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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

QUANTITY AND QUALITY OF PRINCIPAL RIVERS ENTERING THE SOUTHERN UTE AND UTE MOUNTAIN UTE INDIAN RESERVATIONS, COLORADO AND NEW MEXICO

By George H. Leavesley

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1975

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QUANTITY AND QUALITY OF PRINCIPAL RIVERS ENTERING THE SOUTHERN UTE AND UTE MOUNTAIN UTE INDIAN RESERVATIONS, COLORADO AND NEW MEXICO

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ABSTRACT

Surface-water resources of the Southern Ute and Ute Mountain Ute Indian Reservations are supplied primarily by the 10 principal rivers of the upper San Juan drainage basin. Mean annual virgin flow of each of these 10 rivers at its point of entry into the reservation was computed from (1) available gaging station, irrigation diversion, and irrigation consumptive use records for gaged basin areas, and (2) a mean annual precipitation-mean annual runoff relationship developed for ungaged basin areas. The San Juan River is the major river of this region; it drains the remaining nine river basins. The mean annual virgin flow of the San Juan River at its entry point to the Southern Ute Reservation is 304,700 acre-feet or 376 hm^3 (cubic hectometres), and at its entry point to the Ute Mountain Ute Reservation, after receiving the flow of the other nine rivers, is 2,001,200 acre-feet (2,470 hm^3). The mean annual virgin flow of the other nine rivers at their points of entry to the reservations are:

Navajo River, 140,500 acre-feet (173 hm^3);
Rio Blanco, 110,700 acre-feet (136 hm^3);
Stollsteimer Creek, 20,700 acre-feet (25.5 hm^3);
Piedra River, 280,400 acre-feet (346 hm^3);
Los Pinos River, 295,900 acre-feet (365 hm^3);
Florida River, 92,300 acre-feet (114 hm^3);
Animas River, 634,600 acre-feet (782 hm^3);
La Plata River, 36,700 acre-feet (45.2 hm^3); and
Mancos River, 53,300 acre-feet (65.7 hm^3).

Quality of water in the 10 rivers was determined from samples collected at the reservations' boundaries in the months of December 1972, and March, June, and August 1973. Each sample was analyzed for pesticide concentration, coliform bacteria count, and chemical constituents. Based on water-quality standards for public and agricultural water supplies recommended by the National Academy of Sciences--National Academy of Engineering Committee on Water Quality Criteria, no significant concentrations of pesticides were found. The Colorado bacteriological standard for these rivers of not more than 1,000 fecal coliform groups per 100 millilitres was not exceeded by any of the samples. Chemical analyses reflect a strong seasonal trend resulting from the large dilution effect of spring snowmelt runoff. During low flow periods, dissolved-solids and sulfate concentrations of 1,780 and 930 mg/l (milligrams per litre), respectively,

for the Mancos River and 554 and 280 mg/l, respectively, on the lower San Juan River exceeded the U.S. Public Health Service drinking-water standards limits of 500 mg/l for dissolved solids and 250 mg/l for sulfate. For irrigation purposes all rivers were found to have a low sodium hazard, and all but the Mancos River were found to have a low to medium salinity hazard. Water in the Mancos River is classed as having a high salinity hazard.

INTRODUCTION

Effective management and use of water resources is based, in part, on the knowledge of the quantity, quality, and reliability of the water supply. While these attributes of supply are controlled to a large degree by natural phenomena, they are also influenced by the legal doctrines governing the ownership and rights to use of the supply. In the State of Colorado, the doctrine of prior appropriation is used in the application of all surface waters to beneficial use. Thus, the quantity and reliability and, to some extent, the quality of the water supply becomes a function of the user's water right priority.

The United States of America, on behalf of the Ute Mountain Ute and Southern Ute Indian Tribes, has filed a lawsuit in the United States District Court for the District of Colorado to adjudicate the Indian water rights in Colorado. The suit claims rights to the use of waters of the Navajo, San Juan, Piedra, Los Pinos, Florida, Animas, La Plata, and Mancos Rivers and waters tributary thereto in the State of Colorado. These waters comprise the major tributaries of the upper San Juan River drainage basin.

Water availability is of great importance to the Indian Reservations because of their location in the arid to semiarid southwest corner of Colorado (fig. 1). The receipt of an adjudicated water right and the knowledge of the quantity and quality of their water supply will provide reservation planners with additional tools and data with which to manage a valuable resource.

English units used in this report may be converted to metric units by the following conversion factors:

From	*Multiply by*	*To obtain*
inches (in.)	25.4	millimetres (mm)
square miles (mi^2)	2.59	square kilometres (km^2)
acres	.4047	hectares (ha)
acre-feet (acre-ft)	1,233	cubic metres (m^3)
	1.233×10^{-3}	cubic hectometres (hm^3)
acre-feet per acre	3,047	cubic metres per hectare (m^3/ha)
miles (mi)	1.609	kilometres (km)

Purpose and Scope

The purpose of this study is to determine the availability and quality of runoff from the upper San Juan River and its major tributaries that pass through the Ute Mountain Ute and Southern Ute Indian Reservations. This study was made by the U.S. Geological Survey at the request of the U.S. Bureau of Indian Affairs. The study data results will be used to aid reservation water-resources planning and may be used in the water rights litigation discussed above.

Ten principal rivers enter and pass through the reservations with one, the San Juan River, passing through the Southern Ute Reservation and then entering the southwest corner of the Ute Mountain Ute Reservation. These 11 entry points are the requested study sites for the determination of water quantity and quality. A twelfth study site, for water quality analysis only, was established on the Mancos River within the Ute Mountain Ute Reservation. The locations of these study sites are shown on figure 1.

Method of Investigation

Water availability for the purpose of this study has been determined as the mean annual virgin flow of the 10 principal rivers of the upper San Juan River drainage basin at the 11 established study sites. Mean annual virgin flow is defined as the mean annual natural flow of a river, undepleted by man's uses. In this region, man's uses are primarily out of basin diversions and consumptive losses associated with irrigation. These uses strongly influence the annual observed flows of all streams and rivers. To avoid confusion with annual yield terminology, estimates of the mean annual undepleted yield of a river have been termed "mean annual virgin flow" and the mean annual observed flows computed from gaging station records have been termed "mean annual historic flow."

Mean annual virgin flow from each of the 11 basin areas lying above the 11 study sites was computed by first determining, where possible, the mean annual historic flow for a gaging station on the basin. Then an estimate of all mean annual depletions associated with man's activities above the gaging station was added to the mean annual historic flow to obtain an estimate of the mean annual virgin flow for the area above the gaging station. Estimates of the virgin-flow contributions for watershed areas between the gaging stations and the reservations' boundaries were made from a precipitation-runoff relationship. This relationship was developed from the estimated virgin flow at all available gaging stations and the mean annual precipitation over the areas above these gaging stations. Mean annual precipitation was computed from an isohyetal map (Iorns and others, 1964, pl. 4) which shows average annual precipitation for the Upper Colorado River Basin for 1921-50. The mean annual virgin flow estimates for the area above the gage and the area between the gage and the study site were then added to obtain the estimated mean

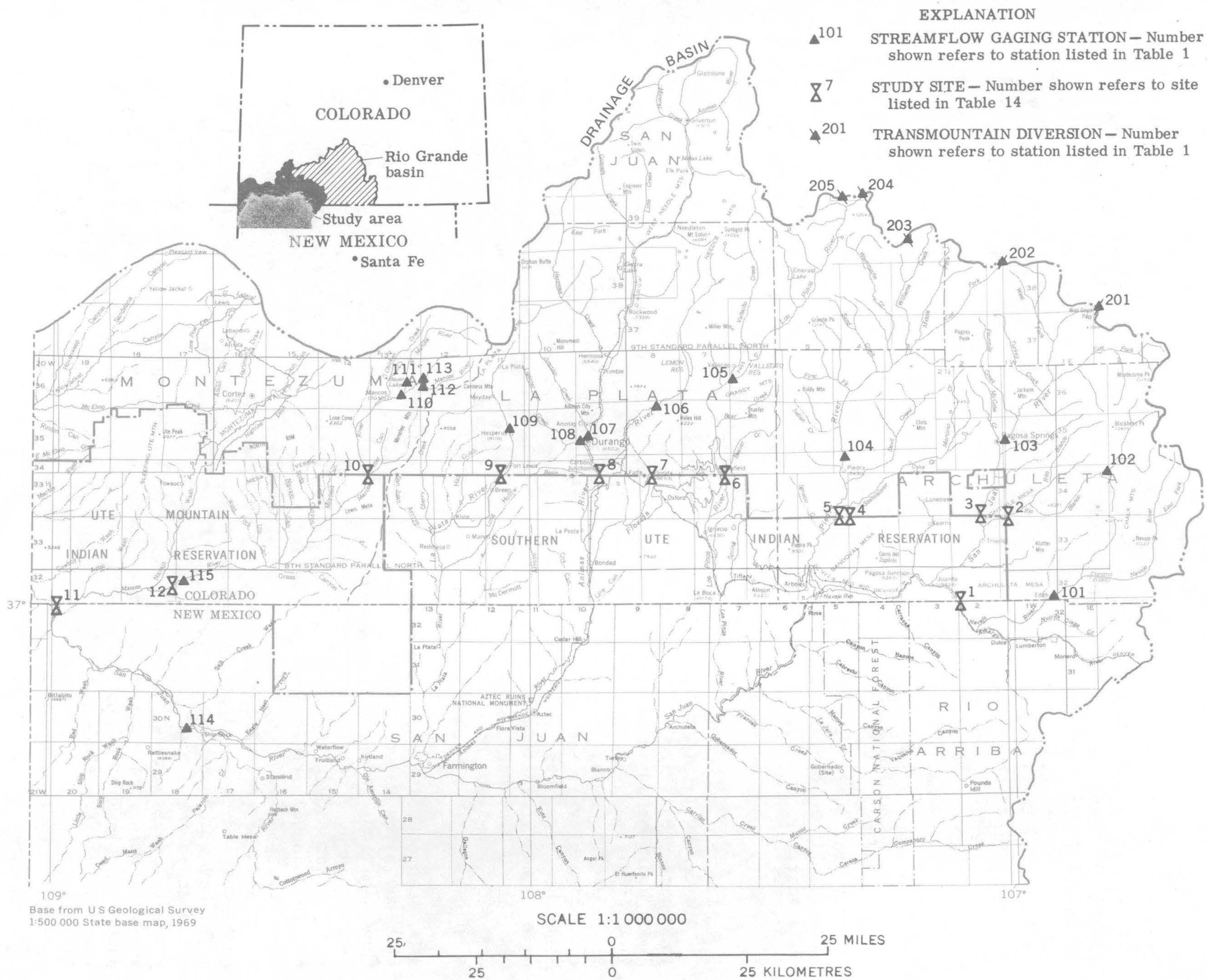

Figure 1.--Map of study area showing gaging stations, study sites, and transmountain diversions in the upper San Juan River drainage basin.

annual virgin flow for the study site. For a basin with no available gage record, mean annual virgin flow was estimated using a channel geometry technique (Hedman and others, 1972) and the precipitation-runoff relationship computed from the gaged basins.

Water quality was determined from analyses of the 1973 water year runoff. A water sample was collected at each study site in the months of December 1972 and March, June, and August 1973. Each sample was analyzed for pesticides, chemical constituents, and coliform bacteria. The December and August samples were also analyzed for streptococcal bacteria. A discharge measurement was made at each study site along with the collection of each sample.

Acknowledgments

The author would like to thank Harold E. Burch, James D. Bennett, Bob Tsiosdia, Ben Hoy, and Paul Smith for their assistance in the collection of field data for this study.

HYDROLOGIC SETTING AND HYDROLOGIC DATA FOR STUDY AREA

The study area is that region within the States of Colorado and New Mexico that is drained by the upper San Juan River and its tributaries (fig. 1). Snowmelt is the primary source of streamflow in the study area and runoff characteristics are typical of snowmelt regions. Snowmelt runoff begins in March or April and produces a period of high flows from May through July. This is followed by a period of flow recession which continues through the fall and winter months. Under natural conditions a period of minimum flow occurs during the late winter months. During the summer months high intensity thunderstorms contribute some runoff to the annual yield of the region.

The flow characteristics of all the principal streams and rivers of the region are strongly affected by irrigation practices. The major effects are that peak flows are reduced by irrigation diversion and low flows are increased by return flow seepage from irrigated areas. Annual water yields are reduced by consumptive losses associated with irrigation practices and by diversion of some water via transmountain diversion ditches to the Rio Grande basin. Diversion of flow from one basin to another within the study region also influences runoff characteristics of those streams involved. Water quality is reduced by return flows which carry increased amounts of dissolved salts and minerals.

Streamflow records have been collected on most of the principal rivers and transmountain diversions in the study area by the U.S. Geological Survey and the Colorado State Division of Water Resources. The streamflow gaging stations and transmountain diversions used in this study are shown on figure 1. Table 1 lists the U.S. Geological Survey station names and downstream order numbers corresponding to the gaging station and transmountain diversion site numbers shown on figure 1.

Table 1.--*U.S. Geological Survey station names and downstream order numbers of the gaging station and transmountain diversion sites shown on figure 1*

Figure 1 site No.	U.S. Geological Survey downstream order No.	Station name
101	09346000	Navajo River at Edith, Colo.
102	09343000	Rio Blanco near Pagosa Springs, Colo.
103	09342500	San Juan River at Pagosa Springs, Colo.
104	09349500	Piedra River near Piedra, Colo.
105	09353500	Los Pinos River near Bayfield, Colo.
106	09363000	Florida River near Durango, Colo.
107	09361500	Animas River at Durango, Colo.
108	09362000	Lightner Creek near Durango, Colo.
109	09365500	La Plata River at Hesperus, Colo.
110	09370000	Mancos River near Mancos, Colo.
111	09368500	West Mancos River near Mancos, Colo.
112	09369000	East Mancos River near Mancos, Colo.
113	09369500	Middle Mancos River near Mancos, Colo.
114	09368000	San Juan River at Shiprock, N. Mex.
115	09371000	Mancos River near Towaoc, Colo.
201	09341000	Treasure Pass ditch
202	09347000	Piedra Pass ditch
203	09348000	Squaw Pass ditch
204	09351000	Fuchs ditch
205	09351500	Raber-Lohr ditch

The primary sources of basic data for this study were (1) U.S. Geological Survey (1954, 1964), for the Colorado River basin which provided historic streamflow data; (2) Iorns, Hembree, and Oakland (1965), and Iorns, Hembree, Phoenix, and Oakland (1964), which supplied mean annual precipitation data; (3) unpublished data of the Colorado State Division of Water Resources which provided records of streamflow diversions for irrigation and irrigated acreage estimates for the areas studied; (4) the official record of the Upper Colorado River Basin Compact Commission, volume III (1948) which contained estimates of virgin flows of the major river basins used in negotiations of the Upper Colorado River Basin Compact; (5) the "Report on Depletion of Surface Water Supplies of Colorado West of Continental Divide," by Leeds, Hill, and Jewett (1953) which dealt specifically with the State of Colorado, and updated the data used in the Upper Colorado River Basin Compact Report; and (6) the "Upper Colorado Region Comprehensive Framework Study," appendixes V, X, and XI, prepared by the Upper Colorado Region State-Federal Inter-Agency Group (U.S. Water Resources Council, 1971) which provided the latest estimates of virgin flows and streamflow depletions for the Upper Colorado region. Some of the basic data used in the preparation of appendix X, "Irrigation and Drainage," of the Comprehensive Framework Study were obtained from the U.S. Soil Conservation Service. These data provided a breakdown for the upper San Juan region of irrigated acreage, consumptive irrigation requirements, and reservoir evaporation estimates by watershed. All reference sources supplied basic water-resources data, but sources 4, 5, and 6 also provided a historic perspective to changes in water availability and use over time.

MEAN ANNUAL VIRGIN FLOW

Mean annual virgin flow at each study site was computed as the sum of the mean annual historic flow from an available gaging station plus the mean annual streamflow depletions above the gaging station plus the mean annual virgin runoff contributions from those watershed areas between the gaging station and the reservation boundary. The following sections discuss in detail the determination of mean annual historic flows, mean annual depletions, and the precipitation-runoff relationship used in the computation of mean annual virgin flows. This is followed by the individual determinations of mean annual virgin flow for each of the study sites.

Table 2 lists the 11 study sites used in the virgin flow part of the study, the estimated mean annual virgin flow at the site, and the area of the drainage basin above the site. Drainage areas were determined by planimetry of U.S. Geological Survey 1:250,000 scale maps of the region.

Table 2.--*Area and mean annual virgin flow estimates for the 11 watersheds bounding the Ute Mountain Ute and Southern Ute Indian Reservations*

Watershed	Area (square miles)	Mean annual virgin flow[1] (acre-feet)
1. Navajo River---------------	468	140,500
2. Rio Blanco-----------------	164	110,700
3. San Juan River No. 1-------	374	304,700
4. Stollsteimer Creek---------	124	20,700
5. Piedra River---------------	485	280,400
6. Los Pinos River------------	333	295,900
7. Florida River--------------	134	92,300
8. Animas River---------------	786	634,600
9. La Plata River-------------	41	36,700
10. Mancos River---------------	167	53,300
11. San Juan River No. 2-------	14,590	2,001,200

[1]Values rounded to nearest 100 acre-feet.

Mean Annual Historic Flows

As the primary source of streamflow for the upper San Juan basin is snowmelt from its mountain areas, the major part of the annual flow occurs between the months of May and August. Annual streamflow fluctuates widely from year to year dependent on annual variations in precipitation. Figures 2 to 4 present in graphic form the annual precipitation recorded at the climatic stations at Durango, Silverton, and Wolf Creek Pass, Colo., respectively. These data have been collected by the U.S. Environmental Data Service (by the U.S. Weather Bureau prior to 1966) and other interested groups, and have been compiled and published by the U.S. Environmental Data Service in the reports, "Climatological Data, Colorado." Also shown on each figure is the cumulative departure from the average precipitation for the period of record at each station. These three stations have the longest periods of precipitation record for the region. Apparent in all three figures are the large annual fluctuations and longer term cyclic trends. These short- and long-term variations in precipitation reflect the need for the use of the longest possible streamflow records to adequately define mean annual observed streamflow and thus permit a "best" estimate of mean annual virgin flow.

Historic streamflow records indicate that the period from 1912 to 1971 provides the longest period of continuous streamflow record for the entire upper San Juan basin. Continuous streamflow records from 1912 to 1971 were available for the gaging stations Navajo River at Edith, Colo., Animas River at Durango, Colo., and the San Juan River at Farmington, N. Mex.; and from 1917 to 1971 for the gaging station La Plata River at Hesperus, Colo. The historic streamflow records available for the remaining rivers in this study were for shorter periods of time which fell within the 1912 to 1971 base period. Mean annual historic flows for these shorter periods of record were adjusted to put all mean annual historic flow estimates on the same time base of 1912 to 1971.

A percentage adjustment factor was computed for the short-period record stations using those stations whose records were complete for the base period 1912 to 1971. Using the corresponding years of a short-period station, the mean annual flow over this period was computed for the base-period stations. This short-term computed mean annual flow was then expressed as a percentage of the base stations' 1912 to 1971 mean annual flow. Using these percentages, estimates of mean annual historic flow for 1912-71 were made for the respective short-period records. The percentage adjustment factor used for a specific short-period station was determined from either a single base-period station or the average of two or more base-period stations depending on the location of the short-period record station with respect to the base-period stations.

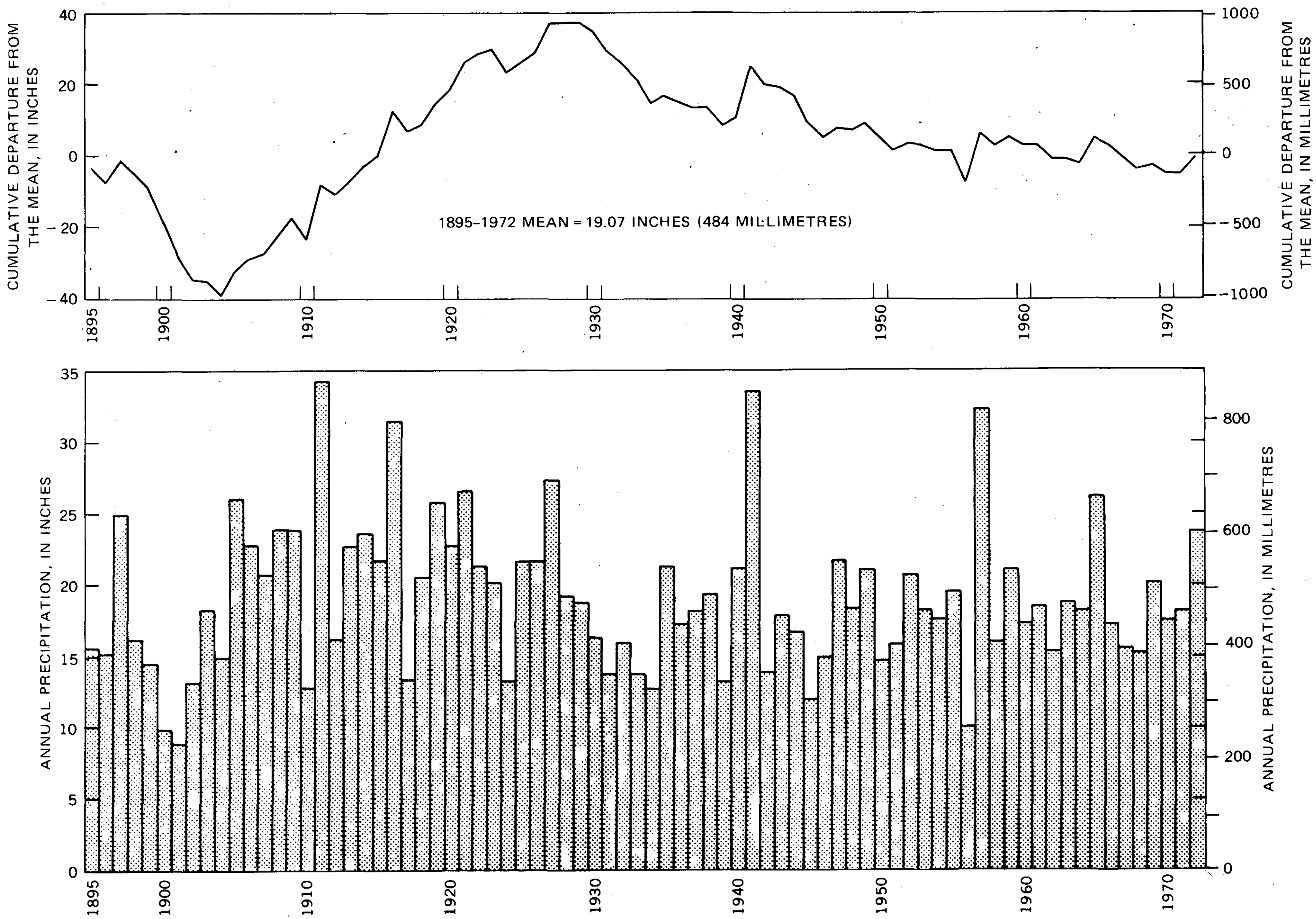

Figure 2.--Annual precipitation and cumulative departure from the mean at Durango, Colo., 1895-1972.

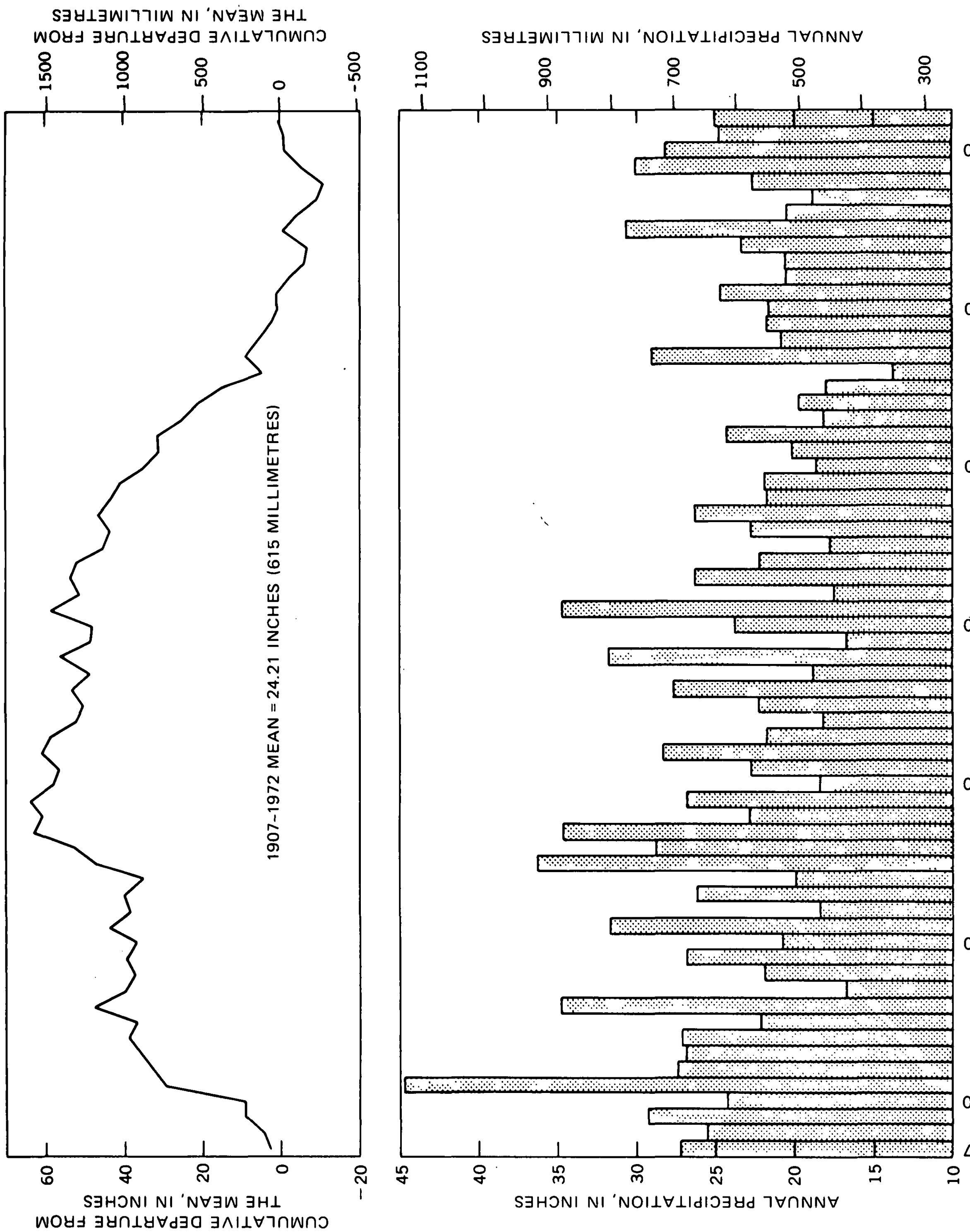

Figure 3.--Annual precipitation and cumulative departure from the mean at Silverton, Colo., 1907-72.

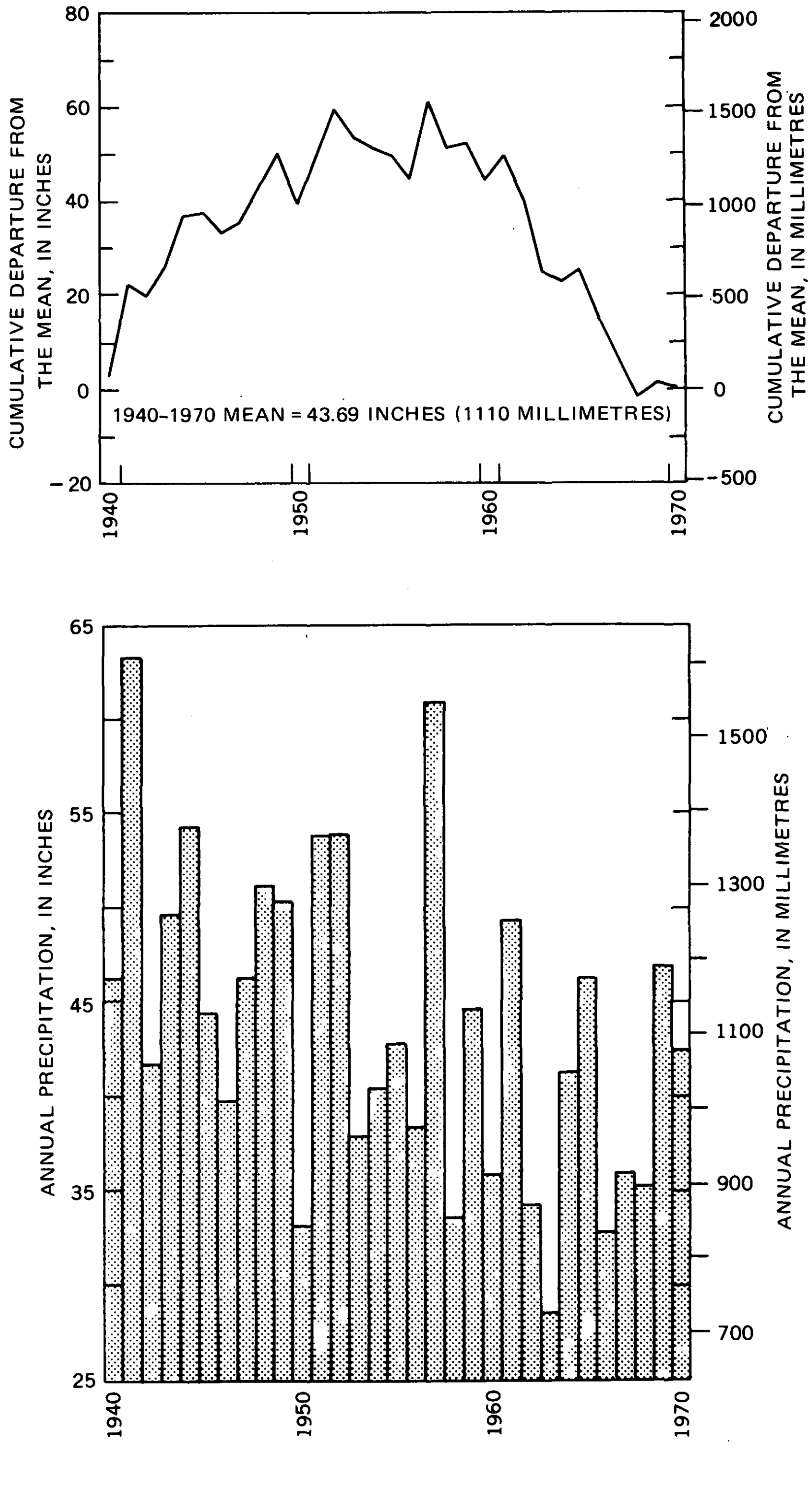

Figure 4.--Annual precipitation and cumulative departure from the mean at Wolf Creek Pass, Colo., 1940-70.

Examination of the data available indicated that changes in mean annual historic flow over time were a result of climatic trends and not of changes in irrigated acreage. Mean annual flow consistently decreased during 1912-71, with, for example, the mean annual flow for the period of 1935 to 1971 being about 10 percent less than that for 1912-71. Recorded changes in irrigated acreage would account for only about 1 percent of this change on most basins with a maximum of about 3 percent on the largest basin.

Mean Annual Depletions

Mean annual depletions are those annual flow losses resulting from man's use of a river. For this region, these losses are primarily out-of-basin diversions and consumptive uses associated with irrigation practices. Some depletion results from municipal and industrial uses but these are quite small.

For the purpose of this report, MADs (mean annual depletions), in acre-feet, for each basin were computed using the equation:

$$MAD = TMD + CLI + ILI, \quad (1)$$

where

TMD = transmountain diversions of water out of a basin, in acre-feet,
CLI = consumptive-use losses from irrigated croplands, in acre-feet,
and ILI = incidental losses associated with irrigation practices, in acre-feet.

Five TMDs (transmountain diversions) located in this region carry water out of the San Juan basin and into the Rio Grande basin (fig. 1). These diversions affect the observed flows of the San Juan River, Piedra River, and Los Pinos River watersheds. Four of the diversions have been used since 1938 and the fifth has been in operation since 1923. The mean annual flow for each of the five diversions was computed for its respective periods of operation and then adjusted to the base period 1912-71.

Consumptive losses (CLI and ILI) from irrigation practices are the largest source of flow depletions in the region. Streamflow diversion records exist for all rivers in the San Juan basin. However, the lack of sufficient data regarding return flows from irrigated areas of this region prohibited the use of diversion records for the determination of CLI. Therefore, CLI for each basin was computed using the equation:

$$CLI = AIA \times KF, \quad (2)$$

where

AIA = average annual irrigated acreage, in acres, and
KF = consumptive-use factor, in acre-feet per acre.

Unpublished records from the Colorado State Division of Water Resources provided estimates for Colorado basins of AIA over the base period 1912-71. The State of New Mexico keeps no irrigation-diversion records, but there are estimates of irrigated acres presented in the official record of the Upper Colorado River Basin Compact Commission (1948) and the U.S. Water Resources Council (1971) report.

The consumptive-use factor KF is simply the estimated unit depletion for a basin expressed as acre-feet of water consumed per acre of land irrigated. KFs are based on crop consumptive-use estimates less effective precipitation. For each basin in this study, a KF was estimated using consumptive irrigation requirements and irrigated acreage data for these basins as computed by the U.S. Soil Conservation Service, Denver, Colo. (unpublished records). The KF for a given basin is a function of basin location, crop types, and availability of water supply. Using the U.S. Soil Conservation Service data, a set of KFs was produced for the region based on cropping and irrigation conditions for 1965. These estimated KFs were adjusted to reflect the average conditions occurring over the base period 1912-71.

Incidental losses (ILI) were primarily the result of evapotranspiration from land areas adjacent to diversion ditches and croplands, and evaporation from irrigation reservoirs. Data from appendix V, "Water Resources," and appendix X, "Irrigation and Drainage," U.S. Water Resources Council (1971) indicated that, for the upper San Juan region, incidental losses to evapotranspiration from phreatophytes and uncropped areas were approximately 10 percent of the consumptive use by irrigated croplands for areas in Colorado and 20 percent for areas in New Mexico. Likewise, with the exception of the major reservoirs, such as Navajo, Vallecito, and Lemon which were considered individually, the evaporation losses from irrigation reservoirs, stock ponds, and other manmade bodies of water in this region were approximately 2 percent of the consumptive use of irrigated croplands. Therefore, the total ILI for each basin in the upper San Juan region was assumed to be 12 percent of the consumptive losses of its irrigated cropland for areas in Colorado and 22 percent for areas in New Mexico.

Precipitation-Runoff Relationship

For ungaged watershed areas a precipitation-runoff relationship was developed for the estimation of their contributions to mean annual virgin flow. Using an isohyetal map (Iorns and others, 1964, pl. 4) showing the mean annual precipitation for the upper San Juan basin for 1921-50, estimates of the mean annual precipitation were determined by planimetry for all watershed areas above gaged points. These mean annual precipitation estimates were then plotted against their respective gage-site estimates of mean annual virgin flow expressed as a percent of the mean annual precipitation. The results of this plotting are shown in figure 5.

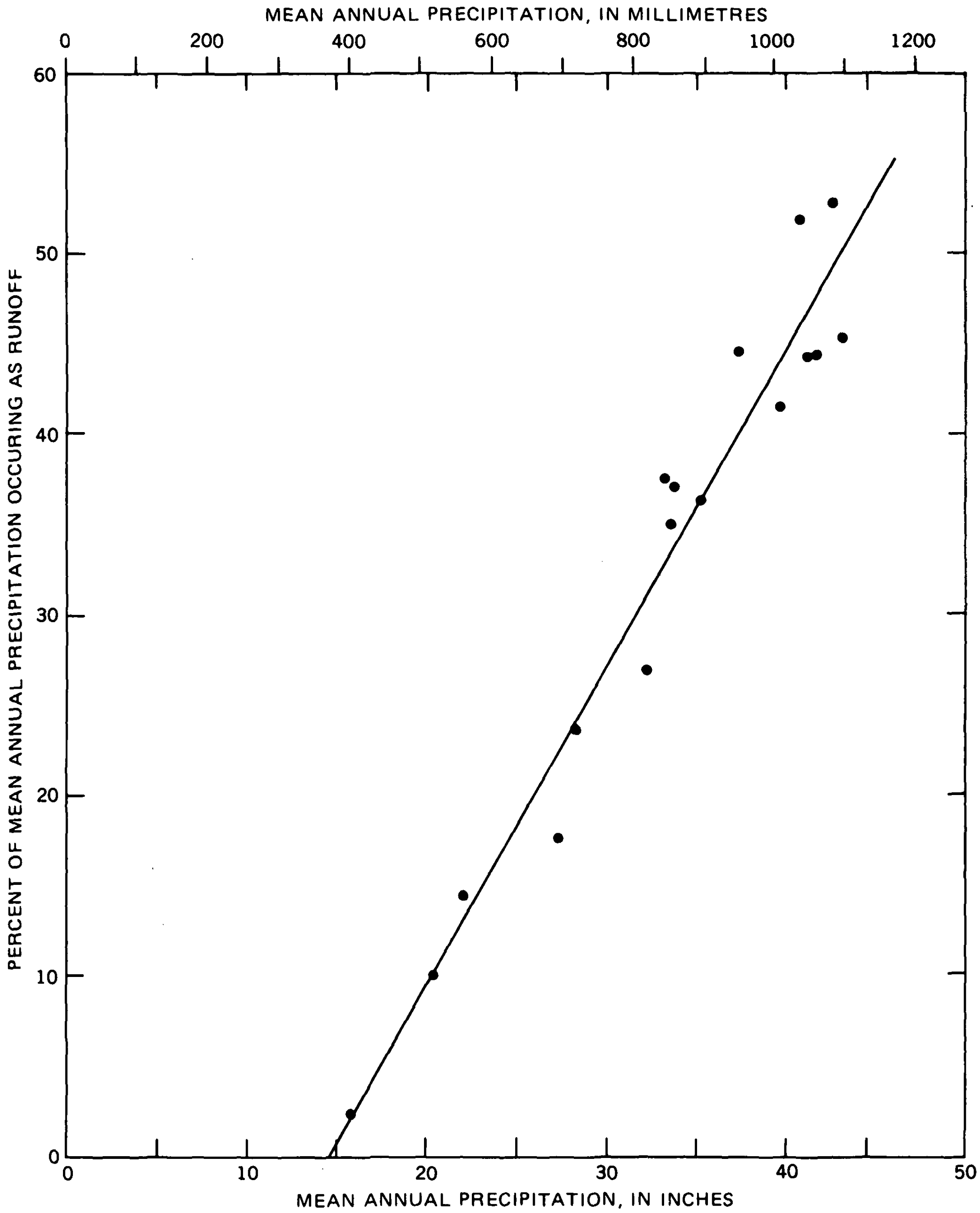

Figure 5.--Relation of percentage of mean annual precipitation occurring as runoff to mean annual precipitation, computed from an isohyetal map by Iorns, Hembree, Phoenix, and Oakland (1964).

The line defining this relationship was fitted using a least-squares linear regression technique. The equation of this line is:

$$PMAP = -25.92 + (1.769 \times MAP) \quad (3)$$

where

PMAP = percent of mean annual precipitation occurring as runoff, and
MAP = mean annual precipitation, in inches.
The correlation coefficient for this relationship is 0.97.

According to the relationship shown in figure 5, those areas receiving less than about 14.7 inches (373 mm) of mean annual precipitation contribute no runoff to streamflow. It is known, however, that these arid to semiarid regions do produce runoff from some storms but that the quantity is dependent upon storm size, type, and intensity.

The absence of mean annual precipitation and percent runoff contribution data below 15.8 inches (401 mm) and 2.3 percent, respectively, makes it difficult to assume that this linear relationship established in figure 5 will hold through the 14.7 inch (373 mm) and 0 percent contribution point. However, natural channel-loss studies conducted by the Upper Colorado River Basin Compact Commission (1948) on channel reaches in those areas receiving less than 14 inches (356 mm) of mean annual precipitation indicated that these reaches have greater streamflow losses than gains.

Mean annual virgin flow contributions from ungaged areas were calculated by first determining from Iorns and others (1964, pl. 4) the MAP for the areas. For areas whose MAP was greater than 14.7 inches (373 mm) equation 3 was used to compute a PMAP. This PMAP was then used in the following equation to compute the mean annual virgin flow (MAVF) contribution in acre-feet:

$$MAVF = (\frac{PMAP}{100} \times MAP \times UA)/12 \quad (4)$$

where MAVF, PMAP, and MAP are as defined above and UA is the area of the ungaged area in acres. For areas whose MAP was less than 14.7 inches (373 mm) the channel losses reported by the Upper Colorado River Basin Compact Commission (1948) were used.

Mean Annual Virgin Flow Computations

The calculations used to compute the mean annual virgin flows for each of the 11 runoff quantity study sites are described and listed in the following analyses. Shown are the mean annual historic flows and the individual components of the mean annual streamflow depletions associated with these historic flows. Also given are the area, MAP, and PMAP for ungaged areas. The use of equation 4 with these three values produced the ungaged-area virgin-flow contributions shown. The total mean annual virgin flow shown for each study site was rounded to the nearest 100 acre-feet (0.12 hm^3) for placement in table 2.

The site numbers preceding the study-point locations correspond to the site numbers shown on figure 1. Likewise, the gaging stations and transmountain diversions cited in the computation discussions are referenced to their site numbers shown on figure 1.

Study Site 1.--Navajo River at Colorado-New Mexico State line at southern boundary of Southern Ute Indian Reservation

The Navajo River watershed above study site 1 is approximately 468 mi^2 (1,212 km^2) in area with approximately 222 mi^2 (575 km^2) located in Colorado and the remaining 246 mi^2 (637 km^2) in New Mexico. Mean annual precipitation for the Colorado part is about 31.8 inches (808 mm) and about 18.3 inches (465 mm) for the New Mexico part. Fifty-eight years (1912-70) of streamflow records were available from the gaging station Navajo River at Edith, Colo., (101, fig. 1) for virgin-flow computations for the 172-mi^2 (445-km^2) area above Edith. The virgin-flow contributions of the Coyote Creek basin located in Colorado and the entire New Mexico part of the watershed were computed using the precipitation-runoff relationship established in figure 5.

The average annual irrigated area above the Edith gaging station for the base time period was approximately 4,000 acres (1,620 ha). The consumptive-use factor for this acreage was estimated to be 0.7 acre-foot per acre (2,130 m^3/ha) irrigated. There were no diversions into or out of the basin above Edith prior to 1970. Because the streamflow corresponds to the base time period no flow adjustment was required. Virgin-flow computations are shown in table 3.

Study Site 2.--Rio Blanco at northern boundary of Southern Ute Indian Reservation

The Rio Blanco watershed above study site 2 is approximately 164 mi^2 (425 km^2) in area. Mean annual precipitation for the basin is about 33.5 inches (851 mm) with an areal range over the basin of from greater than 50 inches (1,270 mm) at the higher elevations to about 20 inches (508 mm) at the lower elevations. Thirty-five years (1935-70) of streamflow records were available from the discontinued gaging station Rio Blanco near Pagosa Springs, Colo., (102, fig. 1) for virgin-flow computations for the 58-mi^2 (150-km^2) area above the gage. The virgin-flow contribution from the remaining 106-mi^2 (275-km^2) area was computed using the precipitation-runoff relationship established in figure 5.

The average annual irrigated acreage above the Pagosa Springs gaging station for the base time period was approximately 1,500 acres (610 ha). The consumptive-use factor for this acreage was estimated to be 0.7 acre-foot per acre (2,130 m^3/ha) irrigated. There were no diversions into or out of the basin above the gage for the period examined. A comparison of observed long-term flow records for 1935-70 versus 1912-71 indicates that the mean annual flow for the shorter period was about 90 percent of the mean annual flow for the longer term period. Virgin-flow computations are shown in table 4.

Table 3.--*Computations of mean annual virgin flow, Navajo River at study site 1*

Mean annual virgin flow	Acre-feet
Mean annual historic flow at Edith, 1912-70, prior to diversions through Azotea Tunnel	112,300
Irrigation use:	
a. Consumptive use on 4,000 acres, use factor of 0.7 . .	2,800
b. Incidental use, 12 percent.	336
Coyote Creek runoff (50 mi^2)	9,670
(Mean annual precipitation of 23.4 inches produces 15.5 percent runoff.)	
New Mexico runoff (246 mi^2).	15,370
(Mean annual precipitation of 18.3 inches produces 6.4 percent runoff.)	
TOTAL. . . .	140,476

Table 4.--*Computations of mean annual virgin flow, Rio Blanco at study site 2*

Mean annual virgin flow	Acre-feet
Mean annual historic flow at gage near Pagosa Springs, 1935-70, prior to diversions through Blanco Tunnel.	61,510
Adjustment to historic flow to extend period of record (90 percent)	6,830
Irrigation use:	
a. Consumptive use on 1,500 acres, use factor of 0.7 . .	1,050
b. Incidental use, 12 percent.	126
Gage to reservation boundary runoff (106 mi^2).	41,170
(Mean annual precipitation of 28.9 inches produces 25.2 percent runoff.)	
TOTAL. . . .	110,686

Study Site 3.--San Juan River at northern boundary of Southern Ute Indian Reservation

The San Juan River watershed above study site 3 is approximately 374 mi^2 (969 km^2) in area. Mean annual precipitation for the basin is about 38.1 inches (968 mm) with an areal range of from more than 60 inches (1,524 mm) at higher elevations to less than 20 inches (508 mm) at lower elevations. Forty years (1910-14, 1935-71) of streamflow records were available from the gaging station San Juan River at Pagosa Springs, Colo., (103, fig. 1) for virgin-flow computations for the 298-mi^2 (772-km^2) area above Pagosa Springs. The virgin-flow contribution from the remaining 76-mi^2 (197-km^2) area was computed using the precipitation-runoff relationship established in figure 5.

The average annual irrigated acreage above Pagosa Springs for the base time period was approximately 8,600 acres (3,480 ha). The consumptive-use factor for this acreage was estimated to be 0.7 acre-foot per acre (2,130 m^3/ha) irrigated. There is one small transmountain diversion above Pagosa Springs which diverts water through Treasure Pass ditch (201, fig. 1) to the Rio Grande basin. A comparison of observed long-term flow records for 1910-14 and 1935-71 versus 1912-71 indicates that the mean annual flow for the shorter period was about 92 percent of the mean annual flow for the longer term period. Virgin-flow computations are shown in table 5.

Study Site 4.--Stollsteimer Creek at mouth at northern boundary of Southern Ute Indian Reservation

The Stollsteimer Creek watershed above study site 4 is approximately 124 mi^2 (321 km^2) in area. Mean annual precipitation for the basin is about 22.5 inches (572 mm) with an areal range of from more than 40 inches (1,016 mm) at the higher elevations to less than 20 inches (508 mm) at the lower elevations. There was no existing streamflow record for this basin. Therefore, the mean annual virgin flow for the basin was computed from the precipitation-runoff relationship established in figure 5.

A study by Hedman, Moore, and Livingston (1972) showed that an estimate of mean annual runoff could be obtained for Colorado mountain streams from measures of channel dimensions. A relationship of width and average depth of cross sections between channel and point bars to mean annual runoff was developed and the resulting standard error of estimate for this relationship was 18.3 percent. A series of channel-geometry measurements was made on Stollsteimer Creek near the reservation boundary and the estimated mean annual streamflow using these measurements was 23,200 acre-feet (28.6 hm^3). This compares closely with the estimated mean annual virgin flow obtained using figure 5. Virgin-flow computations are shown in table 6.

Table 5.--*Computations of mean annual virgin flow, San Juan River at study site 3*

Mean annual virgin flow	Acre-feet
Mean annual historic flow at Pagosa Springs, 1910-14, 1935-71.	265,200
Adjustment to historic flow to extend period of record (92 percent)	23,060
Irrigation use:	
a. Consumptive use on 8,600 acres, use factor of 0.7 . .	6,020
b. Incidental use, 12 percent.	722
Transmountain diversion (Treasure Pass ditch).	156
Pagosa Springs to reservation boundary runoff (76 mi^2)	9,530
(Mean annual precipitation of 21.0 inches produces 11.2 percent runoff.)	
TOTAL. . . .	304,688

Table 6.--*Computations of mean annual virgin flow, Stollsteimer Creek at study site 4*

Mean annual virgin flow	Acre-feet
Total mean annual virgin flow.	20,680
(Mean annual precipitation of 22.5 inches produces 13.9 percent runoff.)	

Study Site 5.--Piedra River at northern boundary of Southern Ute Indian Reservation

The Piedra River watershed above study site 5 is approximately 485 mi^2 (1,256 km^2) in area. Mean annual precipitation for the basin is about 33.0 inches (838 mm) with an areal range of from about 60 inches (1,524 mm) at the highest elevations to less than 20 inches (508 mm) at the lower elevations. Thirty-four years (1911-12, 1938-71) of streamflow records were available from the gaging station Piedra River near Piedra, Colo., (104, fig. 1) for virgin-flow computations for the 371-mi^2 (961-km^2) area above the gage. The virgin-flow contribution from the remaining 114-mi^2 (295-km^2) area was computed using the precipitation-runoff relationship established in figure 5.

The average annual irrigated acreage above the gage for the base time period was approximately 4,500 acres (1,820 ha). The consumptive-use factor for this acreage was estimated to be 0.7 acre-foot per acre (2,130 m^3/ha) irrigated. There are two transmountain diversions above the gaging station, the Piedra Pass ditch (202, fig. 1) and the Squaw Pass ditch (203, fig. 1), which divert water to the Rio Grande basin. A comparison of observed long-term flow records for 1911-12 and 1938-71 versus 1912-71 indicates that the mean annual flow for the shorter period is about 90 percent of the mean annual flow for the longer-term period. Virgin-flow computations are shown in table 7.

Study Site 6.--Los Pinos River at northern boundary of Southern Ute Indian Reservation

The Los Pinos River watershed above study site 6 is approximately 333 mi^2 (862 km^2) in area. Mean annual precipitation for the basin is about 39.1 inches (993 mm) with an areal range of from greater than 60 inches (1,524 mm) at higher elevations to less than 20 inches (508 mm) at lower elevations. Forty-four years (1927-71) of streamflow records were available from the gaging station Los Pinos River near Bayfield, Colo., (105, fig. 1) for virgin-flow computations for the 270-mi^2 (699-km^2) area above the gage. The virgin-flow contribution from the remaining 63-mi^2 (163-km^2) area was computed using the precipitation-runoff relationship established in figure 5.

The average annual irrigated acreage above the gage for the base time period was approximately 500 acres (200 ha). The consumptive-use factor for this acreage was estimated to be 1.0 acre-foot per acre (3,050 m^3/ha) irrigated. There are two transmountain diversions above the gaging station, the Fuchs ditch (204, fig. 1) and the Raber-Lohr ditch (205, fig. 1), which divert water to the Rio Grande basin. In addition, Vallecito Reservoir located upstream from the gaging station has regulated the flows of the Los Pinos River since the reservoir was constructed in 1941. The mean figure for historic annual flow which appears in the following table has been adjusted to account for storage changes in the reservoir plus the estimated annual evaporation loss of 3,100 acre-feet (3.82 hm^3). A comparison of observed long-term flow records for 1927-71 versus 1912-71 indicates that the mean annual flow for the shorter period was about 91 percent of the mean annual flow for the longer term period. Virgin-flow computations are shown in table 8.

Table 7.--*Computations of mean annual virgin flow, Piedra River at study site 5*

Mean annual virgin flow	Acre-feet
Mean annual historic flow at gage near Piedra, 1911-12, 1938-71.	225,300
Adjustment to historic flow to extend period of record (90 percent)	25,030
Irrigation use:	
a. Consumptive use on 4,500 acres, use factor of 0.7 . .	3,150
b. Incidental use, 12 percent.	378
Transmountain diversions:	
a. Piedra Pass ditch	64
b. Squaw Pass ditch.	170
Gage to reservation boundary runoff (114 mi^2).	26,320
(Mean annual precipitation of 24.6 inches produces 17.6 percent runoff.)	
TOTAL. . . .	280,412

Table 8.--*Computations of mean annual virgin flow, Los Pinos River at study site 6*

Mean annual virgin flow	Acre-feet
Mean annual historic flow at gage near Bayfield, 1927-71, adjusted for storage in Vallecito Reservoir since 1941 . . .	254,610
Adjustment to historic flow to extend period of record (91 percent)	25,180
Irrigation use:	
a. Consumptive use on 500 acres, use factor of 1.0 . . .	500
b. Incidental use, 12 percent.	60
Transmountain diversions:	
a. Raber-Lohr ditch.	1,210
b. Fuchs ditch	416
Gage to reservation boundary (63 mi^2).	13,960
(Mean annual precipitation of 24.3 inches produces 17.1 percent runoff.)	
TOTAL. . . .	295,936

Study Site 7.--Florida River at northern boundary of Southern Ute Indian Reservation

The Florida River watershed above study site 7 is approximately 134 mi^2 (347 km^2) in area. Mean annual precipitation for the basin is about 33.9 inches (861 mm) with an areal range of from about 60 inches (1,524 mm) at higher elevations to less than 20 inches (508 mm) at lower elevations. Forty-two years (1910-11, 1917-24, 1926-60) of streamflow records were available from the gaging station Florida River near Durango, Colo. (106, fig. 1) for virgin-flow computations for the 96-mi^2 (249-km^2) area above the gage. The virgin-flow contribution from the remaining 38-mi^2 (98-km^2) area was computed using the precipitation-runoff relationship established in figure 5.

The average annual acreage irrigated above the gage for the base time period was approximately 280 acres (110 ha). The consumptive-use factor for this acreage was estimated to be 1.1 acre-feet per acre (3,350 m^3/ha) irrigated. There is one out-of-basin diversion above the gage which diverts water to Durango. A comparison of observed long-term flow records for 1910-11, 1917-24, and 1926-60 versus 1912-71 indicates that the mean annual flow for the shorter period required no adjustment. Virgin-flow computations are shown in table 9.

Study Site 8.--Animas River at northern boundary of Southern Ute Indian Reservation

The Animas River watershed above study site 8 is approximately 786 mi^2 (2,036 km^2) in area. Mean annual precipitation for the basin is about 37.1 inches (942 mm) with an areal range of from greater than 60 inches (1,524 mm) at higher elevations to less than 20 inches (508 mm) at lower elevations. Sixty-six years (1896-1900, 1904-05, 1910-71) of streamflow records were available from the gaging station Animas River at Durango, Colo., (107, fig. 1) for virgin-flow computations for the 692-mi^2 (1,792-km^2) area above Durango. Twenty-two years (1927-49) of streamflow records were available at the gaging station Lightner Creek near Durango, Colo., (108, fig. 1) for virgin-flow computations for the 66 mi^2 (171 km^2) of the Animas River watershed below Durango and above the reservation boundary. The virgin-flow contribution from the remaining 28-mi^2 (73-km^2) area was computed using the precipitation-runoff relationship established in figure 5.

The average annual acreage irrigated above Durango for the base time period was approximately 4,000 acres (1,620 ha). Approximately 150 acres (60.7 ha) were irrigated above the Lightner Creek gage during the same period. The consumptive-use factor for this acreage was estimated to be 1.1 acre-feet per acre (3,350 m^3/ha) irrigated. There are no diversions out of the basin, and that water not consumed from the Florida River diversion returns to the Animas River below the Durango gage. The period of available streamflow record for the Animas River is of sufficient length that no flow adjustment was required. For the Lightner Creek records, a comparison of observed long-term flow records for 1927-49 versus 1912-71 indicated that the mean annual flow for the shorter period was about 97 percent of the mean annual flow for the longer term period. Virgin-flow computations are shown in table 10.

Table 9.--*Computations of mean annual virgin flow, Florida River at study site 7*

Mean annual virgin flow	Acre-feet
Mean annual historic flow at gage near Durango, 1910-11, 1917-24, 1926-60	79,640
Irrigation use:	
a. Consumptive use on 280 acres, use factor of 1.1 . . .	308
b. Incidental use, 12 percent.	37
Transbasin diversion to Durango.	4,500
Gage to reservation boundary runoff (38 mi^2)	7,810
(Mean annual precipitation of 23.8 inches produces 16.2 percent runoff.)	
TOTAL. . . .	92,295

Table 10.--*Computations of mean annual virgin flow, Animas River at study site 8*

Mean annual virgin flow	Acre-feet
Mean annual historic flow at Durango, 1896-1900, 1904-05, 1910-71.	610,800
Irrigation use above Durango:	
a. Consumptive use on 4,000 acres, use factor of 1.1 . .	4,400
b. Incidental use, 12 percent.	528
Mean annual historic flow at gage on Lightner Creek, 1927-49.	16,330
Adjustment to Lightner Creek historic flow to extend period of record (97 percent)	500
Irrigation use above gage on Lightner Creek:	
a. Consumptive use on 150 acres, use factor of 1.1 . . .	165
b. Incidental use, 12 percent.	20
Gage to reservation boundary runoff (28 mi^2)	1,880
(Mean annual precipitation of 18.5 inches produces 6.8 percent runoff.)	
TOTAL. . . .	634,623

Study Site 9.--La Plata River at northern boundary of Southern Ute Indian Reservation

The La Plata River watershed above study site 9 is approximately 41 mi^2 (106 km^2) in area. Mean annual precipitation for the basin is about 36.7 inches (932 mm) with an areal range of from greater than 50 inches (1,270 mm) at the higher elevations to about 20 inches (508 mm) at the lower elevations. Fifty-five years (1905-06, 1917-71) of streamflow records were available from the gaging station La Plata River at Hesperus, Colo., (109, fig. 1) for virgin-flow computations for the 37-mi^2 (95.8-km^2) area above Hesperus. The virgin-flow contribution from the remaining 4-mi^2 (10.4-km^2) area was computed using the precipitation-runoff relationship established in figure 5.

The average annual acreage irrigated above Hesperus for the base time period was approximately 590 acres (240 ha). The consumptive-use factor for this acreage was estimated to be 0.6 acre-foot per acre (1,830 m^3/ha) irrigated. There is one out-of-basin diversion above Hesperus which diverts water to the Cherry Creek drainage basin. A comparison of observed long-term flow records for 1905-06 and 1917-71 versus 1912-71 indicated that the mean annual flow for the shorter period was about 98 percent of the mean annual flow for the longer term period. Virgin-flow computations are shown in table 11.

Study Site 10.--Mancos River at northern boundary of Ute Mountain Ute Indian Reservation

The Mancos River watershed above study site 10 is approximately 167 mi^2 (433 km^2) in area. Mean annual precipitation for the basin is about 26.7 inches (678 mm) with an areal range of from about 50 inches (1,270 mm) at the higher elevations to less than 20 inches (508 mm) at the lower elevations. Twenty years (1931-51) of streamflow records were available for the Mancos River for virgin-flow computations. Seven years (1931-38) of records were available for the gaging station Mancos River near Mancos, Colo., (110, fig. 1); and 13 years (1938-51) of records were available for the gaging station West Mancos River near Mancos, Colo., (111, fig. 1), the gaging station East Mancos River near Mancos, Colo., (112, fig. 1), and the gaging station Middle Mancos River near Mancos, Colo., (113, fig. 1). The flow for the latter three gages combined to produce an equivalent flow of that measured at the Mancos River near the Mancos gage. Mean annual virgin flow for the 73-mi^2 (189-km^2) area above the Mancos River near the Mancos gage was determined from available records, while the virgin-flow contribution from the remaining 94-mi^2 (243-km^2) area was computed from the precipitation-runoff relationship established in figure 5.

The average annual acreage irrigated above the gage for the base time period was approximately 2,430 acres (980 ha). The consumptive-use factor for this acreage was estimated to be 1.4 acre-feet per acre (4,270 m^3/ha) irrigated. There were no diversions into or out of the basin above the gage. A comparison of observed long-term flow records for 1931-51 versus 1912-71 indicates the mean annual flow for the shorter period was about 97 percent of the mean annual flow for the longer period. From 1949 to 1951 the West Mancos River near Mancos was regulated by the Jackson Gulch Reservoir and the flow for these years was adjusted to account for changes in reservoir storage and reservoir evaporation. Virgin-flow computations are shown in table 12.

Table 11.--*Computations of mean annual virgin flow, La Plata River at study site 9*

Mean annual virgin flow	Acre-feet
Mean annual historic flow at Hesperus, 1905-06, 1917-71. . . .	32,530
Adjustment to historic flow to extend period of record (98 percent)	664
Irrigation use above Hesperus:	
a. Consumptive use on 590 acres, use factor of 0.6 . . .	354
b. Incidental use, 12 percent.	42
Transbasin diversion to Cherry Creek	2,400
Gage to reservation boundary runoff (4 mi^2).	750
(Mean annual precipitation of 23.2 inches produces 15.1 percent runoff.)	
TOTAL. . . .	36,740

Table 12.--*Computations of mean annual virgin flow, Mancos River at study site 10*

Mean annual virgin flow	Acre-feet
Mean annual historic flow at gage near Mancos, 1931-51	40,670
Adjustment to historic flow to extend period of record (97 percent)	1,260
Irrigation use above gage:	
a. Consumptive use on 2,430 acres, use factor of 1.4 . .	3,400
b. Incidental use, 12 percent.	408
Gage to reservation boundary runoff (94 mi^2)	7,560
(Mean annual precipitation of 19.1 inches produces 7.9 percent runoff.)	
TOTAL. . . .	53,298

Study Site 11.--San Juan River at Colorado-New Mexico State line at southern boundary of Ute Mountain Ute Indian Reservation

The San Juan River watershed above study site 11 is approximately 14,590 mi^2 (37,790 km^2) in area and is located in both the States of Colorado and New Mexico. Mean annual precipitation for the Colorado part is about 28.6 inches (726 mm), while for the New Mexico part it is less than 12 inches (305 mm). Forty-five years (1926-71) of streamflow records were available from the gaging station San Juan River at Shiprock, N. Mex., (114, fig. 1) for virgin-flow computations for the 12,900-mi^2 (33,411-km^2) area above Shiprock. Forty-three years (1920-43, 1951-71) of streamflow records were available from the gaging station Mancos River near Towaoc, Colo., (115, fig. 1) for virgin-flow computations for the 550-mi^2 (1,424-km^2) area above the gage. The virgin-flow computations from the remaining 1,140-mi^2 (2,953-km^2) area was computed using the precipitation-runoff relationship established in figure 5.

The average annual acreage irrigated above Shiprock for the base time period was approximately 100,000 acres (40,470 ha) in Colorado and 40,500 acres (16,400 ha) in New Mexico. The consumptive-use factor was estimated to be 1.0 acre-foot per acre (3,050 m^3/ha) irrigated for the Colorado acreage and 1.5 acre-feet per acre (4,570 m^3/ha) irrigated for the New Mexico acreage. Gaged flow of the San Juan River at Shiprock is reduced by five transmountain diversions and regulated primarily by the Navajo and Vallecito Reservoirs. Gaged flow of the Mancos River near Towaoc is regulated by the Jackson Gulch Reservoir. The mean annual historic flows for both rivers were adjusted to account for these diversions, changes in reservoir storage, and reservoir evaporation. Comparison of the observed long-term flow records for the period 1926-71 versus the period 1912-71 indicated that the mean annual flow for the shorter period was about 92 percent of the mean annual flow for the longer-term period. Comparison of the observed long-term flow records for the period 1920-43 and 1951-71 versus the period 1912-71 indicated the mean annual flow for the shorter period was about 95 percent of the mean annual flow for the longer-term period.

The ungaged area between the reservation boundary and the gaging stations at Shiprock and near Towaoc has a mean annual precipitation of approximately 9.7 inches (246 mm). According to the precipitation-runoff relationship of figure 5 those areas receiving less than 14.7 inches (373 mm) of annual precipitation will have losing streams; that is, natural streamflow losses are greater than streamflow gains. This ungaged area does contribute runoff to streamflow but the amount is a function of storm type, size, and intensity, and no measure of this runoff is readily available. However, average estimated natural channel losses have been computed for the river reaches of the San Juan from Shiprock to the Colorado-New Mexico State line and the Mancos from the gage near Towaoc to its mouth at the San Juan River. These estimates were computed by the Upper Colorado River Basin Compact Commission (1948) for 1914-45. These natural-loss estimates considered the inflows from this ungaged area and, therefore, integrated gains and losses from this region. For the determination of the response of this ungaged area, these natural-channel-loss estimates are considered representative for the base period 1912-71. Virgin-flow computations are shown in table 13.

Table 13.--*Computations of mean annual virgin flow, San Juan River at study site 11*

Mean annual virgin flow	Acre-feet
Mean annual historic flow at Shiprock, 1926-71	1,644,100
Adjustment to historic flow to extend period of record (92 percent)	142,970
Irrigation use above Shiprock:	
a. Consumptive use on	
1. 100,000 acres in Colorado, use factor of 1.0 . .	100,000
2. 40,500 acres in New Mexico, use factor of 1.5. .	60,750
b. Incidental use,	
1. Colorado, 12 percent	12,000
2. New Mexico, 22 percent	13,365
Mean annual historic flow at gage on Mancos River near Towaoc, 1920-43, 1951-71	36,400
Adjustment to Mancos historic flow to extend period of record (95 percent)	1,920
Irrigation use above gage near Towaoc:	
a. Consumptive use on 10,000 acres, use factor of 1.4. .	14,000
b. Incidental use, 12 percent.	1,680
Gage to reservation boundary channel losses for Mancos and San Juan Rivers.	(26,000)
TOTAL. . . .	2,001,185

WATER QUALITY

A water sample and an associated flow measurement were taken at each study site during the months of December 1972, and March, June, and August 1973. The measured streamflows at each of the sites for the four sampling dates are shown in table 14. All water samples were analyzed for pesticide concentrations and all samples except those taken on the Mancos River near Towaoc, Colo., were analyzed for chemical constituents and coliform bacteria count. The following are the results of these analyses.

Table 14.--*Streamflow measurements taken at each study site on the four sampling dates*

Study site	Streamflow, in ft^3/s			
	Dec. 18, 1972	Mar. 5, 1973	June 18, 1973	Aug. 13, 1973
1. Navajo River.	20	122	201	49
2. Rio Blanco.	27	45	290	18
3. San Juan River No. 1. .	145	224	2,520	188
4. Stollsteimer Creek. . .	13	85	21	4.1
5. Piedra River.	163	199	1,800	124
6. Los Pinos River	75	168	1,180	460
7. Florida River	21	45	147	8.5
8. Animas River.	395	490	3,650	628
9. La Plata River.	13	6.7	198	7.1
10. Mancos River.	32	[1]43	256	14
11. San Juan River No. 2. .	1,550	2,120	7,440	3,330
12. Mancos River near Towaoc.	23	100	230	2.5

[1]Measurement taken Mar. 6, 1973.

Pesticides

The pesticide analyses were made by two different laboratories. The December 1972 water-sample analyses were made by Controls for Environmental Pollution, Inc., Santa Fe, N. Mex., and their results are shown in table 15. The March, June, and August 1973 sample analyses were made by the U.S. Geological Survey, Austin, Tex. These samples were analyzed to detect the presence of the chlorinated hydrocarbon insecticides Aldrin, DDD, DDE, DDT, Dieldren, Endrin, Heptachlor, Heptachlor epoxide, Lindane, and Chlordane. The June water samples were additionally analyzed to detect the presence of the organic phosphate insecticides Parathion, Methyl parathion, Malathion, and Diazinon, and the chlorinated hydrocarbon herbicides 2,4-D, Silvex, and 2,4,5,-T. With the exception of the detection of 0.01 μg/l (microgram per litre) of DDT in the March sample from the Animas River, no pesticides were detected in any of the samples taken in the months of March, June, and August 1973.

Table 15.--*Pesticide analyses for water samples collected during December 1972*[1]

[Values are expressed as nanograms per litre (ng/l)]

Watershed	Benzene hexa-chloride	Lindane	Hepta-chlor	Aldrin	Hepta-chlor epoxide	Dieldrin	Endrin	DDT
1. Navajo.	10	<10	<15	10	15	30	100	45
2. Rio Blanco.	<15	<15	<15	<15	<15	<45	90	30
3. San Juan No. 1. . .	5	<15	<15	<15	15	40	85	55
4. Stollsteimer. . . .	<15	<15	<15	<15	<15	<50	<50	<50
5. Piedra.	<15	<15	10	5	<15	<50	95	20
6. Los Pinos	10	5	15	10	10	65	45	130
7. Florida	<15	<15	<15	<15	<15	<50	<50	30
8. Animas.	<100	<100	<100	<100	<100	<100	<100	<100
9. La Plata.	<40	<40	<40	<40	<40	<130	<130	25
10. Mancos.	<35	<35	<35	<35	70	110	110	70
11. San Juan No. 2. . .	<50	<50	<50	<50	<50	<150	<150	<150
12. Mancos near Towaoc.	<30	<30	<30	<30	<30	<95	<95	<95

[1]Analyses made by Controls for Environmental Pollution, Inc., Santa Fe, N. Mex.

In a 1972 report of the National Academy of Sciences-National Academy of Engineering Committee on Water Quality Criteria (U.S. Environmental Protection Agency, 1973, p. 76-79), recommendations were made on the limits of pesticide concentrations for public and farmstead water supplies. With the exception of DDD and DDE, recommendations were made for all the pesticides for which analyses were made in this study and these suggested limits are listed in table 16. With regard to DDD, McKee and Wolf (1963) stated that its mammalian toxicity is only about one-fifth that of DDT. Also, tests on the toxicity of DDD and DDE to birds are reported by Edwards (1973) and these results show that, in comparison to DDT, concentrations of 1.9 to 5.6 times greater DDD and 1.4 to 2.7 times greater DDE were required to obtain a toxicity level equal to that of DDT.

A comparison of the pesticide concentrations reported for all study sites with the recommended limits of table 16 shows that none of the samples equals or exceeds the suggested limits.

Table 16.--*Recommended limits of pesticide concentrations for public and farmstead water supplies*[1]

Pesticide	Recommended limit (μg/l)
Aldrin	1
Chlordane	3
DDT	50
Dieldren	1
Endrin	.5
Heptachlor	.1
Heptachlor epoxide	.1
Lindane	5
Organic phosphates	100
Herbicides:	
2,4-D	20
2,4,5-T	2
Silvex	30

[1] From U.S. Environmental Protection Agency, 1973.

Chemical Constituents

The chemical analyses were made by the Bureau of Indian Affairs' Soils Laboratory, Gallup, N. Mex. The results of these analyses on the four water samples collected at each study site are shown in table 17.

Table 17.--*Chemical quality of water samples collected at study sites 1-11 during water year 1973*[1]

[All constituents expressed as mg/l, except where noted]

Date of sample collection	Boron (B)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Phosphorus	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate	Total solids	Dissolved solids	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Alkalinity as $CaCO_3$	Soluble sodium percentage (SSP)	Sodium-adsorption-ratio (SAR)	Specific conductance (µmhos/cm at 25°C)	pH (units)	Irrigation class
STUDY SITE 1 - NAVAJO RIVER																							
Dec. 18, 1972	T	0.03	44	12	20	2.4	0.02	108	8	92	T	0.2	0.3	3,520	264	160	71	89	21	0.67	380	8.2	C2S1
Mar. 5, 1973	0.62	T	66	27	40	3.1	.02	132	T	245	11	.3	1.9	2,870	440	280	170	108	24	1.06	690	8.1	C2S1
June 18, 1973	.18	.12	28	6.1	16	.8	.03	68	4	73	T	.2	.6	306	188	95	39	56	27	.71	260	8.2	C2S1
Aug. 13, 1973	.08	T	38	11	12	2.7	T	109	10	52	T	.2	2.5	299	181	140	50	90	15	.43	340	8.2	C2S1
STUDY SITE 2 - RIO BLANCO																							
Dec. 18, 1972	T	.02	32	6.1	15	1.6	.02	101	10	41	3.6	.1	.2	2,450	173	100	22	83	23	.62	280	8.2	C2S1
Mar. 5, 1973	.40	.18	40	9.7	16	2.0	.03	121	T	73	4.6	.3	1.9	703	180	140	41	99	20	.57	330	8.3	C2S1
June 18, 1973	.18	.20	16	2.4	8.3	.1	.02	52	T	21	T	.1	.2	508	107	50	7	43	26	.51	120	7.9	C1S1
Aug. 13, 1973	T	T	28	6.1	11	2.0	T	96	8	34	T	.2	.2	189	124	95	16	79	20	.48	230	8.3	C1S1
STUDY SITE 3 - SAN JUAN RIVER NO. 1																							
Dec. 18, 1972	.90	.02	30	6.1	24	2.4	.02	92	T	80	3.6	.2	.2	2,840	198	100	25	75	34	1.03	310	8.1	C2S1
Mar. 5, 1973	.48	.05	46	13	23	3.1	T	118	T	110	9.6	.3	1.9	693	254	170	73	97	23	.77	430	8.2	C2S1
June 18, 1973	.04	.20	10	1.2	5.5	T	.02	29	T	20	T	T	.6	595	69	30	6	24	29	.44	80	7.7	C1S1
Aug. 13, 1973	T	T	28	6.1	152	2.4	T	96	T	44	T	.2	.1	214	208	95	16	79	27	.71	260	8.2	C2S1
STUDY SITE 4 - STOLLSTEIMER CREEK																							
Dec. 18, 1972	T	.02	72	23	20	1.6	.02	181	11	130	3.6	.2	.6	545	386	280	130	148	14	.52	590	8.3	C2S1
Mar. 5, 1973	.40	.02	44	19	12	2.0	T	146	T	91	9.6	.3	1.9	2,334	238	190	70	120	12	.38	410	8.3	C2S1
June 18, 1973	.11	T	72	29	29	.8	T	234	T	180	3.6	.3	1.9	510	494	300	110	192	18	.74	730	8.3	C2S1
Aug. 13, 1973	.28	T	62	29	32	2.4	T	181	10	158	T	.2	2.5	470	454	280	130	148	14	.83	640	8.2	C2S1
STUDY SITE 5 - PIEDRA RIVER																							
Dec. 18, 1972	T	.05	46	6.1	14	1.6	T	98	8	72	7.1	.2	.2	280	220	140	59	81	18	.52	340	8.2	C2S1
Mar. 5, 1973	.18	.06	56	8.5	15	2.4	T	113	12	87	8.9	.3	.6	327	214	180	82	93	16	.51	390	8.4	C2S1
June 18, 1973	.11	.20	16	1.2	5.1	.4	T	43	T	24	T	T	.2	524	71	45	9	36	20	.33	110	8.0	C1S1
Aug. 13, 1973	.14	T	50	6.1	16	2.4	T	110	8	71	T	.3	.2	462	248	150	59	91	19	.56	360	8.4	C2S1
STUDY SITE 6 - LOS PINOS RIVER																							
Dec. 18, 1972	T	.03	26	6.1	3.9	1.6	T	90	T	28	1.8	.2	.6	237	107	90	16	74	9	.18	190	8.1	C1S1
Mar. 5, 1973	.40	.05	26	3.6	3.9	1.2	T	83	T	19	4.6	.2	.6	136	102	80	12	68	10	.19	170	7.9	C1S1
June 18, 1973	.18	.03	16	1.2	2.8	.4	T	46	T	11	3.6	.2	.2	95	74	45	7	38	12	.18	100	7.9	C1S1
Aug. 13, 1973	T	T	14	2.4	2.3	T	T	41	T	18	T	.3	.1	96	92	50	16	34	1	.15	110	8.0	C1S1
STUDY SITE 7 - FLORIDA RIVER																							
Dec. 18, 1972	T	.02	60	11	7.4	1.2	T	182	17	38	3.6	.1	1.9	294	233	200	46	149	8	.23	380	8.3	C2S1
Mar. 5, 1973	.48	.02	60	9.7	8.7	1.6	T	162	12	42	9.6	.2	1.9	264	174	190	57	133	9	.28	370	8.2	C2S1
June 18, 1973	.04	.01	42	6.1	5.1	.8	T	118	8	12	8.9	.1	.6	168	156	130	33	97	8	.19	260	8.4	C2S1
Aug. 13, 1973	.28	T	40	13	20	2.0	T	195	12	23	1.8	.2	1.2	253	248	160	--	160	22	.70	410	8.2	C2S1
STUDY SITE 8 - ANIMAS RIVER																							
Dec. 18, 1972	T	.04	80	21	31	2.7	.02	141	12	200	18	.3	.6	566	437	150	36	116	19	.79	660	8.2	C2S1
Mar. 5, 1973	.26	T	82	15	23	3.1	T	150	10	150	26	.4	1.2	544	360	260	140	123	16	.61	600	8.4	C2S1
June 18, 1973	.04	.15	32	4.9	5.1	.4	T	70	T	55	T	.2	.6	506	148	100	42	58	10	.22	220	8.0	C1S1
Aug. 13, 1973	.63	T	60	7.3	16	2.7	T	101	8	100	11	.4	.2	307	286	180	97	83	16	.51	430	8.3	C2S1
STUDY SITE 9 - LA PLATA RIVER																							
Dec. 18, 1972	T	.02	38	7.3	4.4	.8	T	104	T	50	3.6	.2	.6	208	166	120	39	86	7	.17	250	8.1	C2S1
Mar. 5, 1973	.32	T	46	6.1	6.7	1.2	T	109	10	47	6.4	.4	.6	204	139	140	40	90	9	.25	300	8.4	C2S1
June 18, 1973	.11	.09	20	1.2	2.1	T	T	52	T	18	T	.2	.6	663	94	55	12	43	8	.12	130	8.0	C1S1
Aug. 13, 1973	.12	T	40	6.1	5.3	1.2	T	102	8	47	T	.3	.3	199	188	120	41	84	8	.21	270	8.3	C2S1
STUDY SITE 10 - MANCOS RIVER																							
Dec. 18, 1972	T	.02	150	92	83	1.2	T	204	21	680	12	.2	1.2	1,550	1,210	760	590	168	19	1.31	1,530	8.3	C3S1
Mar. 6, 1973	.06	T	170	79	106	6.6	T	186	20	710	18	.3	2.7	3,430	1,270	740	590	152	24	1.70	1,570	8.4	C3S1
June 18, 1973	.04	.07	52	16	19	1.2	T	92	T	140	T	.1	1.2	776	328	200	120	76	18	.6	460	8.0	C2S1
Aug. 13, 1973	.32	T	190	120	120	4.7	T	212	15	930	14	.2	1.2	2,050	1,780	940	770	174	22	1.74	2,030	8.2	C3S1
STUDY SITE 11 - SAN JUAN RIVER NO. 2																							
Dec. 18, 1972	T	T	72	17	47	2.7	.03	133	10	200	14	.3	2.5	2,660	435	250	140	109	29	1.30	660	8.3	C2S1
Mar. 5, 1973	.06	T	70	11	110	5.1	.05	132	21	280	24	.6	2.4	40,232	554	220	110	109	52	3.24	880	8.2	C3S1
June 18, 1973	.11	T	46	8.5	21	1.6	T	103	T	97	T	.3	.6	1,720	242	150	65	85	23	.73	380	8.1	C2S1
Aug. 13, 1973	T	T	48	9.7	26	.4	T	104	9	100	3.6	.2	.6	649	274	160	74	86	26	.89	430	8.5	C2S1

[1]Analyses conducted by the Bureau of Indian Affairs' Soils Laboratory, Gallup, N. Mex.

Apparent in all the analyses is the large seasonal fluctuation in the concentrations of all the constituents. Large snowmelt runoff volumes in the spring have a strong dilution effect on most of the constituents in the analyses. This results in low concentrations in the June and August samples and the highest concentrations in the low-flow period samples of December and March.

Of all the constituents listed in the chemical analyses only pH is presently limited by the State of Colorado's water-quality standards. The permissible pH range for all streams in the study area is from 6.0 to 9.0 (Colorado Dept. Health, 1974). This limit was not exceeded in any of the sample analyses.

Table 18 lists the U.S. Public Health Service drinking-water standards (U.S. Public Health Service, 1962) for those mineral components shown in the study sample analyses. A comparison of these standards with the sample analyses shows that the standards were only exceeded for the constituents of sulfate and dissolved solids. High concentrations of these constituents were found in the March sample on the lower San Juan River (Site 11) and the December, March, and August samples on the Mancos River (Site 10). Fluoride limits are not shown in table 18 because they are an inverse function of the annual average of maximum daily air temperature which varies greatly over the study area. However, none of the fluoride concentrations reported exceeded the upper limit of 0.8 mg/l, which is for areas with an annual average maximum daily air temperature of from 79.3° to 90.5°F (26.3° to 32.5°C).

Table 18.--*Limits of selected mineral components as given in the U.S. Public Health Service drinking water standards (1962)*

Substance	Concentration (mg/l)
Chloride (Cl)	250
Iron (Fe)	.3
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Dissolved solids.	500

The property of hardness is not attributable to any single chemical constituent and, therefore, in water-quality analyses hardness concentrations are reported in terms of an equivalent concentration of calcium carbonate. The terms "hard" and "soft," which describe the ranges of hardness concentrations, are used to qualitatively define a water-supply property which can make the supply objectionable for domestic use. Hem (1970) reports that for domestic water supplies objectionable levels of hardness are reached at concentrations of about 100 mg/l. However, in areas where waters are in contact with limestone or gypsum, hardness concentrations of 200 or 300 mg/l are common. The following hardness ranges were used by Durfor and Becker (1964) to classify "soft" and "hard" waters:

Hardness range (mg/l of $CaCO_3$)	*Description*
0-60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

Using this classification system, waters in the majority of the rivers sampled range from soft to moderately hard during the spring runoff season and from moderately hard to very hard during the remainder of the year.

The quality of the water samples with respect to irrigation use is given under the analysis heading "Class for irrigation water." C1, C2, C3, C4, and S1, S2, S3, S4 represent low, medium, high, and very high salinity and sodium hazards, respectively. These classifications are determined from a relationship between specific conductance and the SAR (sodium-adsorption-ratio) as published by the U.S. Salinity Laboratory Staff (1954). The classifications are used to rate the degree to which a particular water may give rise to salinity problems and undesirable ion-exchange effects (Hem, 1970). Classification of study-site samples indicated that all the rivers sampled had a low sodium hazard and all but the Mancos River had a low to medium salinity hazard. Water in the Mancos is classed as having a high salinity hazard.

Another basis for rating irrigation water is its boron concentration. Using boron-based irrigation-water classifications of the U.S. Salinity Laboratory (as reported in Hem, 1970), the irrigation-season samples of June and August for all rivers except the Animas rated as excellent for boron-sensitive, -semitolerant, and -tolerant crops. The 0.63 mg/l boron in the August sample of the Animas River rated it as good for boron-sensitive crops but excellent for boron-semitolerant and -tolerant crops.

Bacteria

The bacteriological analyses were conducted by the Bureau of Indian Affairs' Soil, Water, and Materials Testing Laboratory, Gallup, N. Mex. The results of these analyses on the four water samples collected at each study site are shown in tables 19 through 22. The results for the December 1972 and the June and August 1973 samples were obtained using the standard membrane-filter technique while the results for the March 1973 samples were obtained using the most-probable-number procedure (Am. Public Health Assoc., 1971).

The State of Colorado's water-quality standards for bacteria in the rivers sampled are stated as, "Bacteriological concentrations do not exceed a geometric mean of 10,000 total coliform groups or 1,000 fecal coliform groups per 100 millilitres based on a minimum of not less than five samples obtained during separate 24-hour periods for any 30-day period, nor do 10 percent of the fecal coliform samples exceed 2,000 groups per 100 millilitres during any 30-day period." (Colorado Dept. Health, 1974.) While the Colorado standards are stated in terms of means of several samples over a 30-day period, the analyses presented in tables 19 to 22 are only single-sample values. However, none of these sample values exceeded the Colorado standards for fecal or total coliform groups.

Table 19.--*Bacteriological analyses of water samples collected Dec. 18, 1972, at 11 study sites*

[Results are expressed as colonies per 100 ml of water][1]

Study site	Coliform group	Fecal streptococcal	Fecal coliform
1. Navajo River.	370	30	220
2. Rio Blanco.	140	60	<10
3. San Juan River No. 1.	3,700	20	225
4. Stollsteimer Creek.	40	30	<10
5. Piedra River.	40	<10	<10
6. Los Pinos River	2,200	125	185
7. Florida River	320	10	<10
8. Animas River.	6,100	520	235
9. La Plata River.	40	10	<10
10. Mancos River.	740	90	205
11. San Juan River No. 2.	1,140	710	100

[1]Analyses made by the Bureau of Indian Affairs' Soil, Water and Materials Testing Laboratory, Gallup, N. Mex.

Table 20.--*Bacteriological analyses of water samples collected Mar. 5 or 6, 1973, at 11 study sites*

[Results are expressed as colonies per 100 ml of water][1]

Study site	Most-probable-number (MPN) index
1. Navajo River.	[2]≥2,400
2. Rio Blanco.	[2]≥2,400
3. San Juan River No. 1.	[2]≥2,400
4. Stollsteimer Creek.	[2] 1,600
5. Piedra River.	33
6. Los Pinos River	49
7. Florida River	33
8. Animas River.	350
9. La Plata River.	13
10. Mancos River.	350
11. San Juan River No. 2.	[2]≥2,400

[1]Analysis made by the Bureau of Indian Affairs' Soil, Water, and Materials Testing Laboratory, Gallup, N. Mex.
[2]Sample contained a gross amount of mud.

Table 21.--*Bacteriological analyses of water samples collected June 18, 1973, at 11 study sites*

[Results are expressed as colonies per 100 ml of water][1]

Study site	Coliform group	Fecal coliform
1. Navajo River	280	80
2. Rio Blanco	250	<10
3. San Juan River No. 1	60	30
4. Stollsteimer Creek	<10	<10
5. Piedra River	<10	30
6. Los Pinos River	60	60
7. Florida River	95	80
8. Animas River	120	20
9. La Plata River	30	20
10. Mancos River	470	210
11. San Juan River No. 2	4,600	1,000

[1]Analyses made by the Bureau of Indian Affairs' Soil, Water, and Materials Testing Laboratory, Gallup, N. Mex.

Table 22.--*Bacteriological analyses of water samples collected Aug. 13, 1973, at 11 study sites*

[Results are expressed as colonies per 100 ml of water][1]

Study site	Coliform group	Fecal streptococcal	Fecal coliform
1. Navajo River	75	30	70
2. Rio Blanco	60	50	10
3. San Juan River No. 1	520	170	80
4. Stollsteimer Creek	50	20	10
5. Piedra River	20	30	10
6. Los Pinos River	180	100	110
7. Florida River	300	240	70
8. Animas River	130	20	20
9. La Plata River	360	80	260
10. Mancos River	800	370	400
11. San Juan River No. 2	2,400	40	600

[1]Analyses made by the Bureau of Indian Affairs' Soil, Water and Materials Testing Laboratory, Gallup, N. Mex.

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