ESTIMATION OF NATURAL STREAMFLOW IN THE JEMEZ RIVER AT THE BOUNDARIES OF INDIAN LANDS, CENTRAL NEW MEXICO

by Edward E. Fischer and John P. Borland

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Cover i

Upper--The Jemez River downstream from San Ysidro, looking south-southwest. Flow is from right to left.

Lower--Jemez Canyon Dam.

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Water Resources Division
505 Marquette NW, Room 720
Albuquerque, New Mexico 87102

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CONVERSION FACTORS

In this report, figures for measurements are given in inch-pound units only. The following table contains factors for converting to the International System of units (SI).

Multiply inch-pound units	By	To obtain SI units
foot	0.3048	meter
cubic foot per second	0.02832	cubic meter per second
mile	1.609	kilometer
acre-foot	1233	cubic meter
square mile	2.590	square kilometer
acre-foot per year	0.001233	cubic hectometer per year

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.

ESTIMATION OF NATURAL STREAMFLOW IN THE JEMEZ RIVER AT THE BOUNDARIES OF INDIAN LANDS, CENTRAL NEW MEXICO

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ABSTRACT

Natural streamflow in the Jemez River at the upstream boundary of the Jemez Reservation, at the Zia-Santa Ana Reservation boundary, and at the downstream boundary of the Santa Ana Reservation was estimated by using available streamflow records and adjusting them by adding estimated losses due to man-made changes within the river basin. Natural streamflow in the river at the Jemez-Zia Reservation boundary was estimated by streamflow-routing techniques. The estimated average annual natural streamflow (and associated estimated standard errors of estimate) in the Jemez River is 53,180 (5,300) acre-feet at the upstream Jemez Reservation boundary, 53,180 (5,300) acre-feet at the Jemez-Zia Reservation boundary, 55,440 (5,740) acre-feet at the Zia-Santa Ana Reservation boundary, and 46,550 (4,720) acre-feet at the downstream Santa Ana Reservation boundary. The contribution of the Rio Salado to the Jemez River is estimated to be 4,930 (2,610) acre-feet per year.

INTRODUCTION

The Jemez River is a stream in central New Mexico that drains more than 1,000 square miles of mountain and semi-desert terrain before joining the Rio Grande (fig. 1). Base flow of the river in the mountainous upper half of the basin is maintained by numerous thermal and mineral springs, making it a perennial stream. Below the mouth of the Rio Salado, the river bed is wide and sandy, and there are occasional periods of no flow.

There are three Indian reservations located within the lower river basin: the Jemez Reservation, the Zia Reservation and the Santa Ana Reservation. Historically, these Indian communities have been located along the river since before the arrival of the first Europeans. The Indians of all three communities have been successful farmers, using diverted surface

water for irrigation. Since the 1880's, the hydraulic characteristics of the drainage basin have been affected by several man-made changes in addition to those changes caused previously by irrigation diversions.

At the request of the U.S. Bureau of Indian Affairs, the U.S. Geological Survey conducted the present study to estimate natural streamflow in the Jemez River at the boundaries of the various Indian lands. Natural streamflow is defined as the streamflow that would occur if there had been no man-made changes in the hydraulic characteristics of the river basin.

The writers appreciate the work of Edward Thomas, chief of the computer section in the New Mexico District, in applying the robust statistical analysis techniques in the computer modeling discussed in Supplemental Information.

PREVIOUS STUDIES

One of the first hydrologic investigations undertaken in the Jemez River basin was by Renick (1931). The purpose of his study was to investigate the ground-water conditions along the Jemez River and other streams. In his report, he describes the river as it flows through the Indian lands:

> . . .[Within the Jemez Pueblo] a broad tract of alluvium borders Jemez Creek [Jemez River]. The Jemez Indians irrigate the bottom land adjacent to Jemez Creek, and are very sucessful in raising crops of hay, grain, beans, potatoes, truck, and fruit. It is estimated that they have about 3,000 acres under cultivation. There are two ditches for diverting the water from Jemez Creek, and these ditches are said to have been constructed before the white man came to this country.
>
> . . . . . .
>
> Jemez Creek flows diagonally southeastward across this grant [Zia Pueblo]. Its channel is about a quarter of a mile wide and in most places is sandy. Most of the water of Jemez Creek is diverted farther upstream by the Jemez Indians and by the residents of San Ysidro, and the Rio Salado generally contributes little. Owing to the scanty supply of water the Sia [Zia] Indians have only about 450 acres under ditch . . . .
>
> . . . . . .
>
> Jemez Creek flows southeastward across this township [which includes the Santa Ana Pueblo grant]. Its channel is filled with silt, sand, and some gravel, and in places it is almost half a mile wide. In this channel there is generally only a very small stream of water, except after heavy rains . . . Jemez Creek in all probability has considerable underflow, and it is very probable that supplies of ground water can be obtained by sinking wells into the alluvium at almost any place along the flood plain of the stream . . . .

Other studies have been made in the Jemez River basin since Renick's work. Conover, Theis, and Griggs (1963) made a study of the geology and hydrology of the northeastern part of the basin to determine the ground-water potential for additional water supplies for Los Alamos (fig. 1). Purtymun (1973) described the geology and geologic structure of a proposed geothermal-energy experimental site within the basin. Purtymun and others (1974) made a preliminary study of the water quality of the Jemez River and Rio Guadalupe to establish background data prior to the geothermal experiments. Trainer (1978) made a geohydrologic study of the region to provide background information for geothermal exploration and research and to investigate the usefulness of hydrology in assessment of the geothermal-resource potential of the region.

DATA USED

A list of streamflow-gaging stations in the Jemez River basin and the period of record at each station is given in table 1. The numbers in the first column of the table are keyed to the station locations depicted in figure 1. The streamflow records of three stations, Jemez River near Jemez (08324000), Jemez River above Jemez Canyon Dam (08328000), and Jemez River below Jemez Canyon Dam (08329000), were used in obtaining the estimates of natural flow.

Jemez Canyon Dam was completed in 1953, and from that time until 1979, the streamflow measured at the station Jemez River below Jemez Canyon Dam generally was the unregulated streamflow; water was not retained behind the dam for any appreciable length of time except during flood flows and for 3 months during the spring of 1958. Since March 1979, however, a permanent pool of several thousand acre-feet has been maintained behind the dam.

The daily values of measured streamflow at Jemez River near Jemez are rated "good." The daily values at Jemez River below Jemez Canyon Dam are rated "poor" before 1979, "fair" in 1979, and "good" since 1980. A rating of "good" means that about 95 percent of the daily values are within 10 percent of the stated values; a rating of "fair," within 15 percent; and a rating of "poor" means that the daily values have less than "fair" accuracy (U.S. Geological Survey, 1981). In this report, "poor" was defined as within 20 percent. These ratings of daily values were used to help determine the error in the estimated natural flows.

All annual values of streamflow in this report are for the water year. The water year is from October 1 to September 30.

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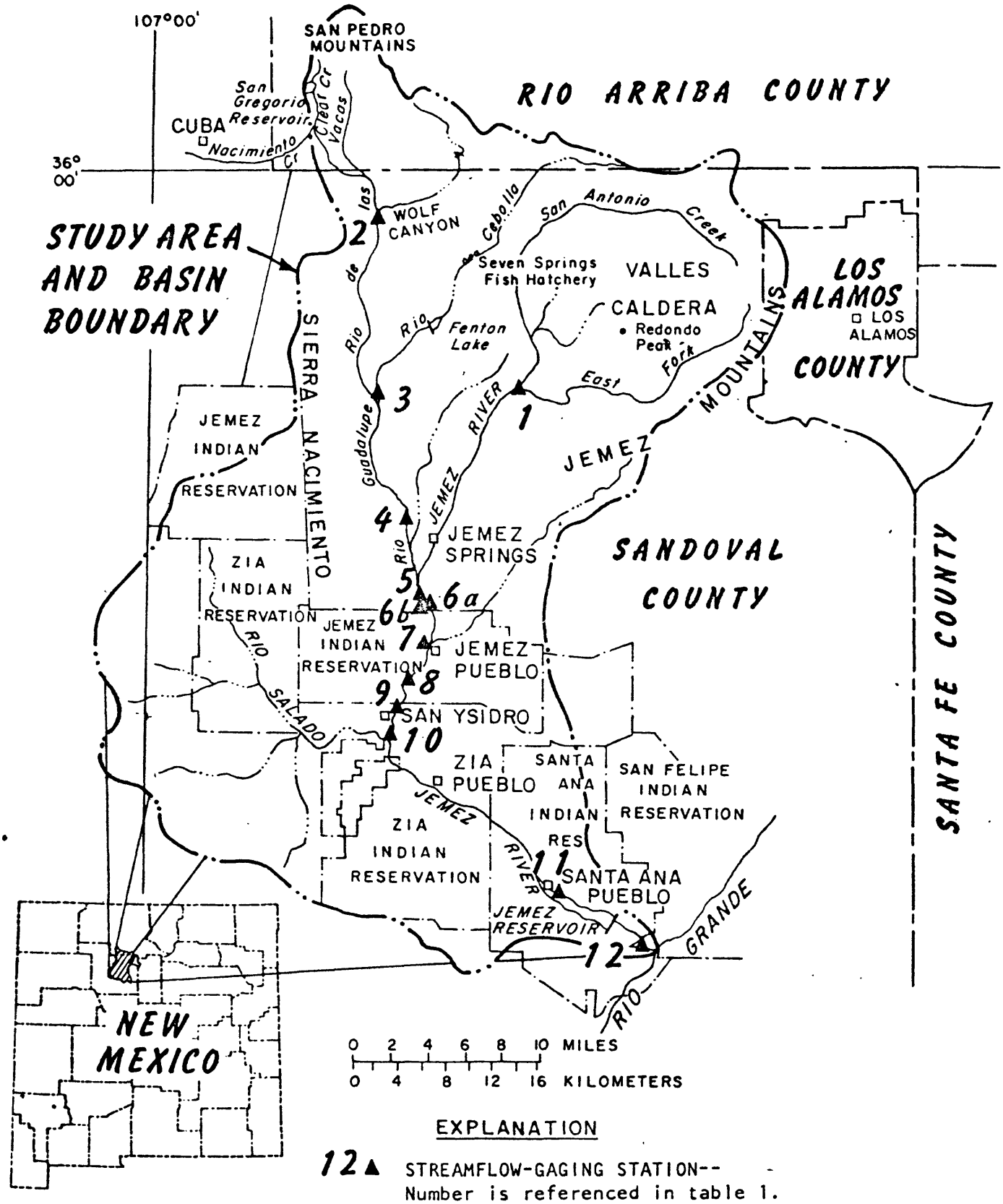

Figure 1.--Jemez River basin.

Table 1. Partial list of streamflow-gaging stations in the Jemez River basin, New Mexico.

Number in fig. 1	Station number	Station name	Drainage area, in square miles	Period of record
1	08321500	Jemez River below East Fork, near Jemez Springs	173	1951-57*, 1958-76
2	08322000	Rio Las Vacas [Rio de las Vacas] near Cuba	-	1939-41
3	08322500	Rio Cebolla near Jemez Springs	-	1939
4	08323000	Rio Guadalupe at Box Canyon, near Jemez	235	1951-76
5	08324000	Jemez River [Jemez Creek] near Jemez	470	1936-41, 1949-50, 1951-52*, 1953-current year
6a	08324500	Jemez east side ditch near Jemez	-	1936-41
6b	08325000	Jemez west side ditch near Jemez	-	1936-41
7	08325500	Antonio Pecos ditch near Jemez	-	1936-41
8	08326000	San Ysidro ditch near San Ysidro	-	1936-41
9	08326500	Jemez Creek [River] at San Ysidro	854	1937-41
10	08327000	Zia ditch near San Ysidro	-	1936-41
11	08328000	Jemez River above Jemez Canyon Dam	961	1953-58
12	08329000	Jemez River below Jemez Canyon Dam [Jemez Creek near Bernalillo]	1,038	1936-38, 1943-current year

*Irrigation seasons only.

METHOD OF STUDY

The methodology described below was employed in estimating natural streamflow in the Jemez River at the boundaries of Indian lands.

1. Man-made changes in the hydraulic characteristics of the Jemez River basin were identified.

2. Estimates of the water losses caused by the man-made changes were made.

3. Natural streamflow at the upstream boundary of the Jemez Reservation was estimated by adding the estimated losses upstream from the station Jemez River near Jemez to the streamflow measured at the station.

4. Natural streamflow at the Jemez-Zia Reservation boundary was estimated by routing the flow downstream from the upstream Jemez Reservation boundary.

5. Natural streamflow at the Zia-Santa Ana Reservation boundary was estimated by: (1) Correlating the streamflow measured at the station Jemez River above Jemez Canyon Dam with the streamflow measured at the station Jemez River below Jemez Canyon Dam; (2) using this correlation to estimate flow at Jemez River above Jemez Canyon Dam during periods of no record; and (3) adding the estimated losses upstream from the station to the streamflow at Jemez River above Jemez Canyon Dam.

6. Natural streamflow at the downstream boundary of the Santa Ana Reservation was estimated by adding the estimated losses upstream from the station Jemez River below Jemez Canyon Dam to the streamflow measured at the station.

Estimates of errors are given as the standard error of estimate. The average annual error in the estimates of natural flow at the upstream boundary of the Jemez Reservation and at the downstream boundary of the Santa Ana Reservation is discussed in a separate section later in the report. Estimates of errors in the estimated natural flow at the two intermediate boundaries are not provided.

Early in the study it was felt that there was a possibility that precipitation and temperature data collected in the upper basin could be correlated with runoff measured at the station Jemez River near Jemez to provide a predictor model for flow at the upstream Jemez Reservation boundary. To this end, statistical methods were applied to concurrent

monthly precipitation, temperature, and runoff data. However, no useful predictor was developed. The results are discussed in the computer modeling part of Supplemental Information.

MAN-MADE CHANGES IN THE BASIN THAT COULD AFFECT FLOW

The man-made changes in the basin that could affect streamflow in the Jemez River include irrigation diversions, an inter-basin diversion from the watershed, and the construction of four reservoirs. Each of the changes is considered in the following paragraphs.

Irrigation diversions

The amount of irrigated acreage has remained about the same since 1936 when the first streamflow records were collected within the basin. Approximately 300 acres are irrigated upstream from the gaging station Jemez River near Jemez, 2,200 acres upstream from Jemez River at San Ysidro, 3,000 acres upstream from Jemez River above Jemez Canyon Dam, and 3,000 acres upstream from Jemez River below Jemez Canyon Dam (U.S. Geological Survey, 1981).

Inter-basin diversion

In 1927, the Nacimiento Community Ditch Association obtained the right to 2,280 acre-feet of water per year to irrigate 1,180 acres of land near Cuba, New Mexico, by an inter-basin diversion. According to their application, the priority for the diversion was established between 1885 and 1890. In 1959, this water right was reduced to 2,068 acre-feet per year to irrigate 1,070 acres of land. This reduction was made to compensate for the estimated water loss due to evaporation from San Gregorio Reservoir, which was completed the previous year.

The water-rights license allows the Association to divert water from both the Rio de las Vacas and Clear Creek (fig. 2). Water diverted from the Rio de las Vacas is conveyed by Cuba Ditch to Clear Creek at a point upstream from the diversion on Clear Creek. Water diverted from Clear Creek is conveyed by the Nacimiento Community Ditch to Nacimiento Creek. Both ditches are earth channels hand dug in the mountainside; segments of Cuba Ditch are lined with stone masonry. The drainage area upstream from these diversions is 16.8 square miles.

During a field trip in the summer of 1981, it was observed that only Nacimiento Community Ditch was operating and that Cuba Ditch was in a state of disrepair. However, according to the Water Rights Bureau of the New Mexico State Engineer, the license to divert water from the Rio de las Vacas is still valid if the Association reactivates the canal. Both diversion sites were included within the boundaries of the San Pedro Parks Wilderness by the Wilderness Act of 1964.

Reservoirs

San Gregorio Reservoir

San Gregorio Dam was built across Clear Creek in 1958 to store water for the Nacimiento Community Ditch Association and to create a fishing lake for the New Mexico Department of Game and Fish (fig. 2). The capacity of the reservoir with the water level at the spillway crest is 254 acre-feet, of which 100 acre-feet is a dead storage pool for the Department of Game and Fish. The surface area at full capacity is 33 acres. The drainage area upstream from the reservoir is about 3 square miles. The reservoir was included within the boundaries of San Pedro Parks Wilderness in 1964.

The design and operation of San Gregorio Reservoir is such that during each spring, snowmelt is collected in the reservoir until it is full, after which additional water flows over the spillway. During the summer, water is released from the lake for diversion to Nacimiento Community Ditch.

Seven Springs State Fish Hatchery

Ponds for the Seven Springs State Fish Hatchery (fig. 1) were built in 1933 by the New Mexico Department of Game and Fish. Water for the hatchery is obtained from springs at the site and from a spring in a nearby canyon. Water from the hatchery empties into the Rio Cebolla. Prior to 1974, the total surface area of the several fish ponds was 13 acres; since that time, the surface area has been 12 acres. The total capacity of the ponds is 75 acre-feet, which was impounded prior to establishment of any streamflow-gaging stations on the Jemez River.

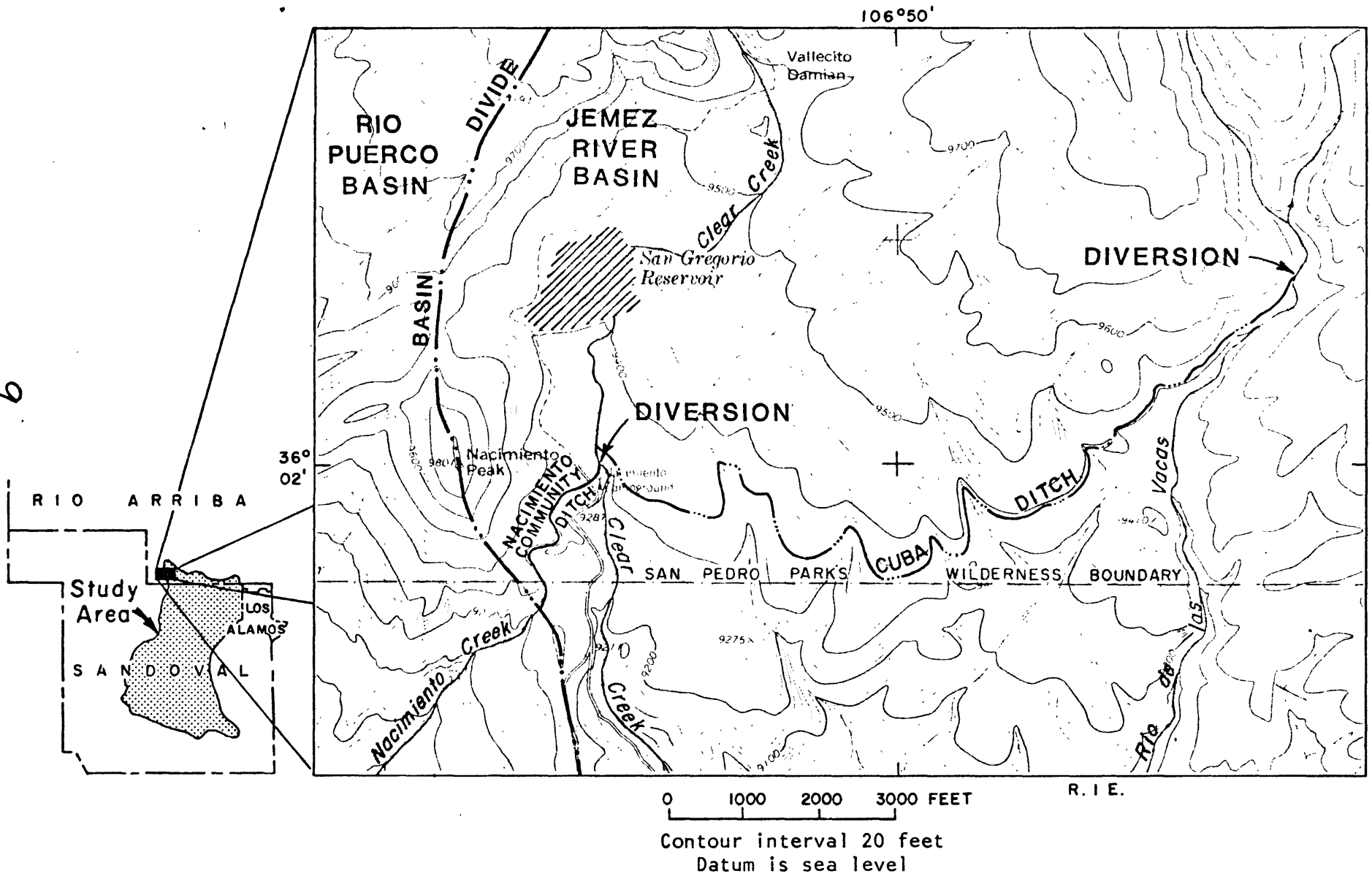

Figure 2.--Nacimiento Community Ditch Association diversion canals.

9

2 signatures enclosed (courtesy + base)

Fenton Lake

Fenton Lake was built on the Rio Cebolla in 1951 by the New Mexico Department of Game and Fish as a wildlife feeding and nesting area (fig. 1). It has also been used as a recreation area. A smaller lake apparently existed prior to 1951, but no information was found concerning it other than that a dam was destroyed during the spring runoff of 1941. The capacity of Fenton Lake is 255 acre-feet with a corresponding surface area of 33 acres.

Jemez Canyon Reservoir

Jemez Canyon Dam was completed in 1953 by the U.S. Army Corps of Engineers. The maximum capacity of the reservoir with water at the spillway crest is 106,100 acre-feet. The original plan for reservoir operation was to desilt all streamflows greater than 30 cubic feet per second by storage for 1 day before release to the Rio Grande, and for possible detention storage during periods of flood stage on the Rio Grande. However, since March 1979 a permanent pool of several thousand acre-feet has been maintained behind the dam.

WATER LOSSES DUE TO MAN-MADE CHANGES

Irrigation diversions

The following terms as defined by Blaney and Hanson (1965) are used in the discussion of water losses due to irrigation:

Consumptive use (evapotranspiration): The unit amount of water used on a given area in transpiration, building of plant tissue, and evaporated from adjacent soil, water surface, snow, or intercepted precipitation in any specified time.

Consumptive irrigation requirement: The depth of irrigation water, exclusive of precipitation, stored soil moisture, or ground water, that is required consumptively for crop production.

Irrigation efficiency: The percentage of irrigation water that is available for consumptive use.

The irrigation efficiency of diversions along the Jemez River is estimated to be between 30 and 50 percent (Israelson and Hansen, 1962). However, most of the water that is not used consumptively remains in the river basin and returns to the river, either as surface runoff or subsurface flow. Therefore, the water lost from the basin due to irrigation is equal to the consumptive irrigation requirement for the crops. To find the water lost upstream from a point along the river, the number of acres irrigated upstream is multiplied by the consumptive irrigation requirement. The consumptive irrigation requirement for crops along the Jemez River is 1.304 acre-feet per acre of irrigated land (Henderson and Sorensen, 1968). No error analysis was provided for the consumptive irrigation requirement, so a value of 10 percent or 0.1304 acre-foot per acre was assumed as the standard error of estimate. The assumed standard error of estimate in the number of acres irrigated was 10 percent.

Inter-basin diversion

Prior to 1959, the maximum allowable diversion from the river basin by the Nacimiento Community Ditch Assocation was 2,280 acre-feet per year. Since 1959, the maximum allowable diversion has been 2,068 acre-feet per year. Because of a lack of diversion records, the maximum diversion allowed was used in estimating the water taken from the drainage basin each year by the diversion. The standard error of estimate assumed was 10 percent, or 228 acre-feet per year before 1959 and 207 acre-feet per year thereafter.

Reservoirs

San Gregorio Reservoir, Seven Springs State Fish Hatchery, and Fenton Lake

The loss of water from the drainage basin attributed to the ponding of water is caused by evaporation. The estimated rate of evaporation at all three sites is 40 inches per year (Soil Conservation Service, 1972). Using this rate of evaporation, the loss from San Gregorio Reservoir is 110 acre-feet per year since 1958; from Seven Springs State Fish Hatchery, 43 acre-feet per year before 1974 and 40 acre-feet per year thereafter; and from Fenton Lake, 110 acre-feet per year since 1951. The standard error of estimate in evaporation estimates is about 20 percent (Winter, 1981), or 0.667 acre-foot per acre, and is applied to the total surface area of reservoirs existing in each year.

Another factor affecting natural flow is the initial filling of the reservoirs. Accordingly, 255 acre-feet were added to the totals in 1951 for the filling of Fenton Lake and 100 acre-feet (dead storage pool) were added to the totals in 1958 for the filling of San Gregorio Reservoir.

Jemez Canyon Reservoir

Before 1979, Jemez Canyon Reservoir was used only as a desilting and flood-retention reservoir so that no water was stored for extended periods. Losses due to ponding of water during that time were insignificant except possibly in 1958 when a pool was maintained for 3 months as a result of high streamflow in the Rio Grande. Losses for those 3 months, however, were not evaluated.

Since March 1979, a permanent pool has been maintained behind the dam. Evaporation estimates by the Corps of Engineers are 2,048 acre-feet in 1979 (water year), 1,552 acre-feet in 1980, and 1,844 acre-feet in 1981 (Corps of Engineers, written communication, 1982). The relative standard error of estimate is 20 percent (Winter, 1981).

"Losses" that were due to reservoir filling are 2,010 acre-feet in 1979, -420 acre-feet in 1980, and 390 acre-feet in 1981. These figures reflect the year-end change in storage from the previous year-end. The total estimated annual losses that were due to storage in Jemez Canyon Reservoir are summarized in table 2. The error figures are for evaporation only; estimates of error were not made for reservoir filling.

Table 2. Estimated annual water loss from the Jemez River basin due to storage in Jemez Canyon Reservoir.

[All values in acre-feet]

Water year	Estimated losses		Total losses	Standard error
	Evaporation	Reservoir filling		
1979	2,048	2,010	4,058	410
1980	1,552	-420	1,132	310
1981	1,844	390	2,234	369

NATURAL STREAMFLOW AT THE UPSTREAM BOUNDARY OF THE JEMEZ INDIAN RESERVATION

The estimated annual natural streamflow of the Jemez River at the upstream boundary of the Jemez Indian Reservation is presented in table 3. The natural flow was computed by adding the estimated losses upstream from the streamflow-gaging station Jemez River near Jemez to the flow measured at the station. The station is approximately 1 mile upstream from the reservation boundary. Water losses due to irrigation of 300 acres upstream from the station were estimated to be 391 acre-feet per year with a standard error of estimate of 39 acre-feet per year.

NATURAL STREAMFLOW AT THE JEMEZ-ZIA INDIAN RESERVATION BOUNDARY

From the point where the Jemez River leaves the Jemez Reservation, the river is a boundary of the Zia Reservation for about 3 miles before turning onto the reservation (fig. 1). An estimate of natural flow was made for the point at which the river leaves the Jemez Reservation.

A conclusive determination of whether the river is a gaining or losing stream as it flows through the Jemez Reservation could not be made. Comparison of the estimated natural flow at the streamflow-gaging station Jemez River at San Ysidro (table 4) with the estimated natural flow at the upstream Jemez Reservation boundary (table 3), based on 3 years of record, indicates that the river was a gaining stream for 2 years and a losing stream for 1 year (table 5). Two seepage investigations in February 1981 also did not yield a conclusive determination. (The results of the seepage investigations are presented in Supplemental Information, Seepage investigations.) In all likelihood, since the river bed is alluvium and the ground-water table is close to the surface in the flood plain (Renick, 1931), the natural flow in the river as it flows through the reservation is basically unchanged. Therefore, the estimate of natural flow in the Jemez River where it leaves the Jemez Reservation is considered to be the same as the estimated natural flow at the upstream Jemez Reservation boundary (table 3). The annual standard errors of estimation were not computed at this point; however, they would be greater than at the upstream boundary because of routing the flow downstream.

The Rio Salado joins the Jemez River near the point where the river turns into the Zia Reservation (fig. 1). As determined by the basin-characteristics formula (Borland, 1970), the average annual contribution of the Rio Salado to the flow in the Jemez River is 4,930 acre-feet. The standard error of estimate of flow in the Rio Salado is 53 percent, or 2,610 acre-feet per year.

Table 3. Estimated natural streamflow of the Jemez River at the upstream boundary of the Jemez Indian Reservation.

[All values in acre-feet]

Year	Jemez River near Jemez streamflow-gaging station		Estimated losses					Upstream Jemez Reservation boundary	
	Recorded streamflow	Standard error	Inter-basin Diversion	San Gregorio Reservoir	State Fish Hatchery	Fenton Lake	Irrigation	Estimated natural streamflow	Estimated standard error
1937	84,030	407	2,280	0	43	0	391	86,740	468
1938	53,200	201	2,280	0	43	0	391	55,910	316
1939	51,110	252	2,280	0	43	0	391	53,820	342
1940	39,040	161	2,280	0	43	0	391	41,750	291
1941	-	-	2,280	0	43	0	391	-	-
1942	-	-	2,280	0	43	0	391	-	-
1943	-	-	2,280	0	43	0	391	-	-
1944	-	-	2,280	0	43	0	391	-	-
1945	-	-	2,280	0	43	0	391	-	-
1946	-	-	2,280	0	43	0	391	-	-
1947	-	-	2,280	0	43	0	391	-	-
1948	-	-	2,280	0	43	0	391	-	-
1949	-	-	2,280	0	43	0	391	-	-
1950	22,960	83	2,280	0	43	0	391	25,670	255
1951	-	-	2,280	0	43	365	391	-	-
1952	-	-	2,280	0	43	110	391	-	-
1953	-	-	2,280	0	43	110	391	-	-
1954	27,320	99	2,280	0	43	110	391	30,140	253
1955	24,970	100	2,280	0	43	110	391	27,790	263
1956	25,790	111	2,280	0	43	110	391	28,610	258
1957	43,580	168	2,280	0	43	110	391	46,400	297
1958	130,200	886	2,280	0	43	110	391	133,000	916
1959	25,600	91	2,068	210	43	110	391	28,420	235
1960	52,740	257	2,068	110	43	110	391	55,460	336
1961	61,990	290	2,068	110	43	110	391	64,710	362
1962	60,560	310	2,068	110	43	110	391	63,280	378
1963	31,560	148	2,068	110	43	110	391	34,280	272
1964	25,820	103	2,068	110	43	110	391	28,540	240
1965	47,010	220	2,068	110	43	110	391	49,730	318
1966	39,500	162	2,068	110	43	110	391	42,220	280
1967	25,380	99	2,068	110	43	110	391	28,100	238
1968	61,080	286	2,068	110	43	110	391	63,800	368
1969	59,790	264	2,068	110	43	110	391	62,510	351
1970	50,880	184	2,068	110	43	110	391	53,600	284
1971	26,700	95	2,068	110	43	110	391	29,420	246
1972	33,060	124	2,068	110	43	110	391	35,780	259
1973	136,600	813	2,068	110	43	110	391	139,300	841
1974	26,970	96	2,068	110	40	110	391	29,690	237
1975	85,200	495	2,068	110	40	110	391	87,920	540
1976	25,610	82	2,068	110	40	110	391	28,330	241
1977	21,220	68	2,068	110	40	110	391	23,940	227
1978	45,230	190	2,068	110	40	110	391	47,950	288
1979	115,400	565	2,068	110	40	110	391	118,100	605
1980	73,880	384	2,068	110	40	110	391	76,600	450
1981	30,700	120	2,068	110	40	110	391	33,420	257

NOTE.--Streamflow data in this table were generated from daily values in the computer backfile. Annual values may vary slightly from those previously published.

Table 4. Estimated natural streamflow of the Jemez River at the streamflow-gaging station Jemez River at San Ysidro.

[All values in acre-feet]

Year	Streamflow at station Jemez River at San Ysidro	Estimated losses					Estimated natural streamflow at station Jemez River at San Ysidro
		Inter-basin Diversion	San Gregorio Reservoir	State Fish Hatchery	Fenton Lake	Irri-gation	
1938	54,880	2,280	0	43	0	2,870	60,070
1939	52,060	2,280	0	43	0	2,870	57,250
1940	35,110	2,280	0	43	0	2,870	40,300

Table 5. Difference in estimated natural flow at the upstream boundary of the Jemez Reservation and the streamflow-gaging station Jemez River at San Ysidro.

[All values in acre-feet]

Year	Estimated natural streamflow		Difference in streamflow
	Upstream Jemez Reservation boundary	Jemez River at San Ysidro	
1938	55,910	60,070	+4,160
1939	53,820	57,250	+3,430
1940	41,750	40,300	-1,450

NATURAL STREAMFLOW AT THE ZIA--SANTA ANA INDIAN RESERVATION BOUNDARY

An estimate of the natural flow in the Jemez River at the Zia-Santa Ana Reservation boundary was obtained by adding the estimated losses upstream from the streamflow-gaging station Jemez River above Jemez Canyon Dam to the streamflow measured at the station. The station is approximately 5 miles downstream from the boundary. Water losses due to irrigation of 3,000 acres upstream from the station were calculated to be 3,910 acre-feet per year.

Since there are only 5 years of record at this station, the record was correlated with the corresponding record at the station Jemez River below Jemez Canyon Dam, and the correlation was used to estimate flow during periods of no record. The regression equation obtained by the least-squares method is:

$$Q_A = 1.224(Q_B) + 94 \qquad (1)$$

where

Q_A = the streamflow measured at the station Jemez River above Jemez Canyon Dam; and

Q_B = the streamflow measured at the station Jemez River below Jemez Canyon Dam.

The estimated natural flow at the Zia-Santa Ana Reservation boundary is given in table 6. A standard error of estimate is not provided because there are only 5 years of record on which to estimate the natural flow.

NATURAL STREAMFLOW AT THE DOWNSTREAM BOUNDARY OF THE SANTA ANA INDIAN RESERVATION

The estimated annual natural streamflow of the Jemez River at the downstream boundary of the Santa Ana Indian Reservation is presented in table 7. The natural flow was computed by adding the estimated losses upstream from the streamflow-gaging station Jemez River below Jemez Canyon Dam to the flow measured at the station. The station is approximately 1 mile upstream from the reservation boundary (fig. 1). Water losses due to irrigation of 3,000 acres upstream from the station were calculated to be 3,910 acre-feet per year with a standard error of estimate of 391 acre-feet per year.

Table 6. Estimated natural streamflow of the Jemez River at the Zia-Santa Ana Reservation boundary.

[All values in acre-feet]

Year	Streamflow at Jemez River above Jemez Canyon Dam	Estimated losses					Estimated natural streamflow at Zia-Santa Ana Reservation boundary
		Inter-basin Diversion	San Gregorio Reservoir	State Fish Hatchery	Fenton Lake	Irri-gation	
1937	90,486*	2,280	0	43	0	3,910	96,720
1938	-	2,280	0	43	0	3,910	-
1939	-	2,280	0	43	0	3,910	-
1940	-	2,280	0	43	0	3,910	-
1941	-	2,280	0	43	0	3,910	-
1942	-	2,280	0	43	0	3,910	-
1943	-	2,280	0	43	0	3,910	-
1944	56,275*	2,280	0	43	0	3,910	62,510
1945	92,359*	2,280	0	43	0	3,910	98,590
1946	16,654*	2,280	0	43	0	3,910	22,890
1947	24,794*	2,280	0	43	0	3,910	31,030
1948	51,771*	2,280	0	43	0	3,910	58,000
1949	67,328*	2,280	0	43	0	3,910	73,560
1950	12,578*	2,280	0	43	0	3,910	18,810
1951	17,046*	2,280	0	43	365	3,910	23,640
1952	40,510*	2,280	0	43	110	3,910	46,850
1953	9,445*	2,280	0	43	110	3,910	15,790
1954	24,760	2,280	0	43	110	3,910	31,100
1955	25,630	2,280	0	43	110	3,910	31,970
1956	16,170	2,280	0	43	110	3,910	22,510
1957	41,620	2,280	0	43	110	3,910	47,960
1958	136,200	2,280	0	43	110	3,910	142,500
1959	34,366*	2,068	210	43	110	3,910	40,710
1960	58,637*	2,068	110	43	110	3,910	64,880
1961	65,051*	2,068	110	43	110	3,910	71,290
1962	53,754*	2,068	110	43	110	3,910	59,990
1963	25,687*	2,068	110	43	110	3,910	31,930
1964	18,833*	2,068	110	43	110	3,910	25,070
1965	46,985*	2,068	110	43	110	3,910	53,230
1966	36,654*	2,068	110	43	110	3,910	42,890
1967	38,417*	2,068	110	43	110	3,910	44,660
1968	63,191*	2,068	110	43	110	3,910	69,430
1969	69,139*	2,068	110	43	110	3,910	75,380
1970	53,178*	2,068	110	43	110	3,910	59,420
1971	17,315*	2,068	110	43	110	3,910	23,560
1972	22,946*	2,068	110	43	110	3,910	29,190
1973	157,990*	2,068	110	43	110	3,910	164,200
1974	19,751*	2,068	110	40	110	3,910	25,990
1975	102,138*	2,068	110	40	110	3,910	108,400
1976	18,013*	2,068	110	40	110	3,910	24,250
1977	17,413*	2,068	110	40	110	3,910	23,650
1978	45,161*	2,068	110	40	110	3,910	51,400
1979	122,494*	2,068	110	40	110	3,910	128,700
1980	83,680*	2,068	110	40	110	3,910	89,920
1981	23,252*	2,068	110	40	110	3,910	29,490

*--Determined from correlation with streamflow at Jemez River below Jemez Canyon Dam. See text for details.

Table 7. Estimated natural streamflow of the Jemez River at the downstream boundary of the Santa Ana Indian Reservation.

[All values in acre-feet]

Year	Jemez River below Jemez Canyon Dam streamflow-gaging station		Estimated losses						Downstream Santa Ana Reservation boundary	
	Recorded streamflow	Standard error	Inter-basin Diversion	San Gregorio Reservoir	State Fish Hatchery	Fenton Lake	Jemez Canyon Reservoir	Irri-gation	Estimated natural streamflow	Estimated standard error
1937	73,850	797	2,280	0	43	0	0	3,910	80,080	926
1938	-	-	2,280	0	43	0	0	3,910	-	-
1939	-	-	2,280	0	43	0	0	3,910	-	-
1940	-	-	2,280	0	43	0	0	3,910	-	-
1941	-	-	2,280	0	43	0	0	3,910	-	-
1942	-	-	2,280	0	43	0	0	3,910	-	-
1943	-	-	2,280	0	43	0	0	3,910	-	-
1944	45,900	486	2,280	0	43	0	0	3,910	52,130	664
1945	75,380	969	2,280	0	43	0	0	3,910	81,610	1,070
1946	13,530	135	2,280	0	43	0	0	3,910	19,760	472
1947	20,180	214	2,280	0	43	0	0	3,910	26,410	510
1948	42,220	558	2,280	0	43	0	0	3,910	48,450	728
1949	54,930	735	2,280	0	43	0	0	3,910	61,160	863
1950	10,200	122	2,280	0	43	0	0	3,910	16,430	478
1951	13,850	284	2,280	0	43	365	0	3,910	20,450	535
1952	33,020	395	2,280	0	43	110	0	3,910	39,360	611
1953	7,640	67	2,280	0	43	110	0	3,910	13,980	468
1954	20,170	348	2,280	0	43	110	0	3,910	26,510	581
1955	19,740	235	2,280	0	43	110	0	3,910	26,080	520
1956	13,280	180	2,280	0	43	110	0	3,910	19,620	488
1957	35,050	350	2,280	0	43	110	0	3,910	41,390	582
1958	111,000	1,860	2,280	0	43	110	0	3,910	117,300	1,910
1959	28,000	394	2,068	210	43	110	0	3,910	34,340	604
1960	47,830	507	2,068	110	43	110	0	3,910	54,070	684
1961	53,070	599	2,068	110	43	110	0	3,910	59,310	746
1962	43,840	705	2,068	110	43	110	0	3,910	50,080	843
1963	20,910	243	2,068	110	43	110	0	3,910	27,150	507
1964	15,310	173	2,068	110	43	110	0	3,910	21,550	487
1965	38,310	395	2,068	110	43	110	0	3,910	44,550	595
1966	29,870	357	2,068	110	43	110	0	3,910	36,110	580
1967	31,310	510	2,068	110	43	110	0	3,910	37,550	677
1968	51,550	558	2,068	110	43	110	0	3,910	57,790	723
1969	56,410	560	2,068	110	43	110	0	3,910	62,650	725
1970	43,370	544	2,068	110	43	110	0	3,910	49,610	703
1971	14,070	138	2,068	110	43	110	0	3,910	20,310	466
1972	18,670	226	2,068	110	43	110	0	3,910	24,910	499
1973	129,000	1,680	2,068	110	43	110	0	3,910	135,200	1,740
1974	16,060	159	2,068	110	40	110	0	3,910	22,300	482
1975	83,370	1,060	2,068	110	40	110	0	3,910	89,610	1,150
1976	14,640	122	2,068	110	40	110	0	3,910	20,880	471
1977	14,150	138	2,068	110	40	110	0	3,910	20,390	466
1978	36,820	370	2,068	110	40	110	0	3,910	43,060	579
1979	100,000	847	2,068	110	40	110	4,058	3,910	110,300	1,040
1980	68,290	417	2,068	110	40	110	1,132	3,910	75,660	684
1981	18,920	202	2,068	110	40	110	2,234	3,910	27,390	622

NOTE.--Streamflow data in this table were generated from daily values in the computer backfile. Annual values may vary slightly from those previously published.

COMPUTATION OF TOTAL ERROR IN THE ESTIMATES OF NATURAL FLOW AT THE UPSTREAM BOUNDARY OF THE JEMEZ INDIAN RESERVATION AND AT THE DOWNSTREAM BOUNDARY OF THE SANTA ANA INDIAN RESERVATION

The error associated with the estimation of natural flow is considered to have a Gaussian (normal) distribution. One measure of this error is the standard error of estimation, s. By definition, then, the likelihood that the true value of a particular component is within one standard error of the estimated value (the confidence interval) is 68 percent. The various components used to estimate natural flow are independent of each other; therefore, the standard error of estimate of natural flow is the square root of the sum of the squares of the several standard errors of estimate (Hogg and Tanis, 1977). In equation form, it appears as:

$$s_N = \sqrt{(s_M)^2 + (s_D)^2 + (s_E)^2 + (s_I)^2} \qquad (2)$$

where

s_N = the standard error of estimate of estimated annual natural flow;

s_M = the standard error of estimate of annual measured streamflow at a gaging station;

s_D = the standard error of estimate of the inter-basin diversion;

s_E = the standard error of estimate of reservoir evaporation; and

s_I = the standard error of estimate of irrigation diversions.

The percentage errors associated with the ratings of daily values at the stations Jemez River near Jemez and Jemez River below Jemez Canyon Dam ("good" = 10 percent, "fair" = 15 percent, "poor" = 20 percent) reflect a confidence interval of 95 percent. The standard error of estimate, s_M , of the annual measured streamflows was found by first dividing the percentages by 1.96 to obtain the standard error for the daily values (Hogg and Tanis, 1977), summing the squares of the daily value errors, and finding the square root of the sum.

The standard error of estimate for evaporation losses, s_E, was applied to the total surface area of the reservoirs existing in any one year.

The standard error of estimate for irrigation was determined from a combination of the standard error in the consumptive irrigation requirement and the number of acres irrigated according to the following formula (Karlin and Taylor, 1975):

$$s_I = \sqrt{(A)(s_{CIR})^2 + (CIR)^2(s_A)^2} \qquad (3)$$

where

s_I = the standard error of estimation for irrigation;

A = the number of acres irrigated;

s_{CIR} = the standard error of estimate of CIR;

CIR = the consumptive irrigation requirement; and

s_A = the standard error of estimate of A.

[Note on the units of $(s_{CIR})^2$ in equation 3: The consumptive irrigation requirement is the mean of the average amount of irrigation water required by an acre of crops. The units of the CIR and its standard error of estimate, s_{CIR}, are acre-feet per acre. But, as a consequence of this average of an average, the units of $(s_{CIR})^2$ in equation 3 are (acre-feet)^2 per acre (Lindgren, 1960).]

The calculation of the standard error in natural flow at the upstream boundary of the Jemez Reservation in 1937 is provided as an example. For 1937, the standard errors, in acre-feet, of the various components are s_M = 407, s_D = 228, s_E = 8.6, and s_I = 39. The fish hatchery was the only reservoir at that time; s_I was calculated by equation 3 for A = 300 acres, s_A = 30 acres, CIR = 1.304 acre-feet per acre, and s_{CIR} = 0.1304 acre-foot per acre. Substitution of these values into equation 2 yields a standard error of estimate of 468 acre-feet.

STATISTICS OF THE ESTIMATED ANNUAL NATURAL STREAMFLOW AT THE BOUNDARIES OF INDIAN LANDS

The estimated annual natural streamflow at each of the boundaries of Indian lands is compiled in table 8. Statistics of the estimated natural streamflow at each of the boundaries are given in figure 3. Each statistic is explained in the following paragraphs.

Table 8. Estimated natural streamflow in the Jemez River at Indian reservation boundaries.

[All values in acre-feet]

Year	Upstream Jemez Reservation boundary		Jemez-Zia Reservation boundary	Zia-Santa Ana Reservation boundary	Downstream Santa Ana Reservation boundary	
	Estimated natural streamflow	Estimated standard error	Estimated natural streamflow	Estimated natural streamflow	Estimated natural streamflow	Estimated standard error
1937	86,740	468	86,740	96,720	80,080	926
1938	55,910	316	55,910	-	-	-
1939	53,820	342	53,820	-	-	-
1940	41,750	291	41,750	-	-	-
1941	-	-	-	-	-	-
1942	-	-	-	-	-	-
1943	-	-	-	-	-	-
1944	-	-	-	62,510	52,130	664
1945	-	-	-	98,590	81,610	1,070
1946	-	-	-	22,890	19,760	472
1947	-	-	-	31,030	26,410	510
1948	-	-	-	58,000	48,450	728
1949	-	-	-	73,560	61,160	863
1950	25,670	255	25,670	18,810	16,430	478
1951	-	-	-	23,640	20,450	535
1952	-	-	-	46,850	39,360	611
1953	-	-	-	15,790	13,980	468
1954	30,140	253	30,140	31,100	26,510	581
1955	27,790	263	27,790	31,970	26,080	520
1956	28,610	258	28,610	22,510	19,620	488
1957	46,400	297	46,400	47,960	41,390	582
1958	133,000	916	133,000	142,500	117,300	1,910
1959	28,420	235	28,420	40,710	34,340	604
1960	55,460	336	55,460	64,880	54,070	684
1961	64,710	362	64,710	71,290	59,310	746
1962	63,280	378	63,280	59,990	50,080	843
1963	34,280	272	34,280	31,930	27,150	507
1964	28,540	240	28,540	25,070	21,550	487
1965	49,730	318	49,730	53,230	44,550	595
1966	42,220	280	42,220	42,890	36,110	580
1967	28,100	238	28,100	44,660	37,550	677
1968	63,800	368	63,800	69,430	57,790	723
1969	62,510	351	62,510	75,380	62,650	725
1970	53,600	284	53,600	59,420	49,610	703
1971	29,420	246	29,420	23,560	20,310	466
1972	35,780	259	35,780	29,190	24,910	499
1973	139,300	841	139,300	164,200	135,200	1,740
1974	29,690	237	29,690	25,990	22,300	482
1975	87,920	540	87,920	108,400	89,610	1,150
1976	28,330	241	28,330	24,250	20,880	471
1977	23,940	227	23,940	23,650	20,390	466
1978	47,950	288	47,950	51,400	43,060	579
1979	118,100	605	118,100	128,700	110,300	1,040
1980	76,600	450	76,600	89,920	75,660	684
1981	33,420	257	33,420	29,490	27,390	622

STREAMFLOW, IN ACRE-FEET PER YEAR

LOCATION	NUMBER OF YEARS OF RECORD	MEDIAN ANNUAL NATURAL STREAMFLOW	MEAN ANNUAL NATURAL STREAMFLOW	STANDARD ERROR OF THE MEAN	AVERAGE ANNUAL ERROR OF ESTIMATION
Upstream boundary of Jemez Reservation	33	46,400	53,180	5300	376
Jemez-Zia Reservation boundary	33	46,400	53,180	5300	-
Zia-Santa Ana Reservation boundary	39	46,850	55,440	5740	-
Downstream boundary of Santa Ana Reservation	39	39,360	46,550	4720	821

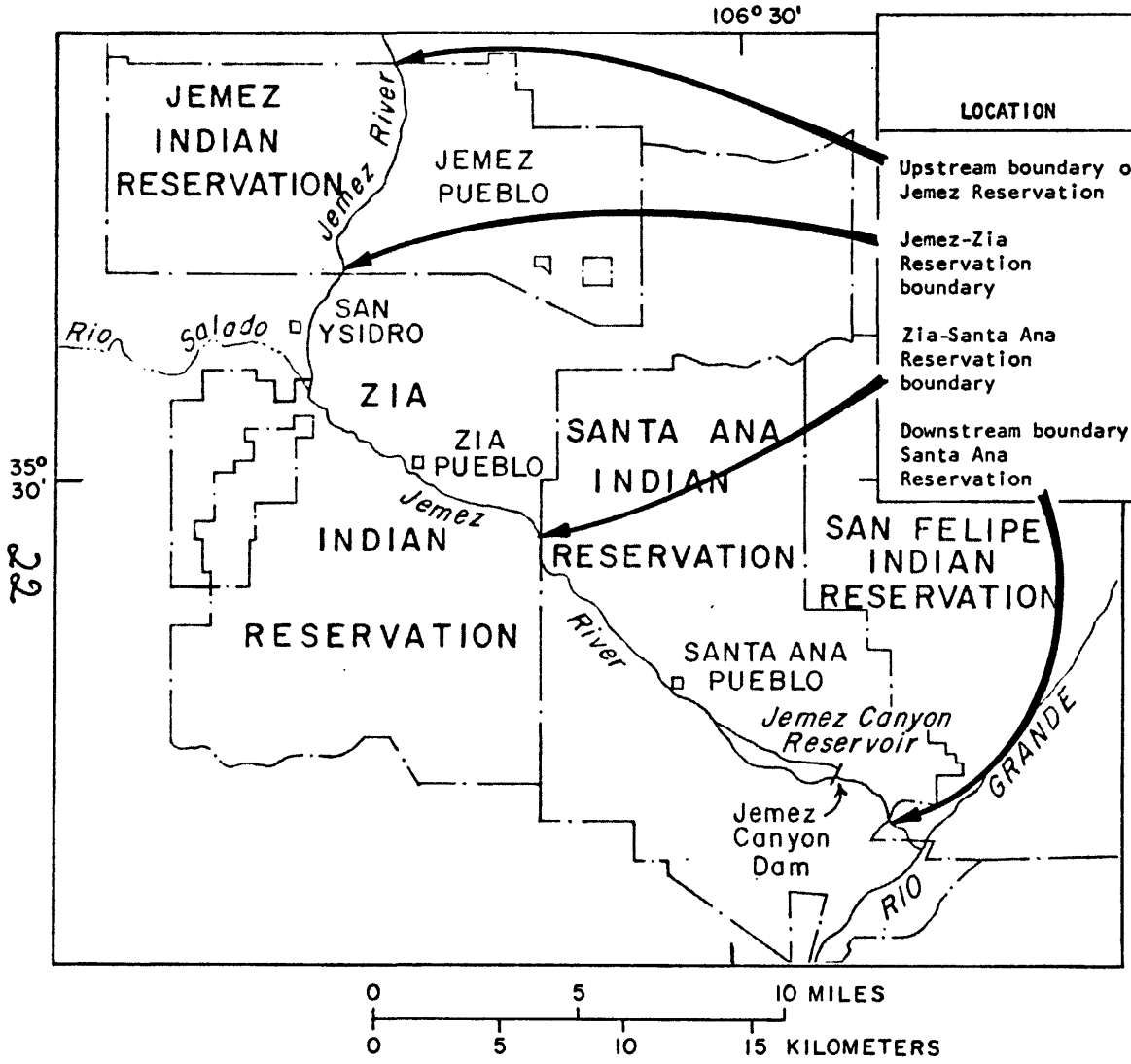

Figure 3.--Median and mean annual natural streamflow in the Jemez River at the boundaries of Indian lands.

2 negatives included (overlay + base)

The median natural streamflow is a measure of position and is the value of streamflow that is just as likely to be exceeded in any one year as not. It was obtained by ordering the annual estimates by magnitude and choosing the middle value. (If there is an even number of values, the median is the average of the two middle values.)

The mean natural streamflow is a measure of the average quantity of water flowing past a point each year. It was obtained by summing the annual natural streamflows and dividing by the number of years for which estimates were provided. The standard error of the mean is a measure of the variability of the annual natural streamflow around the mean natural streamflow.

The average annual error of estimation is an approximate measure of the error in computing natural streamflow from the several components. It was obtained by: (1) Dividing the error for each year by the natural streamflow for that year to obtain a relative error; (2) averaging the relative errors; and (3) multiplying the mean streamflow by the average relative error.

SUMMARY

The annual natural streamflow in the Jemez River at the boundaries of Indian lands was estimated based on existing streamflow records and estimated water losses due to man-made changes in the hydraulic characteristics of the river basin. Thirty-three years of natural flow were estimated at the upstream Jemez Reservation boundary and at the Jemez-Zia Reservation boundary. Thirty-nine years of natural flow were estimated at the Zia-Santa Ana Reservation boundary and at the downstream Santa Ana Reservation boundary.

Errors in the annual natural streamflow were estimated for the upstream Jemez Reservation boundary and the downstream Santa Ana Reservation boundary. Errors were not provided at the Jemez-Zia Reservation or Zia-Santa Ana Reservation boundaries; however, the errors were greater than the errors at the other two boundaries from which the estimates of natural streamflow were derived.

The median natural streamflow, the mean natural streamflow, and the standard error of the mean natural streamflow were determined for all four boundaries. The analysis also provided the average annual error of estimation of natural streamflow at the upstream Jemez Reservation boundary and at the downstream Santa Ana Reservation boundary.

The contribution of the Rio Salado to flow in the Jemez River was estimated from the basin-characteristics formula.

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SUPPLEMENTAL INFORMATION

Seepage investigations

A seepage investigation is a set of streamflow measurements taken at several points along a river. The various measurements are compared, and a determination is made of the amount of water lost or gained by the river between each point.

Two seepage investigations were made during February 1981 on the Jemez River from the streamflow-gaging station Jemez River near Jemez to upstream from the Santa Ana Pueblo bridge, a distance of about 24 river miles, in an attempt to determine the gains and losses in streamflow through this reach. The results of the runs, however, were inconclusive because of unsteady flow conditions in the stream. The data are presented in table 9.

Table 9. Seepage-investigation data obtained for the Jemez River between the streamflow-gaging station Jemez River near Jemez and the Santa Ana Pueblo.

River mile	Location	Discharge measurements, in cubic feet per second	
		Feb. 20, 1981	Feb. 24, 1981
29.9	Jemez River near Jemez, New Mexico (streamflow-gaging station)	32.2	30.0
29.4	Jemez River at Jemez Valley High School	-	27.7
27.5	Jemez River upstream from Vallecito Creek	37.1	26.2
-	Vallecito Creek upstream from Hwy 4 bridge	0.38	0.67
25.9	Jemez River downstream from sewage ponds for Jemez Pueblo	34.7	28.4
22.9	Jemez River upstream from Hwy 4 bridge	35.5	30.0
22.9	Jemez River downstream from Hwy 4 bridge	-	31.6
-	Rio Salado upstream from Hwy 44 bridge	0.29	0.03
19.4	Jemez River downstream from Rio Salado	41.0	31.9
15.0	Jemez River upstream from Zia Pueblo bridge	38.0	43.0
6.0	Jemez River upstream from Santa Ana Pueblo bridge	35.9	39.1

Computer modeling

The runoff data at the streamflow-gaging station Jemez River near Jemez have been collected continuously since 1953; concurrent temperature and precipitation data were recorded by the National Weather Service at Wolf Canyon (fig. 1). Robust statistical methods (Huber, 1981) were applied to these data using optimization procedures suggested by Dorney (1975). The predictor equation that resulted seemed to predict runoff accurately for the spring months (April - June); however, it performed no better than the monthly mean runoff as an estimate of runoff during the other 9 months. Overall, when one considers that a large percentage of runoff occurs in the spring, the predictor did not perform badly, which indicates that the model has some merit; but, it also indicates it is not capable of resolving the hydrologic complexities of the study area.

Much of the inadequacy of the model stems from the fact that the estimation of runoff from a fairly large basin was based on temperature and precipitation data from only one station. This approach is especially inadequate in the summer when precipitation is very localized. It would be more appropriate to consider a model where the drainage basin has been divided into homogeneous hydrologic units and the input of each unit into the entire system considered in turn. Computer modeling of this sophistication, however, was beyond scope of this study.