		118,141
1930	10,500	10,600	1,475,000	168,500		128,920
1929	10,500	26,900	1,463,000	171,000		136,475
1928	10,500	1,280	1,075,000	114,000		154,013
1927	10,500	4,580	2,973,000	1,126,500		157,967
1926	10,500	1,940	2,316,000	708,500		169,433
1925	10,500	4,720	1,063,000	224,500		156,961
1924	10,500	5,750	2,342,000	734,000		151,386
1923	10,500	6,660	2,026,000	599,500		164,578
1922	10,500	3,030	2,330,000	841,500		115,744
1921	10,500	42,600	1,701,000	621,000		135,176
1920	10,500	26,000	5,080,000	2,675,500		126,267
1919	10,500	37,200	2,789,000	1,096,500		133,773
1918						
1917						
1916	10,500	52,300	5,803,000	4,154,000		
1915	10,500	167,000	5,733,000	3,410,000		
1905	10,500	*60,000	6,514,000	5,915,500		

*Estimated

Column 53 now headed Enterprise Canal should be changed to read as follows:

Gillespie Canal

Column 53

GILA RIVER BASIN STREAM FLOW SUMMARY.

	Arlington Upper	Arlington Lower	Simpson Ranch Diversion	Gila below Gillespie Dam	Enterprise Canal	Enterprise Canal
	(49)	(50)	(51)	(52)	(53)	(54)
1940						
1939						
1938			1,500	188,400	8,000	75,320
1937	30,961	29,729	1,500	397,800	8,800	84,020
1936	39,117	31,265	1,500	27,800	8,800	69,030
1935			1,500	128,600	8,800	76,600
1934			1,500	8,050	8,800	55,000
1933			1,500	19,500	8,800	75,451
1932			1,500	452,000	8,800	97,890
1931			1,500	222,000	8,800	95,950
1930			1,500	80,600	8,800	81,800
1929			1,500	111,000	8,800	84,290
1928			1,500	79,100	8,800	130,610
1927			1,500	880,000	8,800	144,370
1926			1,500	554,000	8,800	101,570
1925			1,500	235,000	8,800	80,000
1924			1,500	782,000	8,800	80,000
1923			1,500	506,000	8,800	80,000
1922			1,500	866,000	8,800	100,000
1921			1,500	*585,000	8,800	0
1920			1,500	*2,330,000	8,800	0
1919			1,500	*1,000,000	8,800	0
1918						
1917						
1916				*3,580,000	8,800	0
1915				*2,955,000	8,800	0
1905				*5,070,000	8,800	0

*Obtained from chart 7 by applying column 46 (actual flow from mountain area) and obtaining Gila below Gillespie Dam direct, from which diversions at Gillespie Dam (column 55) are then subtracted.

GILA RIVER BASIN STREAM FLOW SUMMARY.

	Total Diversions at Gillespie Dam	Total actual flow reaching Gillespie Dam	Actual flow from Mt. area less Gillespie Diversions	Gila-Dome	Virgin flow of Gila River at mouth	Gain or loss from Mt. area to Gillespie Dam
	(55)	(56)	(57)	(58)	(59)	(60)
1940						
1939						
1938	83,320	271,720	197,680	45,900	980,000	-9,280
1937	92,820	490,620	492,180	153,700	1,590,000	-94,380
1936	77,830	105,630	53,670	No flow	1,150,000	-25,870
1935	85,400	214,000	253,100	5,910	1,380,000	-124,500
1934	63,800	71,850	-40,300	167	670,000	+43,350
1933	84,251	103,751	-13,750	1,150	950,000	+33,250
1932	106,690	558,690	475,810	266,000	1,930,000	-23,810
1931	104,750	326,750	234,750	103,000	1,380,000	-12,750
1930	90,600	171,300	77,900	15,600	1,090,000	+2.700
1929	93,090	204,090	77,910	17,880	1,080,000	+33,090
1928	139,410	218,510	-25,410	24,300	870,000	+104,510
1927	153,170	1,033,170	973,330	763,980	1,750,000	-93,330
1926	110,370	644,370	598,130	270,100	1,340,000	-44,130
1925	88,800	325,900	135,700	64,900	870,000	+99,300
1924	88,800	870,800	645,200	686,500	1,720,000	+136,800
1923	88,800	594,800	510,700	332,000	1,380,000	-4,700
1922	108,800	974,800	732,700	685,815	1,610,000	+133,300
1921	8,800	595,000	612,200	437,690	1,210,000	
1920	8,800	2,340,000	2,666,700	1,293,690	2,320,000	
1919	8,800	1,005,000	1,087,700	226,950	1,050,000	
1918			20-year average		1,316,000	
1917						
1916	8,800	3,590,000	4,145,000	4,361,080		
1915	8,800	2,960,000	3,400,000	2,324,460	3,360,000	
1905	8,800	5,080,000	5,907,000	3,047,100	3,350,000	
			22-year average		1,501,000	

*From mountain area to Dome direct not using Gillespie measurements.

GILA RIVER BASIN STREAM FLOW SUMMARY.

	Virgin flow at Gillespie Dam	Gain or loss Gillespie to Dome	*Virgin flow of Gila River at mouth
	(61)	(62)	(63)
1940			
1939			
1938	1,160,000	-142,500	960,000
1937	2,470,000	-244,100	1,640,000
1936	1,390,000	-27,800	1,130,000
1935	1,890,000	-122,690	1,370,000
1934	800,000	-7,883	660,000
1933	1,140,000	-18,350	960,000
1932	2,980,000	-186,000	1,950,000
1931	1,800,000	-119,000	1,380,000
1930	1,320,000	-65,000	1,080,000
1929	1,330,000	-93,120	1,080,000
1928	1,070,000	-54,800	920,000
1927	2,595,000	-116,020	1,760,000
1926	2,040,000	-283,900	1,390,000
1925	1,080,000	-170,100	890,000
1924	2,250,000	-95,500	1,620,000
1923	1,810,000	-174,000	1,380,000
1922	2,240,0000	-180,135	1,530,000
1921	1,520,000		1,240,000
1920	4,370,000		2,320,000
1919	2,440,000	20-year	1,050,000
1918		average	1,315,500
1917			
1916	4,980,000		
1915	4,920,000		3,370,000
1905	5,590,000	22-year	3,350,000
		average	1,501,000

*Based on flow from mountain area and at Gillespie Dam

NOTE:

Since the preparation of Column 28 showing the diversions from the Verde River by the City of Phoenix, subsequent information indicates that the figures should be changed as follows:

Year ending Sept.30	Run-off in acre-feet	
	By stream summary	By checked figures for W. S. P.
1935	5,909	13,900
1936	6,136	12,470
1937	6,783	13,830
1938	14,173	15,690

It appears that the change would follow through from Column 28 to affect Columns 30, 40, 45, and 59. The resultant change in the final answer is negligible - less than one tenth of one per cent in the virgin flow of Gila at mouth.

GILA RIVER BASIN STREAM FLOW SUMMARY

Notes on computation sheets

Where the term diversions are used in the computations, they have been considered as consumptive use except where otherwise noted.

Column (1). From U.S.G.S. Water-Supply Papers, adding up all canals in Duncan Valley. It was assumed that 700 acre-feet a year was taken by the York Canal (based on miscellaneous measurements of the canal).

Column (2). For 1936-38, from Gila Water Commissioner's records. For 1936, calendar year only is available; it was assumed the same as the water year on assumption that use in Oct., Nov., and Dec. of 1936 was same as the corresponding months of 1935.

Years 1921-1935 derived from Chart 1, entering the chart with figures from column (5). Chart 1 was made by plotting Safford diversions, column (4) for 1924-31, and column (5) for 1936-38, against column (1) for 1924-31 and column (2) for 1936-1938. The points for 1936-38 are on basis of water used after Firth took charge; the other points are on basis of period when there was little control over the use of water. Although these two sets of points are on different bases, they are believed to represent quite accurately the relation between Safford and Duncan diversions.

Origin of the curve is zero on both scales because Safford would divert little if any water if Duncan had none. The shape of the curve is not known for sure, and might be a straight line, but it makes little difference in the final answer.

Entering the curve with figures from column (5), gives figures in column (2).

Column (3) is 2/3 of column (2). This is based on general knowledge and Firth's statement that water as measured at head of canals (col. (2) is about 50% more than that actually going into consumptive use. This statement is proven by the fact that total diversions in Safford valley are about 1½ times the river loss. Figures of 1905, 1916, 1919, and 1920 were estimated from a review of later years.

Column (4). From U.S.G.S. Water-Supply Papers, adding up all canals in Safford Valley. The figures for Oct., Nov., Dec., 1921 were used in place of those for corresponding months of 1920, which are missing.

Column (5). For 1936-1938, from Gila Water Commissioner's reports. For 1936, calendar year was assumed the same as water year. For computation of 1932-1935, see Chart 2. In fourth column of Chart 2, river loss between Gila-Bonita and Gila-Calva gaging stations is found (some figures are estimates). For 1936-38, it is found that a relation exists between Firth's measured diversions and river loss. This is plotted on Chart 3, which is then used to obtain water used 1932-35.

For the years 1921-31, the canals in Safford Valley were all measured but they do not represent the water used on account of the practice of running water past the gage and then wasting it back into the river. The water used here was roughly determined by assuming that if water were available, Safford Valley would use between 5.5 and 6 acre-feet annually, or about 190,000 acre-feet. If water is not available then it would be proportionately less. Working on this basis, it was considered that water was

available

when the flow at Gila-Bonita station exceeded 100 second-feet; to determine a relationship, the days under 100 second-feet during the irrigation season, March to September, were plotted against water used annually for period 1932-38, except 1934 when no Gila-Bonita record was available. See Chart (4). For 1915, 1919, and 1920, figures in column (5) were computed in a similar manner, using chart 4 and the record of Gila River near Solomonsville.

Column (6), is 66-2/3 % of column (5) based on Firth's statement that during low flow canals divert 1½ times the flow available in river. This is checked by a study of Chart 2 where, for 1936-38, it is seen that Firth's diversions for the 3 years total 406,420 acre-feet, or 64%.

Figures for years prior to 1919 were estimated from review of later years. 1923 and 1925 river loss between Gila-Solomonsville and Gila-San Carlos stations was found greater than given by above methods. Actual loss from river records was therefore used for 1923 and 1925.

Column (7). From U. S. G. S. Water-Supply Papers for 1930-1938, adding together flow at the two stations. For years 1919-1928 figures shown are for station Gila River at Coolidge Dam and Gila River near San Carlos, from Water-Supply Papers; the record for these years is equivalent to the sum of columns (7) and (9). For year 1929, Gila-Calva station was not in and Coolidge Dam was storing water. The natural flow at Coolidge Dam, corresponding to the figures used for 1919-1928, was computed by adding

flow below Coolidge Dam (from Water-Supply Paper), and estimated evaporation. Evaporation was computed using 0.7 of land-pan record for 1938 at Coolidge Dam as kept by Indian Service (copy in U. S. G. S. files). There is no 1929 evaporation record and 1938 record used as best comparable substitute. From this record (x 0.7) evaporation October to July = 58.0 inches, August 14.0 inches, September 10.4 inches. Using published contents of San Carlos Reservoir, and the Indian Service's capacity and area table used 1929-1936, average area exposed to evaporation was arrived at.

October to July	1,200 acres x $\frac{58.0}{12}$	= 5,800 acre ft.
August	3,500 acres x $\frac{14.0}{12}$	= 4,086 acre ft.
September	4,000 acres x $\frac{10.4}{12}$	= 3,470 acre ft.
		13,356 acre ft. (total)

Use 13,000 acre-ft. as evaporation for the year. For bank storage use 17,700 acre-feet, a figure computed by Gila Water Commissioner's office. Then total natural flow at Coolidge Dam in 1929 would have been:

	Acre-ft.
Increase in live storage during yr.	124,500
Dead storage accumulated	25,500
Bank storage	17,700
Evaporation	13,000
Measured outflow below dam	16,700
	197,400

Use 200,000 acre-ft. for 1929. This closely checks Water Commissioner's figure of 202,400 acre-feet.

Column (8) Acreage in New Mexico (except in Duncan Valley) taken from New Mexico State Engineer's report for 1932-1934. On San Francisco River, 5,150 acres are irrigated; on Gila River; Cliff Valley 3,500 acres and Red Rock 1,300 acres. Total in New Mexico is sum or 9,950 acres. Use 10,000 acres. Use consumptive use of 2 acre-ft. per acre because the area is high in altitude. This gives 20,000 acre-ft. per year used in New Mexico except in Duncan Valley.

Column (9) 20% of the Peridot record as given in the U. S. G. S. Water-Supply Papers. This takes care of unmeasured inflow above Coolidge Dam but below Peridot and Calva stations. This inflow is from 320 sq. mi. and, if it was at same rate as Peridot flow per sq. mi., would be $\frac{320}{1070}$ of it (drainage area ratio). As the 320 sq. mi. is at lower elevation, use 20%.

Column (10) From U. S. G. S. Water-Supply Papers.

Column (11) From U. S. G. S. Water-Supply Papers. Published as Gila River near San Carlos for earlier years.

Column (12) is column (10) less column (11) and represents river gain between Coolidge Dam and Kelvin. Most of this gain is from San Pedro River.

Column (13) For 1932-1938 from U. S. G. S. Water-Supply Papers. Prior to 1932, figures are all estimates and include Aravaipa Creek. The general method of estimating is shown on chart (5) where San Pedro-Charleston is plotted against San Pedro-Mammoth plus Aravaipa for years available, 1932, 1933, 1936-38. Using the

published Charleston record as basis, Hadnoth plus Aravaipa was picked from the curve with those exceptions:

1926. Curve figure of 177,000 is too large as the major flood of September is known to have been mostly above Charleston. Use 140,000

1920. Curve gives 55,000; increased to 85,000 on basis of general comparison.

Column (14) From U. S. G. S. Water-Supply Papers. Record for 1919-1921 not used, as Aravalpa for those years is included in the figure derived for column (13)

Column (15) Messrs. Norton and Davis interviewed natives around St. David, particularly Mr. Matteson and got following information: First is listed acreage not disturbed by flood of September, 1926. Second is listed acreage cut from irrigation by that flood, all of which was gradually put back under water by 1938. Third is listed acreage irrigated prior to September , 1926 flood.

Canal	Acres Irrigated Continuously Since Before 1929 to date	Acres cut out By Flood At End of 1926	Total Acres prior to 1927 and Since 1938
Pomerene	718.9	639.8	1,358.7
St. David	439.2	505.2	944.4
Curtis	41.2	166.2	207.4
below Boquillas	255.8	———	255.8
Boquillas	793.6	———	793.6
below San Rafal	312.0	34.5	346.5
near Lewis Springs	33.8	54.9	88.7
Totals	2,594.5	1,400.6	3,995.1

The above is all irrigated by surface diversions; no pumping included. Use of water is taken as 3 acre-ft./acre per year, based on Matteson's estimate and a consideration of other areas.

Using 3 acre-ft/acre and 4,000 acres, 12,000 acre-ft. were diverted 1919-1926. The flood of September, 1926, threw 1,400 acres out of use. This was returned to use gradually until by 1938, all was back in use. The assumption was made that 4,000 acres were irrigated in 1926, 2,600 in 1927, and 150 acres more each year until 1935 when 3,500 were in use; then 100 additional a year until 1938 when the full 4,000 acres were in use again.

Column (16) Figures for 1936-1938 from Gila Water Commissioner's report. For previous years, estimates made by varying the diversion roughly with river flow.

Column (17) is columns (12)-(13)-(14) which is (Gain between Coolidge Dam and Kelvin)--Mammoth-Aravaipa, and represents contribution to the Gila of the area above Kelvin but below Coolidge Dam on the Gila, below Mammoth on the San Pedro and below the gaging station on Aravaipa. The purpose of computing it is to get column (18).

Column (18) is 25% of column (17) and represents the inflow to Gila River between Kelvin and Ashurst-Hayden Dam. This inflow is from an area of 320 sq. mi. The area contributing flow listed as column (17) is 1,010 sq. mi. The 320 sq. mi. is lower in elevation than the 1,010 sq. mi.; therefore instead of taking $\frac{320}{1010}$ of column (17) for column (18), take a lesser amount, or arbitrarily, 25%.

Column (19) is flow at Ashurst-Hayden Dam if there were no diversions and no reservoirs. It is the total of columns (3) + (6) + (7) + (8) + (9) + (12) + (15) + (16) + (18) and shows the virgin out-

flow of the Gila River from the mountain area. From 1919 to 1929 use column (7) for those years.

Column (20) is diversion from Gila River at Ashurst-Hayden Dam. For 1930-1939 it is from figures furnished by Anderson of San Carlos Irrigation and Drainage District. For 1919 to 1929 there is no record. It was estimated two ways:

(1) Using U. S. G. S. records from Water-Supply Papers for Kelvin and (after July 1, 1923) gage heights at Ashurst-Hayden Dam, the Kelvin record was scanned day by day and the amount which would be wasted at Ashurst-Hayden Dam estimated. The gage heights at the dam were a guide. Computation of flow at dam by weir formula gave results absurdly inconsistent with Kelvin flow and so were not used. In estimating the waste the canal capacity of 1,000 sec-ft. after 1922 was kept in mind; also the fact that in winter, diversion would be small. Results of this inspection are listed below. Diversions were computed as Kelvin flow less the waste.

(2) Using figures on acreage irrigated in 1916, 1927, and 1929 furnished by Indian Service, and a use of 4 acre-ft. per acre, the probable use was estimated. Acreage for other years was estimated, using a rapid increase about 1921 when cotton price was high.

Year	White	Indian	Total	Diversion at 4 feet Consumptive use	Waste by inspection explained above under (1)	Diversion computed by (1) above
1916	11,000	2,000	13,000	52,000		
1917	12,000	2,200	14,000	56,000		
1918	14,000	2,400	16,000	64,000		
1919	16,000	2,600	19,000	76,000	674,000	62,000
1920	18,000	2,700	21,000	84,000	606,000	88,000
1921	18,000	2,800	21,000	84,000	390,000	71,000
1922	19,000	3,000	22,000	88,000	42,000	78,000
1923	19,000	3,200	22,000	88,000	270,000	80,000
1924	19,000	3,400	22,000	88,000	268,000	110,000
1925	20,000	3,600	24,000	96,000	115,000	62,000
1926	20,000	3,800	24,000	96,000	266,000	119,000
1927	21,000	4,000	25,000	100,000	204,000	120,000
1928	25,000	5,000	30,000	120,000	50,000	101,000
1929	30,000	5,000	35,000	140,000	37,700	60,000
1930	44,000	11,000	55,000	220,000		

Figures in last column were used for diversions and figures in ext to last column used for waste below Ashurst-Hayden Dam. For 1916, used 52,000. Note that the figure 220,000 for 1930 derived from acreage estimate, checks the figure furnished by Anderson (he furnished 1930 to 1938 figures). For 1915, estimate 50,000. For 1905, Army Engineers' 1914 report gives 8,000 acres, which at 3 acre-ft. gives 24,000. Use 25,000.

Column (21) is column (19) less all diversions, or equals column (19) - (3) - (6) - (8) - (15) - (16) - (20).

This column is not used in the computations, but is made up as a rough check. Prior to use of Coolidge Dam (Nov. 1928), this column shows roughly the flow below Ashurst-Hayden Dam. Since Nov. 1928, it shows roughly the same flow plus or minus changes in storage in San Carlos Reservoir during the year. Minus sign means water was drawn from storage in San Carlos Reservoir.

Column (22) = (10) + (18) - (20), or is flow at Kelvin plus inflow between Kelvin and Ashurst-Hayden Dam, less diversions at Ashurst-Hayden Dam.

Columns (23) and (24) from U. S. G. S. Water-Supply Papers. Published figures for Tonto for 1937 and 1938 are not for entire year; each year was completed on basis of change in storage in Roosevelt Reservoir plus flow at Stewart Mountain less flow in Salt River above Roosevelt Reservoir. The flow shown for Salt-Roosevelt for 1905 is at station just above Verde and includes Tonto Creek and unmeasured inflow, columns (24) and (25). Column (24) for 1905 is therefore blank.

Column (25) represents inflow above Granite Reef Dam but below the three gaging stations Salt-Roosevelt, Tonto, and Verde-McDowell. The area contributing this is 1,577 sq. mi. computed as follows:

Area above three gaging stations		Area above junction of Salt and Verde Rivers	
6,230	Verde-McDowell	6,680	Verde at mouth
4,310	Salt-Roosevelt	6,250	Salt above Verde
813	Tonto	12,930	
11,353		-11,353	
		1,577	sq. mi.

Inflow area between junction of Salt and Verde Rivers and Granite

Reef Dam is neglected. This 1,577 sq. mi. area is adjacent to Tonto Creek but much lower in elevation. If run-off per sq.mi. were comparable to Tonto Creek, run-off would be $\frac{1577}{813}$ of Tonto. As run-off per sq.mi. is less, use 100% of Tonto. This percentage is believed to be good by Hayden of Water Users, and figures resulting from its use check closely with virgin flow figures computed independently by the Water Users. For 1905, the inflow is estimated as 200,000 acre-feet on basis of Salt River records at Roosevelt and at McDowell.

Column (26) From U. S. G. S. Water Supply Papers.

Column (27) Based on reports made to S.R.V.W.U. by one of their men who made detailed investigation of amount of diversions above McDowell. A study and report was made in 1925 and again in 1931. Both showed about 9,000 acres irrigated, with use of about 3.5 feet, or a total use of 31,500 acre-ft. Use 31,000. Present opinion of Hayden of Water Users is that the figure is still substantially correct in 1939.

This area includes all land irrigated above McDowell, as on Granite Creek; most of the land is near Camp Verde. The smelter at Clarkdale has had little effect on amount of land, as the company bought the land they were charged with ruining, and went ahead farming it with hired labor.

Column (28) Figures were furnished to State Colorado River Commission by Salt River Valley Water Users Association. They include water taken at the Verde by pumping from the stream bed, hence really

surface water pumping. Other pumping, mainly since 1935, in Salt River Valley proper, is not included.

No diversion prior to Feb. 1923.

Column (29) from figures furnished to State Colorado River Commission by Hayden of S. R. V. W. U. A. No record prior to 1924, which has been estimated and is not very good.

Column (30) shows flow at Granite Reef Dam if there were no diversions above and no reservoirs. It is the sum of columns (23) + (24) + (25) + (26) - (27) - (28) + (29).

Column (31) Records 1923 to 1936 furnished by parties interested in Hassayampa River development. Copies in U. S. G. S. Tucson office files. Records were collected by W. A. Parish. No record available for 1937. For 1938, U. S. G. S. record is available Jan. 1 to July 1 with Mar. 3 missing. Mar. 3 was estimated as 4,000 sec.-ft. to complete the 6 mo. period total of 13,700 acre-ft. By inspection of other stream records, flow in other 6 months of the year was quite small; total year 1938 estimated as 17,000 acre-ft.

Run-off for 1937 estimated at 86,000 acre-ft. No other stream record was found that varies with any fixed relation to Hassayampa. Partial records from Oct. to Feb. for 1937 shows 62,758 acre-ft. Inspection of other streams shows March was probably high, followed by a low summer. Estimate:

Oct. to Feb.	62,758
Mar.	20,000
Apr.	2,000
May June	200
July, Aug. Sept	1,000
	85,958

Use 86,000 acre-ft.

For 1916 estimate 100,000, based on U. S. G. S. gage-height record and, Agua Fria flow.

For 1915, U. S. G. S. Water-Supply Paper gives run-off at Wagoner as 36,400 acre-ft. Ratio of drainage areas $\frac{\text{Wagoner}}{\text{Box}}$ = $\frac{265}{430}$ = 1.6 Use 1.5 because of lower altitude at Box. Use 54,600.

Records 1919 to 1921 from records furnished by Mittman to State Colorado River Commission.

Column (32) is based on figure of 440 acres under cultivation furnished by Mr. Simons of U. S. B. R. Assume 1,000 A. F. of water used annually, and a greater amount in 1915 and 1916 when development was probably at maximum and plenty of water available.

Column (33) is sum of columns (31) and (32), rounded because of estimation entering (32).

Column (34) From data furnished by W. W. Lane with letter of July 22 to Colorado River Commission. 1919 from U. S. G. S. Water-Supply Paper 509. 1905 from estimate.

Column (35) From same sheet as column (34) 1928 to 1938, (which gives flow into main canal below Lake Pleasant Dam) with 1,000 added as explained below. Prior to 1928 no storage was available and there is only small use by some ranchers estimated as 1,000 acre-ft. per year. The same figure 1,000 is added to 1928-1938 diversions to care for these diversions. The heavy diversion in 1928 followed by almost none in 1929 has been investigated and is checked by the detailed computation sheets. The flow shown in 1929 all occurred in Oct. 1928 to complete the 1928 irrigation season.

Column (36) Virgin flow is same as column (34) plus 1,000 for 1928 to

1938, as there were no diversions above point of measurement of column (34) except the estimated 1,000 acre-ft. Prior to 1928, sum of columns (34) and (35) gives virgin flow.

Column (37). Beginning with use of Lake Pleasant Dam, this shows what is spilled at the dam. Use of dam began in 1927 or 1928. From 1929 to 1938, figures shown are those taken from detailed run-off sheets for Lake Pleasant Reservoir. Only 1931 and 1932 in the years 1929 to 1938 showed any spill. The detailed sheets were loaned by L. H. Lane.

Those sheets show for 1928, 64,800 acre-feet diverted (into canal for irrigation) and 39,780 acre-feet as inflow to Lake Pleasant. The difference, or 25,020, had to come from water stored previous to 1928, assumed to be 1927. Therefore water stored in 1927 must have been 25,020 + 1,930 = 26,950 acre-feet (Evaporation neglected). For 1927, the flow of 327,000 at Lake Pleasant has therefore been reduced by 26,020 to get actual flow below the reservoir. For years prior to 1927, actual flow is same as flow in column (34) as nothing changed it.

Actual flow for 1928 is taken as zero as total inflow for 1928 (39,780) was less than amount in storage in reservoir on Feb. 1, 1928 (45,260 acre-ft.).

Column (38) from U. S. G. S. Water-Supply Papers. Nothing available prior to 1935.

Column (39) furnished by Hayden of S. R. V. W. U. A.

Estimated at 1,100,000 for 1919, 1,227,000 for 1916, and 1,004,900 for 1915 from graph furnished by Hayden. These are calendar year figures but used as water year figures. For 1905 estimated as

130,000 acres at 3.5 acre ft. per acre.

Column (40) is sum of columns (27), (28), (29), and (39), which are all the diversions at and above Granite Reef Dam.

Column (41) furnished by Hayden of Salt River Valley Water Users' Association in form of tables 1920 - 38. For 1919, 1916, and 1915, no figures furnished. Computed from these columns; (25) + (24) + (23) + (26) - (38) - (29) - (39) ± change in storage in Salt River reservoirs less evaporation. Change in storage taken from graph of storage furnished by Hayden of Salt River Valley Water Users' Association. In 1919 gain was 250,000 acre-ft.; in 1916, loss was 20,000 acre-feet; in 1915, gain was 360,000 acre-feet. Evaporation computed for 1932 as a basis was about 70,000 acre-ft.; use 60,000 1919, 1916 and 1915. For 1905 computed as column (30) less (39); there was no reservoir storage.

Column (42) from U. S. G. S. Water-Supply Papers. 1905 estimated.

Column (43) represents surface diversion and does not include pumped water. All diversions are in Santa Cruz County, as all in Pima are pumped. Information obtained by Colorado River Commission Members at Nogales was that 3,000 acres are irrigated, using 3.5 acre-feet per acre per year. Used 10,500 acre-feet on this basis. It is believed that little variation occurred from year to year in amount used.

Column (44) from U. S. G. S. Water-Supply Papers. 1905 was estimated.

Column (45) is total flow which would enter the desert area centering around Phoenix, if there were no diversions and no reservoir storage. It equals columns (19) + (30) - (33) + (36) + (42) + (43) + (44).

Column (46) is sum of columns (22) + (31) + (37) + (41) + (42) + (44).

Column (47) was furnished by Indian Service office at Coolidge to State Colorado River Commission. Data was in form of a daily record. Not used in Gila River computations. Available 1934 to 1938 only.

Column (48) was furnished by Stanford, Court Water Commissioner for the Buckeye area and by Jones, Secretary for Buckeye District. Data in Colorado River Commission files. Data not used in computations.

Columns (49) and (50) furnished for 1936 and 1937 by Stanford, Court Water Commissioner. Copies in State Colorado River Commission files. Not used in computations.

Column (51) is diversion by pumping directly from Gila River, 5 miles above Gillespie Dam. Estimate from evidence in trial of Gillespie Land & Irrigation Co., vs. Simpson, showed 440 acres using 3.5 acre-feet per acre = 1,540 acre-feet. Use 1,500. Not used in computations.

Column (52) from U. S. G. S. Water-Supply Papers, except 1905 - 1921 which is obtained from Chart 7 as explained at bottom of sheet 9 of computations.

Column (53). No actual record exists. Miscellaneous measurements have been made about twice a month since June 1935. Using these as a guide, annual flow was computed as about 8,800 acre-feet, except for 1938 when 8,000 was closer. The water right is for 10 sec.-ft. which would amount to 7,300 acre-ft. a year but measurements have shown the average flow is above this. Hence the estimate of 8,800 acre-ft. back to 1919.

Column (54) is from U. S. G. S. N. B. Papers from May 24, 1935 to 1936. Pre 1926 to 1931, the Gillespie Land and Irrigation Co. furnished to State Colorado River Commission, hydrographs (one for each calendar year) showing flow of Gillespie Canal as computed by the canal company's engineer, Goodman. Daily discharge was taken from these hydrographs and computed as monthly and annual acre-feet. A reduction in these figures was made as explained below, but first, here is method of getting 1932 to 1935:

Gillespie Company furnished all their gage-height books showing canal gage readings for all of 1932, Jan. 1 to Sept. 7, 1933, and Jan. 1 to May 24, 1935. These were converted to discharge by use of a rough rating table made by comparing discharge from Goodman's hydrographs with daily gage height from Gillespie Company's gage readings.

From the above, the record is complete (from 3 sources) for water years 1926-1933 except: in 1933, Sept. 8-30; in 1934, all; 1935, Oct., Nov., Dec. Sept. 8-30, 1932 was estimated. 1934 was estimated by inspection of all related records (particularly Gila-Gillespie Dam for all years and the canal for years other than 1934). To complete 1935, Oct., Nov., Dec. 1934 were taken the same as Oct., Nov., Dec., 1935. This completes 1926-1933. Record for 1932 to 1921 was estimated from inspection of river record and from study of newspaper reports on progress of the project. No diversions prior to 1921 when dam was built. There may have been small diversions the last few months of 1921, but if so, they are negligible.

All the records based on Gillespie Co. records (all prior to May 25, 1935) are believed to get in error progressively because no discharge measurements were made, and, if the rating was good when canal was clean, it would show too much water in later years when fill had occurred. A comparison of overlapping period of Gillespie record and U.S.G.S. record at end of May 1935 shows Gillespie to require a reduction of about 50%. In 1929, two miscellaneous measurements by U.S.G.S. (see 1929 Water-Supply Paper) show Gillespie rating to be about 10% too large. Percent reduction for other years was distributed as follows, assuming clean canal in 1926. So far as known, no cleaning was done prior to 1936.

Year	Percent to reduce Gillespie Canal Co. records to about equal U.S.G.S. records
1926	0
1927	2
1928	5
1929	(10) Based on two miscellaneous measurements
1930	15
1931	21
1932	27
1933	34
1934	42
1935	(50) Based on overlapping record

Column (55) is column (53) plus (54).

Column (56) is column (52) plus (55).

Column (57) is column (46) less (55) and shows actual flow which should arrive at Dome from mountain area except for natural gains and losses (this is on the assumption that Buckeye and diversions in that vicinity are supplied by ground water or return irrigation water; Gillespie diversions were subtracted because they are surface flow diversions).

Column (58). For 1930 - 1933 and 1905 from U. S. G. S. Water Supply Papers. From 1919 to 1928 and 1915, 1916, from U. S. Bureau of Reclamation estimates, filed under name "Gila River near Yuma, Ariz.". For 1929: After May 1, from U.S.G.S. W. S. Paper; prior to March, from U.S.B.R. estimates; for April, U.S.B.R. estimates show dry, but inspection of Gillespie record shows probable flow that month but none for months immediately preceding. The following shows the relation between flow on comparable floods actually measured:

Month	Second-foot days Gillespie	Dome	% of Dome to Gillespie
Aug. 1930	25,200	5,929	23½
Feb. 1931	70,925	39,342	55½
Mar. 1937	67,600	38,200	56½
Mar. 1932	94,500	23,140	24½
Apr. 1929	29,793		

Of above floods, Aug. 1930, flood is most comparable to Apr. 1929 flood. Use 25% of Apr. 1929 flood; then Dome ran 7,400 second-foot-days or 15,000 acre-feet and water year 1929 ran 17,880.

Column (59) is derived by applying column (45) to chart 6.

Chart 6 was made by plotting column (57) against column (58) (actual flow against actual flow). The curve was drawn as a mean of the points giving 1916 no weight and 1919 but little. The shape of the curve above 1,000,000 was based on theoretical considerations of the meaning of the curve as well as on the plotted points. The concave-upward shape of the upper end is checked

by the shape of somewhat similar curves in other studies.

Virgin flow values in column (59) were derived by applying virgin flow figures, column (46), to the curve, allowing each year for the amount actual flow for that year was off the curve, on the theory that virgin flow was off the same amount that year. This gives weight to the plotting of the individual years.

The 30-year mean of column (59) is 1,316,000 acre-feet. This value may be low, rather than high, because:

(1) Any diversions omitted or overlooked would increase the figure and no diversions which were included could be decreased by any appreciable amount.

(2) No pumped diversions were included (except City of Phoenix water supply, which is pumped from wells fed quite directly by trenches from the surface flow of Verde River). Heavy pumping undoubtedly depletes the surface flow. Particularly since 1934, in which period heavy pumping has developed in the Safford, Coolidge, and Phoenix area, surface flow has in some measure been depleted by pumping.

Column (60) is column (56) less (46) and shows change in actual flow from mountain area to Gillespie Dam. The sum of this column for 30 years is close to zero, proving that the diversions by Buckeye, Arlington, and the other canals in the area, are probably from ground water and return irrigation flow.

Column (61), virgin flow at Gillespie Dam, comes from a relationship obtained between column (46) and (56) which is plotted on Chart 7. Chart 7 shows relation between flow from mountain area and

flow at (above) Gillespie Dam. The curve is made up based on actual flow at both points, and is then used to transfer virgin flow from the mountain area (col. 45) to Gillespie Dam. A good relation should exist between the two points, because as shown in column (60), gains and losses are small. Most of the water diverted in the area, as by Buckeye, Arlington, and others, comes from ground water as return flow, and does not vitally affect the relation between flow from mountain area and at Gillespie Dam.

Chart 7 was made by plotting actual flow from mountain area for each year (column 46) against actual flow above Gillespie Dam (column 56) for the available years 1932 to 1950. Origin of curve: If no flow came from mountain area, a little flow might appear at Gillespie Dam. This is shown in 1934. Therefore curve is not drawn to an origin at 0 for Gillespie when mountain area is 0, but is drawn to 40,000 at Gillespie, guided by 1937 and 1934 points.

The proof that the curve should be extended as a straight line is in the fact that column (63) results, obtained using charts 7 and 8, check results in column (59).

Column (62) is column (58) less (52).

Column (63) comes from column (61) and chart 8. Chart 8 is plotted from points showing relation of actual flow at Gillespie Dam to actual flow at Dome 12 miles above mouth of Gila River, and is used to derive virgin flow at Dome from virgin flow at Gillespie Dam. Chart 8 was made by plotting for each year column (52) against column (58).

1916 and 1919 plot wild, 1915 and 1920 fair and all others very good. When it is remembered that the Done records are estimates except for 1905 and 1930-1938, the points are quite consistent. The reason for 1916 and 1919 being off is believed to be in Done records but this cannot be proven. Under some possible patterns of stream flow and rainfall distribution, points might plot as these do. The mean curve however was drawn without giving 1916 any weight and 1919 very little.

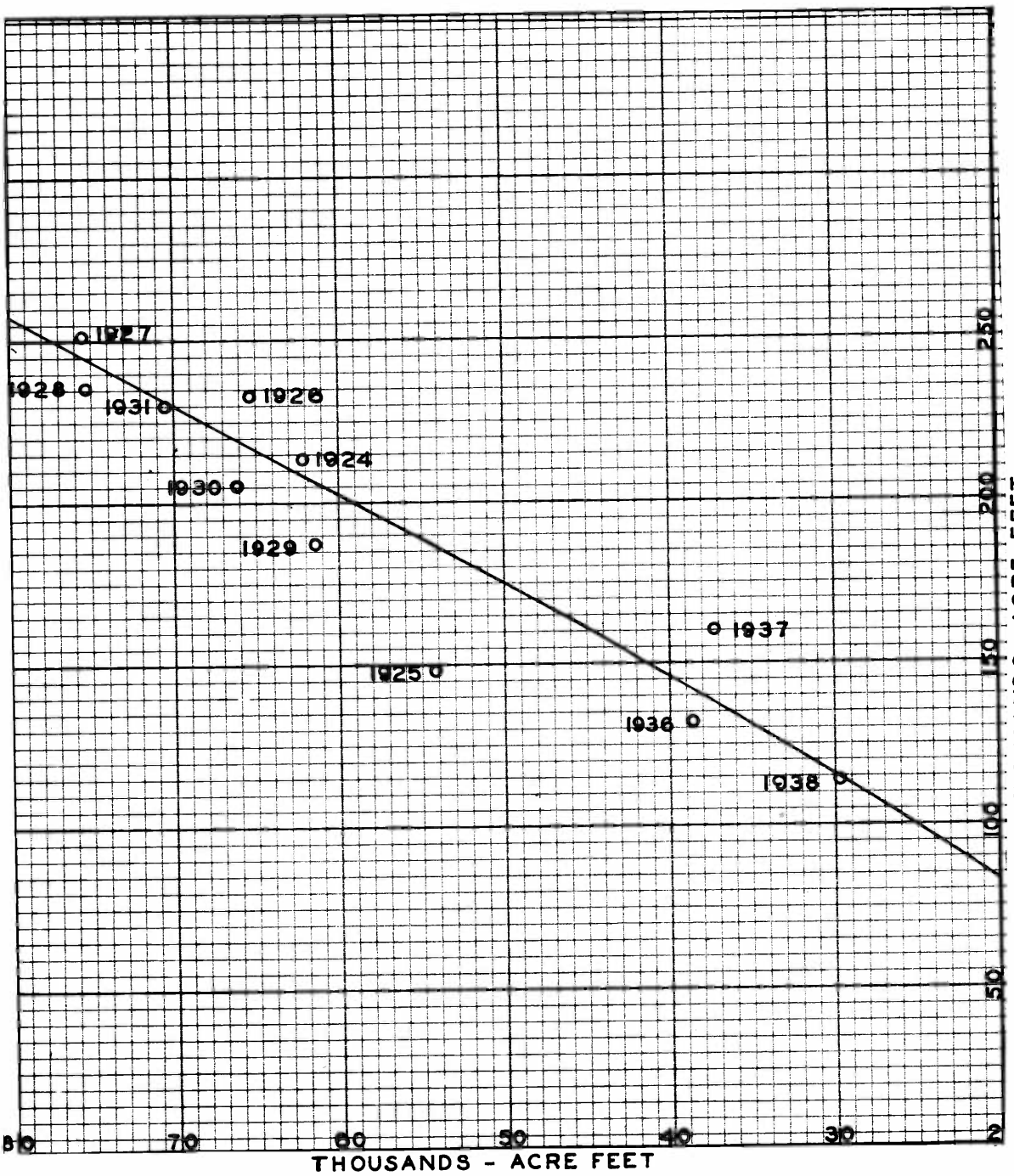
It is to be noted that the highest point 1905 is one of the years of actually measured discharge at Done.

Using the curve, the sheet was entered with column (61) to derive (63). Where the point representing actual flow for a given year plotted off the curve, the amount off was noted, and virgin flow at Done corrected by an equal amount. In this way, the individual characteristics of the flow for a given year are given weight.

Column (63) should check column (59) and does very closely. (59) gives virgin flow at mouth without regard to Gillespie and has the advantage of being derived through a curve, chart 6, which required no high extension.

Columns (59) and (63) is the answer toward which all work has pointed. The average virgin flow of Gila River at mouth for the 20 years 1919-1938 is found to be 1,316,000 acre-feet. This is a minimum figure because pumping diversions from underground water were not taken into account. The years 1915, 1916, and 1905 were not averaged in as they were exceptionally high years.

GILA RIVER BASIN STREAM FLOW SUMMARY



DUNCAN DIVERSIONS

U.S.G.S. & WATER COMMISSIONER'S RECORDS

RELATION BETWEEN DUNCAN & SAFFORD DIVERSIONS

TO COMPLETE MISSING RECORDS OF ONE FROM KNOWN RECORDS OF THE OTHER

COLORADO RIVER COMMISSION OF ARIZONA
ARIZONA STREAM FLOW SUMMARY
3/7/40 Approved Donald C. Scott

CHART 1

GILA RIVER BASIN STREAM FLOW SURVEY

Study of Safford Valley diversions in acre-feet

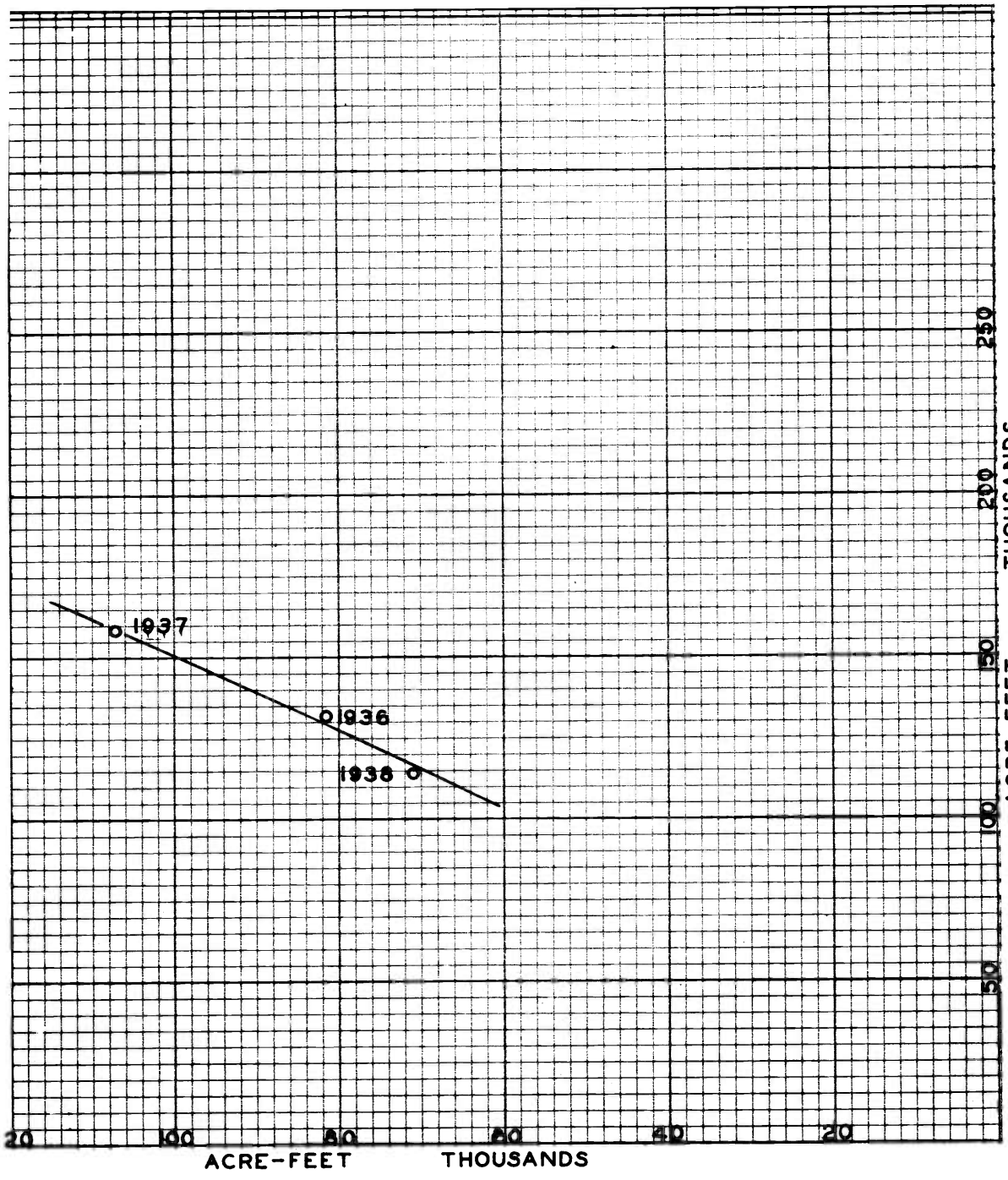
Water year	Gila-Bonita	San Simon-Solomonsville	Gila-Calva	Bonita plus San Simon-Solomonsville minus Calva (River loss)	Safford diversions	Excess of Safford diversion over river loss
1930	345,000	*30,000	310,000	65,000	107,000	42,000
1931	328,000	a/25,000	290,000	63,000	103,000	40,000
1932	305,000	14,700	442,000	77,700	124,000	46,000
1933	240,000	*10,000	140,000	110,000	165,000	55,000
1934	*210,000	* 5,000	100,100	54,900	92,000	37,100
1935	*220,000	b/16,000	149,500	80,500	130,000	49,500
1936	218,300	13,600	150,200	81,700	131,830	50,130
1937	422,400	2,600	317,900	107,100	159,840	52,740
1938	171,100	5,700	106,200	70,600	114,720	44,120

*Estimate.

a/Estimate based on known flow of 24,400 June to September.

b/Estimate based on known flow of 15,700 May to September.

GILA RIVER BASIN STREAM FLOW SUMMARY

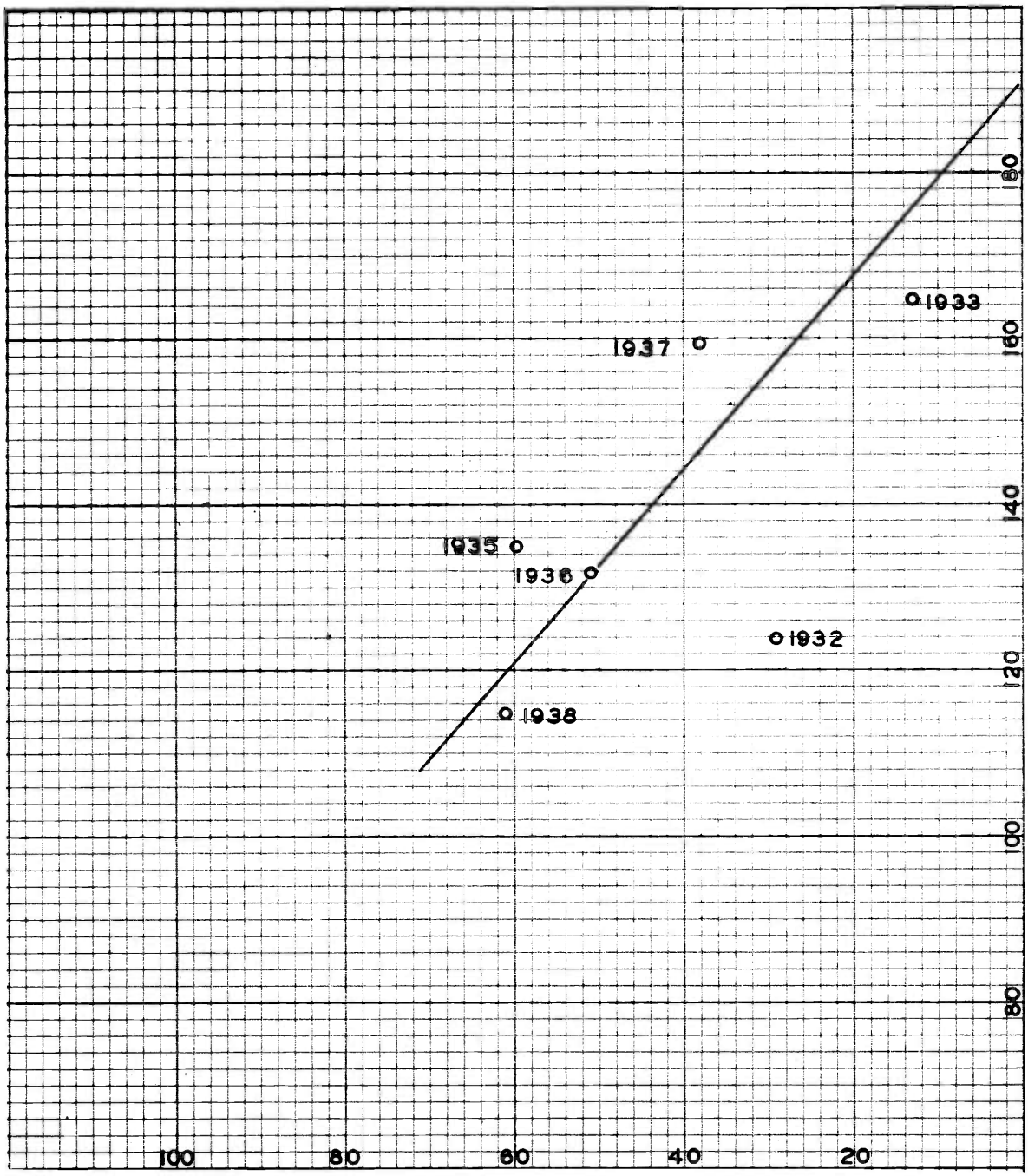


RIVER LOSS BETWEEN GAGING STATIONS
(GILA-BONITA PLUS SAN SIMON-SOLOMONSVILLE)
AND (GILA-CALVA) IN ACRE-FEET ANNUALLY

CHART 3

COLORADO RIVER COMMISSION OF ARIZONA
ARIZONA STREAM FLOW SUMMARY
3/7/40 Approved Donald C Scott

GILA RIVER BASIN STREAM FLOW SUMMARY



NO. DAYS FLOW AT GILA-BONITA GAGING STATION IS BELOW 100 SEC. FT. DURING PERIOD MAR. TO SEPT. OF EACH YEAR

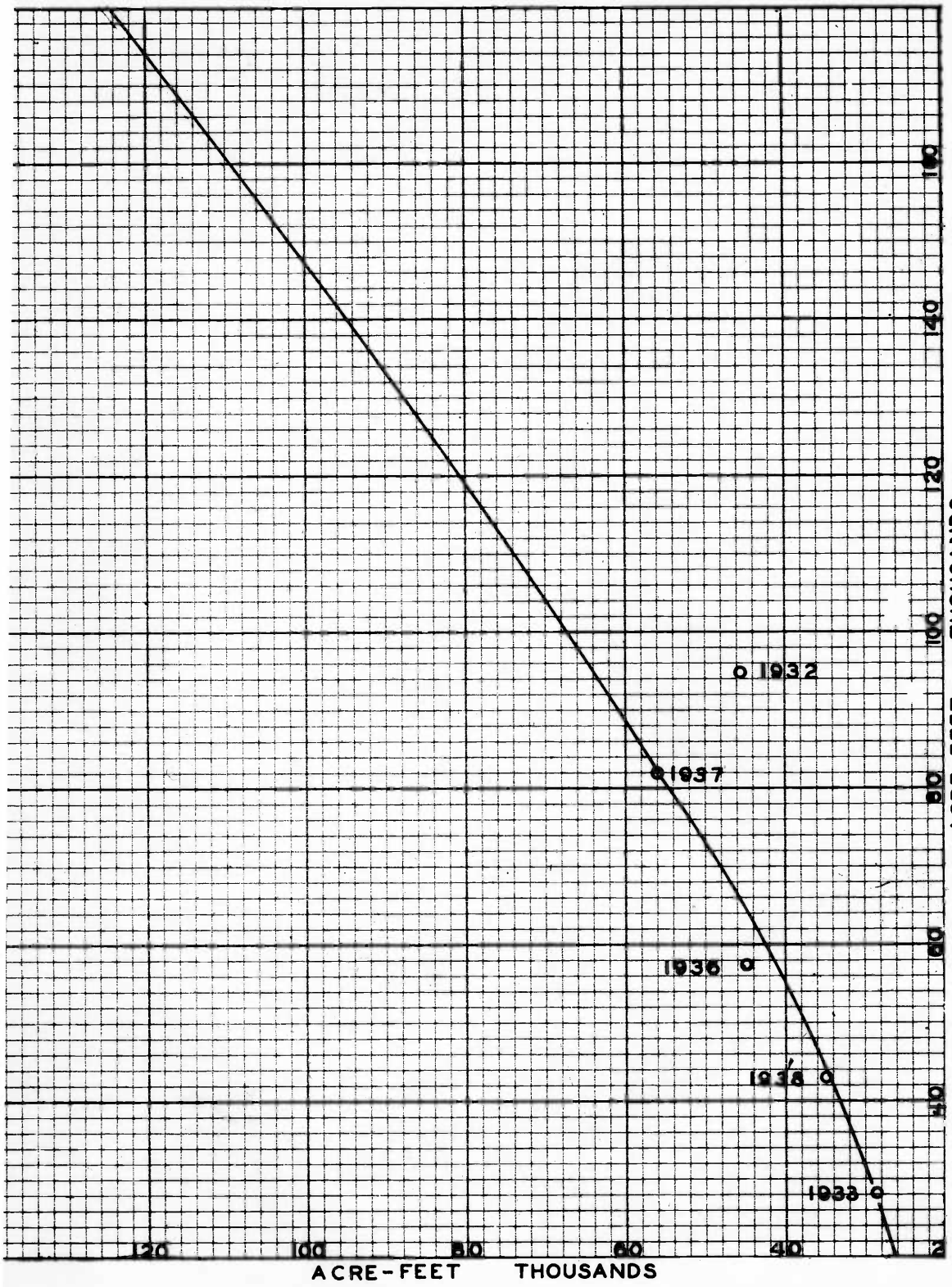
CHART 4

COLORADO RIVER COMMISSION OF ARIZONA

ARIZONA STREAM FLOW SUMMARY

3/7/40 Approved Donald C. Scott

GILA RIVER BASIN STREAM FLOW SUMMARY



SAN PEDRO - MAMMOTH PLUS ARAVAIPA

SAN PEDRO - CHARLESTON

CHART 5

COLORADO RIVER COMMISSION OF ARIZONA
ARIZONA STREAM FLOW SUMMARY
3/7/40 Approved Donald C. Scott

CHART NO. 6

USED TO DETERMINE VIRGIN FLOW AT GILA RIVER MOUTH (COLUMN 59)
FROM VIRGIN FLOW FROM MOUNTAIN AREA (COLUMN 45)

ANNUAL RUNOFF OF GILA RIVER NEAR ITS MOUTH
(ACTUAL FLOW COLUMN 58)
(100 THOUSANDS AC. FT.)

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34

1905
1915
1920
1927
1924
1922
1932
1925
1936
1931
1926
1919
1937
1928
1935
1933-34
1929-30
1938

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 (100 THOUSANDS AC. FT.)

ANNUAL RUNOFF OF GILA RIVER BASIN FROM MOUNTAIN AREA
LESS GILLESPIE DAM DIVERSIONS (ACTUAL FLOW COLUMN 57)

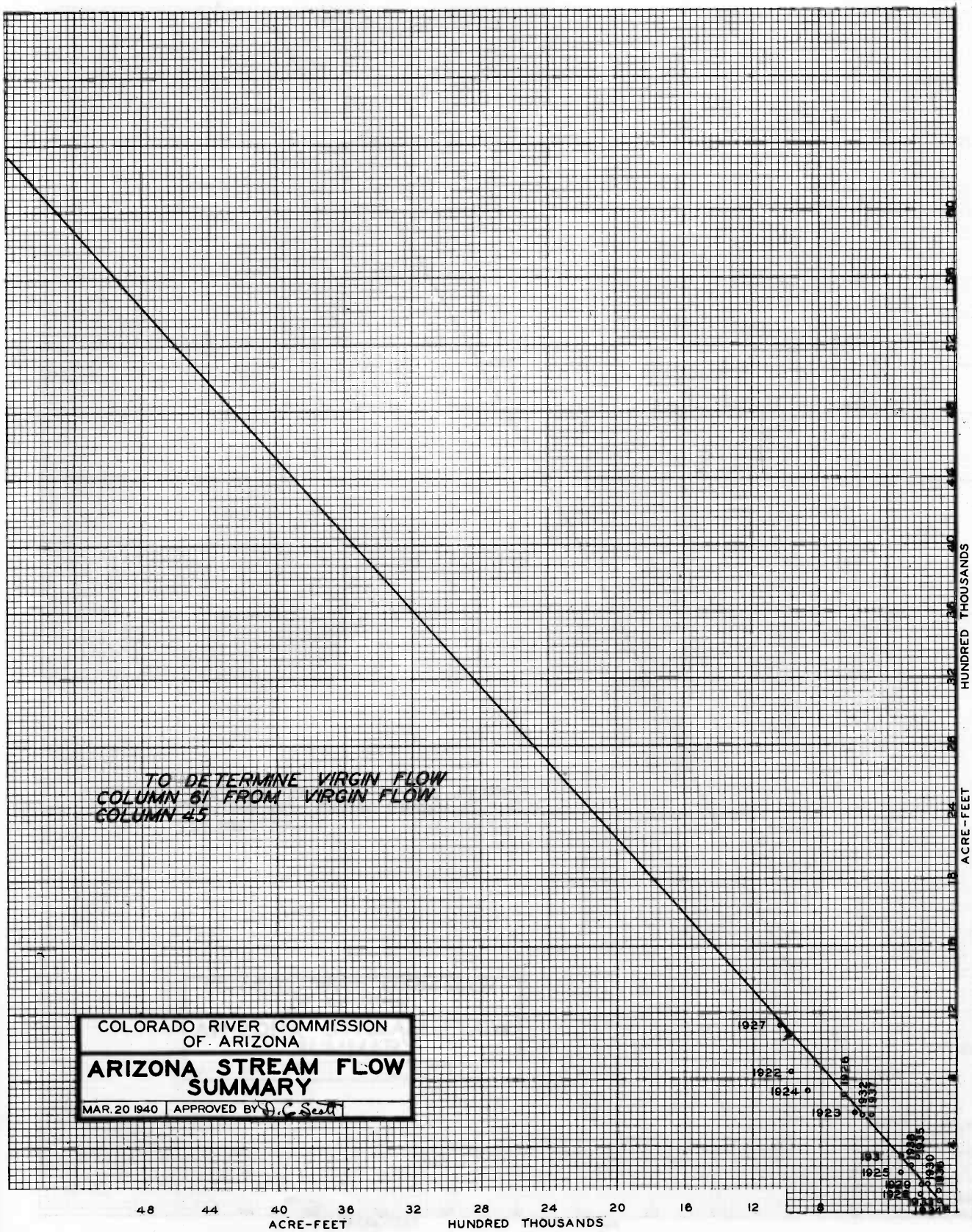
COLORADO RIVER COMMISSION
OF ARIZONA

ARIZONA STREAM FLOW
SUMMARY

3/7/40 Approved Donald C Scott

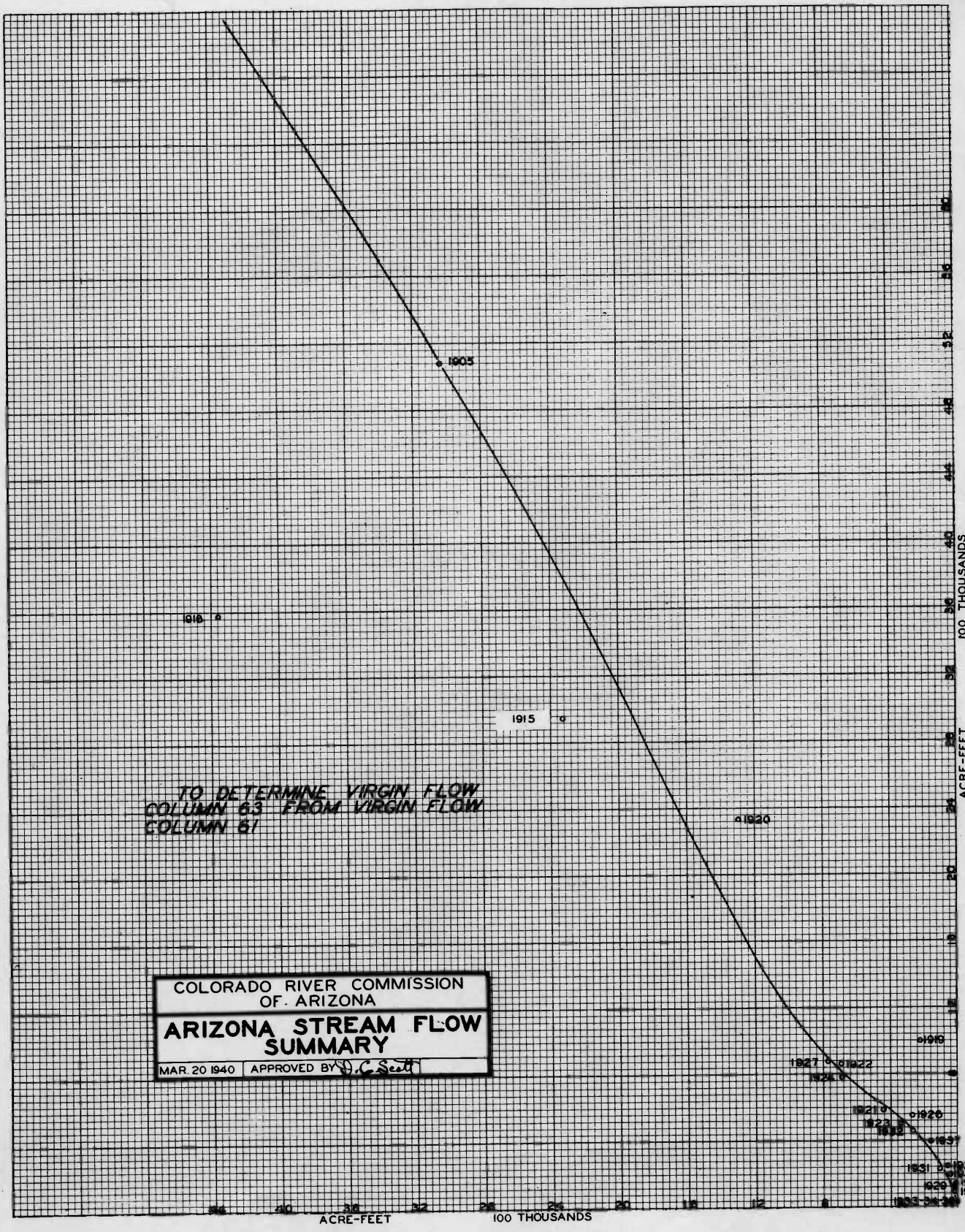
GILA RIVER BASIN STREAM FLOW SUMMARY

CHART 7



GILA RIVER BASIN STREAM FLOW SUMMARY

CHART 8



RUNOFF OF GILA RIVER BELOW GILLESPIE DAM ACTUAL FLOW COLUMN 52

RUNOFF OF GILA RIVER NEAR MOUTH ACTUAL FLOW COLUMN 58

S E C T I O N VII

GILA RIVER BASIN

IN NEW MEXICO

STREAM FLOW SUMMARY

* * *

GILA RIVER BASIN IN N. MEXICO STREAM FLOW SUMMARY.

	Gila-Red Rock	Gila-Fullers Ranch	Gila-Clifton	Diversions above Red Rock	Diversions between Red Rock & Fullers Ranch	Duncan Valley Diversion
	(1)	(2)	(3)	(4)	(5)	(6)
1940						
1939						
1938	95,120	87,600	79,900	7,000	2,600	20,000
1937	221,400	207,800	179,900	7,000	2,600	25,000
1936	94,720	91,310	76,500	7,000	2,600	23,000
1935	91,140	95,040		7,000	2,600	24,000
1934	63,250	77,400		7,000	2,600	15,000
1933	108,000	118,000	100,000	7,000	2,600	31,000
1932	132,000	138,000	109,000	7,000	2,600	22,000
1931	157,000	153,100	130,000	7,000	2,600	31,000
1930	132,100	130,700	130,000	7,000	2,600	22,000
1929	89,500	93,200	113,000	7,000	2,600	19,000
1928	85,100	86,500	72,200	7,000	2,600	19,000
1927				7,000	2,600	26,000
1926				7,000		30,000
1925	52,430			7,000		17,000
1924	170,100			7,000		28,000
1923	143,100			7,000		28,000
1922	50,600					10,000
1921	108,600					21,000
1920						30,000
1919	238,800					30,000
1918						
1917						
1916						30,000
1915						30,000
1905						20,000

GILA RIVER BASIN IN N.M. MARCH SUPPLY FOR SUMMARY

	Duncan Valley Diversions in New Mex.	Virgin flow at Red Rock	Virgin flow at Fullers Ranch	Virgin flow at Gila-Clifton	(9) minus (8)	(10) minus (9)
	(7)	(8)	(10)	(11)	(12)	(13)
1940						
1939						
1938	7,100	102,120	97,280	109,500	-4,840	12,220
1937	8,875	223,400	217,400	214,500	-11,000	-2,900
1936	9,230	101,720	100,910	112,190	-810	11,280
1935	8,250	98,140	104,640		6,500	
1934	5,325	70,250	87,050		16,800	
1933	11,005	115,000	127,600	146,600	12,600	19,000
1932	7,810	189,000	197,600	200,600	8,600	3,000
1931	11,005	164,000	162,700	190,600	-1,300	27,900
1930	7,810	140,100	140,300	161,600	200	21,300
1929	6,745	96,560	107,800	140,600	11,240	32,800
1928	6,745	92,108	96,100	500,400	3,992	4,300
1927	8,875					
1926	10,650					
1925	6,035					
1924	7,810					
1923	8,165					
1922	5,680					
1921	7,455					
1920	10,650					
1919	10,650					
1918						
1917						
1916	10,650					
1915	10,650					
1905	7,100					

GILA RIVER BASIN IN NEW MEXICO STREAM FLOW SUMMARY.

	Run-off per sq. mi. Fullers to Clifton	Run-off per sq. mi. Fullers to Red Rock	Run-off per sq. mi. used below Fullers in New Mex.	Run-off below Fullers Ranch in New Mex.	Virgin flow from Gila Main Stem in New Mex.	Actual flow from Main Stem in New Mexico
	(15)	(16)	(17)	(18)	(19)	(20)
1940						
1939						
1938	13,700	-15,921	8,230	3,020	100,300	83,600
1937	-3,251	-36,184	18,392	6,750	224,150	205,680
1936	12,646	-2,664	8,537	3,150	104,040	85,210
1935		21,382	8,853	3,250	107,890	90,040
1934		55,263	7,364	2,700	89,750	74,820
1933	21,300	41,447	10,795	3,960	131,560	110,960
1932	3,363	28,289	16,717	6,140	203,740	186,330
1931	37,200	-2,908	13,764	3,080	165,780	145,180
1930	28,400	447	11,869	2,660	142,960	125,550
1929	43,733	25,145	9,120	2,040	10[illegible],840	93,500
1928		8,931	8,130	1,820	97,920	81,580
1927						
1926						
Totals	157,0[illegible]1	37,651				

for 1929-33
and 1936-38

GILA RIVER BASIN IN NEW MEXICO STREAM FLOW SUMMARY.

	San Francisco-Glenwood (19)	San Francisco Clifton (20)	Diversions above Glenwood (21)	Virgin Flow at Glenwood (22)	18.0% of 22 (23)	San Francisco flow from flow in 22 plus 23 (24)
1940						
1939						
1938	29,420	74,910	10,400	39,820	5,180	45,000
1937	77,300	183,200	10,400	87,700	11,400	99,100
1936	35,990	98,390	10,400	46,390	6,030	52,420
1935	35,680	92,000	10,400	46,080	5,990	52,070
1934	28,260	74,500	10,400	38,660	5,030	43,690
1933	44,100	107,000	10,400	54,500	7,080	61,580
1932	113,755	264,000	10,400	124,160	16,140	140,300
1931	47,600	124,000	10,400	58,000	7,540	65,540
1930	44,860	90,600	10,400	55,260	7,180	62,440
1929	27,738	91,300	10,400	38,140	4,960	43,100
1928	31,419	80,700	10,400	41,820	5,440	47,260
1927			10,400			
1926			10,400			
1925			10,400			
1924			10,400			
1923			10,400			
1922			10,400			
1921			10,400			
1920			10,400			
1919			10,400			

GILA RIVER BASIN IN NEW MEXICO STREAM FLOW SUMMARY.

	San Francisco actual flow from N.M. (24) minus (21)	Virgin flow of Gila Basin from N. M.	Actual flow of Gila Basin from N. M.	Diversions in N. M.	Loss from N. Mex. line to Gillespie from main stem virgin flow	Same as (29) except New Mexico line to A.-H. Dam
	(25)	(26)	(27)	(28)	(29)	(30)
1940						
1939						
1938	34,600	145,300	118,200	27,100	64,900	41,850
1937	83,700	323,250	294,300	28,375	136,260	87,750
1936	42,020	156,460	127,230	29,230	93,240	60,050
1935	41,670	159,960	131,710	28,250	123,890	79,790
1934	33,290	138,440	108,110	25,325	69,580	44,810
1933	51,180	193,140	162,140	31,005	83,300	53,650
1932	129,900	344,040	310,230	27,810	164,140	105,710
1931	55,140	231,320	200,320	31,005	142,770	91,940
1930	52,040	205,400	177,590	27,810	114,300	73,610
1929	32,700	152,940	126,200	26,745	87,800	56,540
1928	36,860	145,180	118,440	26,745	62,050	39,960
1927						
1926						
1925						

GILA RIVER BASIN IN NEW MEXICO STREAM FLOW SUMMARY.

	Virgin flow at A.-L. Dam if no losses below New Mexico line (31)	New Mexico share of losses in col. (32)	N. Mex's part of virgin flow at Gillespie (33)	New Mex. share of loss Gillespie to Dome (34)	Total loss charged to N. Mex. (35)	New Mex. virgin flow in Gila at Dome (36)
1940						
1939						
1938	340,090	27,770	117,530	20,260	48,030	97,270
1937	713,085	61,770	261,480	37,370	149,340	173,610
1936	487,945	29,900	126,560	23,670	53,570	102,860
1935	648,350	30,570	129,390	35,600	66,170	93,790
1934	364,136	25,500	107,940	18,890	44,390	89,050
1933	435,935	30,010	150,250	24,670	61,580	131,500
1932	858,985	65,740	278,300	96,190	161,930	122,110
1931	747,130	44,200	187,120	43,660	87,860	143,400
1930	506,160	58,250	166,150	30,210	69,460	135,940
1929	459,490	29,220	123,780	23,260	52,480	100,460
1928	324,710	27,740	117,440	16,460	44,200	100,900
1927						
1926						
1925						

GILA RIVER BASIN IN N.M. MEXICO STUDY - PROJ. SUMMARY.

	Arizona part of virgin flow in Gila at Dome
	(37)
1940	
1939	
1938	862,730
1937	1,406,390
1936	1,027,110
1935	1,276,210
1934	570,950
1933	828,440
1932	1,767,890
1931	1,236,540
1930	944,060
1929	979,540
1928	819,020
1927	
1926	
1925	

GILA RIVER BASIN IN NEW MEXICO STREAM-FLOW SUMMARY

Notes on computation sheets.

All figures are annual run-off in acre-feet for year ending Sept. 30.

Where the term diversions are used in the computations, they have been considered as consumptive use except where otherwise note .

Column (1). For 1931-1938 from U.S.G.S. Water-Supply Papers. For 1930 and previous years, from "Surface Water Supply of New Mexico" by New Mexico state engineer.

Column (2). For 1932-1938 from U.S.G.S. Water-Supply Papers. For 1928-1931 used sum of "Gila River at Virden" and "Sunset Canal" as published in U.S.G.S. Water-Supply Papers.

Column (3). From U.S.G.S. Water-Supply Papers. No record for 1934 and 1935. Gila-Clifton for 1928 has record for March 9 to September 30 only.

It was estimated for the full year by comparison of flow at Gila-Clifton plus diversions between Virden Bridge and Gila-Clifton with flow at Virden Bridge as follows:

At Gila-Clifton:
In 1938, Duncan Valley used 4,400 acre-feet of its diversions October 1 to March 8, out of a total diversion of 23,200 acre-feet. Assuming the same distribution in 1928, when total use was 19,000 acre-feet (from column (3) of "Gila River Basin stream flow summary"):

$$\frac{\text{Use Oct. 1 to Mar. 8, 1929}}{19{,}000} = \frac{4{,}400}{23{,}200} = 3{,}600$$

Diversions Mar. 9 to Sept. 30, 1928, in Duncan Valley

= 19,000 - 3,000 = 15,400 acre-feet.

Gila-Clifton actual flow
Mar. 9 to Sept. 30, 1928= 40,400

Sum is 55,800 acre-feet, total Mar. 9 to Sept.30,1928.

At Virden Bridge, actual flow:

Mar. 9 to Sept. 30, 1928 = 37,800
Water year 1938 = 61,700

Then, $\frac{55,800}{\text{Water year 1928 at Gila-Clifton}} = \frac{37,800}{61,700}$

Giving virgin flow at Gila-Clifton, 1928 = 91,200

Diversions = 19,000

Estimated actual flow at Gila-Clifton for 1928 = 72,200 acre-feet.

Column (4). Report of New Mexico state engineer for 1932-1934, page 191, gives 3,500 acres as area irrigated above Red Rock. This figure is checked in other state engineers' reports. At 2-foot consumptive use, this gives 7,000 acre-feet per year used.

Column (5). From same sources as column (4), which give 1,300 acres irrigated or 2,600 acre-feet per year diverted.

Column (6). Copied from Column (3) of "Gila River basin Stream Flow Summary".

Column (7). Gila Water Commissioner Firth in letter states that 35.5% of Duncan Valley irrigated acreage is in New Mexico. Column (7) is 35.5% of column (6).

Column (8) = columns (1) plus (4).

Column (9) = columns (2) plus (4) plus (5). For 1928-1931, it gives virgin flow at Virden bridge.

Column (10) = columns (3) plus (4) plus (5) plus (6).

Column (11) is column (9) minus (8) and represents change in natural flow between Red Rock and Fullers ranch (between Red Rock and Virden bridge 1928 - 1931). The negative quantities show either that there is a natural loss or, more likely, that the records are not accurate within necessary limits.

Column (12) is column (10) minus (9) and represents change in natural flow between Fullers ranch (or Virden bridge 1928-1931) and Gila-Clifton.

Column (13) is column (12) divided by the area contributing the flow, which was 892 sq. mi. 1932-1938 when station was at Fullers ranch and 750 sq. mi. 1929-1931 when station was at Virden bridge.

Column (14) is column (11) divided by the area contributing the flow, which was 304 sq. mi. 1932-1938 when station was at Fullers ranch and 447 sq. mi. 1929-1931 when station was at Virden bridge.

Column (15) is per sq. mi. run-off used in New Mexico below Fullers ranch. It is derived from columns (13) and (14) but not directly, because years of negative run-off are not right. Method used: Total columns (13) and (14) algebraically for 1929-1933 and 1926-1938. Totals are 157.091 and 37.651 or an average of 97.371. This total difference was assumed to be distributed among the years in proportion to the run-off at Fullers ranch for those same years. Total of Fullers ranch run-off for 1929-1933 and 1936-1938 is 1,151,590. Then $\frac{97.371}{1,151.590} = 0.0000846$ acre-feet run-off per sq. mi. from area in New Mexico below Fullers ranch for each second-foot run-off at Fullers ranch for each second-foot run-off at Fullers ranch. Column (15) is obtained by multiplying column (9) by the factor 0.0000846, and represents run-off per sq. mi. from area in New Mexico below Fullers ranch. The results are undoubtedly poor but as only 1.8% of run-off from New Mexico depends on this computation, the possible error in final result is negligible.

Column (16) is column (15) multiplied by area in New Mexico below Fullers ranch, 367 sq. mi. for 1932-1938, and below Virden bridge, 224 sq.

mi. for 1928-1931.

Column (17) is total virgin flow from New Mexico from Gila River itself (not including San Francisco) and is sum of columns (9) and (16).

Column (18) is total actual flow from Gila River in New Mexico (not including San Francisco) and is column (2) + (16) - (7).

Column (19) from U.S.G.S. Water-Supply Papers and "Surface Water Supply of New Mexico". Six months of 1932 was estimated.

Column (20) from U.S.G.S. Water-Supply Papers, except for 1934 and 1935 which were estimated by comp arison with San Francisco-Glenwood on Chart 9.

Column (21). Reports of New Mexico state engineer gave irrigated acreage of San Francisco in New Mexico as 5,200 acres. This is all above Glenwood gaging station. Using 2 acre-feet per acre, use 10,400 acre-feet per year.

Column (22) is column (19) ÷ (21).

Column (23). See map of San Francisco River basin, chart No. 10;

	Square Miles
San Francisco in Arizona above Glenwood	68.3
Blue in New Mexico	47.6
Excess in Arizona in above exchange	20.7
Other area above Glenwood in Arizona	23.2
Area above Glenwood in Arizona after credit is given New Mexico for its part of Blue River area in New Mexico	43.9
Area in San Francisco Basin below Glenwood and in New Mexico	260.1
Credit to Arizona above	43.9
Area in New Mexico below Glenwood after above adjustments	216.2

Then, on a drainage area ratio, the area in New Mexico not accounted for at Glenwood station, and including credit for Blue in New Mexico, is $\frac{216.2}{1663.2}$ or 13.0% of drainage area above Glenwood. The area above Glenwood is 1,663.2 square miles. Column (23) is 13.0% of column (22).

Column (24) is column (22) + (23) and is virgin flow contribution of San Francisco basin from New Mexico.

Column (25) is column (24) - (21) and is actual flow from San Francisco basin in New Mexico.

Column (26) is sum of columns (17) and (24) and is virgin flow of Gila basin from New Mexico.

Column (27) is sum of columns (18) and (25) and is actual flow of Gila basin from New Mexico.

Column (28) is total use in New Mexico and is sum of columns (4), (5), (7), and (21). Column (28) plus (27) equals column (26) within limits of rounding.

Column (29), virgin flow losses, New Mexico to Gillespie Dam, is based on method of Olmstead in "Gila River Flood Control", pp.28-29. His assumption is:

1. That evaporation from water surface in upper Gila basin is 60 inches per year.
2. That evaporation from non-water covered river bed channel is 18 inches per year.
3. That for each mile of river, the wet border lands amount to a width about 1.3 times as great as the water surface.
4. Losses from wet borders assumed as 30% of water surface evaporative loss. Then, losses are:

1 x 60" = 60

1.3 x 18" = 23.4

2.3 / 83.4

36" average yearly evaporation from river surface and wet borders.

Using this figure, Olmstead arrives at an average annual evaporation loss between Duncan diversion dam (just above New Mexico border) and San Carlos River, of 59,600 acre-feet.

Following same method from San Carlos to Ashurst-Hayden Dam:

San Carlos to Christmas quadrangle, 700 feet average width for 6 miles = 680 acres, or, at 3 feet per acre, 2,040 acre-feet annual loss.

Christmas quadrangle, 300 feet average width with length of 30 miles = 1,090 acres. Annual loss = 1,090 x 3 = 3,270 acre-feet.

Ray and Winkelman quadrangles, 700 feet average width with length of 20 miles = 1,700 acres. Annual loss = 1,700 x 3 = 5,100 acre-feet.

Florence quadrangle to Ashurst-Hayden Dam, 400 feet average width with length of 16 miles = 775 acres, or 2,320 acre-feet annual loss.

Ashurst-Hayden Dam to Gillespie Dam, 1,000 feet average width for 110 miles = 13,300 acres. At 3 feet loss per acre, = 39,000 acre-feet annual loss.

Total average annual loss from New Mexico line to Gillespie Dam, the sum of olmsteads figures and those above, equals 112,000 acre-feet for virgin flow.

As a check, results of other studies were used, particularly a graph showing loss per year per mile in the Gila between Gillespie Dam and Dome. Average mean virgin flow at Ashurst-Hayden Dam for 20 years was 514,000 acre-feet (see column (19) of Gila River basin stream flow summary). Applying this to graph, we get 940 acre-feet per year per

mile loss. Consideration of several factors indicated that loss per mile in upper basin would be about ½ that below Gillespie Dam.

Using $\frac{940}{2}$ on the 311 miles of river (the 311 is sum of Olmstead's mileage from Duncan dam to San Carlos and mileages below San Carlos as given above), we get 146,000 acre-feet annual loss. This is a reasonable check on the figure of 112,000 acre-feet above.

Taking 112,000 acre-feet as annual mean loss from New Mexico line to Gillespie Dam, it is necessary to find how the loss varies from year to year. As there is a direct relation between quantity of flow and loss, it is assumed that the loss varies from year to year in a straight line relation with the virgin flow at Ashurst-Hayden Dam. The annual mean virgin flow at Ashurst-Hayden Dam for 20 years was 514,000 acre-feet. Loss for any year, which is figure in column (29), was computed as:

$$\frac{\text{Virgin flow at Ashurst-Hayden Dam that year}}{514,000} \times 112,000.$$

Column (30) is that part of total loss occurring above Ashurst-Hayden Dam. From data above, it is seen that of total loss, all but 39,900 acre-feet occurs above Ashurst-Hayden Dam. Then proportion above is $\frac{112,000 - 39,900}{112,000} = 64.4\%$ and column (30) is 64.4% of (29).

Column (31) is column (30) plus column (19) of main Gila study and puts the flow on a comparable basis with column (26). That is, both column (26) and (31) are virgin flows at two points, with no losses occurring between.

Column (32). In Column (29) we have total losses out of the main Gila from New Mexico line to Gillespie Dam. New Mexico's proportion of the virgin flow, without losses, at Ashurst-Hayden Dam is a moderate measure of New Mexico's share of the total losses. New Mexico's share is column (26) divided by column (31). This proportion times

column (29) gives column (32). If anything, this gives losses too small for New Mexico because, whereas New Mexico's water suffers loss throughout the stretch from New Mexico to Gillespie, all of Arizona's water traverses a shorter distance; yet the losses are distributed on basis of flow at Ashurst-Hayden Dam. Water from San Pedro River runs in main Gila from Winkelman to Gillespie, but is charged losses according to its part of the flow at Ashurst-Hayden Dam, whereas New Mexico's water runs several times as far and is charged losses at same rate.

Column (33) is column (26) less column (32) and is that part of New Mexico's virgin flow which reaches Gillespie Dam after deducting natural channel losses.

Column (34). New Mexico's share of losses Gillespie to Dome is taken in proportion to New Mexico's share of flow at Gillespie and is equal to Loss x $\frac{\text{New Mexico virgin flow at Gillespie}}{\text{Total virgin flow at Gillespie}}$ =

$\frac{\text{(Col. 61 of main Gila study - Col. 63 of same)}}{\text{(Col. 61 of main Gila study)}}$ x Col. 33.

This, again, probably charges New Mexico with too small a part of the losses, because the loss obtained from Col. 61 - 63 is a net loss, and is really the loss from Gillespie to Dome plus the gain from natural inflow to that reach.

Column (35) is sum of columns (32) and (34).

Column (36) is column (26) less column (35) and shows New Mexico's contribution to Colorado River through the Gila River system.

Column (37) is column (63) of main Gila study less column (36) of this study and shows Arizona's part of the Gila River virgin flow into Colorado River.

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