ESTIMATED NATURAL STREAMFLOW IN THE RIO SAN JOSE UPSTREAM FROM THE PUEBLOS OF ACOMA AND LAGUNA, NEW MEXICO

By Dennis W. Risser

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CONVERSION FACTORS

In this report, measurements are given in U.S. customary units only. The following table contains factors for converting to metric units.

Multiply U.S. customary units	By	To obtain metric units
foot	0.3048	meter
cubic foot per second	0.02832	cubic meter per second
inch	25.40	millimeter
mile	1.609	kilometer
square mile	2.590	square kilometer
acre	0.4047	hectare
acre-foot	0.001233	cubic hectometer

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

Water Year: Most of the hydrologic data in this report are presented by water-year, which begins on October 1 and ends on September 30.

ESTIMATED NATURAL STREAMFLOW IN THE RIO SAN JOSE UPSTREAM FROM THE PUEBLOS OF ACOMA AND LAGUNA, NEW MEXICO

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ABSTRACT

The development of surface and ground water, which began about 1870 in the western Rio San Jose drainage basin, has probably changed the flow of the Rio San Jose on the Pueblos of Acoma and Laguna. The purpose of this study was to estimate the natural streamflow in the Rio San Jose that would have entered pueblo land if no upstream water development had taken place.

Estimates of natural flow are based upon streamflow records, precipitation records, and historical accounts of streamflow and spring discharge in the basin. Natural streamflow in the Rio San Jose at the western boundary of the Pueblo of Acoma is estimated to be between 12,000 and 14,000 acre-feet per year, based on 55 years of recorded and reconstructed streamflow data from water years 1913 to 1972. Natural streamflow at the western boundary of the Pueblo of Laguna is estimated to be between 16,000 and 18,000 acre-feet per year for the same period. The actual error in these estimates of natural streamflow is impossible to assess and may be very large because many assumptions were made, the accuracy of which are unknown. However, the maximum amount of error that can be quantified probably is less than 25 percent.

INTRODUCTION

Purpose and scope

Surface- and ground-water resources have been extensively developed in the western part of the Rio San Jose drainage basin for many years. Since about 1870, both surface and ground waters have been used in increasing quantities from the Rio San Jose basin upstream from the Pueblos of Acoma and Laguna. The Indians are concerned that this development has significantly decreased the streamflow in the Rio San Jose on their lands. To address this concern, the U.S. Bureau of Indian Affairs requested a study by the U.S. Geological Survey to estimate the natural streamflow in the Rio San Jose.

The purpose of this study was to estimate the natural streamflow in the Rio San Jose at the upstream boundaries of the Pueblos of Acoma and Laguna. Natural streamflow is defined for this study as the streamflow that would have occurred if water development in the basin upstream from the pueblos had never taken place.

The scope of this study was limited to obtaining the best possible estimates of the natural streamflow of the Rio San Jose using available records and historical accounts of streamflow in the basin. Computer modeling of rainfall-runoff relations or the ground-water-flow system was outside the scope of this study.

Location

The Rio San Jose basin is situated in west-cental New Mexico in parts of Valencia, Cibola, and McKinley Counties (fig.1). The study area includes 1,300 square miles of the Rio San Jose basin upstream from the western boundary of the Pueblo of Laguna. The Rio San Jose is formed about 3 miles upstream from the village of Bluewater at the confluence of Bluewater Creek and Mitchell Draw. Bluewater Creek has always been perennial to the mouth of Bluewater Canyon, although since 1927 streamflow has been regulated at the head of the canyon by Bluewater Dam. Mitchell Draw is an ephemeral stream that flows primarily in response to summer rainstorms. The Rio San Jose flows to the east for about 90 miles where it joins the Rio Puerco near the southeast corner of the Pueblo of Laguna. The major communities along the Rio San Jose in the study area are Bluewater, Grants, McCartys, and Acomita.

A simplified schematic diagram shows the location of major flows to and from the Rio San Jose (fig. 2). Some of the flows shown in the figure are natural and some have been created by the activities of man.

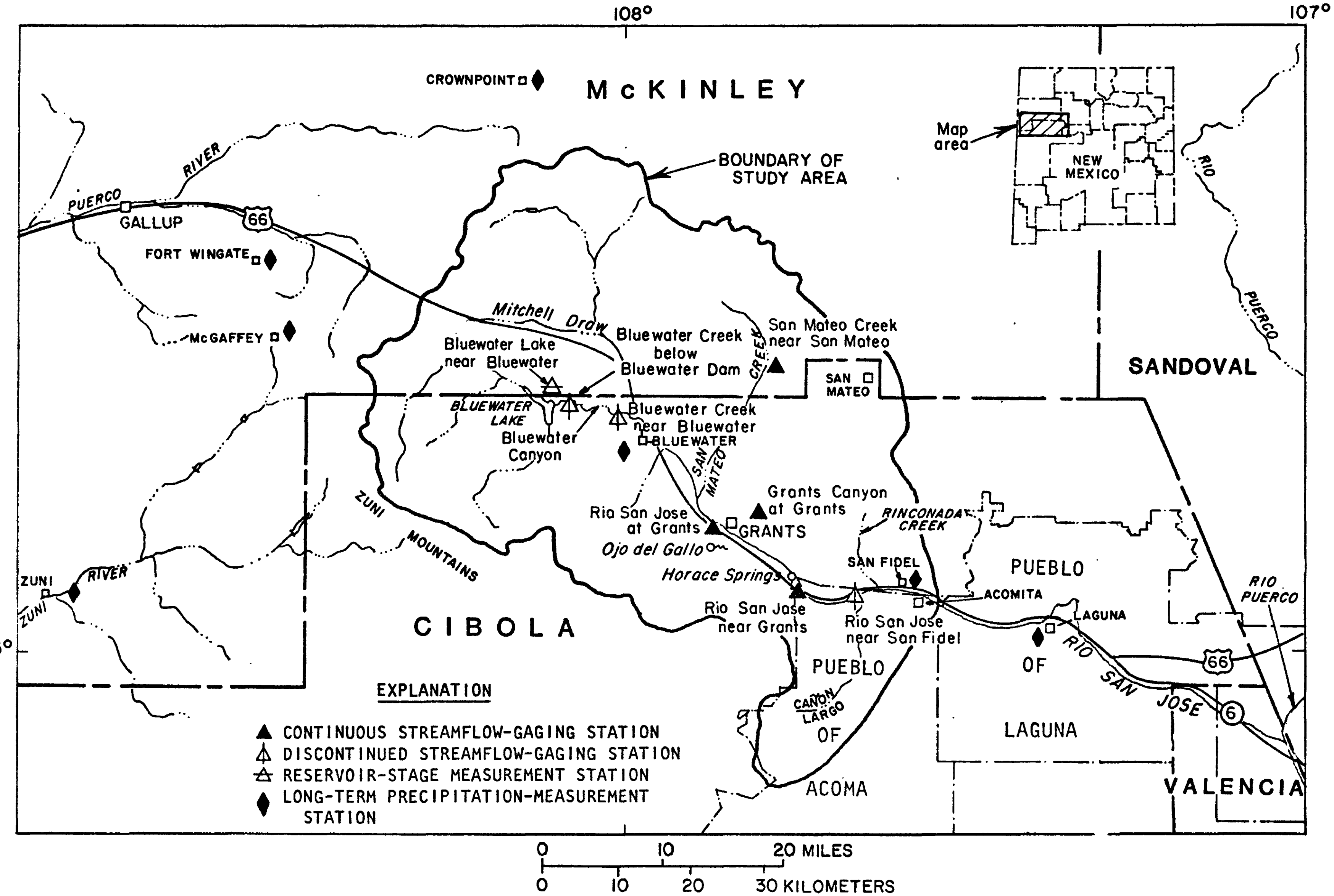


Figure 1.--Location of study area and data-collection stations.

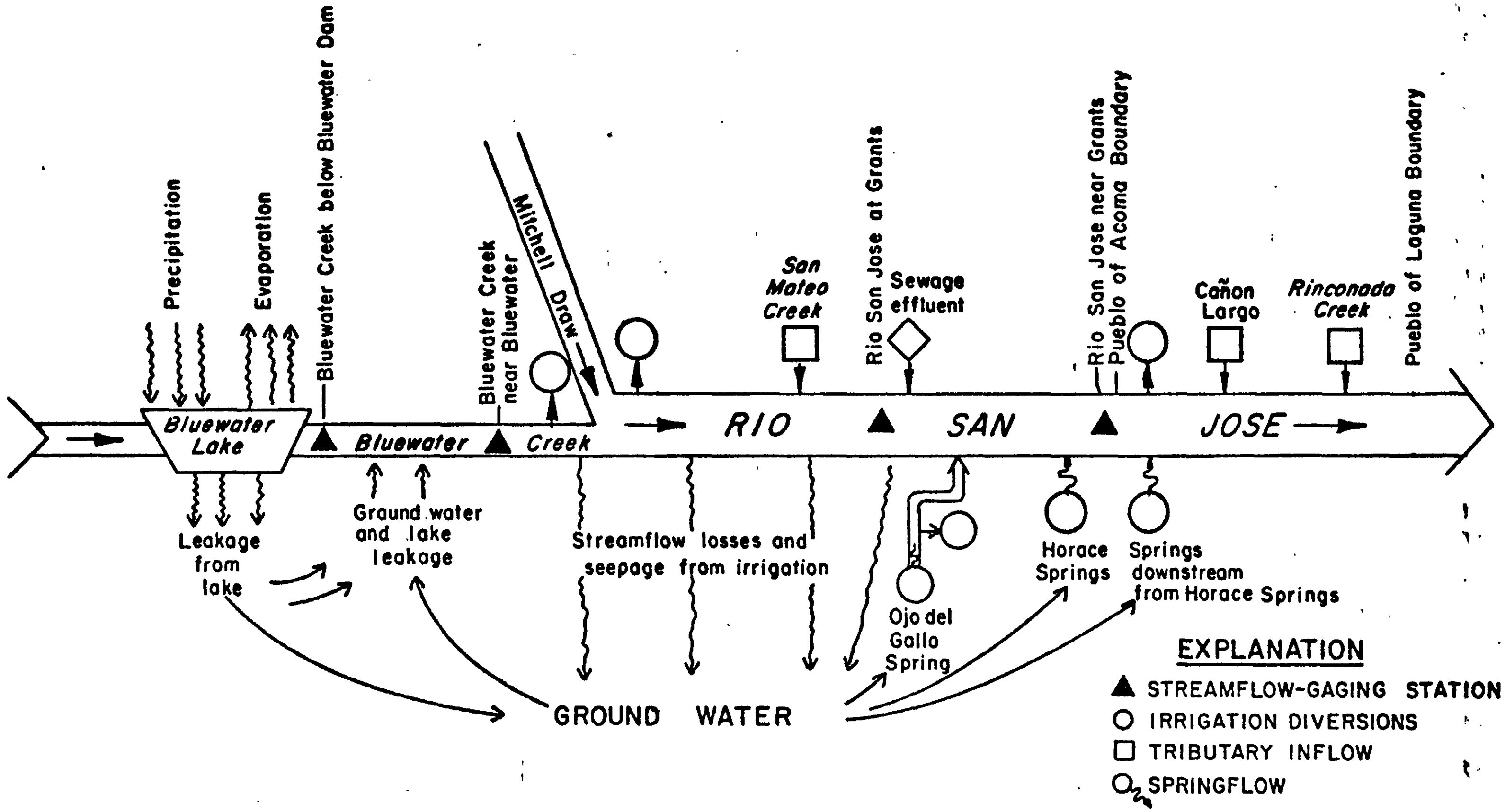


Figure 2.--Schematic diagram showing major natural and man-induced flows to and from the Rio San Jose.

Previous investigations

Several investigations have been made that contain information on the hydrology of the study area. An irrigation survey of the Rio Grande basin was conducted by Follett (1896). His work contains information on the quantity of water used for irrigation in the Rio San Jose basin. Hodges (1938) worked for the Bureau of Indian Affairs on a study of the irrigation and water supply of the Indian pueblos of New Mexico. Included in his work are quantitative measurements of streamflow and irrigation diversions along with many personal accounts from Pueblo Indians and non-Indian residents concerning the streamflow of the Rio San Jose. A reconnaissance study of the ground-water resources in the Grants-Bluewater area was made by Morgan (1938). A detailed study of the Grants-Bluewater area was conducted by Gordon (1961). He discussed the occurrence and movement of ground water and the quality of water in the major aquifers. Rapp (1960) conducted a short study on the availability of water for irrigation on the Pueblo of Acoma. Dinwiddie and Motts (1964) studied the availability of ground water primarily in the alluvium along the Rio San Jose and its tributaries on Acoma and Laguna Pueblo lands.

Methods of investigation

The approach used to estimate the natural streamflow in the Rio San Jose at the western boundaries of the Pueblos of Acoma and Laguna was controlled mainly by the limited availability of early streamflow and springflow records. Records for the years prior to the regulation of flow by Bluewater Dam in water year 1928 exist only for streamflow-gaging stations near Bluewater and at Grants, beginning about water year 1913 (fig. 3 and table 1). Therefore, the problem was divided into two parts: (1) Evaluating the natural streamflow contributed mainly by runoff from the basin upstream from Grants; and (2) evaluating the natural flow from Ojo del Gallo, Horace Springs, and tributary streams that contribute water to the Rio San Jose downstream from Grants. The evaluation of runoff upstream from Grants was based on estimates of natural streamflow at Bluewater Creek near Bluewater, where the most complete, long-term streamflow record was available. The record at this station was used to help estimate natural streamflow downstream in the Rio San Jose at Grants and at the western boundaries of the Pueblo of Acoma and Laguna. The natural quantity of springflow contributed by Ojo del Gallo and Horace Springs was estimated on the basis of historical accounts, miscellaneous measurements of springflow, and continuous records of streamflow from the gaging station on the Rio San Jose near Grants.

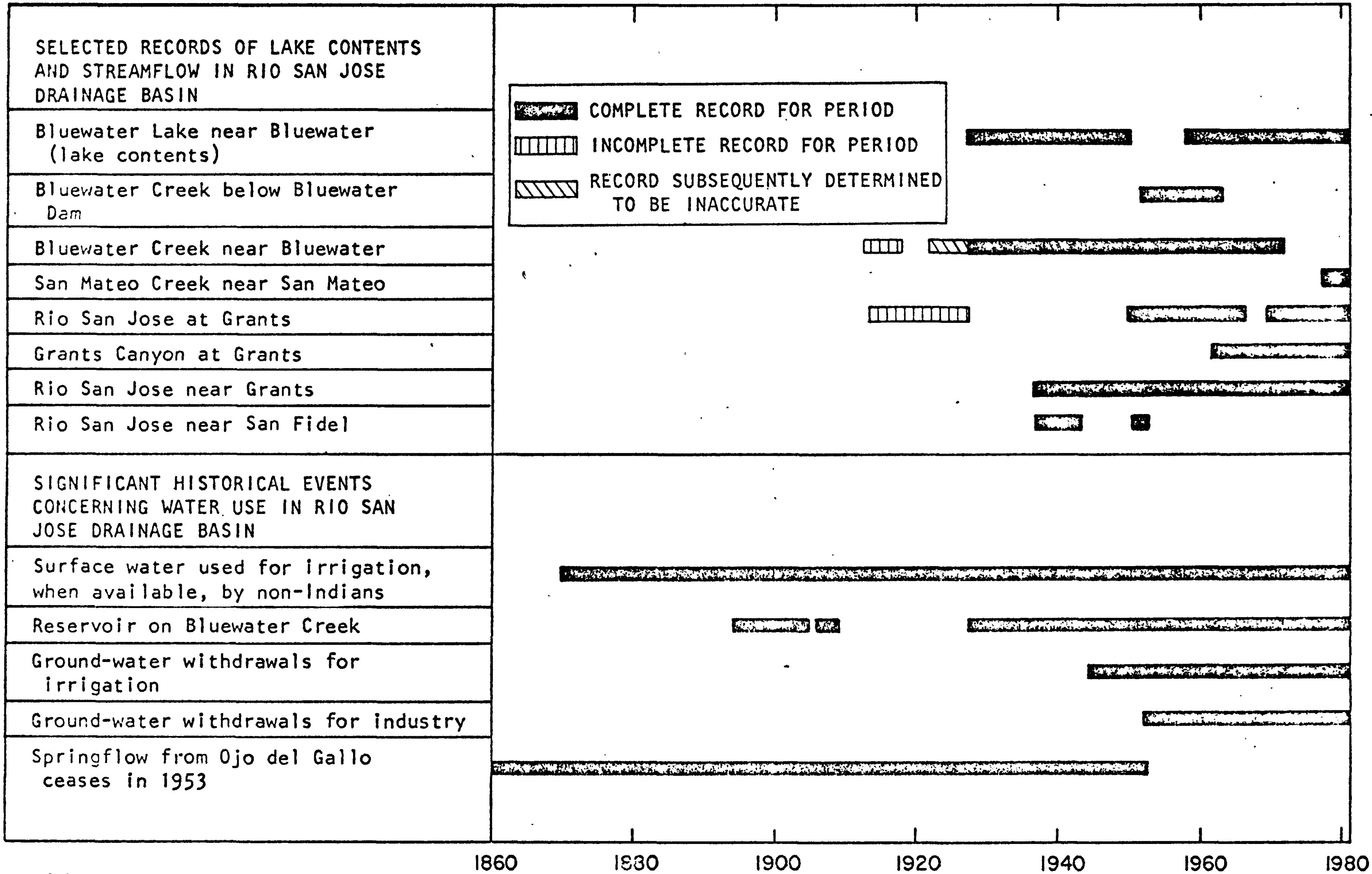


Figure 3.--Chronology of collection of surface-water records and water use in the Rio San Jose basin.

Estimates of the natural streamflow in Bluewater Creek near Bluewater and the Rio San Jose at Grants were divided into the three time intervals that correspond to the times in which historical changes of water use took place in the basin (fig. 3). The time intervals are:

Time Interval 1 (water years 1913-27)

During these years, no permanent dam existed on Bluewater Creek and the stream was virtually unregulated. Surface water, when available from Bluewater Creek, was diverted for irrigation at the mouth of Bluewater Canyon. Water also was diverted for irrigation downstream from Horace Springs by the Acoma and Laguna Indians. Springflow from Ojo del Gallo was used during summer months for irrigation. Collection of streamflow records started in water year 1913.

Time Interval 2 (water years 1928-44)

The natural streamflow of the Rio San Jose was partially regulated by construction of Bluewater Dam on Bluewater Creek. Surface water continued to be diverted for irrigation from Ojo del Gallo, Bluewater Creek, and Rio San Jose during summer months.

Time Interval 3 (water years 1945-72)

The streamflow was partially regulated by Bluewater Dam. Large-scale ground-water withdrawals for irrigation and industrial use began. Springflow from Ojo del Gallo decreased and finally ceased completely. Effluent from the wastewater-treatment plant at Grants was added to the flow of the Rio San Jose. Surface water was diverted for irrigation from Bluewater Creek and Rio San Jose during summer months. The streamflow-gaging station on Bluewater Creek near Bluewater was discontinued after water year 1972. This was the key station used in estimating natural flow to the Pueblos of Acoma and Laguna.

FACTORS AFFECTING NATURAL STREAMFLOW

Prior to water development in the basin, the natural streamflow in the Rio San Jose on the Pueblos of Acoma and Laguna was sustained by surface runoff and springflow. During the years when there was no reservoir on Bluewater Creek, snowmelt from the Zuni Mountains provided a large component of the streamflow that reached pueblo lands (Hodges, 1938, p. 396; U.S. Geological Survey, 1891, p. 276). Storm runoff from Mitchell Draw and other tributaries of the Rio San Jose provided streamflow primarily during summer months. In addition, the flow from two major springs, Ojo del Gallo and Horace Springs, probably had a combined constant flow of about 10 to 12 cubic feet per second, most of which contributed to the streamflow of the Rio San Jose.

The streamflow recorded at gaging stations near Bluewater and at Grants had a decreasing trend since the records were started in water year 1913 (table 1, figs. 4 and 5). The apparent decrease in average streamflow may be attributed to natural factors, such as changes in precipitation patterns, and to man-induced factors, such as irrigation, reservoir construction, and ground-water withdrawals. From 1870 when non-Indian settlers began diverting water for irrigation until the present (1980), both natural and man-induced changes have taken place in the Rio San Jose basin. To accurately estimate the natural flow in the river, the effects of the natural changes need to be distinguished from the man-induced changes.

Precipitation changes

The quantity, intensity, and duration of precipitation all affect the volume of runoff from a drainage basin. Although long-term data on changes in the intensity and duration of precipitation are not available, records are available that show changes in the quantity of precipitation in and around the Rio San Jose basin during the past 80 to 100 years (table 2, fig. 6).

Annual precipitation at seven stations in the area is shown in figure 6. Graphs of the cumulative departure from mean precipitation for the period of record at each station are shown in figure 7. The cumulative-departure curve was constructed by calculating the mean precipitation for the available years of record, finding the difference between the mean value and recorded precipitation for each year, and plotting the algebraic sum of the differences in chronological order. Steeply rising or declining sections of the curve represent wet or dry time periods where for several years in succession the recorded precipitation differed from the mean in the same direction.

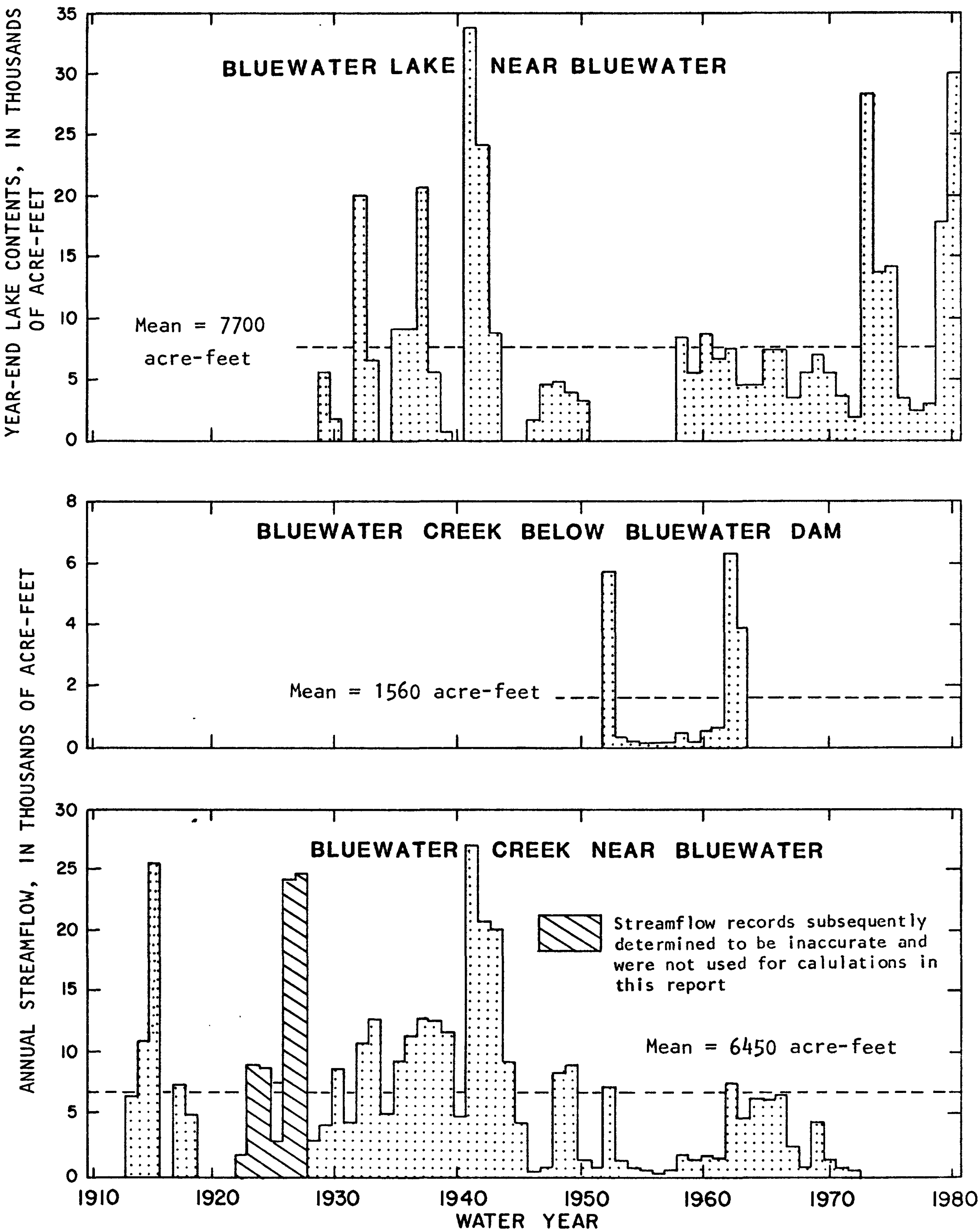


Figure 4.--Annual lake contents and streamflow for gaging stations on Bluewater Creek.

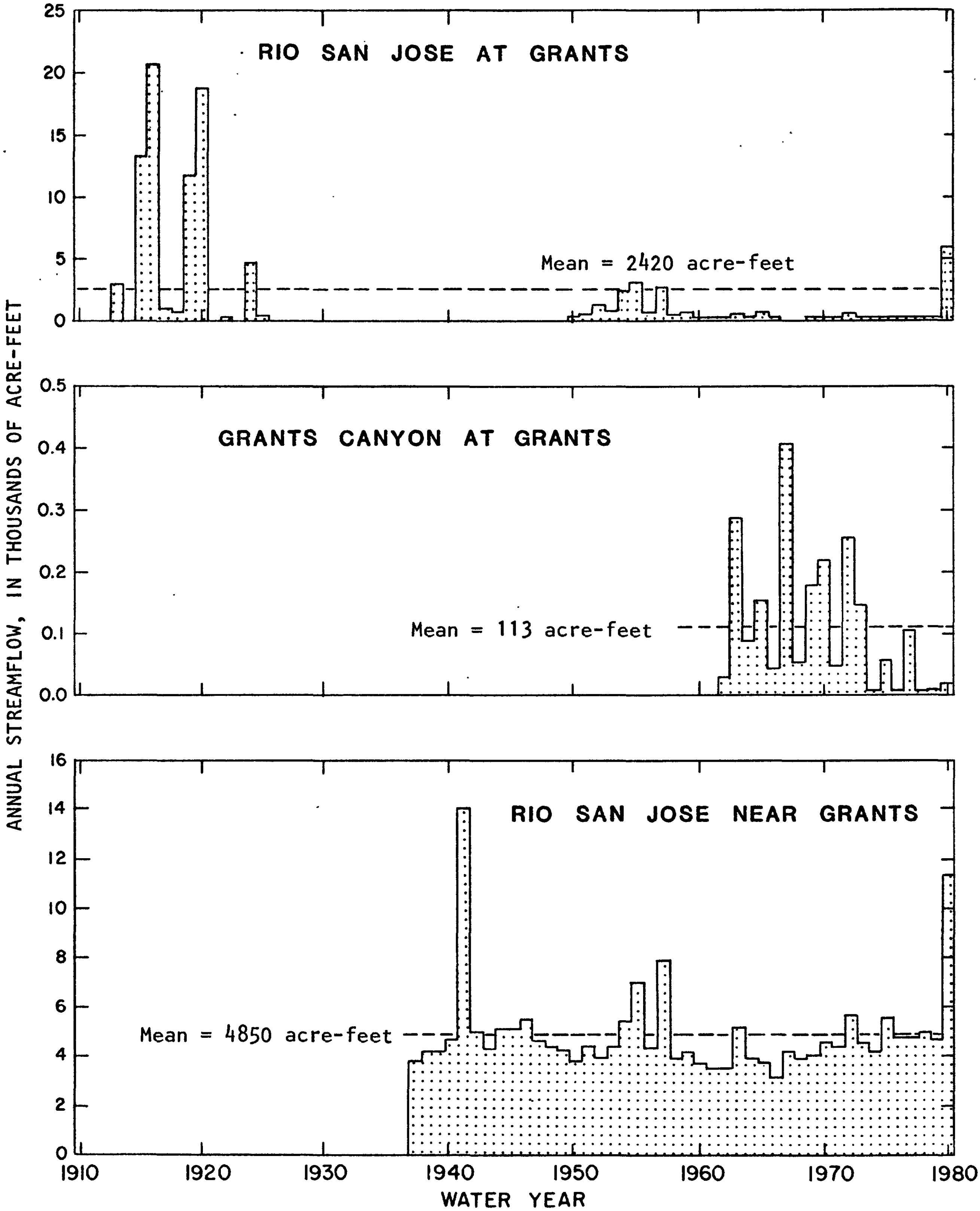


Figure 5.--Annual streamflow data for selected gaging stations on the Rio San Jose and at Grants Canyon.

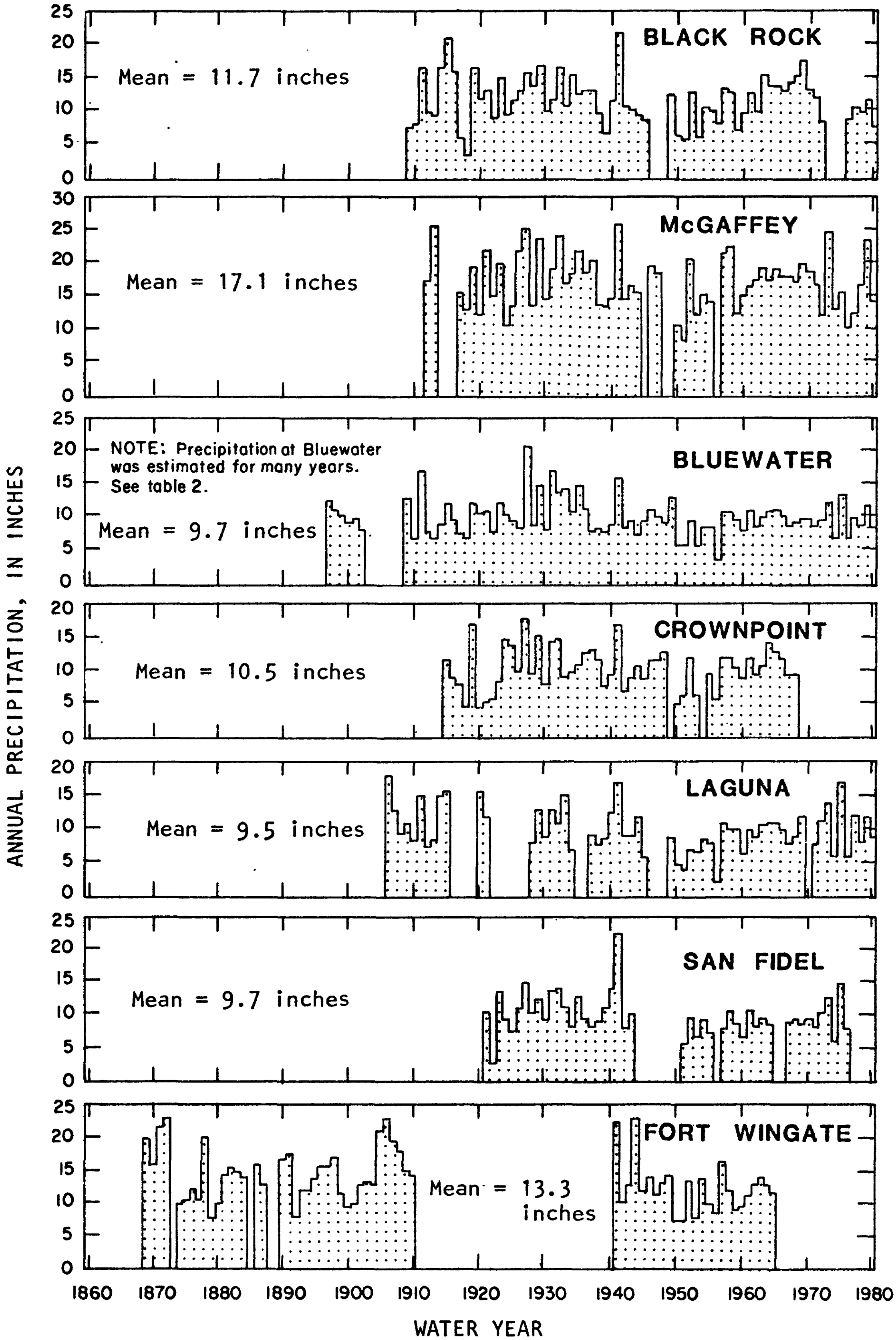


Figure 6.--Long-term precipitation records for stations within and near the Rio San Jose basin.

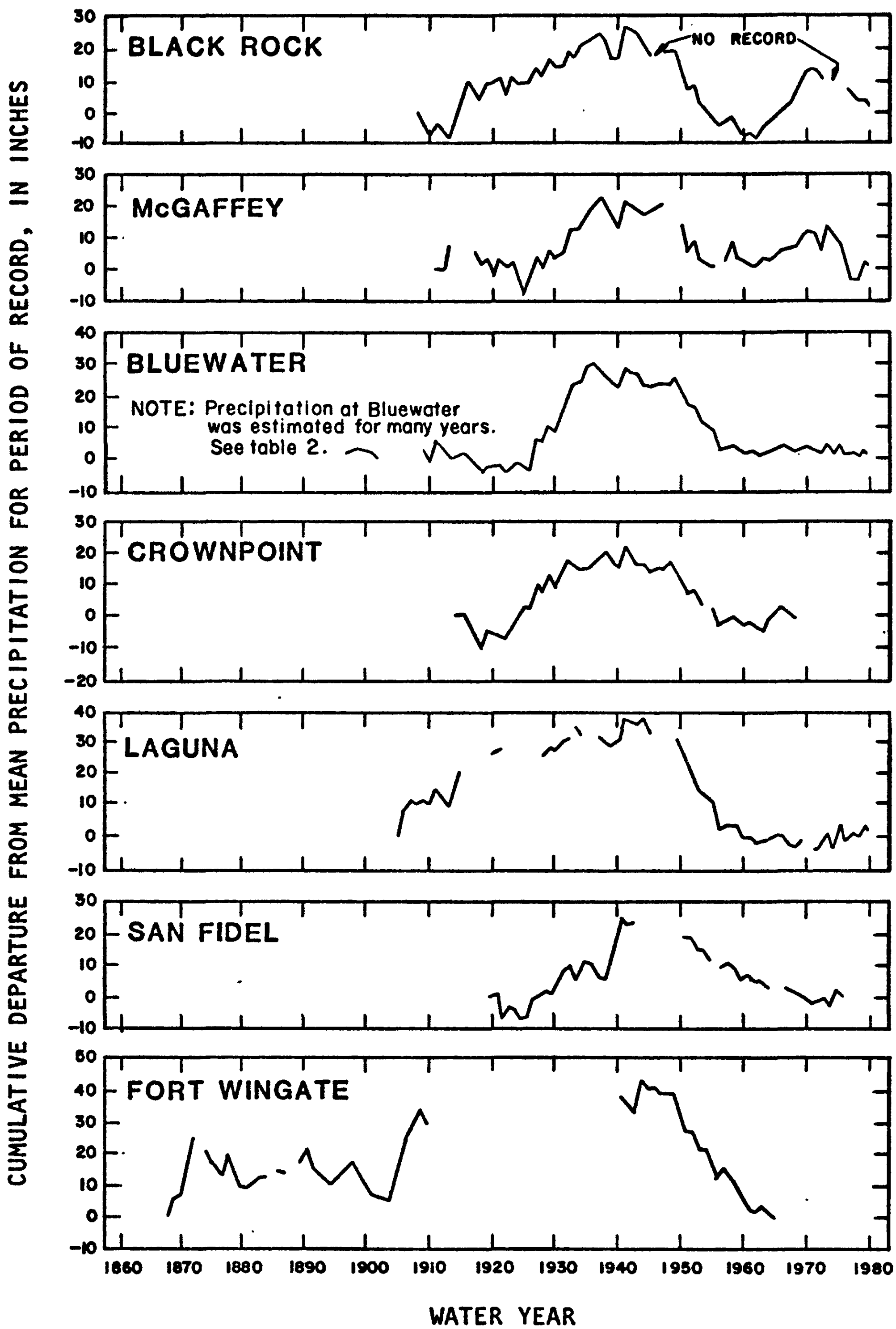


Figure 7.--Cumulative departure from mean precipitation for the period of record at stations within and near the Rio San Jose basin.

At most of the stations within and near the basin, the precipitation recorded from the mid-1920's to the mid-1930's was greater than the mean value for the available period of record. However, the late 1940's to the early 1960's were years with less than average precipitation at most stations. The records for other periods show mixed trends or about average precipitation.

It is significant that the quantity of precipitation falling on the basin has not remained constant through time. The changes in precipitation alone, regardless of water uses by man, could result in natural changes in streamflow.

Activities of man

The activities of man have altered the natural streamflow of the Rio San Jose. The use of surface water in the basin began with diversions for irrigation from the Rio San Jose by the Pueblo Indians. Follett (1896) lists as "very old", four irrigation ditches used by the Indians in 1896 to irrigate about 4,750 acres along the Rio San Jose.

Diversions for irrigation in the Rio San Jose basin increased shortly after non-Indians settled the Grants-Bluewater area during the 1870's. Settlers built an irrigation ditch with a capacity of 12 cubic feet per second in 1870 to divert the springflow from Ojo del Gallo near San Rafael (Hodges, 1938, p. 373). Prior to that time, the springflow had discharged into a swamp from which a channel led into the Rio San Jose at a point about 3 miles downstream from Grants (Hodges, 1938, p. 340). Soon after 1880, the settlers diverted part of the flow of Bluewater Creek for irrigation about 1 mile downstream from the site of the streamflow-gage near Bluewater.

The demand for water by settlers in the valley upstream from the Pueblo of Acoma rapidly increased. In 1894, an earth dam was constructed on Bluewater Creek at the head of Bluewater Canyon. The dam was used until 1905 when it was washed out. A new dam, built shortly after on the same site, was washed out in 1909. During 1909-26, no dam existed on Bluewater Creek, but streamflow was used, when available, to irrigate an estimated 2,000 to 2,500 acres annually in the Grants-Bluewater area (Gordon, 1961, p. 13). In 1927, the Bluewater-Toltec Irrigation District built an 80-foot-high concrete dam on Bluewater Creek. The resultant Bluewater Lake, which is in use today, has a capacity of 44,200 acre-feet of water and a permanent recreation pool of about 3,400 acre-feet.

Decreases in the volume of surface water available for irrigation led to the development of large-capacity irrigation wells in the Grants-Bluewater area. The first irrigation well in the area was drilled in 1944. By the end of 1946, 16 large-capacity wells were in use, most of which obtained water from the San Andres Limestone and the underlying Glorieta Sandstone of Permian age (Gordon, 1961, p. 51). Lowering the water level in the San Andres-Glorieta aquifer is one possible explanation of why ground-water discharge to the Rio San Jose and Ojo del Gallo gradually decreased.

Ground-water use began to shift from irrigation to industrial applications during the early 1950's, shortly after the discovery of uranium in the area. One of the first large-capacity industrial wells was drilled by the Anaconda Company in 1951 (Gordon, 1961, p. 53). By 1958, eight large-capacity industrial wells were in use.

Since about 1957, the wastewater-treatment plant for the city of Grants has added effluent to the channel of the Rio San Jose at a point about 1 mile east of Grants. About 1978 a flow of about 1-2 cubic feet per second of effluent became perennial from the treatment plant to Horace Springs. The effluent travels undiluted (except during times of storm runoff) for about 8 miles in the streambed of the Rio San Jose to Horace Springs. The effluent that reaches the springs is mixed with about 5 cubic feet per second of springflow. This mixture, plus occasional storm runoff, constitutes the present streamflow of the Rio San Jose measured by the streamflow-gaging station (Rio San Jose near Grants) at the western boundary of the Pueblo of Acoma.

ESTIMATES OF NATURAL STREAMFLOW

Bluewater Creek near Bluewater

Streamflow in Bluewater Creek, measured at the gaging station Bluewater Creek near Bluewater, is a composite of surface-water runoff from the basin upstream from the gage and ground-water discharge from the San Andres-Glorieta aquifer in Bluewater Canyon (fig. 2). The streamflow measured at this station has apparently decreased, possibly owing to regulation by Bluewater Lake and to ground-water withdrawals from the San Andres-Glorieta aquifer (fig. 4). Therefore, the streamflow measured after 1927 probably is not representative of natural conditions in the basin.

Time Interval 1. (water years 1913-27)

The streamflow at the site of the gaging station Bluewater Creek near Bluewater for water years 1913-27 was the natural, unregulated flow of the stream, without any significant irrigation diversions upstream from the station (table 1 and fig. 4). A complete record is available at this station only for water years 1913, 1914, 1915, 1917, and 1918. In addition, streamflow records exist for 1922 through 1927. However, the values of streamflow reported for these years were subsequently found to be inaccurate (U.S. Geological Survey, 1960, p. 466) and, therefore, were not used in this study. The total streamflow for water years 1913, 1914, 1915, 1917, and 1918 was 54,100 acre-feet. The mean annual streamflow for these 5 years was 10,800 acre-feet.

Time Interval 2. (water years 1928-44)

Streamflow during these years was affected by regulation at Bluewater Dam. The change in the monthly distribution of actual gaged streamflow measured near Bluewater is shown for periods before and after dam construction (fig. 8). During water years 1913-27, before Bluewater Dam was constructed, 79 percent of the annual streamflow took place during March through May, mainly as a result of snowmelt from the Zuni Mountains. Regulation by the dam, from water year 1928 to the present (1980), shifted the high-flow period towards the summer months when water is released for irrigation (fig. 8). All of the water used for irrigation from Bluewater Creek was diverted downstream from the streamflow-gaging station near Bluewater.

The measured streamflow of Bluewater Creek near Bluewater totaled 186,100 acre-feet for the 17 years of record between water years 1928 and 1944 (table 1). The mean annual streamflow for this period was about 10,900 acre-feet. However, changes in storage in the lake and water losses due to evaporation from the lake need to be added to the gaged flow during this period to approximate natural streamflows. Leakage from the lake is assumed to return to Bluewater Creek in Bluewater Canyon, upstream from the streamflow-gaging station, where ground water discharges into the stream.

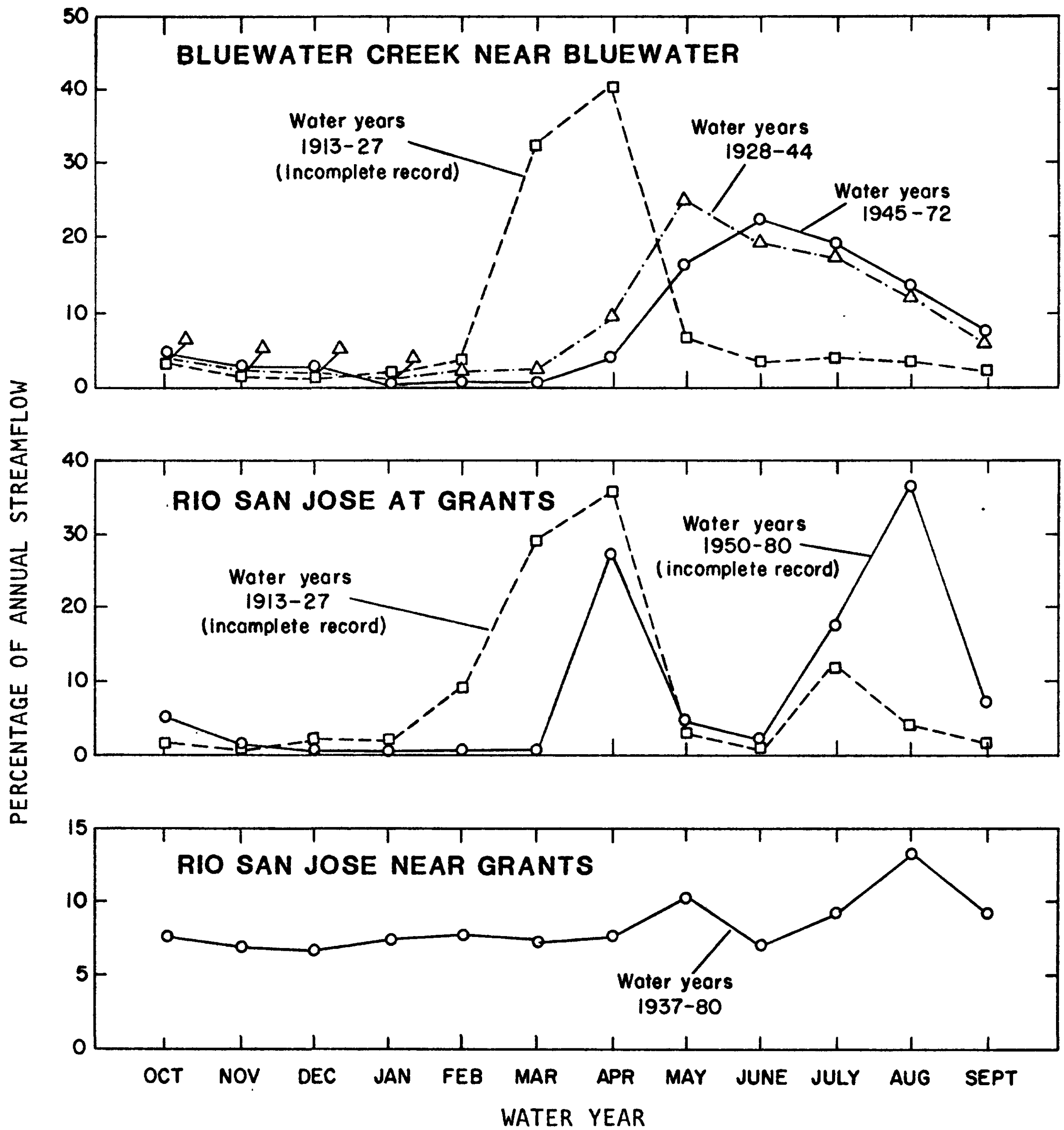


Figure 8.--Monthly distribution of annual streamflow at selected gaging stations.

Gross annual evaporation losses from Bluewater Lake were calculated from estimated monthly evaporation rates and reservoir surface area. The mean monthly evaporation rates were derived based on a mean annual evaporation rate of 40 inches per year (U.S. Department of Agriculture, 1972a) and monthly percentages of annual evaporation from Blaney and Hanson (1965, p. 54). The monthly rates used are shown in the following table:

Month	Percent of gross annual evaporation (Blaney and Hanson, 1965, p. 54)	Estimated gross evaporation rate, in inches per month	Estimated gross evaporation rate, in feet per month
January	3	1.2	0.10
February	4	1.6	.13
March	8	3.2	.27
April	11	4.4	.37
May	13	5.2	.43
June	14	5.6	.47
July	13	5.2	.43
August	11	4.4	.37
September	9	3.6	.30
October	7	2.8	.23
November	4	1.6	.13
December	3	1.2	.10
Annual total	100	40.0	3.33

Published month-end stage and contents data (U.S. Geological Survey, 1961-80) were used to compute lake surface area from the area stage capacity curves compiled for the lake. The gross monthly evaporation rates were multiplied by the lake surface area, in acres, to obtain the quantity of water evaporated each month. The values of gross monthly evaporation were totaled for each year to arrive at the gross annual evaporation.

Stage and contents data of Bluewater Lake were not available for water years 1947, 1948, and 1951 through 1957. For these years, gross annual evaporation was estimated by relating streamflow in Bluewater Creek near Bluewater to the gross annual lake evaporation calculated for the available years of record (fig. 9).

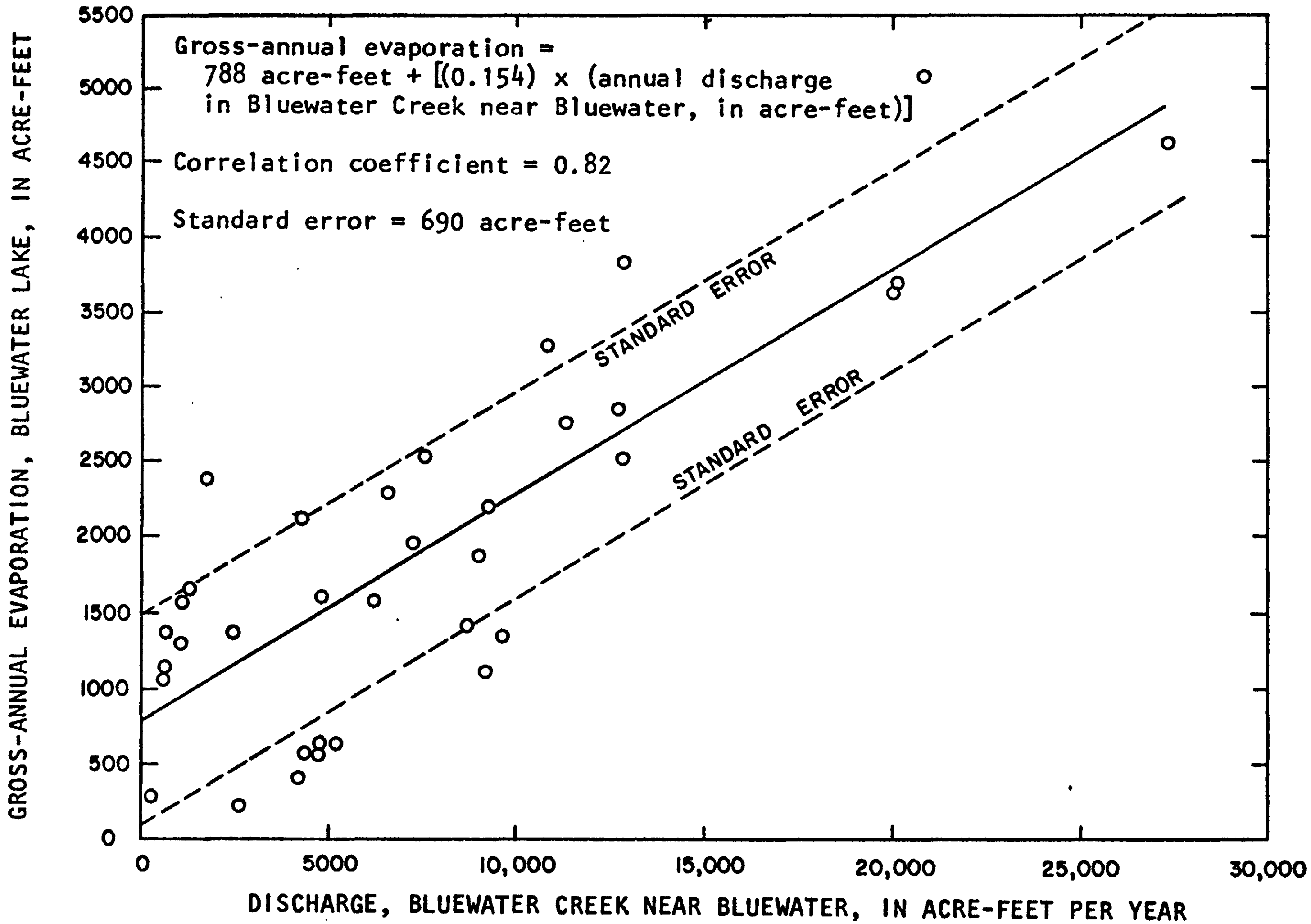


Figure 9.--Relation between annual discharge of Bluewater Creek near Bluewater and estimated gross annual evaporation from Bluewater Lake.

An estimate of the volume of water probably lost from the basin due to Bluewater Lake is given by the net evaporation from the lake surface. Net evaporation is calculated by subtracting the annual precipitation that falls on the lake from the gross annual evaporation determined previously (table 3).

Because there is no precipitation gage at Bluewater Lake, the precipitation recorded at the village of Bluewater, about 8 miles to the southeast, was adjusted to represent precipitation falling on the lake. Average precipitation at Bluewater is about 9.7 inches per year (table 2 and fig. 6), and the average precipitation at the lake is about 12 inches per year according to the U.S. Department of Agriculture (1972b). Therefore, each value of monthly precipitation recorded at Bluewater was multiplied by 12/9.7 or about 125 percent to represent more closely the volume of precipitation at the lake. Each resulting value for monthly precipitation was multiplied by the lake surface area at the end of that month and these products were added to obtain an annual volume of precipitation on the lake. These values were subtracted from the gross annual evaporation volumes to obtain the probable net water loss volumes (table 3).

The net water loss from the basin caused by evaporation from Bluewater Lake was about 26,600 acre-feet for the 17 years of record between water years 1928 and 1944. This volume was added to the gaged streamflow at Bluewater Creek near Bluewater to estimate the natural streamflow as shown below:

Estimate of natural streamflow at Bluewater Creek near Bluewater, water years 1928-44

Total gaged streamflow...............	186,100 acre-feet
Total estimated losses due to evaporation from Bluewater Lake.......................	26,600 acre-feet
Net change in Bluewater Lake contents.............................	0 acre-feet
Total estimated natural streamflow...	212,700 acre-feet
Estimated mean annual natural streamflow for 17 years (rounded)....	12,500 acre-feet

Time Interval 3. (water years 1945–72)

During this 28-year interval, 82,540 acre-feet of streamflow was recorded in Bluewater Creek near Bluewater, which averages to an annual flow of 2,950 acre-feet. However, the gaged streamflow was affected by water losses due to evaporation from Bluewater Lake and possibly by ground-water withdrawals from the San Andres-Glorieta aquifer.

The effect of Bluewater Lake on streamflow near Bluewater was estimated according to methods described in the previous section. The net evaporation loss was estimated to be about 27,900 acre-feet between 1945 and 1972 (table 3). Adding this volume to the gaged streamflow of 82,540 acre-feet and adding the net increase in reservoir storage of 2,900 acre-feet gives an adjusted streamflow of about 113,300 acre-feet for the time interval or an average of about 4,000 acre-feet per year.

Withdrawals of ground water from the San Andres-Glorieta aquifer have lowered the potentiometric surface and possibly affected streamflow in Bluewater Creek. The San Andres-Glorieta aquifer discharges water into Bluewater Creek between Bluewater Dam and the streamflow-gaging station near Bluewater. Streamflow measurements at the gaging stations downstream from the dam and near Bluewater for water years 1952-63 showed ground-water discharge to this reach of between 178 and 1,380 acre-feet per year (table 1). However, the amount of ground-water discharge measured during this period may have already been affected by the large-scale ground-water withdrawals that began about 1944. Ground-water discharges in this reach prior to 1944 may have been greater than those measured between water years 1952 and 1963.

Natural streamflow was estimated by relating precipitation to runoff from the basin upstream from the gaging station Bluewater Creek near Bluewater. This type of comparison was used because at about the time that large-scale ground-water withdrawals began in 1944 the climatic conditions in the area seemed to be changing. The goal of this analysis was to estimate the natural streamflow in the Rio San Jose that would have occurred during this period of changing climatic conditions.

Annual streamflow at Bluewater Creek near Bluewater was related to the annual precipitation at Bluewater for the available period of streamflow record (fig. 10). The annual streamflow near Bluewater was adjusted to account for evaporation losses and storage changes in Bluewater Lake during water years 1928-72 (table 4). A "least squares" regression line was fit to the data collected from water years 1913-44, which was prior to the advent of large-scale ground-water withdrawals in the basin. The equation is:

$$y = 1,957 (x) - 7,585$$

where

y = annual adjusted streamflow in Bluewater Creek near Bluewater, water years 1913-44, in acre feet; and

x = annual precipitation at Bluewater, water years 1913-44, in inches.

The equation can be used to compute the most probable volume of streamflow near Bluewater for a given quantity of precipitation at Bluewater under the conditions that existed prior to the beginning of ground-water withdrawals. Values of streamflow measured from water years 1945-72 generally plot below the regression line for streamflow measured from water years 1913-44 (fig. 10). This indicates that for a given quantity of precipitation, the basin apparently yielded less streamflow in years after 1944, when large-scale ground-water withdrawals began. This apparent decrease can be estimated by computing the expected streamflow for water years 1945-72 from the precipitation-runoff relation constructed for water years 1913-44. The quantity of streamflow computed from this relation represents a rough estimate of the natural quantity of streamflow that would have occurred during water years 1945-72 as shown below.

Time interval, water years	Years of record available	Streamflow in Bluewater Creek near Bluewater, adjusted for evaporation losses and storage changes in Bluewater Lake, in acre-feet	Streamflow in Bluewater Creek near Bluewater, computed from precipitation-runoff relation, in acre-feet	Estimated mean annual natural streamflow in Bluewater Creek near Bluewater, in acre-feet
1945-72	28	113,300	276,000	10,000

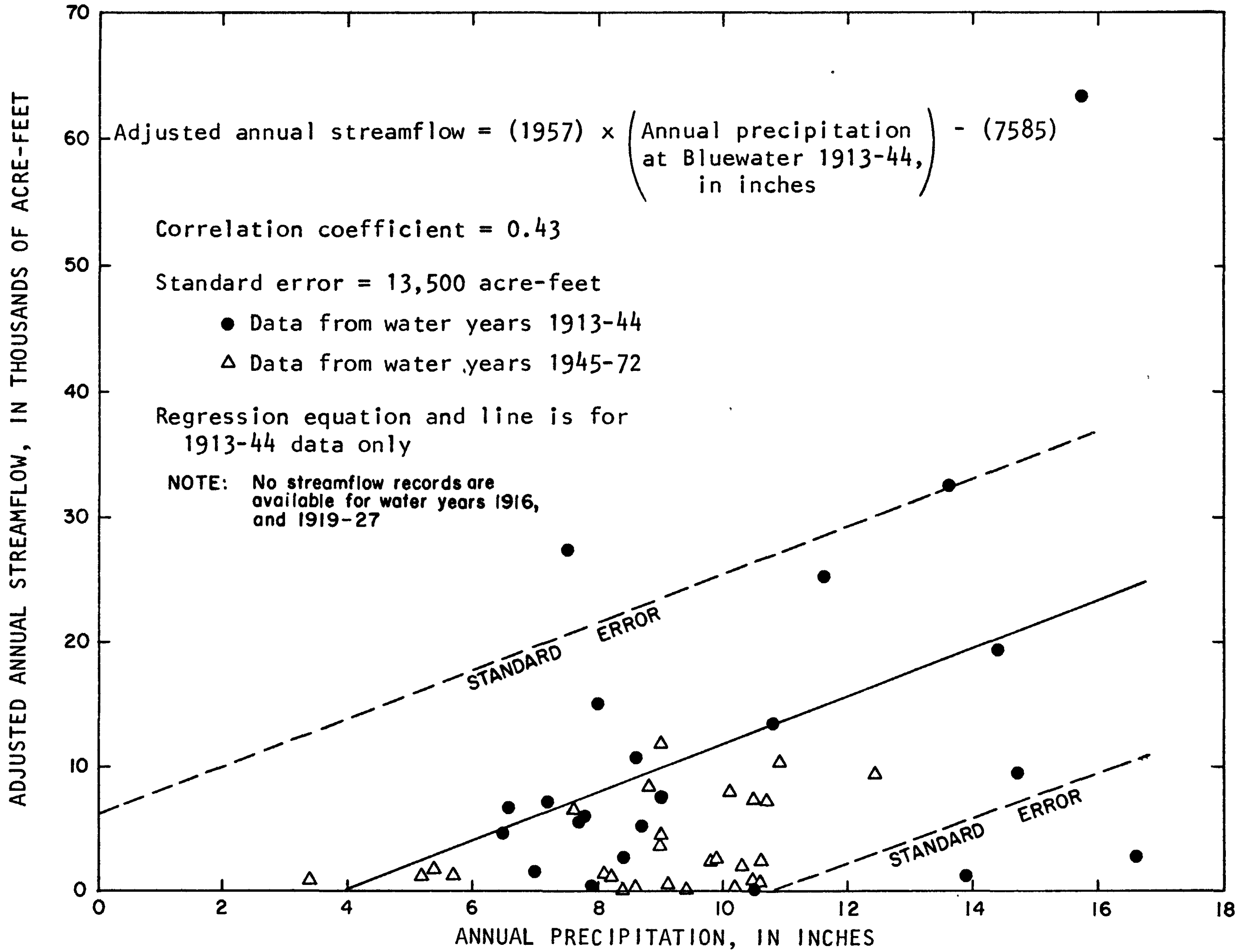


Figure 10.--Relation between annual precipitation at Bluewater and adjusted annual streamflow in Bluewater Creek near Bluewater, water years 1913-72.

The difference between the estimate of natural streamflow of 276,000 acre-feet and the streamflow adjusted for evaporation losses and storage changes in Bluewater Lake of 113,300 acre-feet is about 163,000 acre-feet for the 28-year period. Streamflow depletion caused by ground-water withdrawals is one possible explanation of this difference.

Time Intervals 1 - 3 (water years 1913-72)

Estimates of natural streamflow in Bluewater Creek near Bluewater for the three different intervals under consideration are summarized on table 5. Based on 50 years of record for water years 1913-72, the average natural flow in Bluewater Creek near Bluewater is estimated to be about 11,000 acre-feet per year.

Rio San Jose at Grants

Streamflow in the Rio San Jose measured at the gaging station at Grants is a composite of runoff principally from Bluewater Creek, Mitchell Draw, and San Mateo Creek (fig. 2). The gaging station was in operation most of the time at this site for water years 1913-25 and for water year 1950 to the present (1980). The records indicate a marked decrease in streamflow (fig. 5).

The distribution of average monthly streamflow past this gaging station is distinctly bimodal in character (fig. 8). For water years 1913-27, March through May snowmelt from the Zuni Mountains contributed about 68 percent of the annual flow, whereas runoff in response to summer thunderstorms during July through September accounted for about 18 percent of the annual streamflow. For water years 1950-80, March through May runoff at Grants was only 31 percent of the annual flow, mainly because of regulation by Bluewater Lake.

Time Interval 1 (water years 1913-27)

The streamflow of the Rio San Jose was measured for 10 of the years during water years 1913-27 at the gaging station at Grants (fig. 5, table 1). The total streamflow measured for years 1913, 1915 through 1920, 1922, 1924, and 1925 was 74,340 acre-feet. The mean annual streamflow was 7,430 acre-feet. Although there was no dam on Bluewater Creek during these years, water was diverted for irrigation at the mouth of Bluewater Canyon, located downstream from the gaging station near Bluewater and upstream from the gaging station at Grants.

The approximate volume of water diverted for irrigation was estimated based on the number of acres irrigated, measured precipitation at Bluewater, and the quantity of water in Bluewater Creek available during the irrigation season (April through September). According to Gordon (1961, p. 13), about 2,000 to 2,500 acres were irrigated each year from 1913 to 1927. The volume of water consumptively used by crops was estimated to be about 20 inches per growing season (Blaney and Hanson, 1965, p. 60), which includes the quantity of precipitation for those months. Irrigation efficiencies were assumed to be about 50 percent based on figures given in Blaney and Hanson (1965, p. 28-32). The irrigation requirement was calculated by dividing the consumptive use by the irrigation efficiency.

The volume of water diverted from the stream was estimated by comparing the monthly irrigation requirement with the monthly streamflow in Bluewater Creek near Bluewater. The monthly irrigation requirement was assumed to be the same for each month of the growing season. If the irrigation requirement was greater than the streamflow for that month, the volume of applied water was considered to be equal to the streamflow. If, however, the monthly streamflow was greater than the irrigation requirement, the volume of applied water was considered to be equal to the irrigation requirement for the month. The monthly values of applied water were summed for the growing season of each year. The estimated annual values are shown in the following table:

Water year	Streamflow in Bluewater Creek near Bluewater (April - September), in acre-feet	Irrigation requirement in acre-feet (estimated)	Applied water, in acre-feet (estimated)
1913	5,350	5,500	1,500
1915	16,240	4,700	3,100
1916	11,200	5,800	3,800
1917	2,440	5,500	2,100
1918	1,040	6,000	1,000
1919*	-	4,500	3,500
1920*	-	4,900	3,000
1922	384	4,900	384
1924	1,800	4,900	1,600
1925	383	5,700	384
Total (rounded)	38,800	52,400	20,400

* Indicates year of incomplete streamflow record. Applied water estimated from other streamflow and precipitation records.

For the 10 years of record between water years 1913 and 1927, about 20,400 acre-feet of water probably were diverted for irrigation at the mouth of Bluewater Canyon. Therefore, the irrigation diversions need to be added to the streamflow measured in the Rio San Jose at Grants for the period. Even under natural conditions, however, a part of the flow of Bluewater Creek near Bluewater seeps into the ground before reaching Grants. Thus, the estimated volume of water diverted for irrigation needs to be decreased to represent the volume of the diverted water that would have reached Grants under normal conditions. The ratio of the gaged streamflow in Bluewater Creek near Bluewater to the gaged flow in the Rio San Jose at Grants for non-irrigation periods (October through March) was used as an index of how the diverted flow should be adjusted. During the non-irrigation months, Mitchell Draw and San Mateo Creek are almost always dry; therefore, the streamflow measured at Grants during these months was mostly from Bluewater Creek. Based on 34 months of concurrent record during water years 1913-27, the direct relation is:

$$\frac{\text{October through March streamflow in Rio San Jose at Grants}}{\text{October through March streamflow in Bluewater Creek near Bluewater}} = \frac{2{,}770 \text{ acre-feet}}{13{,}510 \text{ acre-feet}} = 20 \text{ percent}$$

According to the preceding assumptions, the streamflow measured in the Rio San Jose at Grants possibly was decreased by about 4,100 acre-feet (20 percent of the 20,400 acre-feet of water diverted for irrigation) for the 10 years of record between water years 1913 and 1927. Return-flow of irrigation water to the Rio San Jose probably was not important upstream from Grants because the water table is considerably below the stream between the gaging station near Bluewater and the gaging station at Grants. Irrigation returns probably occurred as seepage to the Rio San Jose between Grants and Horace Springs, where ground-water levels under normal conditions probably were at or above the altitude of the stream.

Adding the adjustment for irrigation of 4,100 acre-feet to the gaged streamflow of 74,340 acre-feet equals an estimate of 78,440 acre-feet for natural streamflow during the 10 years of record. Natural flow in the Rio San Jose at Grants for the years of record from 1913-27, therefore, is estimated to be about 7,800 acre-feet per year.

Time Interval 2 (water years 1928-44)

Streamflow records for the Rio San Jose at Grants are not available for water years 1928-44. However, the streamflow at Grants can be estimated by assuming that the relation between the flow at Bluewater Creek near Bluewater and the flow in the Rio San Jose at Grants (adjusted for irrigation withdrawals) remained constant from Time Interval 1 to Time Interval 2. For the 4 water years of complete, concurrent record (1913, 1915, 1917, and 1918), the relation between measured streamflow at the two locations is shown below:

$$\frac{\text{Rio San Jose at Grants (gaged flow + adjustment for irrigation)}}{\text{Bluewater Creek near Bluewater}} = \frac{19{,}510 \text{ acre-feet}}{43{,}190 \text{ acre-feet}} = 45 \text{ percent}$$

If this relation had remained constant, then the same relation should have existed between the streamflow at the two sites for water years 1928-44. The estimated natural streamflow for Bluewater Creek near Bluewater during water years 1928-44 averaged about 12,500 acre-feet per year. Therefore, the average natural streamflow in the Rio San Jose at Grants for the same 28-year period should have been about 45 percent of the 12,500 acre-feet per year estimated for Bluewater Creek near Bluewater. Thus, the estimate of the natural streamflow at Grants for water years 1928-44 probably is about 5,600 acre-feet per year.

Time Interval 3 (water years 1945-72)

Streamflow in the Rio San Jose at Grants was measured for water years 1950-66 and 1969-72 during Time Interval 3 (figs. 4 and 7, table 1). The streamflow measured during the 21 years of record totaled 13,850 acre-feet and averaged about 660 acre-feet per year. However, the gaged flow probably was affected by Bluewater Lake, surface-water diversions, and possibly ground-water withdrawals in the Rio San Jose basin. If the relation between streamflow in Bluewater Creek near Bluewater and in the Rio San Jose at Grants remained constant with time, the natural streamflow in the Rio San Jose can be estimated using the same procedures as described for Time Interval 2. Therefore, the natural streamflow in the Rio San Jose at Grants would have been about 45 percent of the estimated natural streamflow in Bluewater Creek near Bluewater. The estimated natural streamflow in Bluewater Creek near Bluewater for water years 1945-72 was about 10,000 acre-feet per year, so the natural streamflow in the Rio San Jose at Grants would probably have been about 4,500 acre-feet per year.

Time Intervals 1 - 3 (water years 1913-72)

A summary of the estimates of natural streamflow in the Rio San Jose at Grants is shown below. The estimate of natural streamflow of the Rio San Jose at Grants is about 5,000 acre-feet per year. This estimate mainly was based on 10 years of streamflow recorded at Grants for water years 1913-27 and on the 45 years of streamflow recorded upstream for Bluewater Creek near Bluewater for water years 1928-72.

Time Interval	Water years	Years of record	Estimated annual natural streamflow, Rio San Jose at Grants, in acre-feet (rounded)
1	1913-27	10	7,800
2	1928-44	17	5,600
3	1945-72	28	4,500
—	1913-72	55	5,000

Rio San Jose at western boundary of the Pueblo of Acoma

Streamflow in the Rio San Jose at the western boundary of the Pueblo of Acoma has been measured since water year 1937 at the gaging station near Grants (figs. 2 and 5, table 1). Although the streamflow, which averaged about 4,850 acre-feet per year, has remained almost uniform through time, the sources of the flow have changed. In recent years, wastewater effluent from the city of Grants has been added to the streamflow of the Rio San Jose. The effluent began to reach the pueblo on an intermittent basis about 1957, shortly after the wastewater-treatment plant was constructed at its present location on the Rio San Jose. At present (1980) the streamflow that enters the Pueblo of Acoma consists of springflow from Horace Springs, wastewater effluent from the city of Grants, and surface-water runoff from the basin upstream from the pueblo. In years past, under natural conditions, the flow of the Rio San Jose to the Pueblo of Acoma was provided by springflow from Ojo del Gallo, springflow from Horace Springs, and surface-water runoff from the basin upstream. Each of the components is evaluated separately in the following sections.

Springflow from Ojo del Gallo

Although the springflow from Ojo del Gallo has ceased, there is evidence that the flow from the spring at one time directly contributed to the flow in the Rio San Jose. A dry channel is present from a meadow east of San Rafael to the Rio San Jose about 4 miles downstream from Grants. Hodges (1938, p. 339) reported the flow of Ojo del Gallo to be 7 cubic feet per second in August and November 1937. Hodges (1938, p. 341) also measured as much as 4.0 cubic feet per second in the channel leading from Ojo del Gallo to the Rio San Jose in 1938. Hodges (1938, p. 340) made some additional deductions concerning the flow from Ojo del Gallo. "At the present time [1938], during the winter months, the entire flow of Ojo del Gallo would reach Horace, if it was not prevented from doing so by storage dams, and diversions away from the channel." He also stated, "Before irrigation was started at San Rafael it is obvious that practically the entire flow of Ojo del Gallo, less transpiration loss in swamp during summer, reached the Rio San Jose at Horace and combined with the flow of Horace Springs."

The statements suggesting that, aside from evapotranspiration losses in the swamp, most of the flow from Ojo del Gallo reached the Rio San Jose at Horace Springs are supported by measurements made by Hodges (1938, p. 341). His measurements show no seepage losses in the Rio San Jose from the railroad overpass on U.S. Highway 66 to Horace Springs.

The earliest account of the streamflow in the Rio San Jose on the Pueblo of Acoma also indicates that springflow from Ojo del Gallo was reaching Horace Springs (U.S. Geological Survey, 1891. p. 276). "The principal tributary of the Puerco is the San Jose, or, as known at the head waters, Bluewater Creek, which enters from the west. Below the Big Spring, near the town of San Jose, this creek was discharging from 10 to 12 second-feet in February, 1889." In this account, "Big Spring" probably is a reference to Horace Springs and "town of San Jose" to the present village of San Fidel. The estimate of 10 to 12 cubic feet per second of streamflow in the Rio San Jose downstream from Horace Springs indicates that 5 to 7 cubic feet per second of springflow from Ojo del Gallo was contributing to the streamflow, as was pointed out by Hodges (1938, p. 337). This estimate assumes the natural flow from Horace Springs was about 5 cubic feet per second and that no contributions of flow from upstream runoff were occurring at that time.

Although the previous accounts indicate that the springflow from Ojo del Gallo at one time averaged about 5 to 7 cubic feet per second, the reason that the springflow ceased is not entirely known. Discharge from the spring decreased during the late 1940's and by 1953 was insufficient for irrigation of gardens in San Rafael (Gordon, 1961, p. 47). The decrease in springflow corresponded closely with the beginning of a dry period thoughout the basin (fig. 7) and with the advent of large-scale, ground-water withdrawals for irrigation from the San Andres-Glorieta aquifer. Certainly, lack of recharge during the dry years from the late 1940's through the 1950's could have decreased the springflow. However, if lack of precipitation had been the major factor contributing to the decrease in flow from Ojo del Gallo, then the flow should have increased from the late 1950's until the present (1980) during years of about normal precipitation (fig. 7).

Horace Springs

Springflow from Horace Springs in 1980 contributed the majority of the streamflow in the Rio San Jose. The flow from the springs has long been assumed to be relatively unchanged from its natural condition (Gordon, 1961, p. 48). However, changes in surface runoff, irrigation, and ground-water withdrawals could have altered the flow from the springs. The streamflow gaged in the Rio San Jose near Grants at the Pueblo of Acoma boundary (downstream from the springs) was compiled for successive 10-year periods beginning in water year 1940 to test for changes in springflow (fig. 11).

The streamflow measured at the gaging station from July through September includes a large percentage of storm runoff. Streamflow measured from November through June, in comparison, contains very little runoff from the basin upstream from the gaging station. The average November through June streamflow for water years 1940-49 was 6.4 cubic feet per second. During these years, springflow from Ojo del Gallo was reaching the gaging station on the Pueblo of Acoma boundary in the winter non-irrigation months. Probably about 1.5 cubic feet per second of springflow from Ojo del Gallo contributed to the gaged streamflow of the Rio San Jose at the Pueblo of Acoma boundary for water years 1940-49.

November through June streamflow averaged 4.9 cubic feet per second during the low-runoff months for water years 1950-59. During these years, probably no springflow from Ojo del Gallo contributed to the gaged flow at the Pueblo of Acoma boundary. The average gaged streamflow for this period of 4.9 cubic feet per second probably is the most representative estimate of the springflow from Horace Springs.

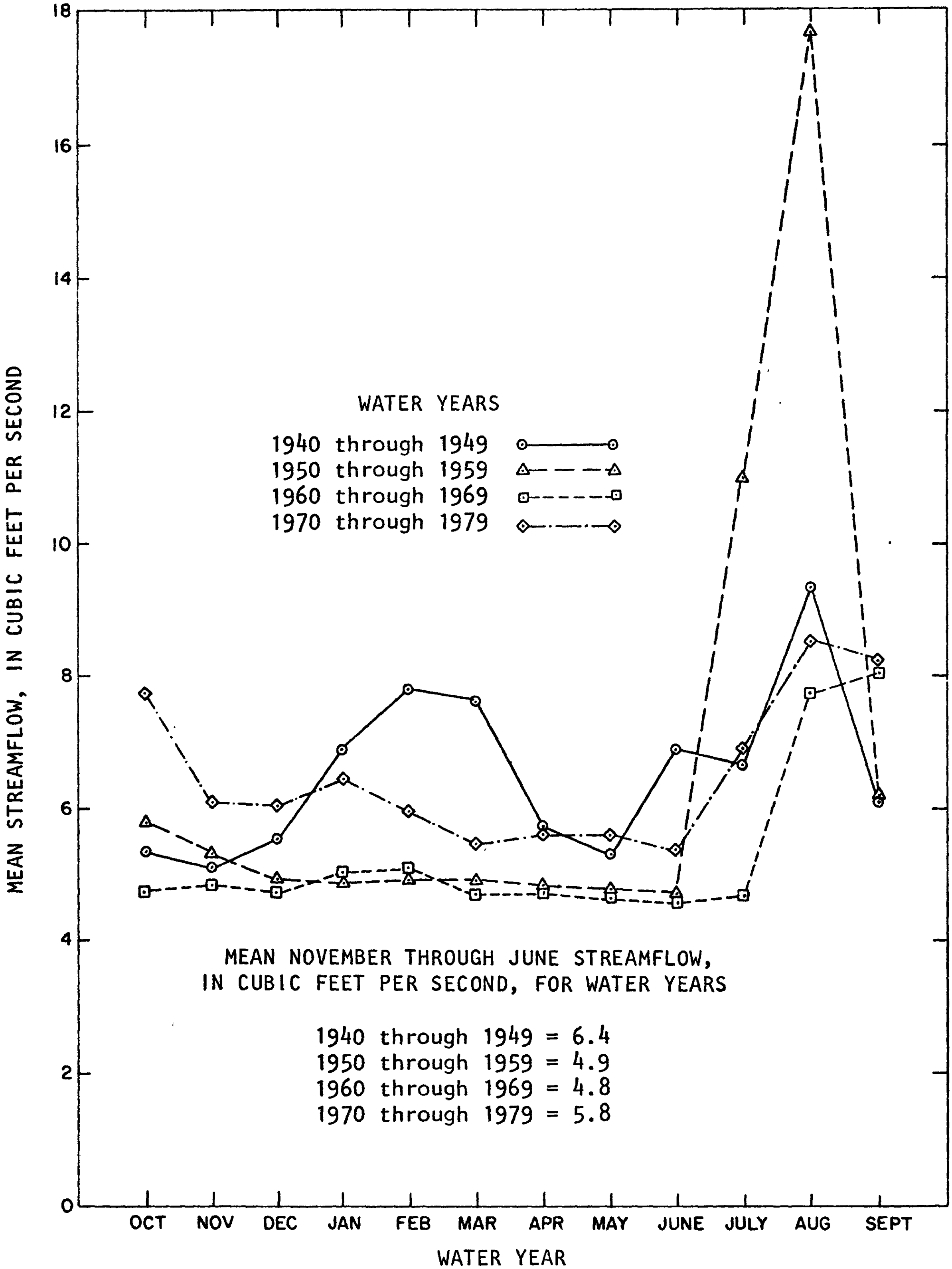


Figure 11.--Mean monthly streamflow in the Rio San Jose near Grants.

The average November through June flow for water years 1960-69 was 4.8 cubic feet per second, nearly the same as the flow measured for water years 1950-59. Wastewater from the city of Grants began to reach Horace Springs intermittently about 1957. Evidently the quantity of wastewater was not large enough to cause a noticeable difference in the average November through June streamflow measured in the Rio San Jose near Grants for water years 1960-69.

The increase in streamflow to about 5.8 cubic feet per second for non-runoff months for water years 1970-79 probably was due to the increase in wastewater from Grants. The recorded increase in streamflow of about 1 cubic foot per second corresponds fairly well with the reported discharge rates of from 1 to 2 cubic feet per second from the wastewater-treatment plant since 1977.

The natural streamflow in the Rio San Jose contributed from Horace Springs is best approximated by water years 1950-59 when the springflow averaged 4.9 cubic feet per second. This corresponds to an average annual springflow of about 3,600 acre-feet.

Time Intervals 1 - 3 (water years 1913-72)

The natural streamflow for the Rio San Jose at the western boundary of the Pueblo of Acoma was composed of water from three sources: Ojo del Gallo, Horace Springs, and runoff upstream from the pueblo (fig. 2). The quantity of runoff added to the Rio San Jose between Grants and Horace Springs was assumed to be negligible. Streamflow from the major tributary between Grants and Horace Springs averaged 113 acre-feet per year for water years 1962-80 (fig. 5 and table 1). The estimated natural streamflow in the Rio San Jose at the western boundary of the Pueblo of Acoma is about 12,000 to 14,000 acre-feet per year based on 55 years of recorded and reconstructed data.

Time interval	Water years	Estimated mean annual streamflow in the Rio San Jose at Grants, in acre-feet	Estimated mean annual springflow from Ojo del Gallo, in acre-feet	Estimated mean annual springflow from Horace Springs, in acre-feet	Estimated mean annual natural streamflow in Rio San Jose at western Acoma boundary, in acre-feet
1	1913-27	7,800	3,000 - 5,000	3,600	14,400 - 16,400
2	1928-44	5,600	3,000 - 5,000	3,600	12,200 - 14,200
3	1945-72	4,500	3,000 - 5,000	3,600	11,000 - 13,000
—	1909-72	5,000	3,000 - 5,000	3,600	12,000 - 14,000

Rio San Jose at western boundary of the Pueblo of Laguna

The streamflow in the Rio San Jose at the western boundary of the Pueblo of Laguna has not been gaged for any continuous period of time. The natural streamflow at this location may have been affected for many years by Bluewater Lake, ground-water withdrawals, and irrigation diversions from the Rio San Jose in the Grants-Bluewater area and on the Pueblo of Acoma.

Time Intervals 1 - 3 (water years 1913-72)

The natural streamflow of the Rio San Jose that enters the Pueblo of Laguna is equal to the natural flow entering the Pueblo of Acoma plus the increase in streamflow caused by surface- and ground-water discharge across Acoma lands. Hodges (1938, p. 338) measured an increase in streamflow due to ground-water discharge of 2.5 cubic feet per second from the western Acoma boundary to McCartys. Stream gains in this reach evidently have not changed much since that time, as shown by the miscellaneous streamflow measurements of the Rio San Jose listed below. These measurements were made during winter months when no irrigation withdrawals were taking place on the Pueblo of Acoma.

Date of measurement	Streamflow at western Pueblo of Acoma boundary, in cubic feet per second	Streamflow at McCartys, in cubic feet per second	Net streamflow gain, in cubic feet per second
03-22-73	4.5	7.6	3.1
04-12 73	5.5	7.7	2.2
04-26-73	5.3	7.6	2.3
03-12-74	4.9	6.6	1.7
11-29-74	4.6	7.1	2.5
03-28-75	4.3	6.4	2.1
03-27-79	4.9	7.6	2.7
Average	4.9	7.2	2.4

Based on several seepage investigations, additional ground-water discharge of about 0.5 cubic foot per second is taking place to the Rio San Jose between McCartys and the Pueblo of Laguna at the present time (1980). This quantity is assumed to be the natural increase in streamflow in this reach although part of this quantity may be the return of irrigation water. The total stream gains from ground water across Acoma lands are about 3 cubic feet per second or 2,200 acre-feet per year.

Surface water is also added to the Rio San Jose from several small tributaries on the Pueblo of Acoma. The mean annual streamflows from the two largest tributaries, Rinconada Creek and Cañon Largo, were calculated to be 1,100 and 900 acre-feet, respectively, using a technique described by Borland (1970).

Average natural flow at the western boundary of the Pueblo of Laguna was probably between about 16,000 and 18,000 acre-feet per year based on 55 years of recorded and reconstructed data. Averages are summarized below by time interval.

Time Interval	Water years	Estimated mean annual natural streamflow in the Rio San Jose at the western Pueblo of Acoma boundary, in acre-feet	Estimated mean annual streamflow gains from ground water across the Pueblo of Acoma, in acre-feet	Estimated mean annual surface water additions from Rinconada Creek and Canon Largo, in acre-feet	Estimated mean annual natural streamflow in the Rio San Jose at the western Laguna boundary, in acre-feet
1	1913-27	14,400 - 16,400	2,200	2,000	19,000 - 21,000
2	1928-44	12,200 - 14,200	2,200	2,000	16,000 - 18,000
3	1945-72	11,000 - 13,000	2,200	2,000	15,000 - 17,000
—	1913-72	12,000 - 14,000	2,200	2,000	16,000 - 18,000

ACCURACY OF ESTIMATES

The accuracy of the estimates of natural streamflow in the Rio San Jose on the Pueblos of Acoma and Laguna is impossible to evaluate. The accuracy of the estimates is dependent upon the accuracy of the historical accounts, the hydrologic assumptions made throughout the study, and the many simplified empirical relations used to approximate complex associations among variables. Error in the historical accounts and in the basic assumptions used probably is impossible to determine. Error introduced to streamflow estimates through the empirical relations, however, may be approximately evaluated.

The natural streamflow in the Rio San Jose entering the Pueblo of Acoma was estimated by evaluating the contributions of flow from Ojo del Gallo, Horace Springs, and runoff from the basin upstream of the pueblo. The accuracy of flow estimates from these three sources may be judged separately.

The contribution of springflow from Ojo del Gallo was estimated over what was considered to be the widest probable range of values (3,000 - 5,000 acre-feet per year). Therefore, errors in the estimate probably were incorporated within the large range.

The streamflow from Horace Springs was estimated from gaging-station records for water years 1950-59. The assumption was made that the gaged flow during November through June consisted entirely of springflow. The accuracy of this assumption cannot be evaluated; however, the accuracy of the individual streamflow measurements is probably within 5 percent.

The estimate of runoff from the basin upstream from the pueblos undoubtedly contains the greatest error. The estimates of runoff reaching the pueblos were based on incomplete streamflow records at gaging stations near Bluewater and at Grants. To adjust these records, computations were made to evaluate the effect of Bluewater Lake and irrigation diversions. Error introduced in the calculation of evaporation from Bluewater Lake using a pan-to-lake coefficient of 0.7 is about ±50 percent (Winter, 1981, p. 111). Another large source of error was introduced in calculating the natural streamflow of Bluewater Creek near Bluewater for water years 1945-72. The standard error of the precipitation-runoff relation used to adjust the streamflow to approximate natural conditions is 1,350 acre-feet. Errors made in estimating upstream runoff, however, are not as significant as they may seem because such a large proportion of the streamflow entering the pueblos is contributed from other sources.

If the errors discussed are additive, which is unlikely, then the maximum error that can be quantified in the estimate of natural streamflow of the Rio San Jose at the western boundary of the Pueblo of Acoma is less than 25 percent.

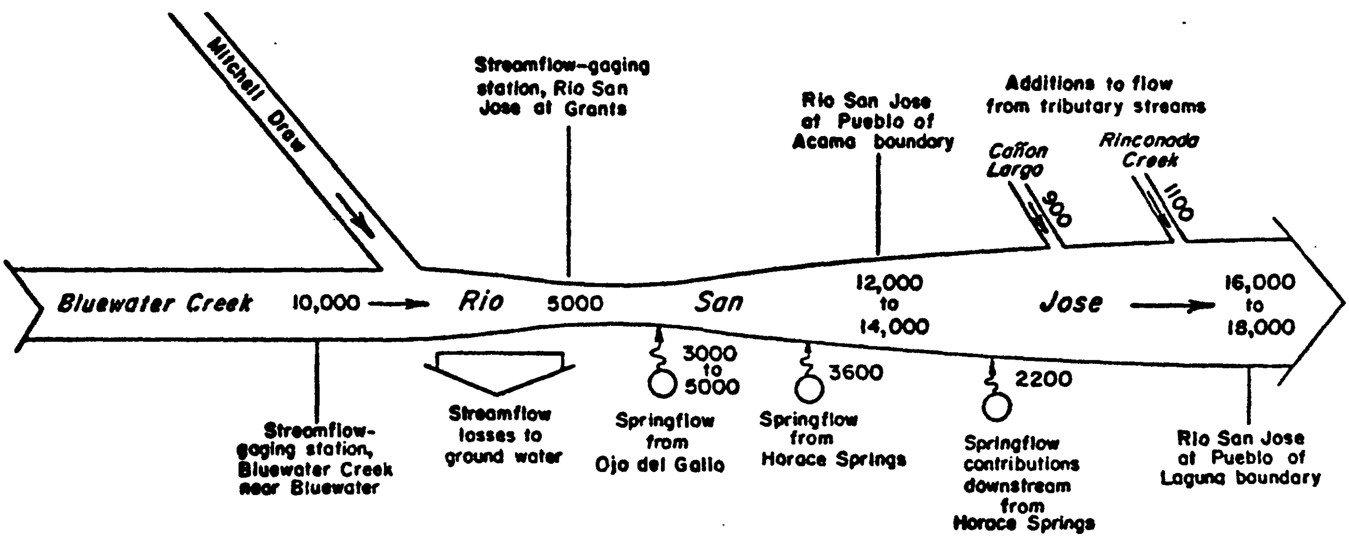
SUMMARY

The development of surface and ground water in the western Rio San Jose drainage basin, which began about 1870, probably has changed the flow of the Rio San Jose on the Pueblos of Acoma and Laguna. The purpose of this study was to estimate the natural streamflow in the Rio San Jose that would have entered the pueblos if no upstream water development had taken place.

No continuous streamflow measurements were made at the pueblo boundaries prior to regulation of the flow by Bluewater Lake; therefore, the study was approached first by computing the best possible estimate of natural streamflow at Bluewater Creek near Bluewater, where the most complete streamflow records were available. The values obtained were used to help estimate the natural streamflow of the Rio San Jose at Grants, at the western boundary of the Pueblo of Acoma, and at the western boundary of the Pueblo of Laguna.

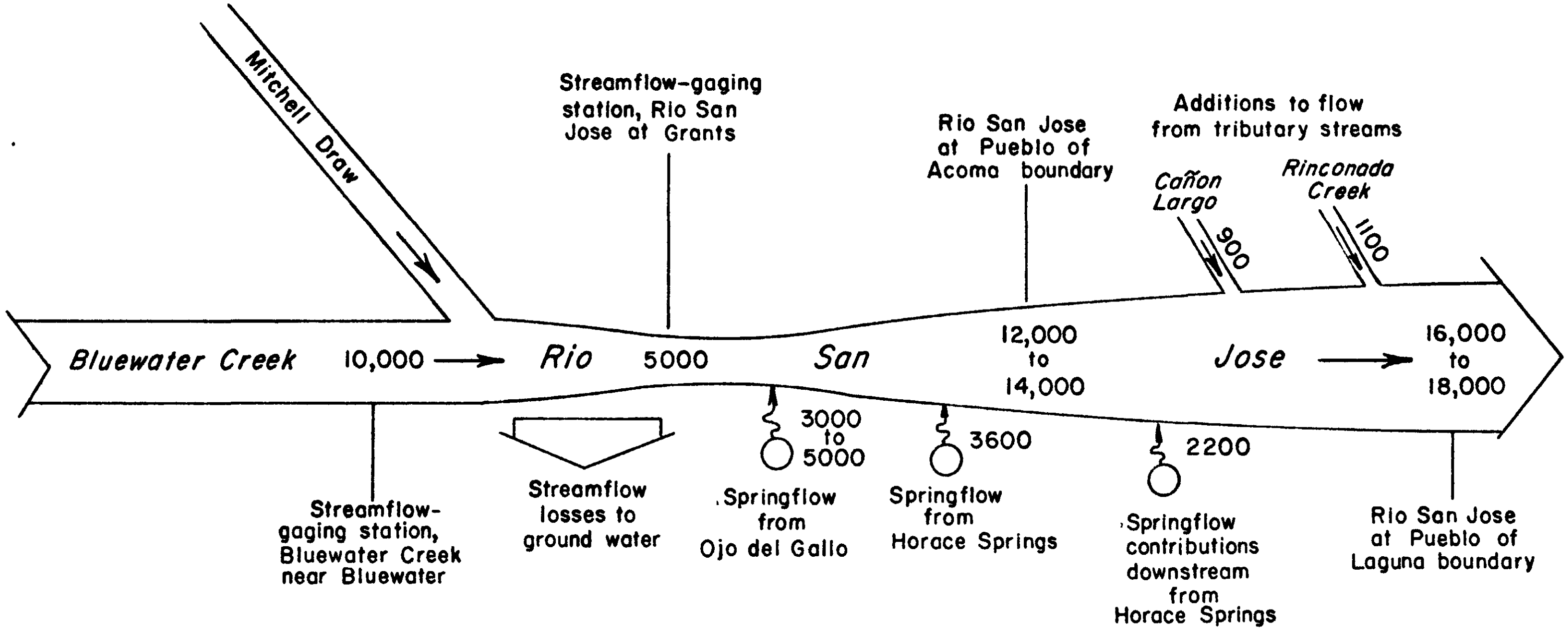
The mean annual natural streamflow in the Rio San Jose entering the Pueblo of Acoma was computed by summing the estimated contributions from upstream runoff at Grants and Ojo del Gallo and Horace Springs. At the Pueblo of Laguna boundary, the mean-annual natural streamflow in the Rio San Jose was estimated as the flow entering the Pueblo of Acoma plus surface- and ground-water inflow across the Pueblo of Acoma. A summary of the streamflow estimates is shown in table 6 and figure 12.

The accuracy of the estimates of natural streamflow are impossible to determine, however, approximations indicate that the part of the error that can be quantified is less than 25 percent.



NOTE: Values shown are estimates of natural streamflow, in acre-feet per year, for 1913-72.

Figure 12.--Schematic diagram showing estimated natural streamflow in Bluewater Creek and Rio San Jose, 1913-72.



NOTE: Values shown are estimates of natural streamflow, in acre-feet per year, for 1913-72.

REFERENCES

Blaney, H. F., and Hanson, E. G., 1965, Consumptive use and water requirements in New Mexico: New Mexico State Engineer Technical Report 32, 82 p.

Borland, J. P., 1970, A proposed streamflow-data program for New Mexico: U.S. Geological Survey open-file report, 71 p.

Dinwiddie, G. A., and Motts, W. S., 1964, Availability of ground water in parts of the Acoma and Laguna Indian Reservations, New Mexico: U.S. Geological Survey Water-Supply Paper 1576-E, 62 p.

Follett, W. W., 1896, Rio Grande waters: U.S. Senate Document 229, 55th Congress, Second session, 3 pts., 287 p., in Hodges, P. V., 1938, Report on irrigation and water supply of the pueblos of New Mexico in the Rio Grande basin: U.S. Department of the Interior, Indian Irrigation Service, 438 p.

Gordon, E. D., 1961, Geology and ground-water resources of the Grants-Bluewater area, Valencia County, New Mexico: New Mexico State Engineer Technical Report 20, 109 p.

Hodges, P. V., 1938, Report on irrigation and water supply of the pueblos of New Mexico in the Rio Grande basin: U.S. Department of the Interior, Indian Irrigation Service, 438 p.

Morgan, A. M., 1938, Ground water conditions in a portion of the San Jose - Bluewater Valley in the vicinity of Grants, New Mexico: U.S. Geological Survey open-file report, 15 p.

New Mexico State Engineer, 1956, Climatological summary, New Mexico. Precipitation 1949-1954: New Mexico State Engineer Technical Report 6, 407 p.

_____, 1959, Hydrologic summary, New Mexico--Streamflow and reservoir content 1888-1954: New Mexico State Engineer Technical Report 7, 326 p.

Rapp, J. R., 1960, Reconnaissance of ground water for irrigation, Acoma Indian Reservation, Valencia County, New Mexico: U.S. Geological Survey open-file report, 28 p.

U.S. Department of Agriculture, 1972a, Gross annual lake evaporation New Mexico, in U.S. Bureau of Reclamation, 1976, New Mexico water resources assessment for planning purposes: U.S. Bureau of Reclamation, map 8.

U.S. Department of Agriculture, 1972b, Normal annual precipitation, in U.S. Bureau of Reclamation, 1976, New Mexico water resources assessment for planning purposes: U.S. Bureau of Reclamation, map 9.

U.S. Geological Survey, 1891, Twelfth annual report of the Director of the United States Geological Survey, part II-irrigation, 576 p., 270 figs.

______1960, Compilation of records of surface waters of the United States through September 1950, part 8, Western Gulf of Mexico basins: U.S. Geological Survey Water-Supply Paper 1312, 633 p.

______1964, Compilation of records of surface waters of the United States, October 1950 to September 1960, part 8, Western Gulf of Mexico basins: U.S. Geological Survey Water-Supply Paper 1732, 574 p.

______1961-80, Water resources data for New Mexico: U.S. Geological Survey annual water-data reports.

Winter, T. C., 1981, Uncertainties in estimating the water balance of lakes: Water Resources Bulletin, v. 17, no. 1, p. 82-115.

Table 1. Annual contents data for Bluewater Lake and annual streamflow for selected gaging stations in the Rio San Jose basin, water years 1913-80

Water year	Bluewater Lake near Bluewater, contents on Sept. 30, in acre-feet	Streamflow in Bluewater Creek below Bluewater Dam, in acre-feet	Streamflow in Bluewater Creek near Bluewater, in acre-feet	Streamflow in Rio San Jose at Grants, in acre-feet	Streamflow in Grants Canyon at Grants, in acre-feet	Streamflow in Rio San Jose near Grants, in acre-feet
1913	-	-	6,070	2,950	-	-
1914	-	-	10,900	-	-	-
1915	-	-	25,200	13,240	-	-
1916	-	-	-	20,830	-	-
1917	-	-	7,190	974	-	-
1918	-	-	4,730	807	-	-
1919	-	-	-	11,720	-	-
1920	-	-	-	18,690	-	-
1921	-	-	-	-	-	-
1922	-	-	[1]1,550	142	-	-
1923	-	-	[1]8,833	-	-	-
1924	-	-	[1]8,780	4,710	-	-
1925	-	-	[1]2,740	274	-	-
1926	-	-	[1]24,030	-	-	-
1927	0	-	[1]24,550	-	-	-
1928	0	-	2,700	-	-	-
1929	5,600	-	4,040	-	-	-
1930	1,800	-	8,750	-	-	-
1931	0	-	4,260	-	-	-
1932	19,800	-	10,800	-	-	-
1933	6,500	-	12,800	-	-	-
1934	0	-	4,980	-	-	-
1935	9,000	-	9,320	-	-	-
1936	9,000	-	11,390	-	-	-
1937	20,500	-	12,830	-	-	3,790

[1]Streamflow data subsequently determined to be inaccurate

Table 1. Annual contents data for Bluewater Lake and annual streamflow for selected gaging stations in the Rio San Jose basin, water years 1913-80 - Continued

Water year	Bluewater Lake near Bluewater, contents on Sept. 30, in acre-feet	Streamflow in Bluewater Creek below Bluewater Dam, in acre-feet	Streamflow in Bluewater Creek near Bluewater, in acre-feet	Streamflow in Rio San Jose at Grants, in acre-feet	Streamflow in Grants Canyon at Grants, in acre-feet	Streamflow in Rio San Jose near Grants, in acre-feet
1938	5,500	-	12,710	-	-	4,080
1939	400	-	9,740	-	-	4,070
1940	0	-	4,760	-	-	4,650
1941	33,600	-	27,090	-	-	13,960
1942	24,000	-	20,700	-	-	4,900
1943	8,600	-	20,020	-	-	4,250
1944	0	-	9,210	-	-	5,040
1945	0	-	4,170	-	-	5,020
1946	1,500	-	317	-	-	5,500
1947	[2]2,800	-	667	-	-	4,520
1948	4,800	-	8,410	-	-	4,340
1949	3,900	-	9,000	-	-	4,200
1950	3,100	-	1,090	153	-	3,720
1951	-	-	586	420	-	4,300
1952	-	5,760	7,140	1,100	-	3,820
1953	-	350	1,080	719	-	4,320
1954	-	111	679	2,420	-	5,360
1955	-	69	502	3,010	-	6,970
1956	-	73	251	600	-	4,150
1957	-	76	338	2,690	-	7,830
1958	8,320	514	1,780	397	-	3,880
1959	5,510	194	1,300	512	-	4,160
1960	8,580	569	1,810	66	-	3,620
1961	6,490	726	1,620	10	-	3,560
1962	7,440	6,360	7,620	26	-	3,510
1963	4,420	3,900	4,860	333	285	5,050
1964	4,380	-	6,230	209	85	3,850
1965	7,370	-	6,160	506	150	3,740
1966	7,370	-	6,620	78	40	3,170
1967	3,300	-	2,550	-	403	4,160

[2]Contents on December 31, 1947

Table 1. **Annual contents data for Bluewater Lake and annual streamflow for selected gaging stations in the Rio San Jose basin, water years 1913-80 - Concluded**

Water year	Bluewater Lake near Bluewater, contents on Sept. 30, in acre-feet	Streamflow in Bluewater Creek below Bluewater Dam, in acre-feet	Streamflow in Bluewater Creek near Bluewater, in acre-feet	Streamflow in Rio San Jose at Grants, in acre-feet	Streamflow in Grants Canyon at Grants, in acre-feet	Streamflow in Rio San Jose near Grants, in acre-feet
1968	5,420	-	740	-	49	3,880
1969	6,980	-	4,320	11	173	4,000
1970	5,170	-	1,180	154	215	4,570
1971	3,550	-	854	42	45	4,320
1972	2,900	-	668	395	256	5,660
1973	28,140	-	-	72	144	4,490
1974	13,590	-	-	25	3.5	3,620
1975	17,050	-	-	89	54	5,520
1976	3,430	-	-	29	3.9	4,610
1977	2,400	-	-	11	105	4,610
1978	3,010	-	-	0	0.9	4,900
1979	17,800	-	-	92	3.4	4,630
1980	29,830	-	-	5,880	18	11,120
Total (rounded)	362,900	18,700	[3]322,700	94,390	2,034	213,420
Years of record	47	12	[3]50	39	18	44
Means (rounded)	7,700	1,560	[3]6,450	2,420	113	4,850

[3]Calculated without including data for water years 1922-27.

Table 2. Long-term precipitation records for stations within and near the Rio San Jose basin, water years 1869 to 1980

[Data for Bluewater enclosed in parentheses were estimated from the least-squares relation of annual precipitation at Bluewater to precipitation recorded at Laguna, Crownpoint, San Fidel, McGaffey, Fort Wingate, and Black Rock. The mean value of precipitation estimated from three of these stations with the largest correlation coefficient was used.]

	Precipitation, in inches						
Water year	Black Rock	McGaffey	Bluewater	Crownpoint	Laguna	San Fidel	Fort Wingate
1869	-	-	-	-	-	-	19.1
1870	-	-	-	-	-	-	15.1
1871	-	-	-	-	-	-	21.2
1872	-	-	-	-	-	-	22.3
1873	-	-	-	-	-	-	-
1874	-	-	-	-	-	-	9.4
1875	-	-	-	-	-	-	9.9
1876	-	-	-	-	-	-	11.7
1877	-	-	-	-	-	-	10.1
1878	-	-	-	-	-	-	19.8
1879	-	-	-	-	-	-	7.0
1880	-	-	-	-	-	-	9.3
1881	-	-	-	-	-	-	13.9
1882	-	-	-	-	-	-	14.9
1883	-	-	-	-	-	-	14.2
1884	-	-	-	-	-	-	13.6
1885	-	-	-	-	-	-	-
1886	-	-	-	-	-	-	15.3
1887	-	-	-	-	-	-	12.5
1888	-	-	-	-	-	-	-
1889	-	-	-	-	-	-	-
1890	-	-	-	-	-	-	16.3
1891	-	-	-	-	-	-	17.0
1892	-	-	-	-	-	-	7.2
1893	-	-	-	-	-	-	11.3
1894	-	-	-	-	-	-	11.3
1895	-	-	-	-	-	-	13.1
1896	-	-	-	-	-	-	15.4
1897	-	-	11.9	-	-	-	15.1
1898	-	-	10.6	-	-	-	16.5

Table 2. Long-term precipitation records for stations within and near the Rio San Jose basin, water years 1869 to 1980 - Continued

Water year	Black Rock	McGaffey	Bluewater	Crownpoint	Laguna	San Fidel	Fort Wingate
	Precipitation, in inches						
1899	-	-	9.8	-	-	-	10.9
1900	-	-	8.6	-	-	-	9.0
1901	-	-	9.5	-	-	-	9.2
1902	-	-	7.6	-	-	-	12.3
1903	-	-	-	-	-	-	12.8
1904	-	-	-	-	-	-	12.4
1905	-	-	-	-	-	-	20.8
1906	-	-	-	-	17.5	-	22.6
1907	-	-	-	-	12.5	-	18.9
1908	-	-	-	-	9.0	-	17.8
1909	7.5	-	12.3	-	10.5	-	14.8
1910	7.9	-	6.1	-	8.1	-	8.9
1911	16.1	-	16.7	-	14.6	-	-
1912	9.6	16.9	7.4	-	7.1	-	-
1913	9.4	25.1	6.6	-	8.0	-	-
1914	16.3	-	8.6	-	14.8	-	-
1915	20.8	-	11.6	11.0	15.1	-	-
1916	15.3	-	9.1	8.5	-	-	-
1917	10.5	15.1	7.2	7.7	-	-	-
1918	7.9	12.8	6.5	4.1	-	-	-
1919	16.3	18.7	11.8	16.8	15.5	-	-
1920	11.9	12.0	10.1	8.9	11.2	-	-
1921	13.1	21.7	10.3	9.8	-	10.1	-
1922	8.7	14.7	7.4	10.1	-	2.6	-
1923	14.9	19.4	11.9	13.0	-	13.2	-
1924	9.4	10.3	9.9	14.6	-	8.9	-
1925	11.6	13.3	9.2	13.4	-	7.0	-
1926	13.0	21.7	8.1	9.9	-	10.7	-
1927	15.7	25.0	20.3	17.5	-	14.8	-
1928	8.8	13.1	8.4	9.0	7.7	10.0	-

Table 2. Long-term precipitation records for stations within and near the Rio San Jose basin, water years 1869 to 1980 - Continued

Water year	Precipitation, in inches						
	Black Rock	McGaffey	Bluewater	Crownpoint	Laguna	San Fidel	Fort Wingate
1929	16.9	23.2	14.7	15.0	12.4	12.1	-
1930	9.8	14.5	7.8	7.6	8.4	8.9	-
1931	11.7	18.9	16.6	14.2	12.4	13.4	-
1932	16.2	24.0	13.6	14.5	10.3	13.6	-
1933	10.4	16.9	13.9	8.6	14.8	11.0	-
1934	15.2	18.3	10.5	9.5	6.5	7.8	-
1935	12.3	21.9	14.4	10.7	-	12.9	-
1936	13.0	18.6	10.8	12.7	-	9.0	-
1937	13.0	20.6	7.5	12.9	8.8	7.9	-
1938	9.6	13.4	7.9	11.3	7.6	8.7	-
1939	6.5	13.2	7.7	7.2	8.3	10.9	-
1940	11.4	14.6	8.7	9.2	12.2	13.6	-
1941	21.7	25.8	15.7	16.9	16.7	22.2	22.1
1942	10.5	14.3	8.0	6.7	8.7	7.8	9.9
1943	10.1	16.7	9.0	8.4	8.6	9.9	12.1
1944	9.3	15.3	7.0	10.4	11.5	-	22.5
1945	8.4	-	9.0	8.6	5.1	-	11.4
1946	-	19.6	10.3	11.2	-	-	13.5
1947	-	18.6	(9.8)	11.1	-	-	11.0
1948	-	-	9.0	12.3	-	-	12.9
1949	12.2	-	12.4	-	8.4	-	13.9
1950	6.0	10.5	(5.2)	4.7	4.1	-	7.1
1951	5.6	8.5	(5.7)	5.9	3.9	5.2	7.0
1952	12.8	20.1	8.8	11.7	6.5	9.1	13.3
1953	5.8	12.0	5.4	6.0	6.5	6.6	7.5
1954	10.1	14.9	8.1	-	8.1	9.0	13.6
1955	10.0	13.9	8.1	8.9	7.5	7.0	9.4
1956	8.1	-	3.4	5.6	1.8	-	8.4
1957	13.3	21.5	10.6	11.9	10.6	7.5	16.0
1958	12.9	22.6	(10.4)	11.6	9.6	10.6	11.7

Table 2. Long-term precipitation records for stations within and near the Rio San Jose basin, water years 1869 to 1980 - Concluded

Water year	Black Rock	McGaffey	Bluewater	Crownpoint	Laguna	San Fidel	Fort Wingate
	Precipitation, in inches						
1959	7.2	12.2	(9.4)	9.9	9.6	8.5	8.8
1960	9.9	15.1	(7.6)	8.3	5.9	6.4	9.2
1961	12.8	16.5	(10.3)	11.3	9.6	10.6	10.9
1962	9.7	17.4	(8.6)	8.9	8.3	7.9	12.7
1963	15.1	18.9	(9.9)	10.2	10.1	9.5	13.8
1964	13.5	17.6	(10.7)	13.9	10.6	8.2	12.4
1965	13.5	19.1	(10.9)	12.6	10.6	-	11.2
1966	13.2	17.9	(10.1)	11.3	9.7	-	-
1967	14.1	18.1	(8.6)	9.1	7.4	8.9	-
1968	15.2	17.4	(9.0)	9.2	8.4	9.0	-
1969	17.7	19.9	(10.5)	-	11.7	8.3	-
1970	13.0	18.8	(10.2)	-	-	9.2	-
1971	12.0	16.7	(8.4)	-	7.2	8.0	-
1972	8.2	12.0	(9.1)	-	10.7	9.8	-
1973	-	24.7	(12.2)	-	13.3	12.3	-
1974	-	13.0	(6.7)	-	5.5	5.8	-
1975	-	15.7	(13.0)	-	16.7	14.9	-
1976	8.6	10.1	(6.4)	-	5.2	7.2	-
1977	10.2	12.4	(9.9)	-	11.9	-	-
1978	9.8	16.7	(8.6)	-	7.9	-	-
1979	11.8	23.4	(11.4)	-	11.6	-	-
1980	7.7	14.2	(7.9)	-	8.3	-	-
Totals	770.7	1,060.0	756.9	544.3	571.1	446.5	835.2
Years of record	66	62	78	52	60	46	63
Means	11.7	17.1	9.7	10.5	9.5	9.7	13.3

Table 3. Estimates of water loss by evaporation from Bluewater Lake, water years 1928-72

[Precipitation at the lake is based on 125 percent of the precipitation at Bluewater, which was estimated for water years 1947, 1950-51, and 1958-72. See p. 19 and table 2.]

Water year	Gross lake evaporation, in acre-feet	Precipitation on lake surface, in acre-feet	Net water loss, in acre-feet
1928	200	20	180
1929	420	370	50
1930	1,400	290	1,110
1931	630	220	410
1932	3,300	1,200	2,100
1933	2,500	810	1,690
1934	630	170	460
1935	2,200	870	1,330
1936	2,800	810	1,990
1937	3,800	780	3,020
1938	2,900	610	2,290
1939	1,300	280	1,020
1940	890	140	750
1941	4,700	2,100	2,600
1942	5,100	1,200	3,900
1943	3,600	770	2,830
1944	1,100	200	900
1945	570	90	480
1946	270	90	180
1947	[1]890	310	580
1948	[1]2,100	620	1,480
1949	1,900	570	1,330
1950	1,300	230	1,070
1951	[1]900	180	720
1952	[1]1,900	460	1,440
1953	[1]960	160	800
1954	[1]890	220	670
1955	[1]870	200	670
1956	[1]830	90	740
1957	[1]840	310	530

[1] Records of lake storage not available, gross evaporation estimated based on flow of Bluewater Creek

Table 3. Estimates of water loss by evaporation from Bluewater Lake, water years 1928-72 - Concluded

Water year	Gross lake evaporation, in acre-feet	Precipitation on lake surface, in acre-feet	Net water loss, in acre-feet
1958	1.100	400	700
1959	1,700	560	1,140
1960	2,400	640	1,760
1961	2,000	720	1,280
1962	2,500	760	1,740
1963	1,600	560	1,040
1964	1,600	600	1,000
1965	2,000	770	1,230
1966	2,300	810	1,490
1967	1,400	420	980
1968	1,300	400	900
1969	2,100	770	1,330
1970	1,600	570	1,030
1971	1,100	320	780
1972	1,100	340	760
Rounded Totals			
1928-44	37,500	10,800	26,600
1945-72	40,000	12,170	27,900

Table 4. Adjustment of annual streamflow record of Bluewater Creek near Bluewater for the effects of Bluewater Lake, water years 1928-72

Water year	Gaged streamflow, in acre-feet	Change in lake contents, in acre-feet	Net evaporation loss from lake, in acre-feet	Streamflow, in acre-feet, adjusted for evaporation losses and change in lake contents
1928	2,700	0	180	2,880
1929	4,040	+5,600	50	9,690
1930	8,750	-3,800	1,110	6,060
1931	4,260	-1,800	410	2,870
1932	10,800	+19,800	2,100	32,700
1933	12,800	-13,300	1,690	1,190
1934	4,980	-6,500	460	-1,060
1935	9,320	+9,000	1,330	19,650
1936	11,390	0	1,990	13,380
1937	12,830	+11,500	3,020	27,350
1938	12,710	-15,000	2,290	0
1939	9,740	-5,100	1,020	5,660
1940	4,760	-400	750	5,110
1941	27,090	+33,600	2,600	63,290
1942	20,700	-9,600	3,900	15,000
1943	20,020	-15,400	2,830	7,450
1944	9,210	-8,600	900	1,510
1945	4,170	0	480	4,650
1946	317	+1,500	180	1,997
1947	667	+1,300	580	2,547
1948	8,410	+2,000	1,480	11,890
1949	9,000	-900	1,330	9,430
1950	1,090	-800	1,070	1,360
1951	586	NA	720	[1]1,360
1952	7,140	NA	1,440	[1]8,580
1953	1,080	NA	800	[1]1,880
1954	679	NA	670	[1]1,349
1955	502	NA	670	[1]1,172
1956	251	NA	740	[1]991
1957	338	NA	530	[1]868

[1]Adjusted for evaporation losses only.

Table 4. Adjustment of annual streamflow record of Bluewater Creek near Bluewater for the effects of Bluewater Lake, water years 1928-72 - Concluded

Water year	Gaged streamflow, in acre-feet	Change in lake contents, in acre-feet	Net evaporation loss from lake, in acre-feet	Streamflow, in acre-feet, adjusted for evaporation losses and change in lake contents
1958	1,780	NA	700	[1]2,480
1959	1,300	-2,810	1,140	-370
1960	1,810	+3,070	1,760	6,640
1961	1,620	-2,090	1,280	810
1962	7,620	+950	1,740	10,310
1963	4,860	-3,020	1,040	2,880
1964	6,230	-40	1,000	7,190
1965	6,160	+2,990	1,230	10,380
1966	6,620	0	1,490	8,110
1967	2,550	-4,070	980	-540
1968	740	+2,120	900	3,760
1969	4,320	+1,560	1,330	7,210
1970	1,180	-1,810	1,030	400
1971	854	-1,620	780	14
1972	668	-650	760	778
Rounded Totals				
1928-44	186,100	0	26,600	212,700
1945-72	82,540	[2]+2,900	27,900	113,300

[1]Adjusted for evaporation losses only.
[2]Change in lake contents is the difference between year-end contents in 1945 and year-end contents in 1972. Sum of numbers in column is different due to years of missing record.

Table 5. Summary of natural streamflow estimates, Bluewater Creek near Bluewater

Time Interval	Water years	Years of record	Average annual precipitation at Bluewater, in inches	Gaged streamflow, in acre-feet	Estimated total natural streamflow, in acre-feet (rounded)	Estimated mean annual natural streamflow, in acre-feet (rounded)
1	1913-27	5	8.1	54,100	54,100	10,800
2	1928-44	17	10.1	186,100	212,700	12,500
3	1945-72	28	8.9	82,540	276,000	10,000
--	1913-72	50	9.3	322,700	543,000	11,000

Table 6. Summary of natural streamflow estimates in the Rio San Jose at Grants, at the western boundary of the Pueblo of Acoma, and at the western boundary of the Pueblo of Laguna

Time Interval	Water years	Estimated mean annual natural streamflow in the Rio San Jose at Grants, in acre-feet	Estimated mean annual natural springflow from Ojo del Gallo, in acre-feet	Estimated mean annual natural springflow from Horace Springs, in acre-feet	Estimated mean annual natural streamflow in Rio San Jose at at western Pueblo of Acoma boundary, in acre-feet	Estimated mean annual natural surface- and ground-water gains across Pueblo of Acoma, in acre-feet	Estimated mean annual natural streamflow in the Rio San Jose at the western Pueblo of Laguna boundary, in acre-feet
1	1913-27	7,800	3,000-5,000	3,600	14,400-16,400	4,200	19,000-21,000
2	1928-44	5,600	3,000-5,000	3,600	12,200-14,200	4,200	16,000-18,000
3	1945-72	4,500	3,000-5,000	3,600	11,000-13,000	4,200	15,000-17,000
—	1913-72	5,000	3,000-5,000	3,600	12,000-14,000	4,200	16,000-18,000