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FLOOD AND RECHARGE RELATIONSHIPS OF THE LOWER RIO PUERCO NEW MEXICO

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INTRODUCTION

The Rio Puerco, largest of the New Mexico tributaries to the Rio Grande, drains a watershed area of 7,350 mi2 (19,040 km') in the northwest quadrant of the state (fig. 1). This region includes parts of the Colorado Plateau, Basin and Range, and Southern Rocky Mountain physiographic provinces. From its source 10,500 ft (3200 m) above sea level in Sandoval County, the Rio Puerco flows southward for about 170 river miles (274 km) through a varied landscape of steep canyons, narrow alluvial valleys and sloping mesas to join the Rio Grande near the community of Bernardo.

The gradient of the Rio Puerco is about 78 ft/mi (14.8 m/km) in the reach above the confluence with Arroyo Chico, 13 ft/mi (2.5 m/km) to the confluence with the Rio San Jose and about 8 ft/mi (1.5 m/km) to its mouth at the Rio Grande. Annual precipitation in its basin ranges from an average of 7 in. (180 mm) in the lower elevations to over 17 in. (430 mm) in the mountainous areas. Much of the rainfall, which occurs as a result of convective thunderstorms from July through October, produces rapid runoff, flash flooding and severe erosion. The river is notorious for its high concentrations of suspended sediment, and is a major contributor to sediment deposition in the middle Rio Grande valley from San Acacia to Elephant Butte Reservoir, 80 mi (129 km) from its mouth.

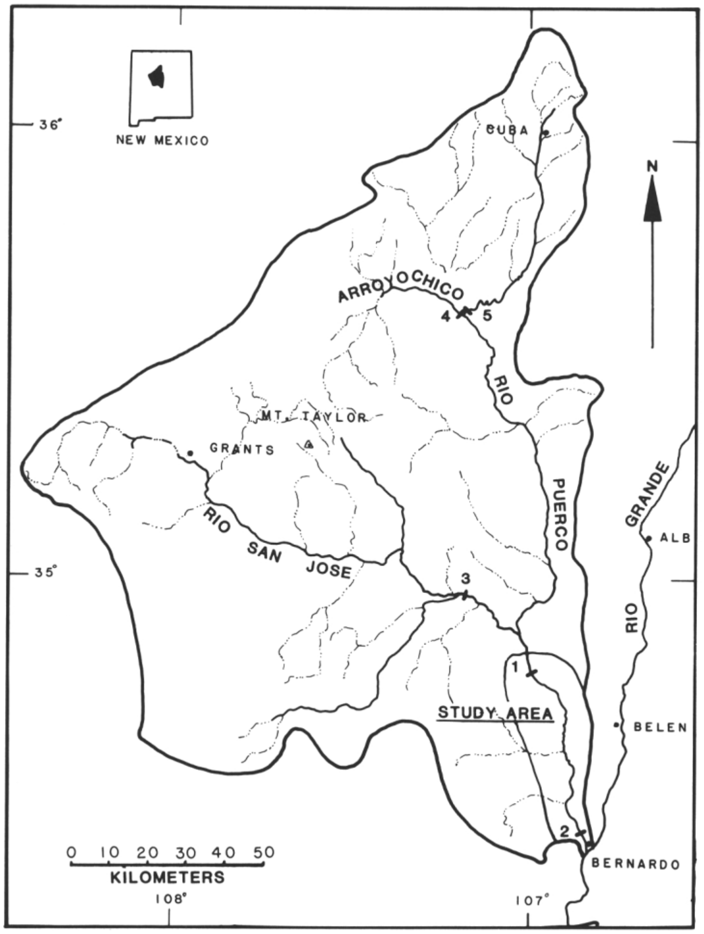


Figure 1. The Rio Puerco drainage basin showing the location of the study area. Numbers 1 through 5 are the locations of stream gaging stations: (1) Rio Puerco at Rio Puerco, (2) Rio Puerco near Bernardo, (3) Rio San Jose at Correo, (4) Arroyo Chico near Guadalupe, and (5) Rio Puerco above Arroyo Chico near Guadalupe.

The Rio Puerco is a losing stream; that is, it loses water through its bed. The records of surface-water flow from 1940 to 1976 at the Rio Puerco and Bernardo gaging stations show that an average of about 1.7 x 106 ft3/mi/yr (30,000 m3/km/yr) is lost by infiltration in the 48 mi (78 km) of channel between these two stations. Flood and recharge relationships in an alluvial river system, such as the Rio Puerco, depend upon many factors, including geology and geomorphology, peak discharge, flow duration, climate, vegetation, and the occurrence and movement of groundwater in underlying sediments. Some results of a study that concentrated on the area of the lower Rio Puerco, extending from the mouth of the Rio San Jose southward to the confluence of the Rio Puerco and the Rio Grande at Bernardo, New Mexico, are presented in this paper.

PHYSIOGRAPHY OF THE LOWER RIO PUERCO DRAINAGE BASIN

The lower Rio Puerco valley below the confluence of the Rio San Jose lies between two upland areas underlain by thick deposits of late Cenozoic basin fill: the Llano de Albuquerque to the east and a gently sloping plain to the west called the Llanos del Rio Puerco. The surface of the Llano de Albuquerque is partly covered by a caliche cap more than one meter thick that developed during the post 500,000 to 600,000 years on deposits of the upper Santa Fe Group—Sierra Ladrones Formation (Machette, 1978). Quaternary basalt flows and cinder cones emplaced about 0.140 ± .038 m.y. ago cover an area of about 30 mi, (78 km') on the Llano de Albuquerque in Valencia and Sandoval Counties (Kelley and Kudo, 1978). Surface-water drainage from the Llano de Albuquerque in this area contributes little water to the Rio Puerco, but is locally significant for erosion of tributary arroyos or for construction of alluvial fans. Large arroyos west of the valley, such as Comanche and Alamito Arroyos in Socorro County, are capable of discharging large amounts of runoff into the Rio Puerco during the summer months.

GEOLOGY OF THE LOWER RIO PUERCO

A detailed description of the late Cenozoic geology of the lower Rio Puerco region is beyond the scope of this study. The reader is referred to reports by Bryan and McCann (1937, 1938), Kelley and Wood (1946), Wright (1946), Spiegel (1955), Titus (1963), Kelley (1977), Tedford (1981), Hawley and others (1982), Love and others (1982), Young (1982), and Love and Young (this guidebook).

The Rio Puerco is incised into Santa Fe Group sediments in the Albuquerque basin. The Santa Fe Group is a thick accumulation of terrestrial sediments that were deposited in intermontane basins during late Oligocene to middle Pleistocene time. The exposed basin fill is mainly of Pliocene and Pleistocene age and consists of thinly bedded, pale to reddish-brown sand, silt, clay, and conglomerate. Volcanic flows and sills are interbedded with the sediments, which are often poorly indurated. The Santa Fe Group within the Albuquerque basin has been penetrated to great depths by test wells. One such well, Shell Isleta No. 2, drilled in the vicinity of the Isleta volcanic center in 1979 and 1980, penetrated 21,266 ft (6482 m) of Cenozoic rocks (Black, 1982). Much of this section is probably Santa Fe basin fill with a thin overlay of Quaternary surface deposits.

Geology of the Valley Fill

The lower Rio Puerco flows southward through a broad valley two to three kilometers wide, carved into basin-fill sediments of the Sierra Ladrones Formation of the upper Santa Fe Group. The size of the valley and the thickness of its alluvial fill suggest there was a major period of stream degradation in response to changes in climate and vegetation, and to changes in base level in the Rio Puerco drainage basin and along the Rio Grande. The exact timing of maximum erosion of the Rio Puerco valley is not known, but it is conceivable that it took place before latest Pleistocene time when the Rio Grande channel flowed at a level 65 to 100 ft (20 to 30 m) below its present floodplain (Love and others, 1982; Davie and Spiegel, 1967; Hawley and others, 1976).

The alluvium of the Rio Puerco valley represents successive cycles of alluviation and entrenchment within Holocene time. Radiocarbon dating of archaeological sites, commonly within one meter of the valley fill surface, indicates that the valley floor had aggraded almost to its present level 2,000 to 3,000 years ago (Love and others, 1982). Radiocarbon dating of sediments in Tapia Canyon, an ephemeral tributary of the Rio Puerco northwest of Albuquerque, brackets the last major period of alluviation between 2500 and 1000 years before the present (Shepherd, 1978). Love and others (1982) document late cutting and backfilling of channels as much as 20 ft (6 m) deep during the Pueblo IV occupation period about 600 years ago.

Maximum aggradation of the valley alluvium is characterized by floodplain deposits of laminated dark-brown silt, clay and fine sand as much as 5 ft (1.5 m) thick. Periodic heavy discharges overflowed shallow banks of the Rio Puerco in the past, spreading sediment-laden water over the entire floodplain surface, especially in low-lying areas. Samples of floodplain deposits obtained in the SW'/4, NEI14, NE'/4, sec. 26, T4N, RIW, 2165 ft (660 m) west of the present channel, show an average silt and clay content of 98 percent at its base, 96 percent in the mid-section and 91 percent at the top; along the valley margin these deposits are frequently overlain by tributary alluvium, colluvium, and eolian sand.

Figure 2 is a geologic well-log of valley-fill sediments in the SD/4, SW'/4, NWI/4, sec. 13, T5N, R1W in Valencia County. Although this well was drilled to a depth of 110.5 ft (33.7 m) at a location 25.3 ft (7.7 m) below the surface of the valley fill, it failed to reach the underlying sediments of the Santa Fe Group. Therefore, the thickness of the fill at this site is greater than 135.8 ft (41.4 m). The fill consists of unconsolidated sand, silt, gravel, and clay, which ranges from pale to dark grayish-brown in color; some of the clayey beds are red. Gravel deposits are more common below a depth of 70 ft (21 m). Table 1 shows the approximate composition, color, gravimetric water content and ratio of sand to silt and clay at five clay intervals. The most abundant constituent of the clays is kaolinite, followed by smaller amounts of illite, montmorillonite and mixed layers of clay minerals. The relative proportions of these minerals do not change significantly with depth.

Table 1. Characteristics of selected clay zones of Rio Puerco valley fill.

Location: SE1/4, SW1/4, NW1/4, sec. 13, T5N, R1W, 55.5 ft (16.9 m) west of stake B, on west bank of Rio Puerco channel, Valencia County, New Mexico.
Date: July 10, 1982
Elevation of ground surface: 4890.02 ft (1490.48 m) above sea level
Depth of Hole: 110.5 ft (33.7 m)

Depth (meters)	Approximate Ratios, in Percent				Color	w %	Sand %	Silt-Clay %
	Illite %	Mont. %	M. L. %	Kaol. %				
3.2-3.8	9.5	10	16	64.5	10YR4/3	16	20	80
12.2-12.9	13	20	3	64	10YR4/2	31	22	78
14.5-14.9	13	18	2	67	10YR4/2	31	16	84
19.4-19.8	9	16	18.5	56.5	10YR4/3	32	17	83
29.0-29.7	13	22.5	4.5	60	10YR4/2	25	25	75

NOTE: Approximate ratios of illite, montmorillonite, mixed layers of clay minerals and kaolinite determined by x-ray diffraction of slide samples.
w = Gravimetric water content by weight, in percent
Sand = Weight percent of clastics having grain diameter >0.062 mm.
Silt-Clay = Weight percent of clastics having grain diameter <0.062 mm.

In addition, x-ray diffraction showed high amounts of quartz, feldspar, calcite, and dolomite, but little or no chlorite in clay- and silt-sized sediments. The composition and maximum diameter of clasts of the basal gravel samples are shown in Table 2. In general, the majority of pebbles consist of quartz, basalt, limestone and shale with very low amounts of obsidian or rhyolite.

The recent alluvium beneath the channel of the lower Rio Puerco consists of about 18 ft (5.5 m) of unconsolidated, fine to medium sand and intercalated clay layers underlain by 1.5 ft (0.5 m) of medium- to coarse-grained sand, thalweg gravels with clasts as much as 2.4 in (6 cm) in diameter, and armored clayballs.

Description of Active Channel

Bryan (1928, 1940, 1941) and Bryan and McCann (1938) were the first to examine geomorphic changes in the Rio Puerco channel that have occurred since the mid-19th century. Later investigators (Tuan, 1966; Patton, 1973; Schumm, 1977; Elliot, 1979) looked at climatic and vegetative factors governing erosion and sedimentation processes of the Rio Puerco and other rivers in the Southwest. Detailed descriptions of the geomorphological evolution of the lower Rio Puerco valley based on archaeoloical evidence are available (Love and others, 1982; Betancourt, 1980).

The lower Rio Puerco has developed an active inner channel and floodplain within an arroyo 150 to 820 ft (46 to 250 m) wide between walls of Holocene valley-fill 26 to 43 ft (8 to 13 m) high. Common sedimentologic features of the channel and floodplain include sandbars, ripples and dunes, meandering thalweg, natural levees, oxbows, eolian sand, and point-bar deposits. Sand deposited by the stream is generally light brown (10YR6/4 in the Munsell color charts, 1975 ed.) whereas

Table 2. Clast composition of basal gravels in Rio Puerco valley fill, west of Belen, New Mexico.

Depth (meters)	Qtz. %	Gran. %	Bas. %	Rhy. %	Obsid. %	LS %	SS %	SH %	Other %	Total %	n	Diam. (cm)
30.0-30.5	37.1	11.4	8.6	0.0	0.0	14.3	20.0	5.7	2.9	100	35	2.5
30.0-31.2	20.3	10.9	20.3	1.6	0.0	14.1	9.4	17.2	6.2	100	64	3.0
31.2-32.0	30.0	12.1	13.1	0.0	0.9	19.6	13.1	5.6	5.6	100	107	4.7
32.0-32.8	31.7	14.6	19.5	0.0	2.4	7.3	19.5	2.4	2.4	99.8	41	5.1
32.8-33.7	18.0	10.0	17.1	0.9	1.8	19.8	15.3	11.7	5.4	100	111	4.4

NOTE: Samples obtained from auger hole B5 in the SE1/4, SW1/4, NW1/4, sec. 13, T5N, R1W, Valencia County, New Mexico on July 10, 1982.
Ground surface elevation = 4890.02 ft (1490.48 m) above sea level.
Clast sizes in diameter column are maximum values in centimeters.

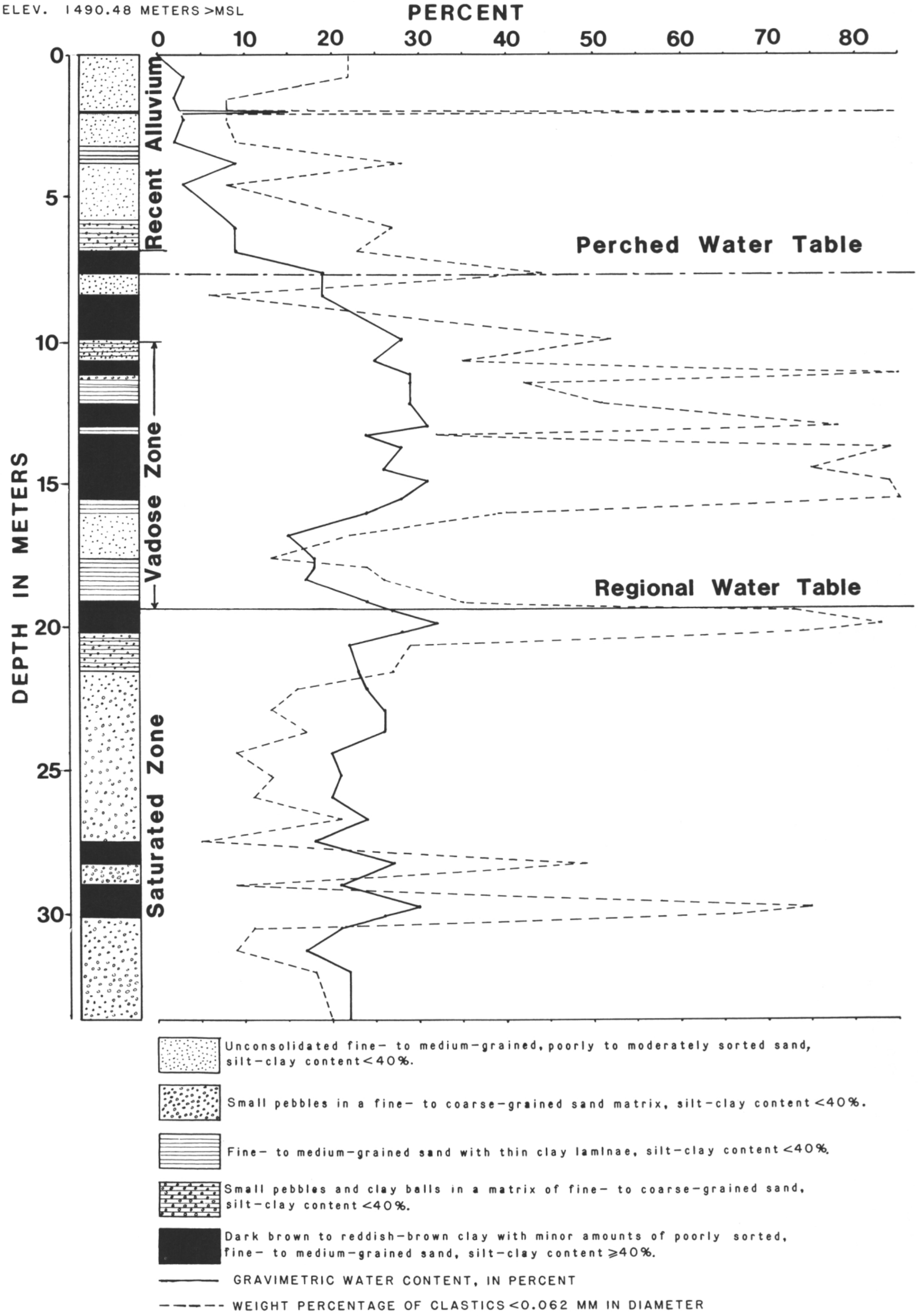


Figure 2. Geologic well-log of Rio Puerco valley fill in SE¹/₄, SW¹/₄, NW¹/₄, sec. 13, T5N, R1W, 55.5 ft (16.9 m) west of the active channel. Soil moisture contents were determined from samples taken during drilling on July 10, 1982.

clay sediments commonly range from reddish brown (2.5YR4/4) to dark brown (10YR4/3).

The channel meanders throughout much of its length. In 1979, sinuosity of the lower 31 mi (50 km) between the Rio Puerco and Bernardo gages averaged 1.57 (ratio of stream length to straight-line distance). Based on photographs taken in 1954 and 1979, it has been estimated that more than 90 percent of the modern channel has shifted laterally during the past 35 years (Love and others, 1982).

HYDROLOGY OF THE LOWER RIO PUERCO

Peak Discharge

Nine gaging stations are located on the Rio Puerco and its tributaries. The locations of five principal stations discussed in this report are given in Figure 1. Daily discharge and peak flood data for these sites are available in Water-Supply Papers and Water-Data Reports published each year by the U.S. Geological Survey. The longest continuous record, from November, 1939, to the present, is from the Bernardo gaging station, 3 mi (4.8 km) northwest of the confluence of the Rio Puerco and the Rio Grande. Continuous records at the Rio Puerco gaging station date from March, 1934, to December, 1976. Intermittent discharge records exist for both sites as early as 1910.

Figure 3 shows the flood record of the lower Rio Puerco for the water years 1929 and 1934 to 1982 (a water year extends from October 1 to September 30). During this period, peak discharges averaged 9,082 cfs (257.2 m3/s) at Rio Puerco and 5,664 cfs (160.4 m3/s) at Bernardo. Over the 37-year period from 1940 to 1976, peak flows averaged 7,101 cfs (201 m3/s) at Rio Puerco and 5,405 cfs (153 m3/s) at Bernardo. Most floods occurred during the month of August, followed by lower frequencies in September and October.

Since 1940, a cyclic pattern in peak discharge (fig. 3) has emerged with years of low peak discharge in 1948, 1962, and 1978 (at 14- to 16-year intervals) and years of high flow in 1941, 1955, and 1972 (at 14- to 17-year intervals). Data obtained before 1934 is not sufficiently reliable for trend analysis.

Large reduction in discharge is possible when tributary inflow between Rio Puerco and Bernardo is small. For example, peak flow in 1967 was 38 percent lower at Bernardo than it was at Rio Puerco. Bank and floodplain storage, streambed infiltration, and evapotranspiration are all factors that contribute to this reduction of flow. In 1941, 1943, and 1954, discharge was higher at Bernardo than at Rio Puerco. Heavy flows from large, east-flowing tributaries such as Comanche and Alamito Arroyos in northern Socorro County were responsible for this increase.

The time it takes for a flood crest to travel along the Rio Puerco depends on discharge, slope, and channel shape. Hydrographs from 1940 to 1976 show that the average flood crest traveled from the mouth of Chico Arroyo to the Rio San Jose in 20 hours, from the Rio San Jose to the Rio Puerco gage station in two hours, and from Rio Puerco to Bernardo in 14 hours, at an average velocity of 5 ft/s (1.5 m/s) (Corps of Engineers, 1978).

Figure 4 gives frequency curves for the five gaging stations along the main reach of the Rio Puerco and its tributaries. These curves relate flood magnitude to frequency of occurrence over the flood record.

Flow Duration

Using the criteria suggested by Hedman and Osterkamp (1982), streams that have flow from 10 to 80 percent of the time are intermittent; those that flow less than 10 percent of the time are ephemeral. Most intermittent streams with drainage areas larger than 500 mi2 (1300 km') will have discharge more than 10 percent of the time because of prolonged snowmelt at higher elevations and greater runoff during the summer months. From 1940 to 1976, the Rio Puerco flowed an average of 55 percent of the time at the Rio Puerco gage. From 1940 to the present,

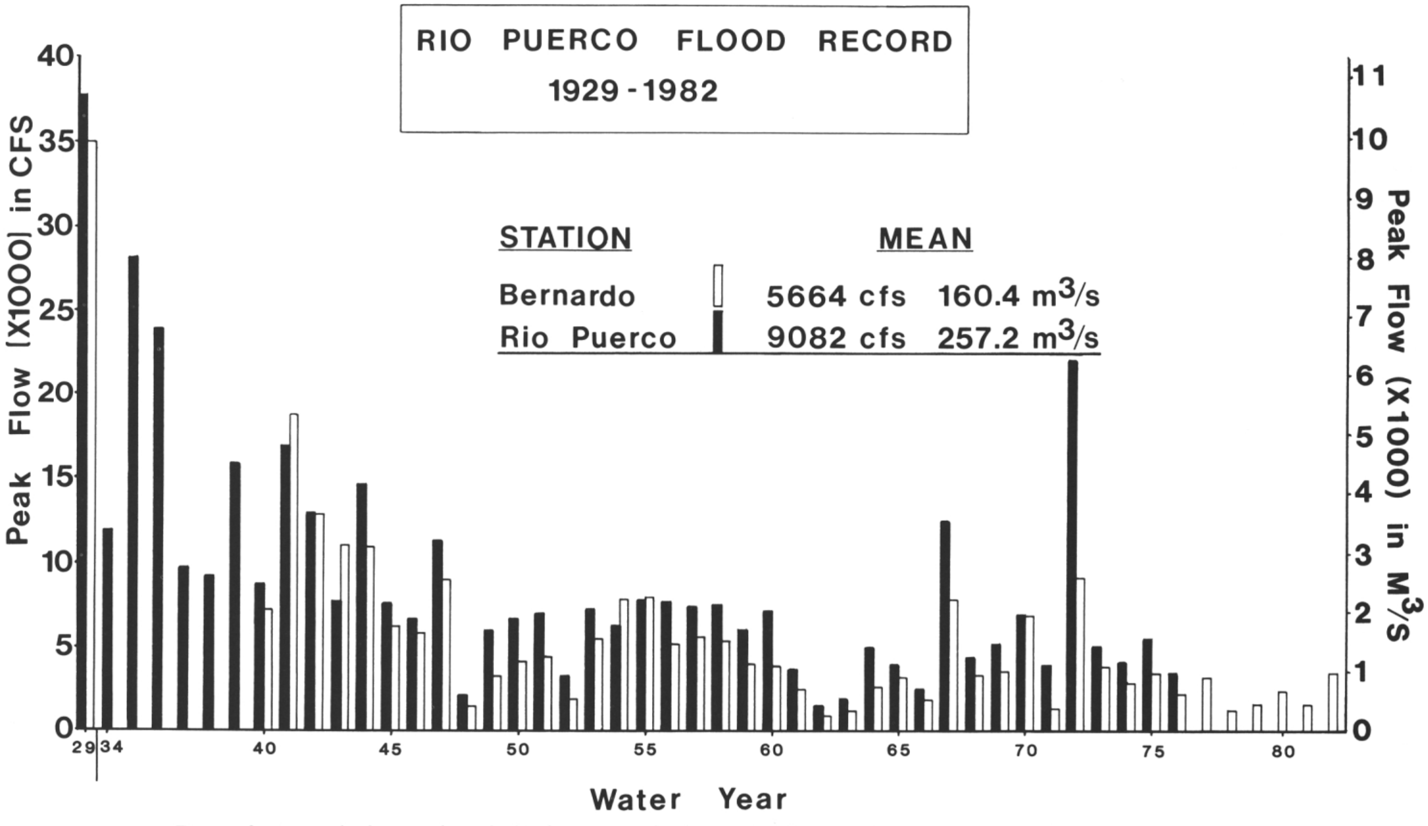
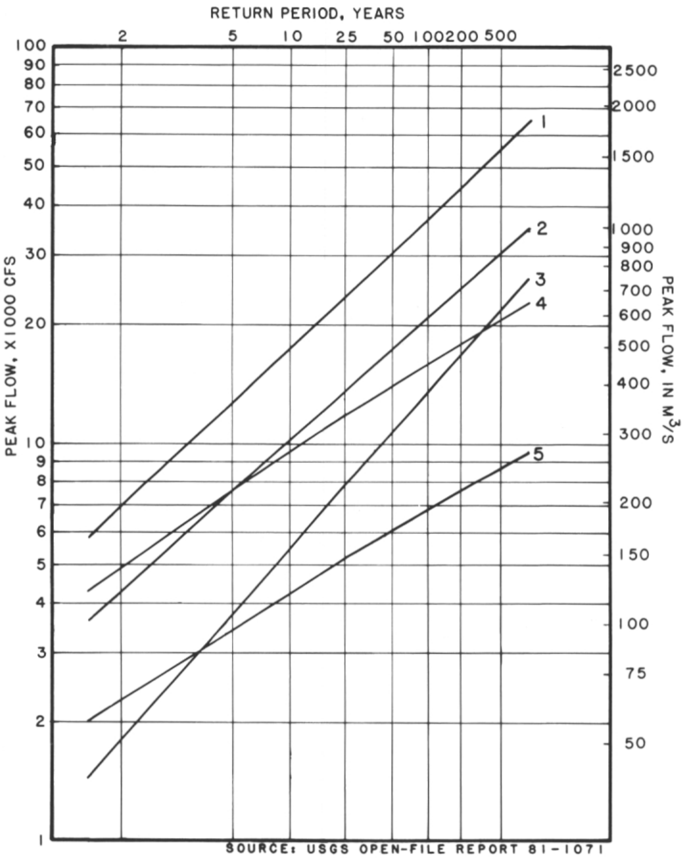


Figure 3. Record of annual peak discharges of the lower Rio Puerco for water years 1929 and 1934 to 1982.



SOURCE: USGS OPEN-FILE REPORT 81-1071

Figure 4. Pearson Type III distribution curves at five stream gaging stations in the Rio Puerco basin. Such curves represent estimates of the cumulative distributions of the flood record and relate flood magnitude to frequency of occurrence. See Figure 1 for gage station locations.

the stream flowed an average of 30 percent of the time at the Bernardo gage. The difference between the two gages is caused by evapotranspiration and channel losses.

Runoff in the higher elevations of the Rio Puerco watershed flows into three main tributaries north of the study area: Arroyo Chico, which drains an area of 1390 mi.' (3600 km') north of Mount Taylor; Rio Puerco north of Arroyo Chico, which flows south from highlands in the San Pedro Peaks—Nacimiento Mountains region; and Rio San Jose, which flows east and southeast from Grants and Laguna, New Mexico. An analysis of average monthly discharge records from 1952 to 1979 showed that flow contribution to the lower reach of the Rio Puerco averaged 40 percent from above Arroyo Chico, 32 percent from Arroyo Chico, and 28 percent from the Rio San Jose.

Although all three tributaries are important sources of inflow to the lower reach throughout the flow period, individual dominance is generally seasonal. From December through April, most flow stems from the Rio San Jose basin, which has many springs; from late spring to early summer, flow is dominated by the Rio Puerco above Arroyo Chico in the form of meltwater runoff; and from late summer to early autumn, flow is dominated by runoff from thunderstorms in the Arroyo Chico basin.

Flood History

On October 4, 1913, the Rio Puerco reached a gage height of 9.5 ft (2.9 m) at the Rio Puerco gaging station, but discharge was not determined at this or other stations. To provide better discharge records, a concrete control was built a short distance downstream from the gage in 1922.

During the night of August 12, 1929, a large flood swept through the valleys of the Rio Puerco, Rio Salado (see Simcox, this guidebook) and Rio Grande and entered the northern end of Socorro Valley. By midnight of August 13, the crest of the flood had passed San Marcial and destroyed valuable cropland and several villages, including San Acacia, San Antonito, and San Marcial. On August 9 and 10, torrential rains had fallen on the west and north slope of Mount Taylor in the Rio Puerco watershed. Precipitation records at Crownpoint, Bluewater, and Jemez Springs show rainfall totals of 3.20 in. (81 mm), 3.57 in. (91 mm), and 2.56 in. (65 mm), respectively. Flow velocities along the lower reach of the Rio Puerco approached 6 mi/hr (10 km/hr) as water surged toward the Rio Grande at Bernardo (New Mexico State Engineer, 1930).

The maximum discharge of the Rio Puerco at Rio Puerco station was computed by a broadcrested-weir formula (New Mexico State Engineer, 1930):

Depth (D) --- 16.02 ft (4.88 m)
Width (W) = 182 ft (55.5 m)
Weir Constant (C) = 2.70
Discharge = CWD = 31,509 cfs (892.3 m3/s)

At Bernardo gaging station, three miles upstream from the mouth of the Rio Puerco, the maximum discharge was computed from the slope-area method:

Section Width = 518 ft (157.9 m)
Section Area =4,006.5 ft' (372.2 m2)
Slope = .00175
Kutter's coefficient of roughness "n" = 0.35
Discharge (by Kutter's formula) =30,643.7 cfs (867.8 mys)

The largest flood since 1880 occurred on September 23, 1929, only 42 days after the flood of August 12. Widespread and heavy rains fell over the entire Rio Grande drainage area from Socorro north to the Colorado stateline from September 21 to 23. The Rio Puerco contributed a greater share (58 percent) to the total flood than in the preceding flood. Computation of the maximum discharge at the Rio Puerco gaging station by weir formula yielded 37,700 cfs (1068 m3/s) at a gage height of 18 ft (5.5 m). The flood also damaged cropland and settlements in the middle Rio Grande valley, washed out the Atchison, Topeka and Santa Fe Railroad trestle west of Los Lunas, New Mexico, and de- stroyed the gage recorder. The maximum discharge of the flood at Bernardo was estimated to be 35,000 cfs (991 m3/s) by the slope-arna method (New Mexico State Engineer, 1930).

The third largest flood since 1880 occurred on August 21, 1935 after heavy rainfall fell over the headwaters of the Rio Puerco and the Rio San Jose during early and mid-August. A peak discharge of about 28,000 cfs (800 m3/s) was recorded at the Rio Puerco gage on August 21. Nearly 40 percent of this discharge was contributed by the Rio San Jose, which had a record flow of 11,000 cfs (312 m3/s) at Correo, New Mexico. This discharge, although large for the Rio San Jose, was smaller than that of September 23, 1929.

A smaller flood occurred on August 4, 1936. A general storm over the Rio Puerco watershed produced a peak flow of 24,000 cfs (680 m3/s) at the Rio Puerco gaging station and, together with the Rio Grande, attained a peak of 27,400 cfs (776 m3/s) at San Acacia, about 10 miles (16 km) downstream of the confluence of the two rivers.

Record high rainfall produced large floods in May, September, and October of 1941. The heaviest flow occurred at 3 p.m. on September 23 at the Rio Puerco gage and 11 p.m. on the same day at Bernardo with peak discharges of 16,900 cfs (479 m3/s) and 18,800 cfs (532 m3/s), respectively. The large increase in flow over the lower reach of the Rio Puerco is attributed to heavy storm runoff in eastward-flowing tributaries, such as Comanche and Alamito Arroyos north of Bernardo. This demonstrates that widespread rainfall over the lower Rio Puerco basin, as well as areas to the north, can reduce the time for a floodcrest to travel from Rio Puerco to Bernardo from 14 hours to 8 hours.

Extensive thunderstorm activity over both the Rio Grande and Rio Puerco basins produced peak discharges of 7,610 cfs (215 m3/s) on August 10, 1967 in the Rio Grande near Bernardo and 12,600 cfs (357 1113/s) on August 12 at the Rio Puerco gage. A record level of discharge for the Rio Puerco above Arroyo Chico occurred on July 29, 1967, with a flow of 6,940 cfs (179 m3/s). This is the largest flood on record for that tributary.

Heavy rains in the Arroyo Chico watershed on September 12, 1972 produced a peak discharge of 15,200 cfs (430 m'is), the highest flow on record for the Arroyo Chico gage near Guadalupe, New Mexico. The flood increased in intensity as it flowed downstream, producing a peak discharge of 22,200 cfs (629 m3/s) with a gage height of 5.35 ft (1.63 m) at the Rio Puerco gage on September 13. A discharge of 9,220 cfs (261 m3/s), with a gage height of 14.5 ft (4.42 m) was recorded at the Bernardo gage on September 14. Although the instantaneous flood peak was 58 percent higher at Rio Puerco than at Bernardo, the total volume of the flow was actually quite similar. Therefore, it took a shorter time for the same volume to pass the Rio Puerco gage station.

Effects of Floods on Channel Morphology

Large floods have great erosive and destructive power. They cause widening and deepening of the Rio Puerco channel and transport large quantities of sediment into the middle Rio Grande valley. During a rising flood stage, an increase in flow velocity and shear stress on the streambed results in channel scour. The whole width of the flow tends to cut downward as the stage rises; sediment tends to fill the channel again during the falling stage (Leopold and others, 1964). Auger holes drilled in the position of the 1929 flood thalweg in T5N, R1W reveal channel deposits 10 to 20 ft (3 to 6 m) below the level of the present streambed. These mark the maximum extent of channel incision of the Rio Puerco into valley fill since entrenchment began over a century ago.

HISTORIC CHANGES IN VEGETATION

The principal vegetation of the Rio Puerco arroyo is willow (Salix sp.), rabbitbush (Chrysothamnus nauseosus), cottonwood (Populus fremontii), and saltcedar (Tamarix sp.). In 1927, the latter species was introduced 32 mi (51.5 km) upstream from the mouth for erosion control (Bryan and Post, 1928), but has caused profound changes in riparian vegetation, channel geometry, and streamflow. The plants thrive in areas that have a gently sloping or flat river bank with a gradually receding flood flow during the growing season (April to October). A mature tree may produce up to 600,000 seeds, which are capable of germinating quickly on a floodplain or water surface (Bowser, 1957). According to Renner (1915), who observed tamarisk growth during the construction of the Suez Canal in Egypt, the roots may go as deep as 30 m.

Along the streams in the southwestern United States, a dense stand of tamarisk usually indicates that the water table is within 13 to 23 ft (4 to 7 m) of the surface (Horton and Campbell, 1974). Although the amount of water used by saltcedar in the lower Rio Puerco is not known, figures cited in studies of other southwestern streams may be comparable. A study in the Safford Valley of the Gila River in Arizona during 1943 and 1944 showed that under favorable conditions, the annual rate of water use by saltcedar was more than 9 acre-ft/acre (2.74 x 106 m3/km) when the depth to water was 4 ft (1.2 m) to about 7 acre-ft/acre (2.1 x 106 m3/km) when the water level was at a depth of 8 ft (2.4 m) (Gatewood and others, 1950). In a later study near Buckeye, Arizona, van Hylckama (1974) reported annual water consumptions of 7 acre-ft/acre when depth to water was 4.9 ft (1.5 m) to 3.3 acre-ft/acre (1.0 x 106 ml/km) when depth to water was 8.9 ft (2.7 m). Site differences in annual water use are caused by variations in growth density, length of the growing season, and soil-moisture salinity.

Temperature largely controls saltcedar growth and transpiration. Gatewood and others (1950) determined that saltcedar transpiration practically ceased in the autumn on days when the maximum air temperature was less than 23°C and began again in the spring when temperatures rose above 23°C.

Aerial photographs taken by the Soil Conservation Service in 1935 show sparse saltcedar growth along the Rio Puerco channel. North of the Valencia-Socorro County line, densities of less than 20 trees per kilometer of channel were not uncommon; however, the density of saltcedars, already high in the middle Rio Grande valley, tended to increase to the south. A large stand of saltcedar on the Rio Puerco in 1935, consisting of groups of several hundred trees, existed in the western half of sec. 30, T4N, RIE, between Comanche and Alamito Arroyos. Larger concentrations of saltcedar growth were present farther south in sec. 18, T3N, R1E at the mouth of Mariano Draw.

After 1941, during a period of lower peak discharges, consolidation and rapid growth of this phreatophyte accelerated upstream along the banks and inner-floodplain. By 1954, dense stands had developed in the channel north of Arroyo Chico. The long-term effects of saltcedar growth along the lower Rio Puerco include increases in area inundated by floods, sediment deposition in areas of saltcedar growth, channel stabilization, and depletion of streamflow magnitude.

OCCURRENCE AND MOVEMENT OF GROUND WATER

In general, infiltration of water varies directly with the hydraulic conductivity of the porous material, area perpendicular to flow, and hydraulic gradient, but varies inversely with water viscosity. The hydraulic conductivity of saturated geologic materials is relatively constant over time below the water table but is a function of negative pressure head or capillary forces above the water table (Bouwer, 1964). Several authors have evaluated factors that influence rates of infiltration from losing streams in the southwestern United States (for example, Keppel and others, 1962; and Burkham, 1970). These include the hydraulic conductivity of the streambed, stream area and depth of the channel, velocity of streamflow, river stage, temperature, entrapment of air in channel sediments, and the relation of the water table to the stream.

Hydraulic Conductivity of the Streambed and Recent Alluvium

The Rio Puerco flows across moderately to well-sorted, fine- to medium-grained sand along most if its reach; however, during periods of low flow the channel bottom accumulates silt and clay between sand grains that tend to reduce hydraulic conductivity. Several investigators (Burkham, 1970; Moore and Jenkins, 1966) examined grain-size distributions in streambeds and reported that the upper several centimeters of sand was siltier and less permeable than that below. For my study, I used a constant-head permeameter, sieves, and hydrometer to measure grain size and permeability. In an area located in the western half of sec. 13, T5N, R1W, moderate to high hydraulic conductivities were found in the upper 6.5 ft (2 m) of the channel alluvium, which consists mainly of moderately-sorted, fine- to medium-grained sand. The hydraulic conductivities of 23 samples taken on the streambed surface at 82-ft (25-m) intervals to a depth of 6 cm range from 7.4 ft/day (2.25 m/day) to nearly 109 ft/day (33 m/day), with a mean of 52 ft/day (15.7 m/day). Samples obtained at depths of 1.5, 3.3, 5.0, and 6.6 ft (0.5,

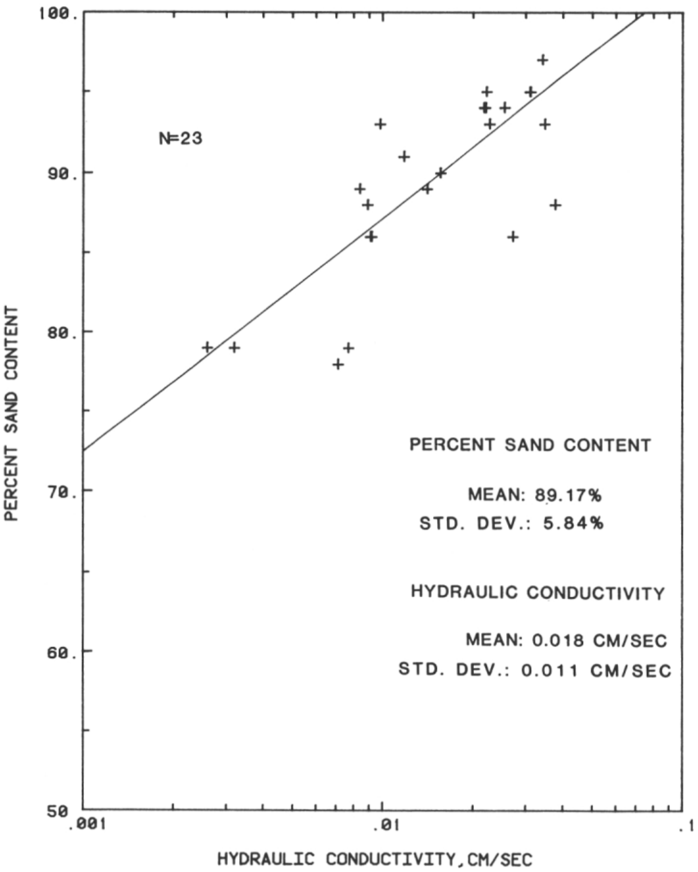


Figure 5. Relationship of hydraulic conductivity and sand content for channel sands of the lower Rio Puerco in central New Mexico.

1.0. 1.5, and 2.0 m) in channel sands in the SD/4, SW'/4, NW ,/4, sec. 13, T5N, R1W produced hydraulic conductivities of 34.3, 20.0, 34.3, and 45.5 ft/day (10.4, 6.0, 10.4, and 13.8 m/day), respectively. In a study of solute distributions within a soil profile, Biggar and Nielsen (1976) determined that 100 observations were necessary to estimate the hydraulic conductivity within ± 50% of its true value. Kiesling and others (1977) found that only 2 to 16 samples were required to estimate the average log of the hydraulic conductivity to within ± 10% of the estimated mean. The optimum number of samples at a given site depends on individual soil variability. Additional samples of Rio Puerco channel sediments should be analyzed to increase the accuracy of these estimates.

Figure 5 shows a strong correlation between hydraulic conductivity that is log-normally disttibuted and grain size that is normally distributed. In general, if silt and clay content is greater than 40 percent, the hydraulic conductivity of the Rio Puerco channel sands is likely to be about 3.3 ft/day (1 m/day) of less. Where horizontal clay laminae are present in channel sands, vertical hydraulic conductivities may be reduced to as low as 2.8x 10-7 ft/day (8.6x 10-s m/day) (Freeze and Cherry, 1979).

Annual transmission losses average about 1.7 x 106 ft3/mi (30,000 m3/km) from Rio Puerco gage to Bernardo gage, a distance of 48 river miles (78 km). Very low flows of about 5 cfs (0.15 m'/s) during the winter and spring are entirely lost through infiltration and evaporation; higher flows of less than 10 cfs (<0.3 m3/s) are lost during the summer months through infiltration, evaporation, and phreatophyte activity. From 1940 to 1976, the only period for which records are available at both stations, peak discharges in the lower 31 mi (50 km) of the river were reduced by an average of 24 percent due to overbank storage, bank storage, and evapotranspiration. This figure is mostly associated with short periods of high flow.

Detailed study of a channel cross section in the SE'/4, SW'/4, NW'/4, sec. 13, T5N, R1W, 7 mi (11.3 km) west of Belen, New Mexico, revealed a perched water table about 18 ft (5.5 m) below the streambed. Clay layers at the base of recent alluvium restrict the vertical movement of groundwater, creating a perched zone high above the regional water table, which is about 60 ft (18.3 m) below the channel (fig. 2). Titus (1963) found similar perched zones in the Rio Grande valley north of Belen, New Mexico.

The hydrographs of mean daily discharge of the Rio Puerco and the piezometric response of the perched water table to this flow are shown in Figures 6a and 6b. At least twice, on August 28 and September 19, the river overflowed its banks with peak discharges of more than 2,260 cfs (64 m3/s) and 3,600 cfs (102 m3/s). Groundwater measurements during the summer and winter flow seasons show the water table rising more than 5 ft (1.5 m) beneath the channel since day 48 (August 17, 1982). The growth rate of the mound at this location is clearly influenced by stream discharge. The development of perched groundwater zones

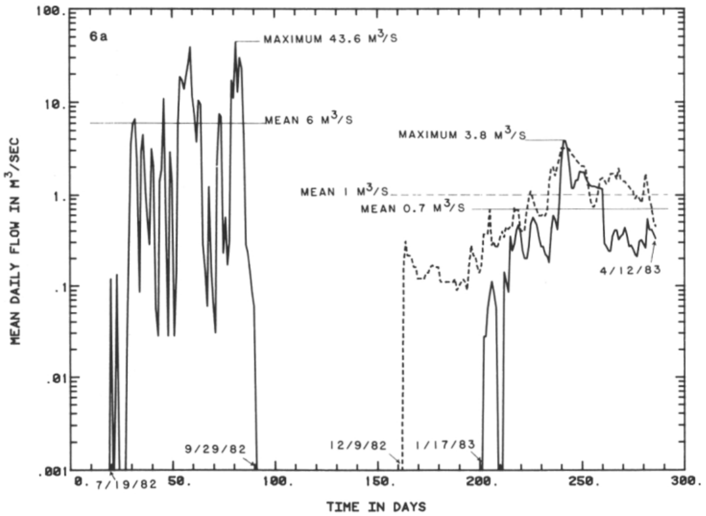


Figure 6a. Hydrograph from the Bernardo gage from July 19, 1982 to April 12, 1983; the dashed line represents the hydrograph record for the Rio Puerco gage from December 9, 1982 to April 12, 1983. Discharge data from July to September, 1982 do not exist for this gage.

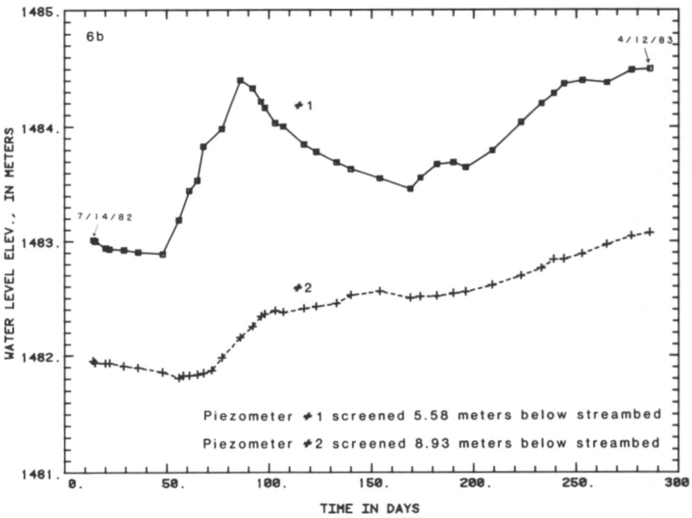


Figure 6b. Elevation of the perched water table in SE$^1/_4$, SW$^1/_4$, NW$^1/_4$, sec. 13, T5N, R1W for the same period.

in other channel areas would depend, among other factors, on channel geometry, variations between vertical and horizontal hydraulic conductivity within the recent alluvium, phreatophyte activity, thickness and lateral continuity of clay beds beneath the channel, and degree of saturation.

CONCLUSIONS

The results of this study support the following conclusions:

1. Exploratory drilling in July, 1982, showed that the Rio Puerco valley fill 7 mi (11.3 km) west of Belen, New Mexico, is more than 135.8 ft (41.7 m) thick.
2. Thicknesses of recent channel alluvium commonly range between 10 and 20 ft (3 and 6 m) near or along the channel of 1929, but less in other areas. The 1929 flood, largest since 1880, widened and deepened the arroyo to a large degree. Channel lag deposits frequently delineate the contact between older valley fill and recent alluvium in the Rio Puerco channel.
3. The rapid spread of the phreatophyte Tamarix since 1927 has fostered the development of a narrow channel and inner floodplain, aggradation of the streambed, and the reduction of flood magnitude along the reach between Rio Puerco and Bernardo.
4. Discharge records indicate that the lower Rio Puerco is an intermittent stream flowing an average of 55 percent of the time at Rio Puerco gage and 30 percent of the time at Bernardo gage. Most of the discharge occurs from July through October.
5. Hydraulic conductivities of Rio Puerco channel sands at a site 7 mi (11.3 km) west of Belen, New Mexico, range from 7.4 ft/day (2.25 m/day) to nearly 109 ft/day (33 m/day) in sediments with clay and silt contents of less than 22 percent.
6. Average infiltration rates of about 5 cfs (0.15 m3/s) during the winter season and 10 cfs (0.3 m3/s) during the summer months were determined along the 48 mi (78 km) reach (channel distance) between the Rio Puerco and Bernardo gaging stations.
7. A perched water table in the SE1/4, SW i/4, NW,/4, sec. 13, T5N, R1W underlies the Rio Puerco streambed at a depth of about 18 ft (5.5 m) and fluctuates in response to discharge.

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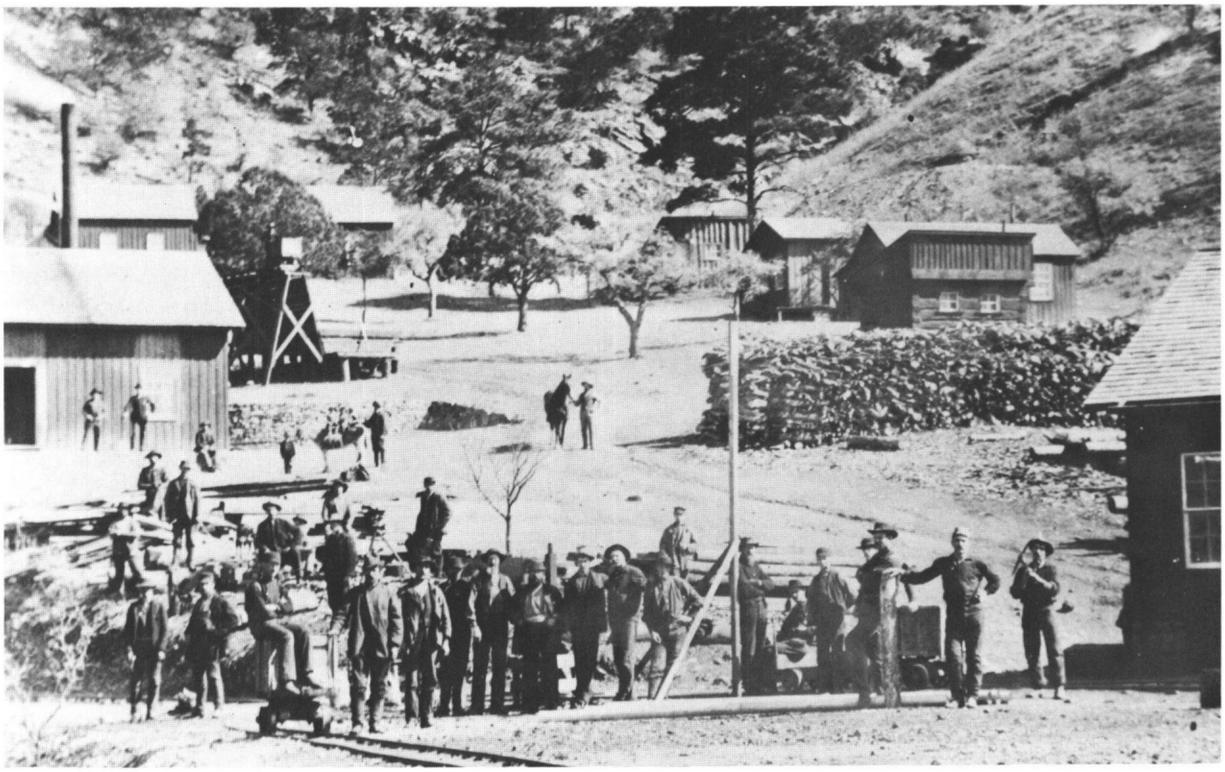
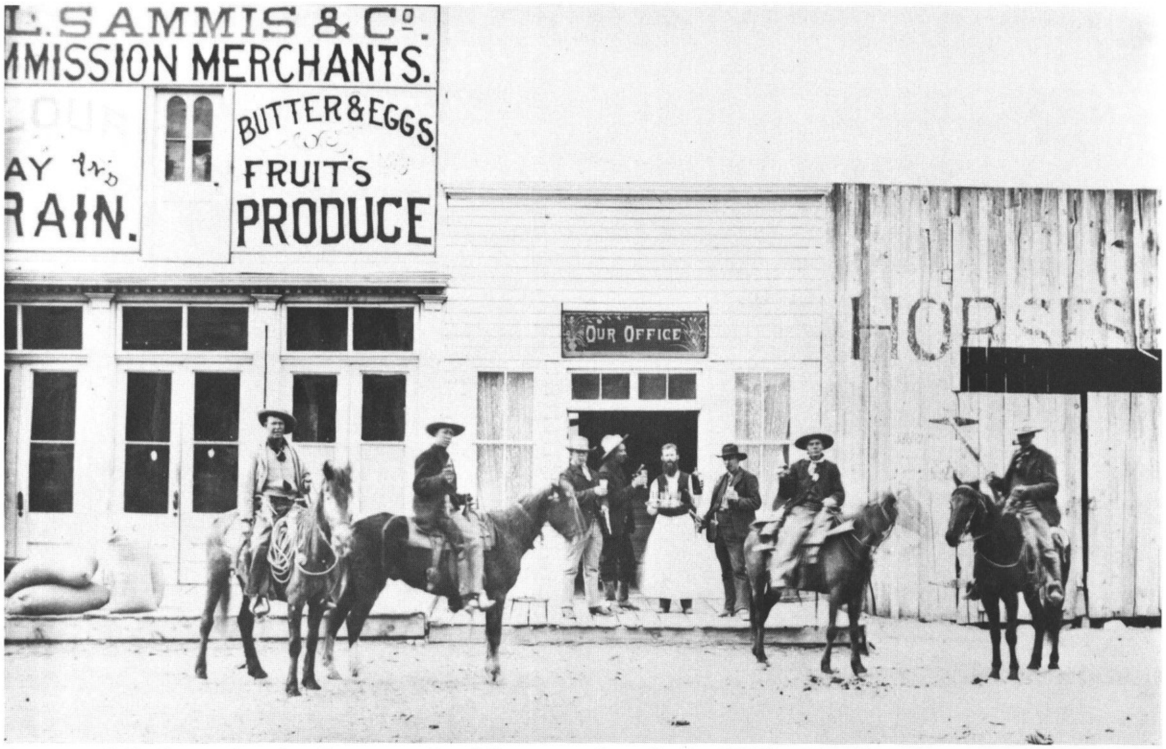


Mine crew at Kelly, New Mexico, ca. 1885. When photographer Smith exposed this view of off-duty miners (possibly awaiting shift change) Kelly camp was in the midst of its first big boom. Once a Kelly miner himself (and fortunately an occupation he gave up in favor of photography) Smith doubtless knew most of these men on a first-name basis. Note the ever-present stacks of cordwood (right-center)—fuel for cookstove and steam boiler alike. Kelly camp would die along with the rest of the lead-silver industry in 1893, only to be born again phoenix-like after 1904, this time as a producer of zinc. Joseph E. Smith photo, courtesy Ed Smith; New Mexico Bureau of Mines and Mineral Resources collection.



A group of the boys whooping it up at a local Socorro saloon in the 1880's. The cleverly contrived name of the establishment enabled the gang to remain off the domestic hook by having to work late at "our office." Could that be a bottle of Lancers in the barkeep's left hand? Photo by Joseph E. Smith, courtesy Ed Smith; New Mexico Bureau of Mines and Mineral Resources collection.

Prior to the appearance of the automobile (and eventually the pick-up truck) all local freight was delivered by teams and wagons. Here no less than 12 oxen yoked to tandem wagons are moving a storeload of furniture southbound down California street in early day Socorro. This same ox train may well have delivered ore from Kelly to Park City before the Magdalena branch railroad was completed in early 1885. Photo by Joseph E. Smith, courtesy Ed Smith; New Mexico Bureau of Mines and Mineral Resources collection.