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Nevada Department of Conservation and Natural Resources

Trends in Streamflow on the Humboldt River between Elko and Imlay, Nevada, 1950–99

Scientific Investigations Report 2005-5199

U.S. Department of the Interior
U.S. Geological Survey

FRONT COVER: Photographs of Humboldt River at Blossom bridge near Valmy, Nevada, upstream of the streamflow gage at Comus. Top photograph is from the bridge looking downstream on June 9, 1999 during high flow. Bottom photograph is from the bridge looking downstream on October 18, 2001 during a period of no flow. Photographs taken by D.E. Prudic.

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U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
P. Patrick Leahy, Acting Director

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile (ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Trends in Streamflow on the Humboldt River between Elko and Imlay, Nevada, 1950–99

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Abstract

The Humboldt River is an important source of water in north-central Nevada. It provides water to several communities and is used extensively for agriculture. Farmers began diverting flow from the river in the 1860's. Conflicts over water diversions along the river led to the adjudication of water rights and to the construction of Rye Patch Dam and Reservoir in the 1930's. Increased ground-water withdrawals beginning in the 1960's have raised concerns regarding their effects on streamflow. The purpose of this report was to analyze streamflow trends from 1950 to 1999 in relation to precipitation and ground-water withdrawals at five streamflow gages on the Humboldt River from Elko to Imlay, Nevada.

Effects of ground-water withdrawals have been superimposed on the variation of streamflow caused by climate, which during 1950–99 was highly variable. Annual runoff normally increased from the streamflow gage near Elko to Palisade because of tributary inflow and ground-water discharge, which maintained a baseflow during the late summer to early winter. Annual runoff normally decreased downstream of Palisade because of irrigation diversions, infiltration of streamflow into the alluvium, and evapotranspiration. The river often ceased to flow downstream of Palisade during late summer because of minimal ground-water discharge to its channel.

The ratio of annual runoff to precipitation varied considerably at all streamflow gages with generally higher ratios during periods of above mean annual precipitation and lower ratios during periods of below mean annual precipitation. Highest ratios were estimated for Lamoille Creek, a headwater stream in the Ruby Mountains, where the average ratio was about 0.7, which indicates that about 70 percent of the precipitation in the drainage area above the streamflow gage became runoff. The ratio of runoff to effective precipitation decreased downstream along the Humboldt River such that on average only 2 percent of the annual precipitation in the drainage area above the streamflow gage near Imlay, Nevada became runoff. This implies that 98 percent of the annual precipitation was lost to evapotranspiration or to ground-water storage.

Ground-water withdrawals above the streamflow gage at Palisade had no significant effect on annual runoff above Palisade on the basis of multiple linear regressions that included annual runoff at an upstream gage, and annual precipitation volumes and ground-water withdrawals between streamflow gages. Ground-water withdrawals between Palisade and Comus had no significant effect on annual runoff to a probability of 0.05 at Comus until 1992, when discharge of water directly to the river from mining operations had a significant effect that slightly increased annual runoff at Comus. Ground-water withdrawals in the reach between Comus and Imlay were significant to a probability of 0.04 and slightly decreased annual runoff at Imlay. Most ground-water withdrawals in the reach between Palisade and Comus were in alluvial basins distant from the river, whereas much of the ground-water withdrawals in the reach between Comus and Imlay were either near the mouths of alluvial valleys adjacent to the Humboldt River Valley or the withdrawals were within the valley proper.

Introduction

The Humboldt River Basin covers an area of nearly 17,000 mi^2 in Nevada, and it is the only major river basin that is entirely in the State (fig. 1). Streamflow of the Humboldt River and its tributaries and ground water are used by diverse and sometimes competing interests. Streamflow historically has been used for agricultural purposes—mainly irrigation of crops and meadows. However, wetlands along the river and its tributaries provide wildlife habitat, and infiltration of streamflow is a source of recharge to underlying aquifers. Prior to 1980, most ground-water withdrawals in the Humboldt River Basin were for municipal and domestic use, irrigation of crops, watering stock, and industrial use at a few mines. Since 1990, ground-water withdrawals in the basin have increased as a result of development of large gold mines and a corresponding increase in population.

Federal, State, and local government agencies and other groups are concerned about the long-term viability of the water resources of the Humboldt River Basin because of the increased demand for ground water and the need to dewater several of the gold mines. (The word "dewater" as used in this report refers to the pumping of ground water for the purpose

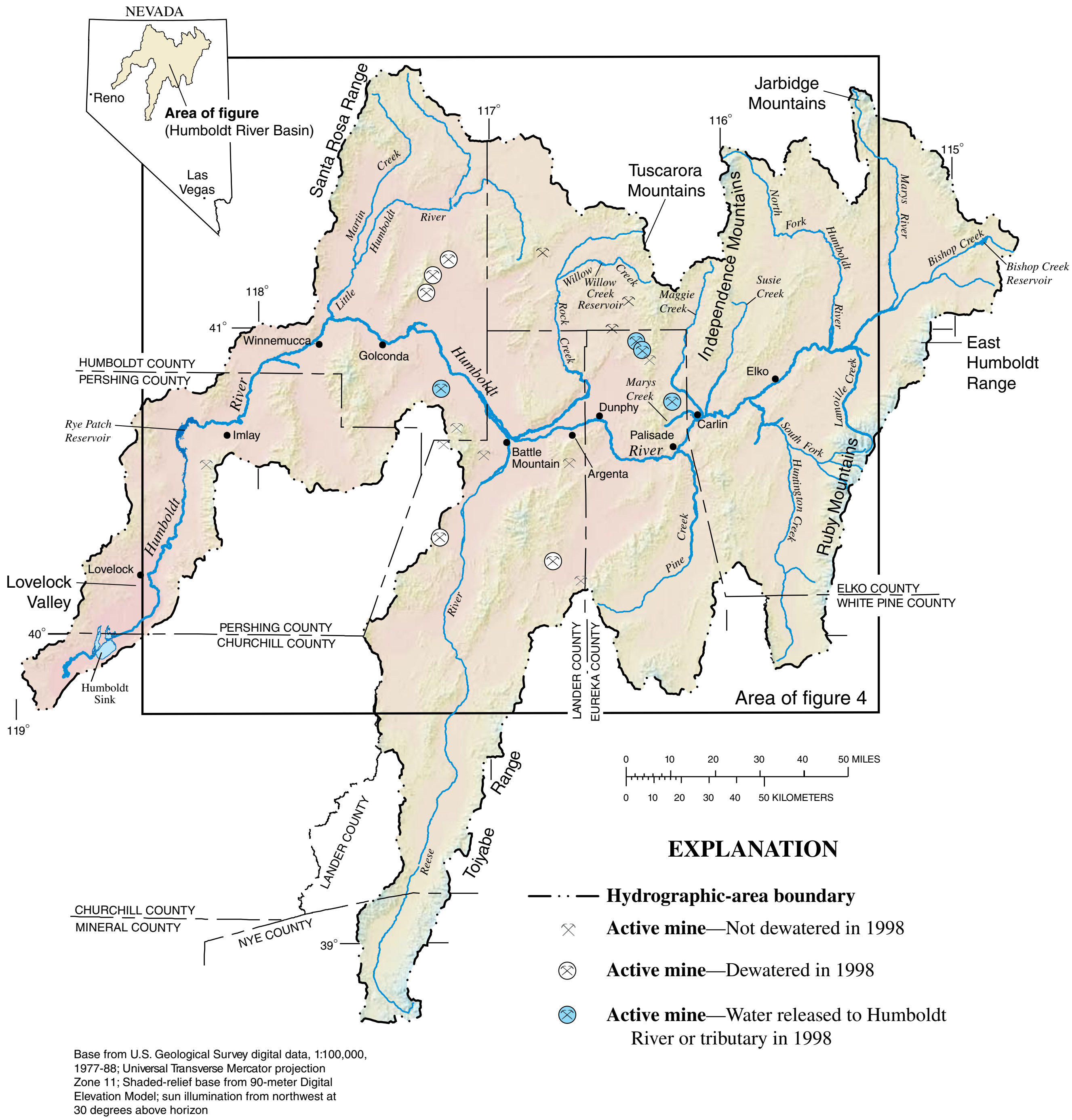


Figure 1. Locations of cultural features including major mines in the Humboldt River Basin, north-central Nevada.

of lowering water levels in order to maintain a dry and workable mine). In response to this concern, the U.S. Geological Survey (USGS), in cooperation with the Nevada Department of Conservation and Natural Resources (NDCNR), has undertaken the Humboldt River Basin Assessment. The objectives of the assessment are to (1) provide scientific appraisals of the ground-water and surface-water resources of each hydrographic area in the Humboldt River Basin, (2) determine the contribution of each area to the quantity and timing of flow in the Humboldt River, and (3) determine the effects of all major water uses in the basin.

Purpose and Scope

The purposes of this report are threefold. The first was to evaluate streamflow conditions and trends on the Humboldt River and three of its tributaries during 1950–99. This period was used for the flow analysis because several streamflow gages were in continuous operation since the mid-1940's (table 1). The second purpose was to determine the variation in annual runoff in relation to precipitation. The third purpose was to evaluate the effects of ground-water withdrawals on annual runoff.

Streamflow records for Lamoille and Martin Creeks were particularly important for this analysis because neither of these drainages have been affected by man's activities to the extent experienced by the other drainages in the Humboldt River Basin. Thus, any short-term or long-term changes in the flow of either stream during 1950-99 were the result of climate variability. Contrastingly, streamflow along the Humboldt River and several other tributaries have been affected during the past 140 years or so by numerous irrigation diversions, construction of reservoirs, channel modification, and, most recently, by the discharge of water to the Humboldt River and to Maggie Creek from mining operations.

Approach

The results of this study are based on streamflow and precipitation data collected during water years 1950–99. Water year used herein is the 12-month period October 1 through September 30. The water year is designated by the calendar year in which the 12-month period ends. These data consist of daily mean discharges at five streamflow gages on the main stem of the Humboldt River between Elko and Imlay and at three streamflow gages on Lamoille, Rock, and Martin Creeks (fig. 2 and table 1). Daily mean discharges for each gage were obtained from the USGS National Water Information System on the World Wide Web (WWW) at http://waterdata.usgs.gov/nv/nwis/nwis. The data also consist of precipitation measured at 36 weather stations in or adjacent to the Humboldt River Basin (fig. 2). Daily precipitation and temperature were obtained from the National Oceanic and Atmospheric Administration, National Climatic Data Center (1999) and from the Natural Resources Conservation Service (1999) and twice annual precipitation was obtained from high-altitude precipitation-storage gages from the Nevada Division of Water Resources (NDWR), State Engineer's Office (Carson City, Nevada, written commun., 2000).

The streamflow data were analyzed with graphical methods using annual runoff, mean monthly, and mean daily discharges separated into three periods (1950–70; 1971–91; and 1992–99) that represent changes in the volumes and distribution of ground-water withdrawals. Annual volumes of precipitation were estimated using the measurements from the weather stations and by dividing the Humboldt River Basin into regions that had different mean annual precipitation in relation to land-surface altitude. Multiple linear regression techniques were used to determine the relation between annual runoff and precipitation volume at each of the streamflow gages, and to evaluate the effects of ground-water withdrawals on annual runoff at streamflow gages on the Humboldt River.

Acknowledgments

Several people contributed to the study. Matt Dillon, Kim Groenwald and other employees from the Nevada Division of Water Resources provided assistance for obtaining information on water use, drillers' logs, and streamflow diversions. Information from drillers' logs and crop inventories from the Nevada Division of Water Resources was entered into an Excel spreadsheet by Katherine K. Henkelman (USGS) and provided important information on the history of ground-water development. Information on county and city population demographics from 1950 to 1999 was compiled by Rachel M. Caskey (USGS) from information from the U.S. Bureau of the Census (1952, 1983, 1991, and 2003) and from the Nevada State Demographer (Jeff Hardcastle, Reno, Nevada, written commun., 2005).

The USGS principal cooperator for the Humboldt River Basin Assessment has been the Nevada Department of Conservation and Natural Resources. However, financial support has been provided by the mining industry and state and local government. Support from the mining industry has come from Barrick Gold Corporation, Newmont Mining Corporation, Santa Fe Pacific Gold Corporation, Glamis Gold Limited, and Getchell Gold Corporation. Support from state and local government has come from Nevada's Legislative Committee on Public Lands, Nevada Division of Water Resources, Eureka County, and the Humboldt River Basin Water Authority.

Geographic Setting

Physiography

The headwaters of the Humboldt River are in the Ruby, Jarbidge, and Independence Mountains and East Humboldt Range in northeastern Nevada (fig. 1). The main stem of the river receives flow from several tributaries including Marys River, the North Fork Humboldt River, Lamoille Creek, the

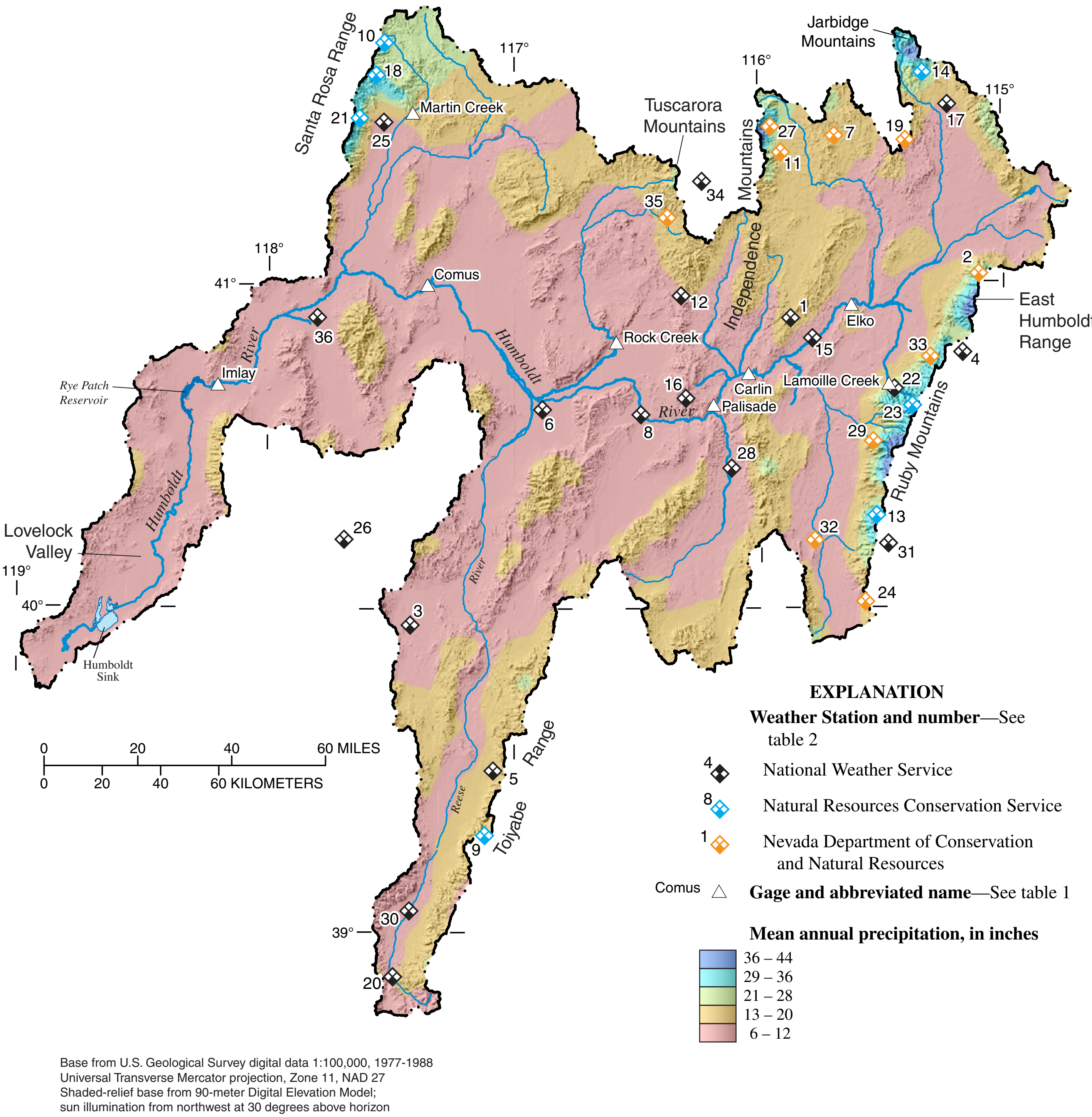


Figure 2. Distribution of mean annual precipitation and locations of streamflow gages and weather stations used in analysis of streamflow trends in the Humboldt River Basin, north-central Nevada. Mean annual precipitation was estimated for 1960–91 by Daly and others (1994) for all of Nevada. Estimates of mean annual precipitation for a 2.4 square mile grid were provided by G.H. Taylor (Oregon Climate Service, Oregon State University, written commun., 1997).

Table 1. Actively operating streamflow gages as of 1999 in the Humboldt River Basin above Imlay, Nevada

[Shaded stations are those shown in figure 2 and discussed in this report. Data for each streamflow gage can be obtained from http://waterdata.usgs.gov/nv/nwis/]

Station Number	Station Name	Drainage Area (square miles)[1]	Annual runoff for period of record to 1999 [2] (acre-feet)	Period of Record to water year 1999
10313400	Marys River Below Orange Bridge near Charleston	72	36,210	1991 to 1999
10315500	Marys River above Hot Springs Creek, near Deeth	415	47,770	1943 to 1980, 1982 to 1999
10315600	Marys River below Twin Buttes near Deeth	516	42,100	1991 to 1999
10316500	Lamoille Creek near Lamoille	25	32,870	1915 to 1923, 1943 to 1999
10318500	Humboldt River near Elko	2,780	186,600	1895 to 1902, 1944 to 1999
10319900	South Fork Humboldt River above Tenmile Creek near Elko	898	92,110	1989 to 1999
10320000	South Fork Humboldt River above Dixie Creek, near Elko	1,150	87,560	1948 to 1982, 1988 to 1999
10321000	Humboldt River near Carlin	4,340	278,700	1943 to 1999
10321590	Susie Creek at Carlin	194	7,420	1992 to 1999
10321925	Simon Creek near Highway 766 near Carlin	46	980	1996 to 1997
10321940	Maggie Creek above Maggie Creek Canyon near Carlin	332	25,010	1997 to 1999
10321950	Maggie Creek at Maggie Creek Canyon near Carlin	334	16,270	1989 to1999
10322000	Maggie Creek at Carlin	396	22,870	1913 to 1924, 1992 to1999
10322150	Marys Creek at Carlin	45	4,210	1989 to 1999
10322500	Humboldt River at Palisade	5,050	291,900	1902 to 1906, 1911 to 1999
10323425	Humboldt River at Old U.S. 40 Bridge, at Dunphy	7,390	329,100	1991 to 1999
10324500	Rock Creek near Battle Mountain	864	29,700	1918 to 1925, 1927 to 1929, 1945 to 1999
10324700	Boulder Creek near Dunphy	77	62	1991 to 1999
10325000	Humboldt River at Battle Mountain	8,860	272,100	1896 to 1897, 1921 to 1924, 1945 to 1981, 1991 to 1999
10327500	Humboldt River at Comus	12,200	247,400	1884 to 1926, 1945 to 1999
10329000	Little Humboldt River near Paradise Valley	1,030	16,660	1921 to 1928, 1943 to 1999
10329500	Martin Creek near Paradise Valley	175	25,430	1921 to 1999
10333000	Humboldt River near Imlay	15,500	207,700	1935 to 1941, 1945 to 1999

[1] Drainage area rounded to three significant figures or to nearest square mile when less than 100 (from Stockton and others, 2004).

[2] Annual runoff for period of record to water year 1999 reported by Jones and others (2000).

South Fork Humboldt River, and Susie, Maggie, Marys, and Pine Creeks, and occasionally from Rock Creek and the Reese and Little Humboldt Rivers (fig. 1).

The study area consists of the main stem of the Humboldt River from the streamflow gage near Elko to the streamflow gage near Imlay, a distance along the river channel of 307 mi (fig. 2). This reach of the river includes the uppermost streamflow gage on the river (near Elko) to the lower most streamflow gage (near Imlay) that is above Rye Patch Reservoir. The study area also includes three of its tributaries—Lamoille, Rock, and Martin Creeks (fig. 2).

Land-surface altitudes in lowlands of the Humboldt River Basin range from less than 3,900 ft at the Humboldt Sink in the western part of the basin to more than 5,000 ft in the eastern part. Land-surface altitudes in mountain ranges are more than 11,000 ft in parts of the Ruby Mountains, East Humboldt Range, and the southern Toiyabe Range. The terms low-altitude and high-altitude are used to refer to runoff sources for the streamflow gages discussed herein. Low-altitude areas are at altitudes of less than 6,000 ft and high-altitude areas are at altitudes above 6,000 ft.

The Humboldt River flows through a broad valley from northeast to southwest. This valley is several miles wide and is well defined where it is bounded by mountain ranges, and less well defined at the mouths of large tributary valleys such as those of the Reese and Little Humboldt Rivers. The Humboldt

River passes through four canyons—the first near Elko, the second near Carlin, the third near Palisade, and the fourth above Golconda (fig. 1).

Climate

The flow of the Humboldt River depends almost entirely on the annual snowpack that accumulates each winter in the Ruby, Jarbidge, and Independence Mountains, and the East Humboldt Range (fig. 2). Mean annual precipitation ranges from about 6 in. near the Humboldt Sink to more than 36 in. in the Ruby Mountains (fig. 2). Year-to-year and longer-term variations in annual precipitation result in corresponding variations in flow of the river.

The Humboldt River Basin is characterized by four climatic types (Houghton and others, 1975, p. 3), which can be described as (1) mid-latitude desert, with cold winters, hot summers, and arid conditions (2) mid-latitude steppe, with cold winters, hot summers, and semi-arid conditions; (3) subhumid continental, with cold winters and moderate precipitation; and (4) humid continental with cold winters and heavy precipitation. Mid-latitude desert and steppe climate types generally correspond to lowlands in the Humboldt River Basin. The subhumid continental climate type generally corresponds to mountain ranges. The humid continental type is restricted to the highest parts of the mountains in the eastern part of the Humboldt River Basin. This latter climate type covers only a small part of the basin, but accounts for a large percentage of the total runoff of the Humboldt River in most years.

Mean annual precipitation at the three long-term weather stations at or above 6,000 ft ranged from 13.17 in. at Austin to 16.12 in. at Lamoille, whereas mean annual precipitation at four long-term weather stations in the basin lowlands

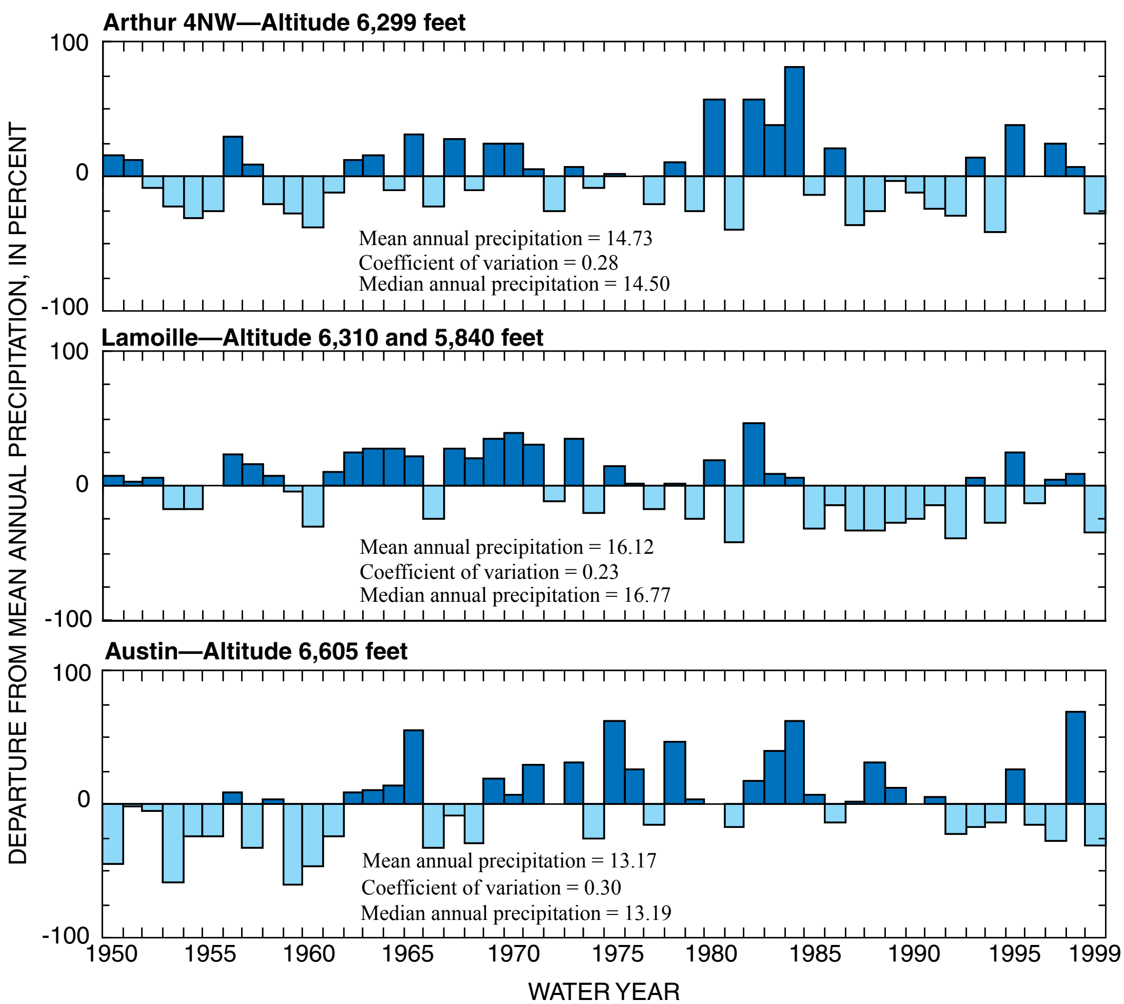


Figure 3. Departures from mean annual precipitation at selected weather stations, water years 1950–99. Weather stations are listed in table 2 and shown in figure 2. (Precipitation data are from the National Oceanic and Atmospheric Administration, National Climatic Data Center, 1999.)

(between 4,300 ft to almost 5,100 ft altitude) ranged from 8.06 in. at Battle Mountain to 9.63 in. at Elko for the 50-yr period from 1950 to 1999 (fig. 3). Lower coefficients of variation (standard deviation divided by the mean annual precipitation) were estimated for the stations on the eastern side of the basin indicating that precipitation is generally less variable than to the west. The least coefficient of variation was determined for the weather station at Lamoille on the west side of the Ruby Mountains suggesting that the high mean annual precipitation areas (areas in fig. 2 with mean annual precipitation greater than 20 in.) may have less variability than areas with less mean annual precipitation.

The 1950's through the early 1960's were characterized by two droughts as indicated by the negative departures from mean annual precipitation (fig. 3). The severity of both droughts was greater in western parts of the Humboldt River Basin where precipitation during some years was less than half of the 50-yr mean. The 1950's were preceded by a wetter than average period over much of the Humboldt River Basin. The wetter period of above mean annual precipitation started in the late 1930's and continued into the 1940's (Eakin and Lamke, 1966, p. 19). The 1960's through the 1970's had several alternating periods of generally above and below mean annual precipitation. The wet years from 1982 to 1984 were well above mean annual precipitation at most stations, sometimes as much as 50 percent or more and increased precipitation was not limited to the higher elevations as shown by the large departures at Elko, Beowawe, and Winnemucca. The effect of these three wet years was that the annual runoff of the Humboldt River in 1984 was the largest ever recorded at all the streamflow gages.

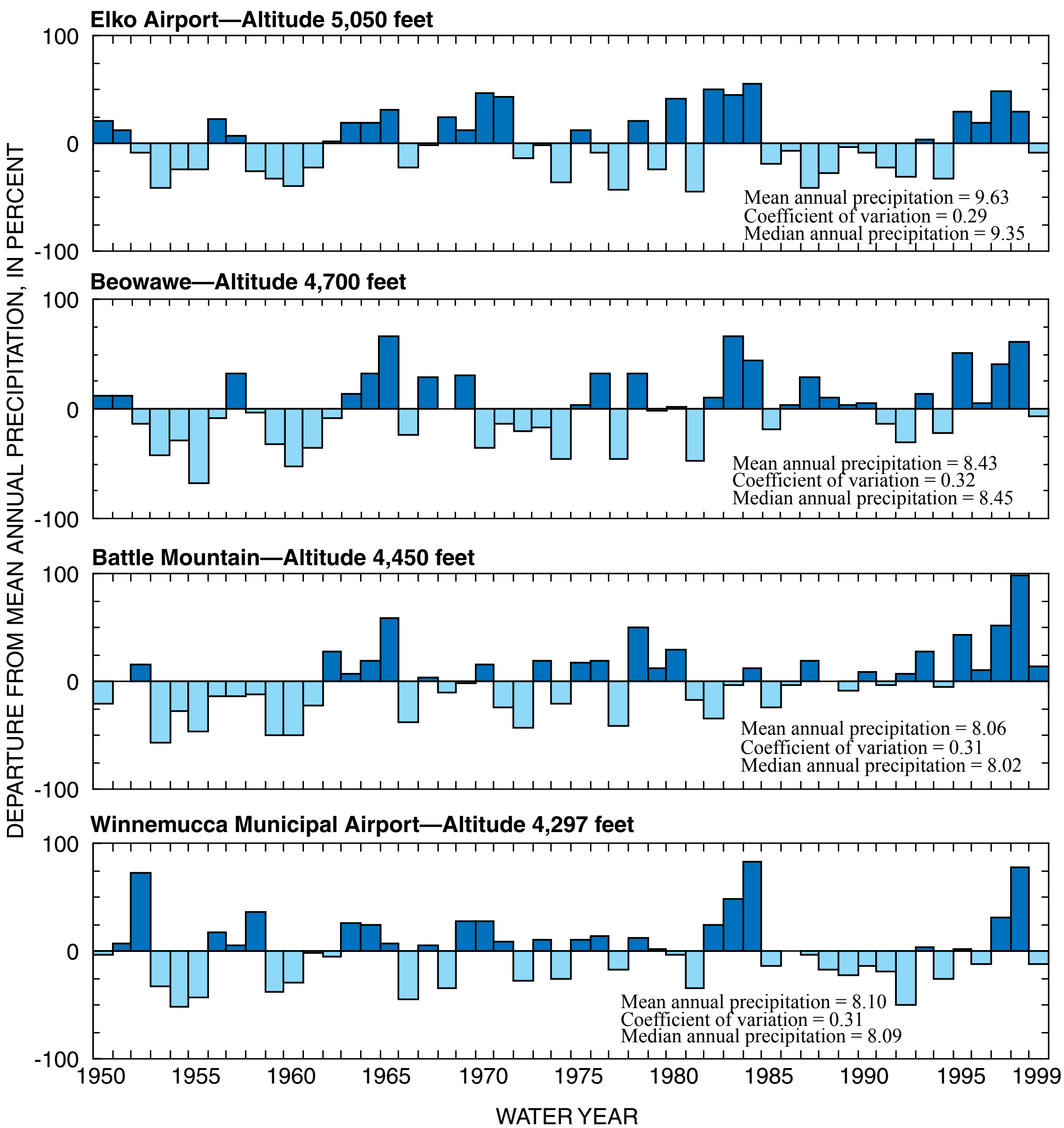


Figure 3. Continued.

The wet years of 1982–84 were followed by a drought that began about 1985 and continued through 1994. The severity of this drought differed across the Humboldt River Basin and was most pronounced at the three eastern stations near the Ruby Mountains (Arthur 4NW, Lamoille, and Elko) and at Winnemucca. The greater severity of the drought in the eastern part of the basin is where much of the annual runoff in the Humboldt River is generated. The mid to late 1990's was generally above mean annual precipitation at the four low-altitude stations. During this same period, each of the three high-altitude stations had two years of below mean annual precipitation.

History of Water Resources Development

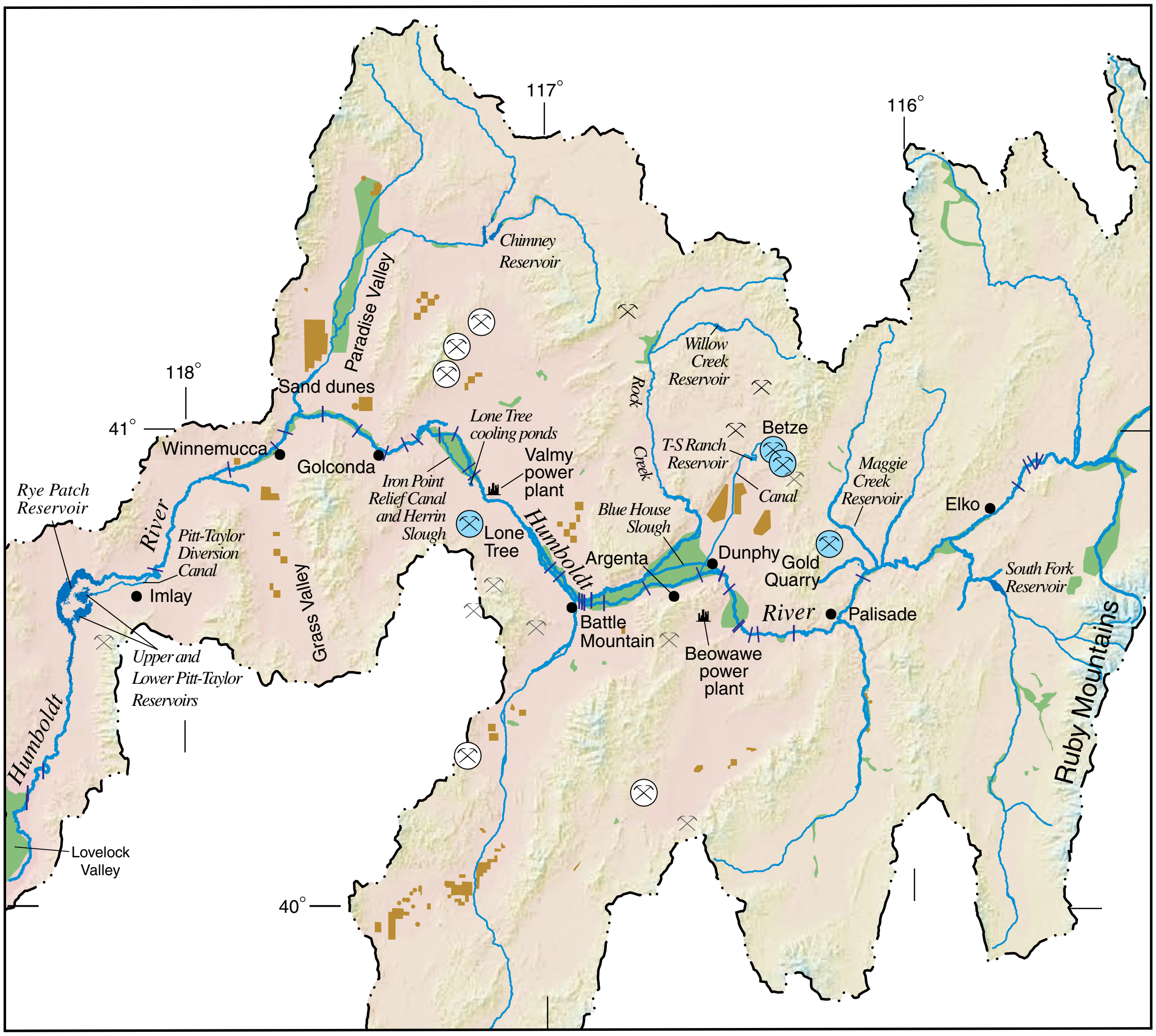
Surface-Water Diversions for Irrigation

Diversion of flow from the Humboldt River and its tributaries for irrigating meadows and crops is, and has been, the principal use of surface water in the Humboldt River Basin. The first large ranching operations in the basin were established between about 1862 and 1872 (Horton, 2000, p. 102–103). The completion of the Transcontinental Railroad was particularly important to the establishment of these operations because the railroad was needed for transportation of cattle to markets. During high flows of spring and early summer, the river overtops its banks and spreads out in abandoned channels, and thus naturally irrigates low lying meadows. Ranchers and farmers began diverting water into canals and ditches for irrigation of crops and meadows. The first diversions, based on year of priority, were put into use in the Lovelock area in 1861, in the Elko area in 1862, and the Winnemucca and Imlay areas in 1863 (Hennen, 1964b, p. 154, 170, 177, and 178). By the late 1800's, diversions on the upper Humboldt River were so prolific that streamflow rarely reached the Lovelock area in average or dry years (Horton, 2000, p. 108–109). Conflicts between upstream and downstream users continued to intensify in the early 1900's, and this led not only to the adjudication of Humboldt River water rights in the 1930's (Mashburn and Mathews, 1943), but also to construction of Rye Patch Dam and Reservoir (fig. 4) in 1935–36.

The process of water-rights adjudication on the Humboldt River began with the filing of the Nevada State Engineer's Final Order of Determination in the District Court of Humboldt County and it included the Bartlett Decree, intervening orders by two other judges, and a final decision by the Nevada Supreme Court ending litigation (Mashburn and Mathews, 1943). Besides establishing priorities by year for individual water rights, the adjudication established two districts on the river with irrigation seasons of differing length, and identified three crop types and irrigation requirements for each. Figure 4 shows locations of diversions on the main stem of the river as of the early 1990's.

The upper district on the Humboldt River is that part of the basin upstream from the streamflow gage at Palisade and the lower district extends from Palisade to Lovelock Valley (Malone, 1932, p. 13). The irrigation season in the upper district extends from April 15 to August 15 each year and in the lower district from March 15 to September 15. The three recognized crop types and water requirements are (1) harvest lands—3 ft/yr; (2) meadow pasture—1.5 ft/yr; and (3) diversified pasture—0.75 ft/yr. The Bartlett Decree recognized that the total cultivated area using water from the Humboldt River was 285,238 acres (Mashburn and Mathews, 1943, p. 27). The decree further recognized that 698,379 acre-ft would be required to satisfy all water rights with a priority of 1928 or earlier (Mashburn and Mathews, 1943, p. 28). Because the average annual flow of the river at Palisade at the time of the decree was 255,650 acre-ft (Mashburn and Mathews, 1943, p. 28), serving all water rights in a year of average flow depended on irrigation return flows to the river (Hennen, 1964a, p. 13). As of 1963, 265,791 acres of land with decreed water rights of 666,680 acre-ft were under irrigation in the Humboldt River Basin (Hennen, 1964a, p. 8). As of 2000, 270,978 acres of land with decreed water rights of 674,581 acre-ft were under irrigation (Horton, 2000, p. I–99). These figures do not include lands irrigated by diversions from the Reese River and the Little Humboldt River because both of these streams rarely reach the Humboldt River, and thus have no consistent influence on its flow.

Prior to 1910, the Humboldt River followed a course in its reach between Dunphy and Battle Mountain that now is one to three miles north of its present course. The older channel was abandoned as a result of flooding during February and March 1910 (Foster, 1933, p. 49–50). Blue House Slough and the lowest reaches of Rock Creek mark the abandoned course (fig. 4). After 1910, the present channel was well defined except for a marshy area near Argenta that was called the Argenta Swamp. In this area, the river channel disappeared and flow spread out over an area of marshes and wetlands. Estimates of the total area of the Argenta Swamp have ranged from less than 1,000 acres (Malone, 1932, p. 41–48) to 12,000–15,000 acres (Horton, 2000, p. 24). Flow of the river exited the Argenta Swamp as two channels that joined a few miles east of Battle Mountain (Foster, 1933, p. 50–51). The effect of the Argenta Swamp was that it impeded the flow of the river, especially in the spring, and delayed the arrival of the snowmelt runoff in the Lovelock area. Flow losses in this reach of the river were estimated to range from 4,000 to 12,000 acre-ft/yr mainly because flow had to resaturate the shallow water table in the swamp area before it could continue downstream (Malone, 1932, p. 48). Lovelock area irrigation interests and the Bureau of Reclamation began to consider draining the swamp during the 1930's, but this was not accomplished until the early 1950's when a ditch was constructed to drain the swamp. The ditch is visible from I-80 as a straight section of river channel north of the highway and immediately west of the Argenta railroad siding.



Base from U.S. Geological Survey digital data, 1:100,000, 1977-88; Universal Transverse Mercator projection
Zone 11

EXPLANATION

Area irrigated by:

Diversion from the Humboldt River or one of its tributaries

Ground water

Reservoir

Diversion

Hydrographic-area boundary

Active mine—Not dewatered in 1998

Active mine—Dewatered in 1998

Active mine—Water released to Humboldt River or tributary in 1998

Figure 4. Location of irrigated areas, diversions along the Humboldt River, and reservoirs on or tributary to the Humboldt River.

Ten reservoirs store water in the Humboldt River Basin (figs. 1 and 4). Three are used to store ground water pumped for mine dewatering purposes and seven impound streamflow for irrigation and recreation purposes. Maggie Creek and T-S Ranch Reservoirs and Lone Tree Cooling Ponds store excess ground water pumped from the Gold Quarry, Betze-Post, and Lone Tree Mines, respectively. Figure 5 shows discharge volumes from each of the mine-dewatering storage reservoirs for water years 1990–99. Water from Maggie Creek Reservoir has been released to the Humboldt River by way of Maggie Creek since April 1994 at total annual volumes ranging from 8,840 acre-ft in 1994 to 19,000 acre-ft in 1997. The total volume discharged to Maggie Creek as of 1999 was 84,400 acre-ft. Water from the T-S Ranch Reservoir was released to the Humboldt River by way of a lined canal and pipeline (fig. 4) in 1997–99 at total annual volumes of 24,600 acre-ft, 48,600 acre-ft and 8,600 acre-ft, respectively. Total water released to the river from the T-S Ranch Reservoir as of 1999 was 81,800 acre-ft. Water from the Lone Tree Cooling Ponds has been released to the Humboldt River by way of a lined ditch, Iron Point Relief Canal, and Herrin Slough since June 1992 at total annual volumes ranging from 13,100 acre-ft in 1992 to 45,700 acre-ft in 1999. The total volume released to the Iron Point Relief Canal as of 1999 was 289,000 acre-ft. However, the volume that reached the Humboldt River by way of Herrin Slough probably was less because of seepage and evaporation losses. As of 1999, total ground water released to the Humboldt River, either directly or by way of tributaries, was 455,000 acre-ft (Data source for all releases from NDWR files, 2003).

Four reservoirs impound streamflow on tributaries to the Humboldt River and three reservoirs impound water along or near the main stem of the Humboldt River (figs. 1 and 4). The four reservoirs on tributaries are (1) Bishop Creek Reservoir, with a potential capacity of 30,000 acre-ft and constructed in 1912, is not used because of structural problems; (2) South Fork Reservoir, with a capacity of 42,000 acre-ft and constructed in 1987, is used for recreation and fisheries purposes; (3) Willow Creek Reservoir, with a capacity of 18,000 acre-ft and constructed during 1910–25, is used for irrigation; and (4) Chimney Reservoir, with a capacity of 35,000 acre-ft and constructed in 1974, is used for irrigation and recreation. The three reservoirs on or near the Humboldt River are downstream of Imlay and are used for irrigation in the Lovelock area. The Upper and Lower Pitt-Taylor Reservoirs have a combined capacity of 36,600 acre-ft and were constructed during 1907–11. These two reservoirs are filled by way of the Pitt-Taylor diversion canal only when no storage capacity is available in Rye Patch Reservoir. Rye Patch Reservoir was constructed during 1935–36 and has a storage capacity of 194,300 acre-ft. It is the only impoundment on the main stem of the Humboldt River. This reservoir is also used for recreation. Total usable impoundment capacity in the Humboldt River Basin is about 326,000 acre-ft. However, this capacity is achieved only during the infrequent periods of well above average precipitation and runoff in the Humboldt River Basin.

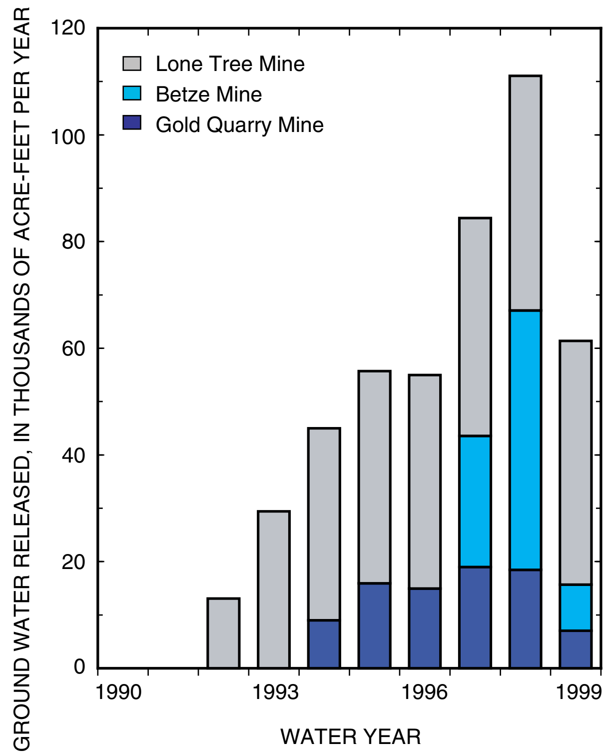


Figure 5. Annual volumes of water discharged to the Humboldt River or Maggie Creek by mining operations, 1990–99. Location of mines is shown in figure 4. (Data are from Nevada State Division of Water Resources, State Engineer's Office, written commun., 2002; Newmont Mining Corporation, written commun., 2004; and Barrick Gold Corporation, written commun., 2004.)

Ground-Water Withdrawals

Ground water is, and historically has been, pumped in the Humboldt River Basin to meet the demands for five principal uses—municipal and domestic, power generation, irrigation, mining, and stock. Power generation and mining use traditionally have been reported as industrial use. The development history of ground-water resources in the Humboldt River Basin from the late 1800's to the 1940's cannot be accurately documented because few records were kept. However, census records from the U.S. Bureau of the Census (1952, 1983, 1991, and 2003) and the Nevada State Demographer (Jeff Hardcastle, Reno, Nevada, written commun., 2005) combined with well drillers' reports from NDWR (Carson City, Nevada, written commun., 2002) provide useful information for making estimates of ground-water withdrawals prior to the time when records were begun in the 1980's.

Populations in the counties that are included in the Humboldt River Basin were nearly static from 1940 to 1960 (fig. 6) on the basis of the decadal census suggesting that there were few changes in development of the water resources resulting from a change in population (both surface and ground water). Populations in all counties in the Humboldt River Basin increased slowly from 1960 to 1980 and correspond to a period when people settled several areas in the Humboldt River Basin, drilled wells, and began irrigating crops. Populations increased dramatically after 1980 as a result of the development of large, low-grade gold deposits and the resultant employment opportunities.

Numbers and types of wells drilled each year since 1949 provided another indication of the development of ground-water supplies. The number of wells drilled each year by type of use is shown in figure 7. The number of wells drilled for stock water remained relatively low throughout the 50-yr period with the number of wells drilled increasing during dry periods (1953–60; 1968; 1977; 1981; 1988–92). Only a few irrigation wells were drilled between 1949 and 1958 and most were for supplemental irrigation when surface water was insufficient. However, many irrigation wells were drilled between 1958 and 1977 when people began settling areas away from the Humboldt River (see fig. 4 for location of areas irrigated with ground water). The number of domestic wells drilled annually remained low until 1977 when the number of wells drilled doubled. There was another large increase in the number of domestic wells drilled starting in 1988 that continued until 1998. The large increase in the number of domestic wells beginning in 1988 coincides with a rapid increase in population in most counties in the Humboldt River Basin (compare figs. 6 and 7). Similar trends occurred with the drilling of monitoring and test wells for gold exploration and mining and for municipal and industrial (power generation and mining) uses that also coincide with a rapid increase in population.

The number of wells drilled for municipal and industrial use declined dramatically after 1998, which corresponds to a decline in the number of new gold mining operations and in the general population for Elko, Humboldt, and Lander Counties (compares figs. 6 and 7). The decline in new gold mining operations also corresponds to a decline in the number of wells drilled for domestic, monitoring, and test purposes after 1996 that preceded the decline in population.

Domestic and Municipal Use

Estimates of ground-water withdrawals for domestic and municipal uses were based on the years between 1988 and 1999 when municipal water use was reported. Comparison of municipal use with the municipal population served for these years provided an approximate per capita water use of 0.4

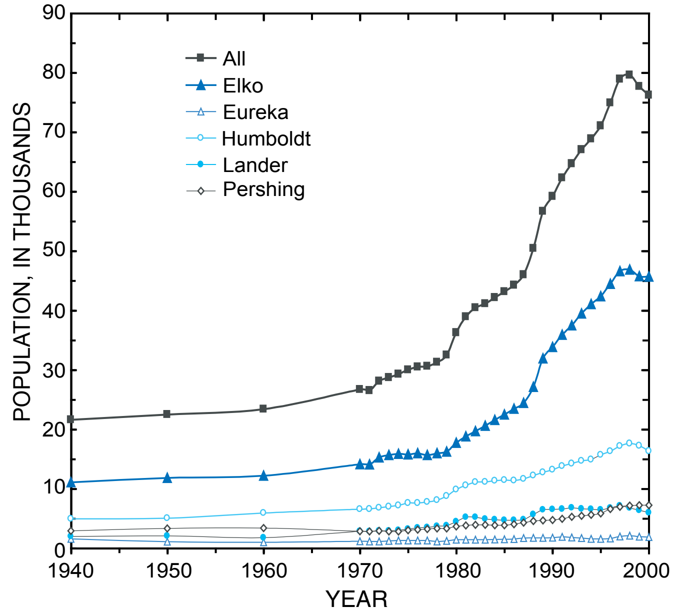


Figure 6. Population trends for counties in the Humboldt River Basin, 1940–99. Data from U.S. Bureau of the Census (1952, 1983, 1991, and 2003), and Nevada State Demographer (Jeff Hardcastle, Reno, Nevada, written commun., 2005).

acre-ft/yr. This value was then used to estimate total municipal use on the basis of municipal populations. Domestic water use was estimated on the basis of the rural population in 1950. It was increased yearly on the basis of the number of new domestic wells drilled every year in each county multiplied by the product of the average number of people per household and the per capita water use. The total estimated municipal and domestic water use ranged from less than 10,000 acre-ft in 1950 to more than 20,000 acre-ft in 1999 (fig. 8).

Irrigation Use

Estimates of ground-water withdrawals for irrigation were based on several sources. Only Paradise Valley north of Winnemucca had annual estimates that extended for 1950–99 (Prudic and Herman, 1996; and crop inventories from NDWR). Annual ground-water withdrawals in other areas of the Humboldt River Basin above Imlay were estimated from previous reports (Eakin, 1961; Zones, 1961; Eakin, 1962; Cohen, 1963; Crosthwaite, 1963; Cohen, 1964; Eakin and others, 1965; Everett and Rush, 1966; Rush and Everett, 1966; Eakin and others, 1976; and Harrill and Prudic, 1998); from maps and air photos showing irrigated acreages during the mid-1970's, from crop inventories compiled annually by NDWR since the early 1980's, and from well drillers' reports

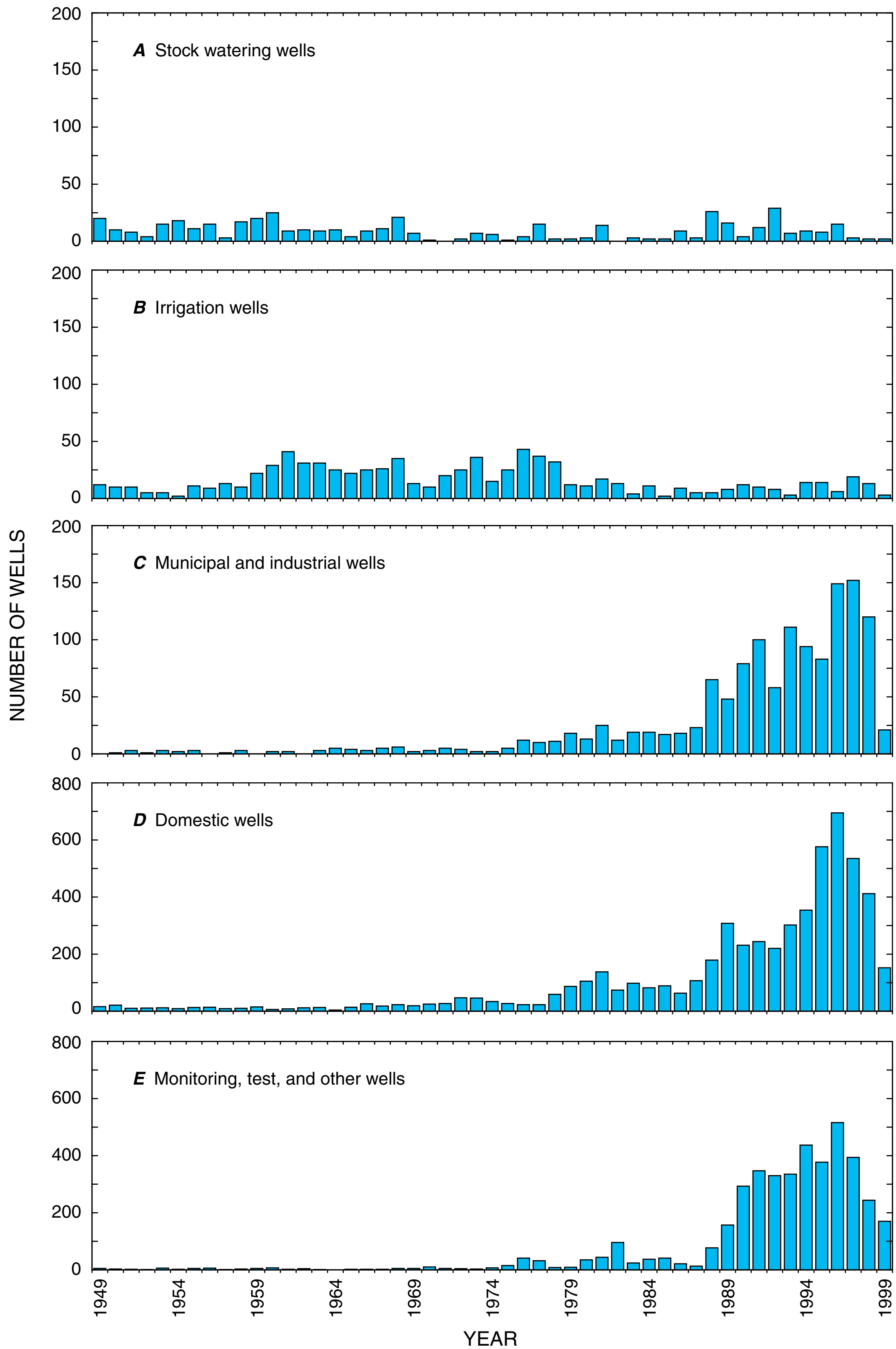


Figure 7. Number of wells drilled annually for different uses in the Humboldt River Basin above Rye Patch Reservoir, 1950–99. Data are from drillers' logs submitted to the Nevada Division of Water Resources, State Engineer's Office, Carson City, Nevada.

for wells serving irrigated fields. The NDWR crop inventories for 1998 were compared with estimates of ground-water withdrawals reported by Plume (2003). Irrigated acreages were converted to ground-water withdrawals on the basis of the following crop requirements: (1) alfalfa, pasture, and potatoes—3 ft/yr, and (2) grains—1.5 ft/yr. Some alfalfa and pasture fields were irrigated with surface water when available and ground water was applied only when surface water was not available. The quantity of supplemental ground water was assumed to be 1 ft/yr. Little or no ground water may be pumped at these types of fields during years of well above-average runoff, whereas ground water would have served all irrigation needs in years of well below-average runoff. Estimated ground-water withdrawals for irrigation increased from a few thousand acre-feet in 1950 to a maximum of about 160,000 acre-ft in 1981 (fig. 8). Estimated ground-water withdrawals for irrigation during 1983–99 ranged from about 100,000 to 130,000 acre-ft/yr.

Industrial Use

Power Generation

Ground-water withdrawals for power generation have been used for cooling at the Valmy Power Plant since 1977 and for withdrawal of geothermal fluids for the Beowawe Geothermal Power Plant since at least 1988. Estimates of ground-water withdrawals for power generation ranged from about 2,000 acre-ft/yr in 1977 to about 12,000 acre-ft/yr in 1994 (fig. 8). Between 1997 and 1999, about 77 percent of the ground water used for cooling at the Valmy plant came from excess water from the nearby Lone Tree Mine (value from NDWR files).

Mining Use

Ground water was pumped for mining use more or less continuously throughout much of the 1900's. However, this use was minor (less than 1,000 acre-ft/yr) compared with other

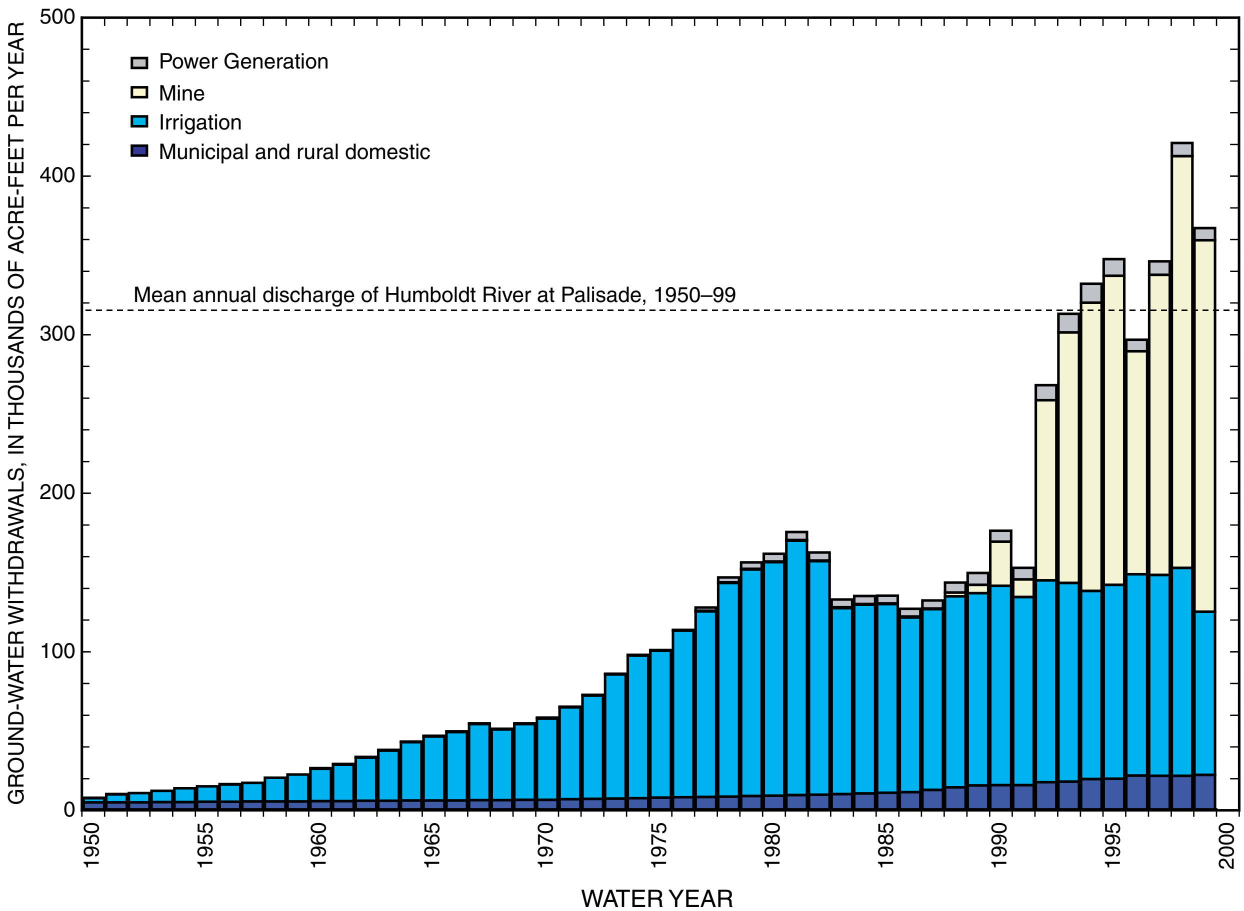


Figure 8. **Estimates of annual ground-water withdrawals in the Humboldt River Basin above Rye Patch Reservoir, 1950–99.**

uses prior to 1990. Mining companies, by the 1980's, recognized the significance of large, low-grade gold deposits in Nevada. Water use for exploiting these gold deposits increased rapidly from about 2,000 acre-ft in 1988 to 28,000 acre-ft in 1990 (fig. 8). This water was used mostly for milling purposes and dust control. By 1992, however, ground-water withdrawals increased dramatically because of the need to dewater some of the mines. As a result, ground-water withdrawals increased to more than 120,000 acre-ft in 1992. Ground-water withdrawals for mining use peaked at about 261,000 acre-ft in 1998 (fig. 8).

Some of the water pumped for mine dewatering after 1991 was discharged to the Humboldt River or to its tributary Maggie Creek (fig. 5). Peak discharge from mine dewatering was in 1998, the same year that ground-water withdrawals for mining use was greatest. In that year, withdrawals for mine dewatering and mine consumptive use accounted for about 78 percent of total ground-water withdrawals in the middle part of the Humboldt River Basin (the drainage area between Palisade and Comus; Plume, 2003, p. 12) and about 62 percent of the total ground-water withdrawals above Rye Patch Reservoir. Of the total volume pumped in the middle part of the Humboldt River Basin for dewatering, 46 percent (96,700 acre-ft) was discharged to the river or to Maggie Creek, 36 percent (74,500 acre-ft) was returned to local aquifers by infiltration or re-injection, 16 percent (33,100 acre-ft) was substituted for other uses (mostly irrigation), and 2 percent (5,260 acre-ft) was lost to evaporation (Plume, 2003, p. 12).

Streamflow

The analysis of streamflow conditions and trends on the Humboldt River presented herein is based on the records for eight streamflow gages, five on the river and one on each of three tributaries, and records from 36 weather stations (fig. 2). The eight streamflow gages have differing periods of record, but all have been in operation since 1945. The 36 weather stations also have varying periods of record, and several have been in operation since before 1950. The 50-yr period of record from water year 1950 to 1999 was selected for analysis of streamflow conditions and trends because streamflow records were continuous for the 8 streamflow gages. This 50-yr period was further subdivided into three shorter periods on the basis of changes in ground-water withdrawals (fig. 8). The three periods reflect differing stages of ground-water development in the Humboldt River Basin. The first period, 1950–70, was one during which ground-water withdrawals increased from less than 10,000 acre-ft/yr to 60,000 acre-ft/yr. The second period, 1971–91, was one during which ground-water withdrawals increased to about 180,000 acre-ft in 1981 and thereafter ranged from 130,000 to 180,000 acre-ft/yr until 1992. The third period, 1992–99, was one during which irrigation withdrawals remained nearly constant, but total ground-water withdrawals increased to more than 420,000 acre-ft in 1998 as a result of mining operations. Tables 1 and 2 list names, periods of record, and other pertinent information for streamflow gages and weather stations, respectively, used for this study.

Trends in streamflow correlate not only with the activities of man but also with climate variations. Although the influence of man's activities on streamflow may seem straightforward, the relation is complicated by the effects of climate variation. Thus, the effects of man's activities on streamflow cannot be completely understood unless the effects of climate variability also are understood. Streamflow response to climate change is difficult to assess because the timing and magnitude of response is highly variable. Ideally, the relation between climate and streamflow at a particular time scale can be defined by comparing streamflow and precipitation records. However, many processes, in addition to annual precipitation, affect streamflow, the most important being variations in ground-water storage and the interaction between streamflow and ground water. Anything that affects ground-water storage indirectly affects runoff and baseflow, and many coupled processes influence ground water, including effects caused by the natural variability in climate, man's activities, and flow and storage in the unsaturated zone.

Streamflow conditions and trends on the Humboldt River and on Lamoille, Rock, and Martin Creeks were analyzed using graphical and statistical techniques. The first technique involved plotting streamflow data for each streamflow gage as time series graphs. The streamflow data presented on these graphs are shown as (1) percent departure of annual runoff from the 50-yr mean annual runoff (figs. 9 and 13); (2) cumulative annual runoff where the value for any year is the sum of all annual runoff up to and including the year for the period being evaluated (figs. 10 and 14); (3) mean monthly discharges (figs. 11 and 17) and mean daily discharges (fig. 19); (4) flow duration in which the percentage of time when discharge of any magnitude was equaled or exceeded (figs. 12 and 18); and (5) the difference in cumulative annual runoff among stations on the Humboldt River (figs. 15 and 16). When data for two or more streamflow gages or for different time periods are shown on the same graph, differences in flow among the streamflow gages and different time periods and the reasons for changes in flow can be evaluated.

Statistical techniques were used to analyze the relation of annual runoff to precipitation. Regression models (Helsel and Hirsch, 1992) were used to evaluate the relation of mean annual precipitation to land-surface altitude and the relation of annual runoff to an effective precipitation volume. An effective precipitation volume that included a percent of precipitation from the two previous years was determined by minimizing the square of the difference in rank between annual runoff and annual precipitation volume (Searcy and Hardison, 1960). Multiple linear regression models (Helsel and Hirsch, 1992) were used to test for the significance of the effective precipitation volume and ground-water withdrawals on annual runoff at streamflow gages along the Humboldt River.

Table 2. Weather stations where precipitation was measured between 1950 and 1999 in the Humboldt River Basin above Imlay, Nevada

[Abbreviations: NDWR, Nevada Division of Water Resources; NRCS, U.S. Dept. of Agriculture, Natural Resources Conservation Service (SNOTEL site); NCDC, National Oceanic and Atmospheric Administration, National Climate Data Center. Station number is shown in figure 2. Regions are shown in figure 21]

Station number	Station Name	Agency	Latitude (degrees minutes)	Longitude (degrees minutes)	Altitude (feet)	Period of Record	Region
1	Adobe Summit	NDWR	4054	11552	6,550	1960–99	3
2	Angel Lake	NDWR	4103	11506	8,380	1959–99	2
3	Antelope Valley Farr	NCDC	3958	11726	4,900	1985–97	6
4	Arthur 4NW	NCDC	4047	11511	6,300	1949–99	2
5	Austin	NCDC	3930	11704	6,605	1950–99	5,6
6	Battle Mountain	NCDC	4037	11653	4,540	1950–99	3,7
7	Beaver Creek	NDWR	4127	11541	6,263	1966–99	2
8	Beowawe	NCDC	4035	11628	4,700	1950–99	3
9	Big Creek Sum	NRCS	3918	11707	8,700	1981–99	5
10	Buckskin Lower	NDWR	4145	11732	6,700	1981–99	1
11	California Creek	NDWR	4124	11554	6,437	1966–99	2
12	Carlin Newmont	NCDC	4055	11619	6,520	1968–99	3
13	Corral Canyon	NRCS	4017	11532	8,497	1980–99	2
14	Draw Creek	NRCS	4139	11512	7,198	1985–99	2,3
15	Elko	NCDC	4050	11548	5,080	1950–99	2,3
16	Emigrant Pass Hwy Station	NCDC	4039	11618	5,760	1955–99	2,3
17	Gibbs Ranch	NCDC	4133	11513	6,000	1953–99	2,3
18	Granite Creek	NRCS	4139	11734	7,800	1981–99	1
19	Hanks Creek	NDWR	4126	11523	6,552	1950–99	2,3
20	Ione Upper Reese River	NDWR	3851	11728	6,995	1953–99	4
21	Lamance	NRCS	4131	11738	5,997	1981–99	1
22	Lamoille PH	NCDC	4041	11528	6,293	1929–71	2
22	Lamoille 3E	NCDC	4044	11526	6,306	1973–75	2
22	Lamoille Yost	NCDC	4043	11531	5,840	1975–99	2
23	Lamoille3	NRCS	4038	11524	7,700	1981–99	2
24	Overland Pass #2	NDWR	4001	11535	6,788	1966–99	2
25	Paradise Valley 1NW	NCDC	4130	11732	4,675	1955–99	1,3
26	Paris Ranch	NCDC	4013	11741	4,140	1967–99	7
27	Pratt	NDWR	4129	11556	6,998	1966–99	2
28	Pine Valley Bailey Ranch	NCDC	4026	11607	5,047	1957–99	2,3
29	Rattle Snake	NDWR	4030	11533	7,198	1966–99	2
30	Reese River O'Toole	NCDC	3904	11725	6,550	1973–99	4,5
31	Ruby Lake	NCDC	4012	11530	6,010	1949–99	2
32	Saddler Ranch	NDWR	4012	11547	5,699	1950–99	2
33	Soldier Creek	NDWR	4046	11515	6,998	1950–99	2
34	Tuscarora	NCDC	4119	11613	6,170	1958–99	2,3
35	Willow Creek	NDWR	4112	11622	5,915	1954–99	3
36	Winnemucca Municipal Airport	NCDC	4054	11748	4,297	1950–99	6,7

Tributaries

A number of tributary streams contribute flow to the Humboldt River, especially in the upper part of the basin. Lamoille Creek was chosen as the tributary to analyze in this part of the basin because it has a long period of record (table 1) and it is not affected by diversions or impoundments above the streamflow gage. Altitude in Lamoille Creek drainage ranges from 6,240 ft at the streamflow gage to more than 11,000 ft along the crest of the Ruby Mountains. The drainage area above the streamflow gage is about 25 mi^2.

Martin Creek also was used for the analysis of tributary flow for the same reasons as Lamoille Creek. Martin Creek is a tributary of the Little Humboldt River (fig. 1), which contributed flow to the Humboldt River in years of well above average runoff and only when a channel was excavated through sand dunes that block the natural channel at the south end of Paradise Valley (Prudic and Herman, 1996). Altitude in the

Martin Creek drainage ranges from 4,660 ft at the streamflow gage to more than 9,700 ft at the crest of the Santa Rosa Range. The drainage area above the streamflow gage is about 175 mi^2. The Martin Creek drainage area differs from that of Lamoille Creek in that only 57 percent of the drainage area is higher than 6,000 ft (table 3).

The flow of Rock Creek is affected by diversions in its upper and lower reaches and by impoundment of streamflow on Willow Creek, its main tributary. However, Rock Creek contributes flow to the Humboldt River in years of above average runoff (Maurer and others, 1996, p. 27). Altitude in the Rock Creek drainage ranges from 4,670 ft at the streamflow gage to 8,600 ft at the crest of the Tuscarora Mountains. The drainage area above the streamflow gage is 864 mi^2; however, only 25 percent of the drainage area is higher than 6,000 ft (table 3).

The characteristics of runoff from the three tributary drainages have some similarities, but they also differ. Mean annual runoff at Lamoille Creek during 1950–99 was 33,000 acre-ft. The geometric mean (mean of the log of annual runoff) was slightly less and the median was slightly more (fig. 9*A*). The coefficient of variation was 0.34 and is slightly more than that for annual precipitation recorded at the Lamoille weather station (fig. 3). The coefficient of variation assuming a log-normal distribution was 0.16. Departures from mean annual runoff ranged from -55 percent in 1959 to 70 percent in 1984 and 1997, and were somewhat greater than the maximum range in departures from mean annual precipitation of about -50 to 50 percent at the Lamoille weather station (fig. 3). The number of departures was evenly distributed between those above and below mean annual runoff. There were 24 yrs when the departure was greater than 5 percent of the mean, 21 yrs when the departure was less than -5 percent of the mean, and 6 yrs when the departure was within 5 percent of the mean.

The mean annual runoff of Martin Creek during 1950–99 was 28,200 acre-ft, which was less than that of Lamoille Creek even though the drainage area of Martin Creek is 7 times larger. The geometric mean was less by almost 5,000 acre-ft and the median was slightly higher (fig. 9*C*). The coefficient of variation indicates greater variability in annual runoff as compared with runoff at Lamoille Creek. Departures from mean annual runoff ranged from -73 percent in 1988 to 180 percent in 1984, again indicating greater variability in annual runoff. The number of departures was evenly distributed between those above and below mean annual runoff. There were 24 yrs when the departure was greater than 5 percent of the mean, 23 yrs when the departure was less than -5 percent of the mean, and only 3 yrs when the departure was within 5 percent of the mean.

The mean annual runoff of Rock Creek during 1950-99 was 31,200 acre-ft (fig. 9*B*), which was less than that of Lamoille Creek even though the drainage area of Rock Creek is 35 times larger. The geometric mean was only 17,500 acre-ft (56 percent of the mean annual runoff) and the median was 23,200 acre-ft. The much lower geometric mean and median annual runoff compared with the mean indicates that the mean annual runoff is skewed by a few years of abnormally high runoff (1952, 1969, 1983, and 1984). The coefficient of variation indicates greater variability in annual runoff as compared with runoff at both Lamoille and Martin Creeks. Departures from mean annual runoff ranged from -95 percent in 1994 to 450 percent in 1984, again indicating greater variability in annual runoff.

The number of departures for Rock Creek was not evenly distributed between those above and below mean annual runoff, unlike Lamoille and Martin Creeks. There were 19 yrs when the departure was more than 5 percent of the mean, 31 yrs when the departure was less than -5 percent of the

Table 3. Drainage areas and percent of areas below and above 6,000 feet altitude for streamflow gages on Lamoille, Rock, and Martin Creeks, and on the Humboldt River near Elko, near Carlin, at Palisade, at Comus, and near Imlay, Nevada

[Locations of streamflow gages are shown in figure 2]

Stream gage	Drainage area in square miles [1]			Percent of total[2]	
	Total	Below 6,000 feet altitude	Above 6,000 feet altitude	Below 6,000 feet altitude	Above 6,000 feet altitude
Tributary streamflow gages					
Lamoille Creek	25	0	25	0	100
Rock Creek	864	646	218	75	25
Martin Creek	175	76	99	43	57
Humboldt River streamflow gages					
Near Elko	2,780	1,220	1,560	44	56
Near Carlin	4,340	2,090	2,250	48	52
At Palisade	5,050	2,490	2,560	49	51
At Comus	12,200	7,130	5,070	58	42
Near Imlay	15,500	9,850	5,650	64	36

[1] Values are rounded to three significant figures unless drainage area was less than 100 square miles then values were rounded to nearest square mile.

[2] Percentages were rounded to nearest percent.

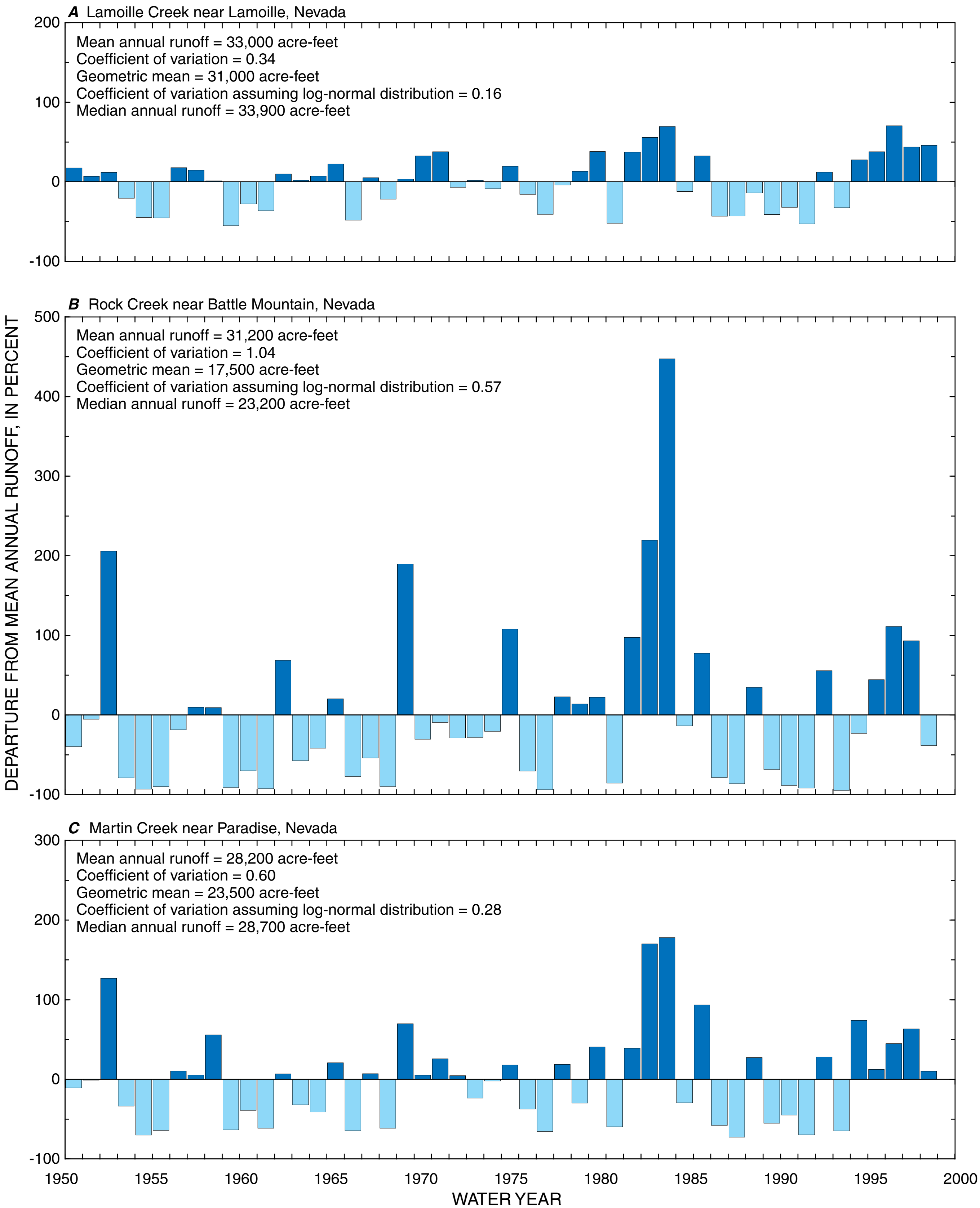


Figure 9. Departures from mean annual runoff at streamflow gages on *A*, Lamoille; *B*, Rock; and *C*, Martin Creeks, water years 1950–99. Locations of streamflow gages are shown in figure 2.

mean, and no years when the departure was within 5 percent of the mean. The large variability in annual runoff at the Rock Creek streamflow gage indicates that the area contributing runoff from year to year is not constant, but rather varies considerably in relation to the distribution of precipitation, to changes in ground-water storage, and perhaps to the operation of Willow Creek Reservoir and diversions within the drainage above the streamflow gage.

Although Lamoille Creek has the smallest watershed of the three tributary streams, it had the largest cumulative runoff during 1950–99 (1.65 million acre-ft compared with 1.56 million acre-ft for Rock Creek and 1.41 million acre-ft for Martin Creek; fig. 10). Each curve shown in figure 10 is the sum of annual runoff since 1950. For example, the value for 1950 is the total runoff for that year, whereas the volume for 1980 is the sum of all annual runoff from 1950 through 1980. The curve for each streamflow gage shows changes in slope that relate to wet (more vertical or steeper slopes) and dry (more horizontal or flatter slopes) periods.

The variation in annual runoff of Lamoille Creek (figs. 9 and 10) was much less than either Rock or Martin Creeks. This indicates the source of runoff for Lamoille Creek above its streamflow gage was from a more consistent annual precipitation as suggested by the low coefficient of variation for precipitation at the Lamoille weather station (fig. 3), from accumulation of a snowpack during years of above average precipitation that slowly dissipated during years of below average precipitation, or from shallow ground water stored within the near surface alluvial deposits within the canyon floor. Runoff volumes for Rock and Martin Creeks were similar from 1950 to 1982 even though the drainage area of Rock Creek was five times larger than that of Martin Creek. This suggests that the proportion of total basin area that contributes runoff to Rock Creek in most years was much less than that for Martin Creek. The similar patterns of cumulative runoff for Rock and Martin Creeks suggest that much of annual variation in Rock Creek was related to variation in precipitation.

Total runoff of Rock and Martin Creeks was much larger than that of Lamoille Creek in 1983 and 1984 (fig. 9) which resulted in a steep increase in cumulative runoff for Rock and Martin Creeks relative to the nearly constant slope for Lamoille Creek (fig. 10). Well above average precipitation during 1983 and 1984 produced large low- and high-altitude snowpacks in the drainages of Rock and Martin Creeks, and as a result a much larger percentage of the drainage area contributed flow to both streams. Because of its larger drainage area, annual flows of Rock Creek greatly exceeded those of Lamoille and Martin Creeks in 1983–84 (fig. 10).

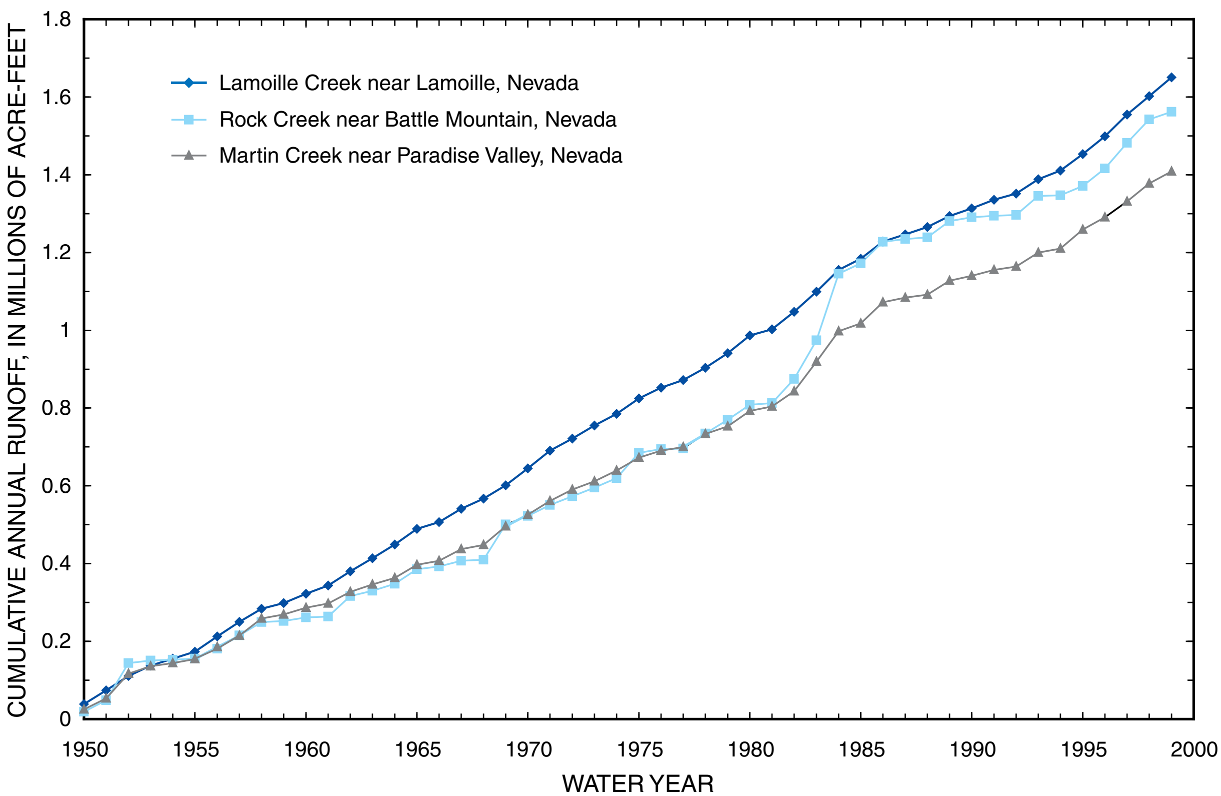


Figure 10. Cumulative annual runoff at streamflow gages on Lamoille, Rock, and Martin Creeks, water years 1950–99. Locations of streamflow gages are shown in figure 2.

Mean annual discharge of the three tributaries to the Humboldt River varied for the three reference periods of 1950–70, 1971–91, and 1992–99 (fig. 11). Mean annual discharge for Lamoille and Martin Creeks was lowest during 1950-70 and highest during 1992–99, whereas mean annual discharge for Rock Creek was highest during 1971–91. The lower mean annual runoff during 1950–70 compared with the other periods is consistent with lower precipitation during that period compared with the later two periods (see fig. 3).

Mean monthly discharge for all three reference periods increased from April through July at Lamoille Creek and from January through June at Martin Creek, whereas mean monthly discharge at Rock Creek differed considerably during 1950–70 compared with the later two periods (fig. 11). The shorter period of high runoff and a later peak in the mean monthly discharge at Lamoille Creek compared with that at Martin Creek is consistent with the Lamoille Creek drainage having a greater percentage of area above 6,000 ft in altitude (table 3).

Lowest mean monthly discharge occurred from December to February at Lamoille Creek, whereas it was in August and September in Martin Creek. The lower winter flows at Lamoille Creek indicate that most of the drainage area was frozen during the winter months, whereas the lower summer flows at Martin Creek indicate that at least part of the drainage was not frozen during the winter months and that evapotranspiration had a greater relative effect on late summer flows than at Lamoille Creek.

Mean monthly discharges at Rock Creek were consistently higher from July to December and were lower from February to June during 1950–70 than either during 1971–91 or during 1992–99 (fig. 11*C*). The later two periods had a pattern of mean monthly discharges that were similar to that at Martin Creek although peak discharge occurred in March and April instead of May (compare figs. 11*B* and 11*C*). The abnormal pattern during 1950–70 suggests greater regulation of water released from Willow Creek Reservoir, whereas the pattern for the later two periods suggests less regulation and a more natural distribution of runoff. Earlier peak discharge in Rock Creek during the later two periods compared with either Martin or Lamoille Creek indicates earlier snowmelt in the Rock Creek drainage. Minimum mean monthly discharges occurred in July and August and suggest that evapotranspiration in the drainage above the streamflow gage had an important effect on runoff.

Flow-duration curves were used to show differences in the character of flow among the tributary streams and to show changes in the character of flow for the three reference periods (fig. 12). The curves show percentages of time that discharge per unit area of a specific magnitude were equaled or exceeded. The percentage is plotted as a normal probability, which means if the flow durations were normally distributed, the curves would plot as a straight line. Discharge per unit area, in cubic feet per second per square mile of the drainage area, was used because this minimizes the effects of drainage-area size. The flat slopes at the high-flow section of each curve (percent of time where indicated discharge per unit area

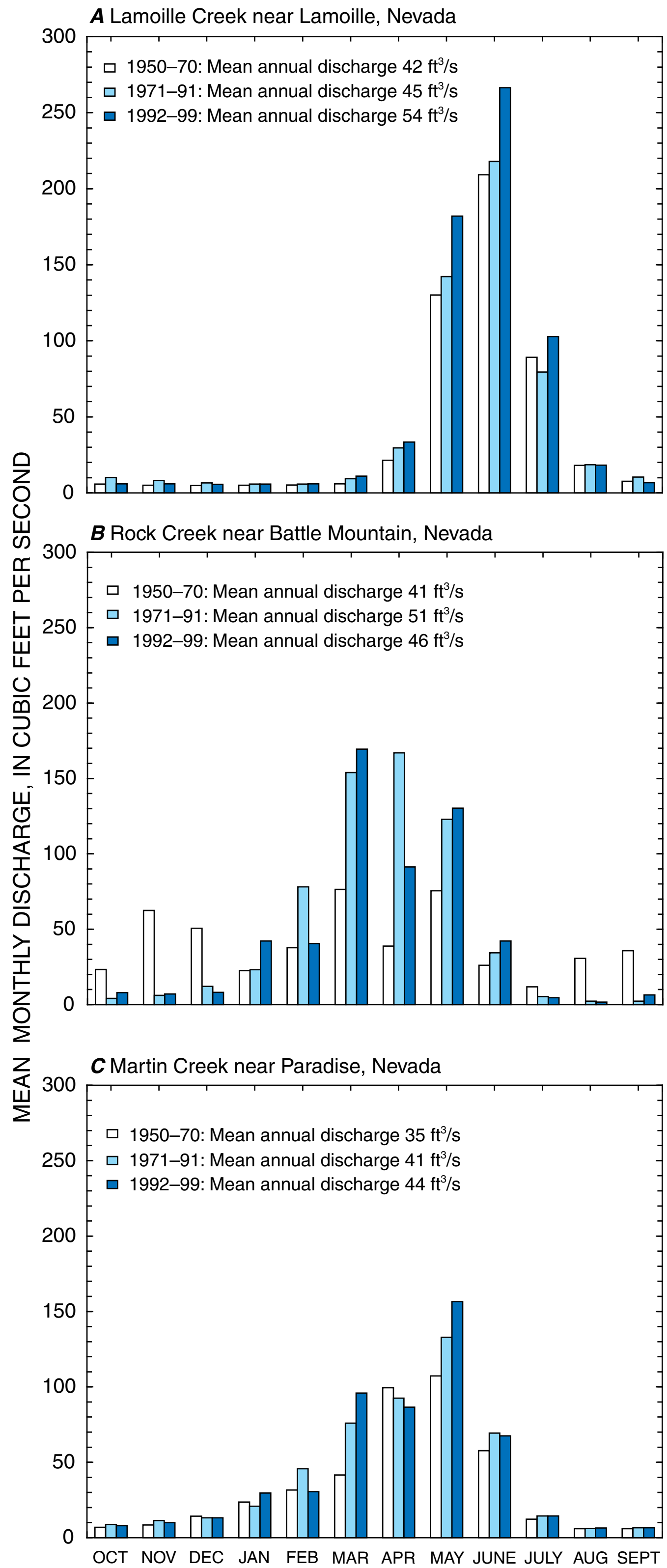


Figure 11. Mean monthly discharges at streamflow gages on *A*, Lamoille; *B*, Rock; and *C*, Martin Creeks, water years 1950–70, 1971–91, and 1992–99. Locations of streamflow gages are shown in figure 2.

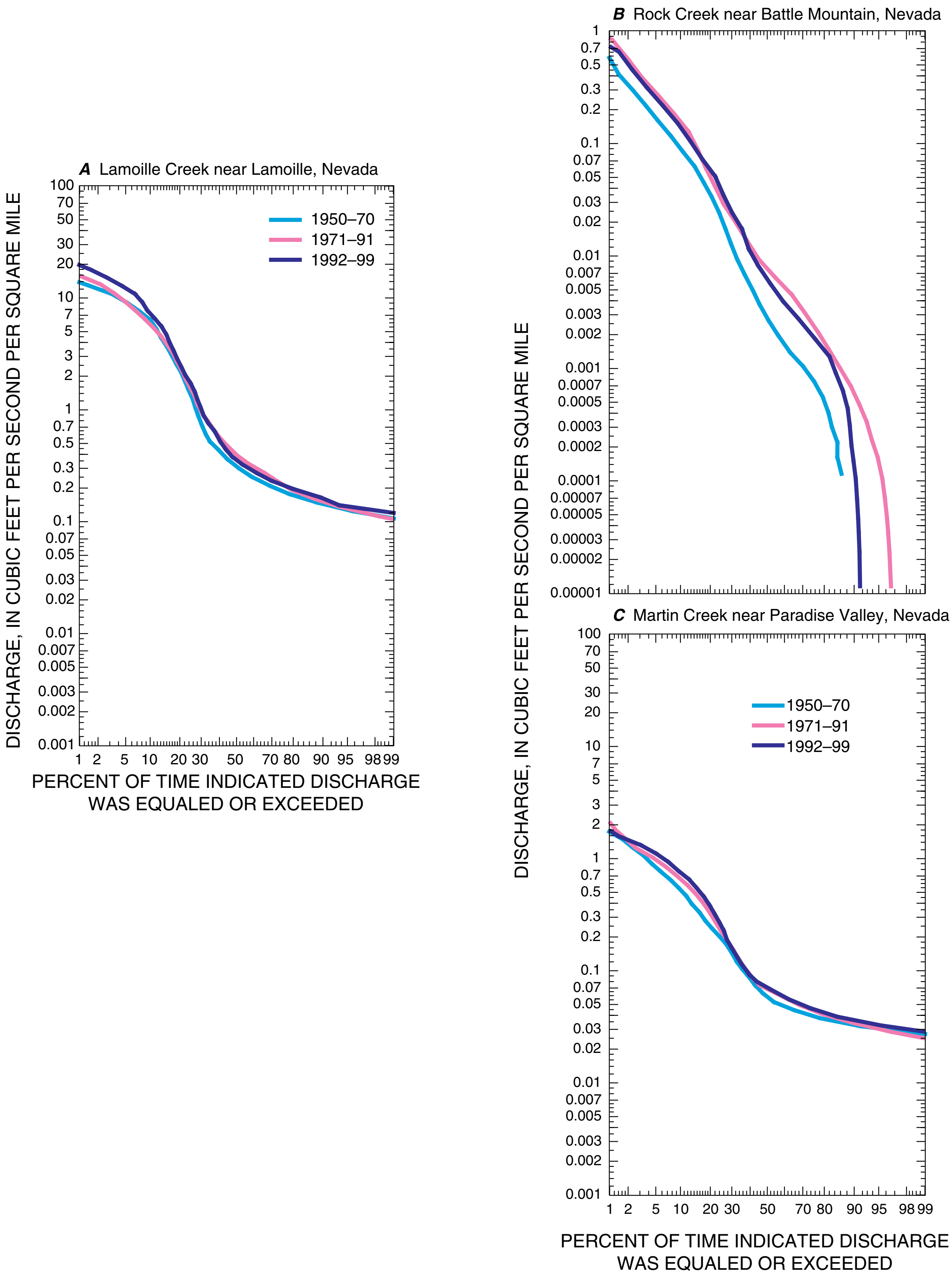


Figure 12. Flow duration at streamflow gages on *A*, Lamoille; *B*, Rock; and *C*, Martin Creeks, water years 1950–70, 1971–91, and 1992–99. Locations of streamflow gages are shown in figure 2.

was equaled or exceeded was less than 10 percent) for all three streams and reference periods are typical of streams dominated by snowmelt runoff, or streams with large floodplain storage, or those that drain swamps (Searcy, 1959, p. 22). Because none of the three tributary streams have large floodplain storage or drain swamps, the likely explanation for the flat slopes is snowmelt runoff.

The flat slopes of the low-flow section of the flow-duration curves (percent of time where indicated discharge per unit area was equaled or exceeded was more than 90 percent) for Lamoille and Martin Creeks are indicative of streams with sustained baseflow (flow maintained by water released from surface- or ground-water storage). The much steeper slope of the low-flow section of the duration curve for Rock Creek is indicative of streams with little to no baseflow (flow is not maintained by surface- or ground-water storage). The differences in low-flow characteristics likely are the result of differences in geology of the three drainages. Poorly permeable metamorphic rocks covered with a relatively thin veneer of soil, colluvium, alluvium, and glacial deposits underlie Lamoille Creek. Volcanic rocks covered with soil, colluvium, and alluvium underlie Martin Creek, and relatively thick Tertiary sediments underlie much of the Rock Creek drainage. The Tertiary sediments that underlie the Rock Creek drainage may be more permeable than the rocks beneath Lamoille and Martin Creek, and ground-water levels in the deposits beneath Lamoille and Martin Creeks probably are close to the stream channel as suggested by the flat slopes on the low-flow section of the flow-duration curves (fig. 12). Part of the snowmelt in the drainages of Lamoille and Martin Creek enters deposits beneath the stream channels where it is temporarily stored and slowly released during the dry summer and fall months. The higher discharge per drainage area for the low-flow section of the flow duration curves for Lamoille Creek compared with Martin Creek suggests greater storage within the drainage of Lamoille Creek (either as ground water or as snowpack) than in the Martin Creek drainage. The near vertical slope of the low-flow section of the flow duration curve for Rock Creek (fig. 12) suggests that the water table is below the level of the streambed and water that infiltrates into Tertiary sediments beneath Rock Creek likely leaves the drainage as subsurface flow. As a result, Rock Creek typically has periods of little or no flow during the summer and fall months.

Lamoille and Martin Creeks had higher flow throughout most of the flow-duration curve during 1992–99 when compared with the two earlier periods, whereas Rock Creek had higher flow throughout most of the flow-duration curve during 1971–91 (fig. 11). The low-flow section of the flow-duration curves for Lamoille and Martin Creeks are nearly the same for all three periods indicating that base flow remained nearly constant during 1950–99. This suggests that water in storage (snowpack, surface impoundments, or ground water) also did not change. The low-flow section of the flow-duration curves for Rock Creek were higher during 1971–91 and 1992–99 than during 1950–70, although little of the low flow was sustained by storage as the slopes of the low-flow section of the flow-duration curves remained nearly vertical.

Humboldt River

The Humboldt River is a stream of highly variable annual runoff. The records of annual runoff at streamflow gages near Elko, near Carlin, at Palisade, at Comus, and near Imlay are characterized by periods of a few to several years of below less than -5 percent and near mean annual runoff (within 5 percent) separated by less frequent periods of a few years of above mean annual runoff (fig. 13). The Humboldt River has experienced periods that are three years or more of below average runoff in every decade during 1950–99, whereas only two periods had three or more years of above average runoff at all streamflow gages and they were 1982–84 and 1995–98.

Not only is the Humboldt River one of variable flow, but the degree of variation increases downstream (fig. 13). Mean annual runoff increased between Elko and Palisade, and decreased between Palisade and Imlay. The coefficient of variation and the coefficient of variation of the log-normal distribution was nearly the same for the streamflow gages near Elko, near Carlin, and at Palisade (fig. 13). The coefficient of variation for the three streamflow gages was greater than that determined for the streamflow gage on Lamoille Creek but was similar to that for the streamflow gage on Martin Creek (compare figs. 9 and 13). The coefficient of variation increased for Comus and Imlay indicating greater variability in annual runoff. The coefficient of variation for the streamflow gages at Comus and near Imlay was similar to that of the streamflow gage on Rock Creek.

Differences in annual runoff and the coefficient of variation indicate major differences in runoff and losses along the Humboldt River above and below the streamflow gage at Palisade. Annual runoff from the drainage above Palisade was dominated by snowmelt runoff from high altitude in headwater parts of the basin (Ruby, Jarbidge, and Independence Mountains, and East Humboldt Range) and annual runoff generally increased from Elko to Palisade as the drainage area increased (Eakin and Lamke, 1966; and table 3). Snowmelt runoff from the Tuscarora Mountains, and Santa Rosa and Toiyabe Ranges downstream of Palisade during most years was lost to irrigation diversions, to natural evapotranspiration, and to infiltration into alluvium prior to reaching the Humboldt River.

Annual runoff on the Humboldt River increased from Elko to Carlin and from Carlin to Palisade as a result of tributary inflow and ground-water discharge to the channel as indicated by greater cumulative annual runoff at the Palisade streamflow gage (fig. 14). Annual runoff normally decreased at streamflow gages below Palisade as a result of irrigation diversions, infiltration of streamflow into alluvium, and evapotranspiration. Annual runoff variations among the five streamflow gages during 1950–82 were fairly subtle as displayed by the changes in the slope of each curve.

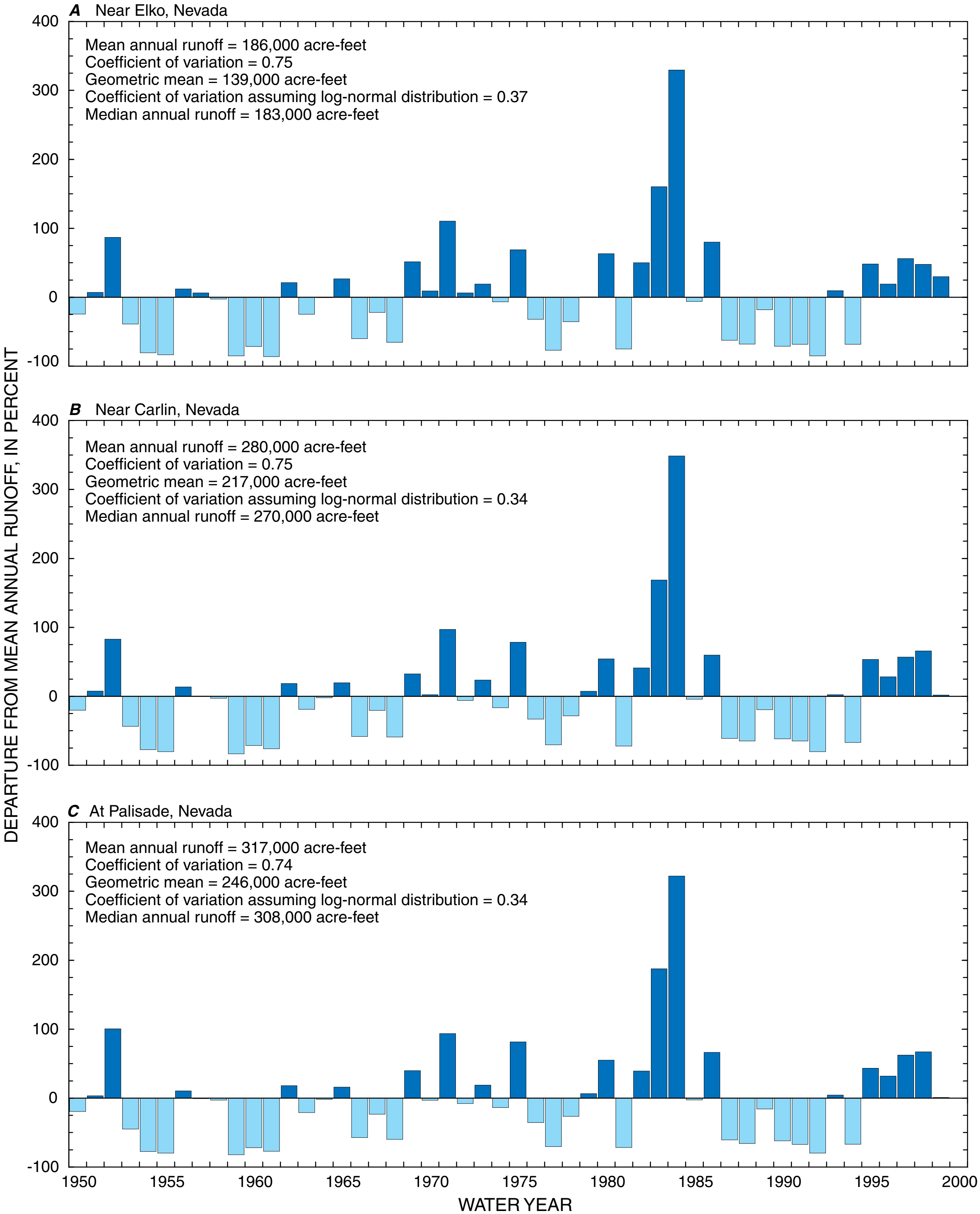


Figure 13. **Departures from mean annual runoff at streamflow gages on Humboldt River *A,* near Elko; *B,* near Carlin; *C,* at Palisade; *D,* at Comus; and *E,* near Imlay, Nevada, water years 1950–99. Locations of streamflow gages are shown in figure 2.**

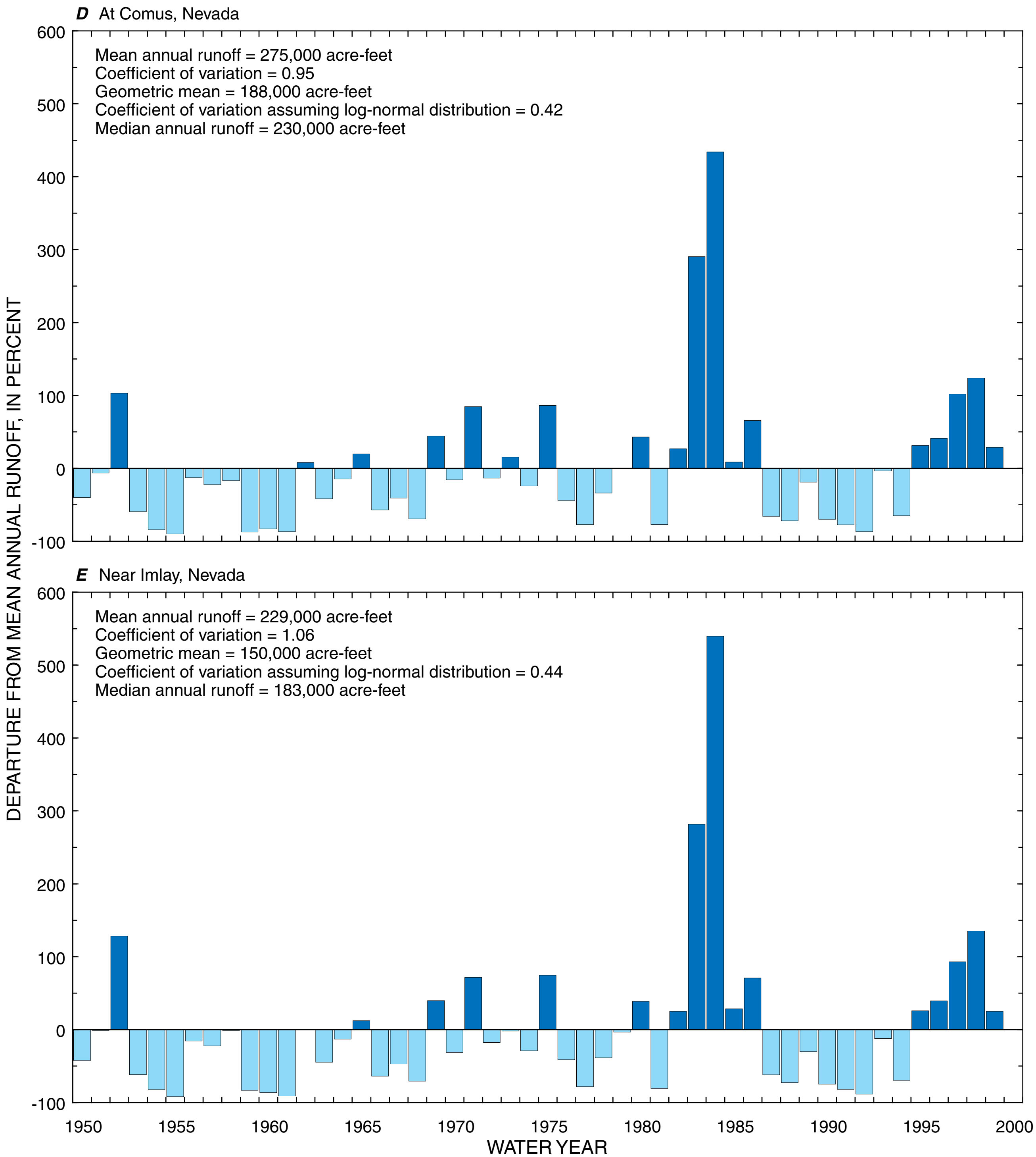


Figure 13. Continued.

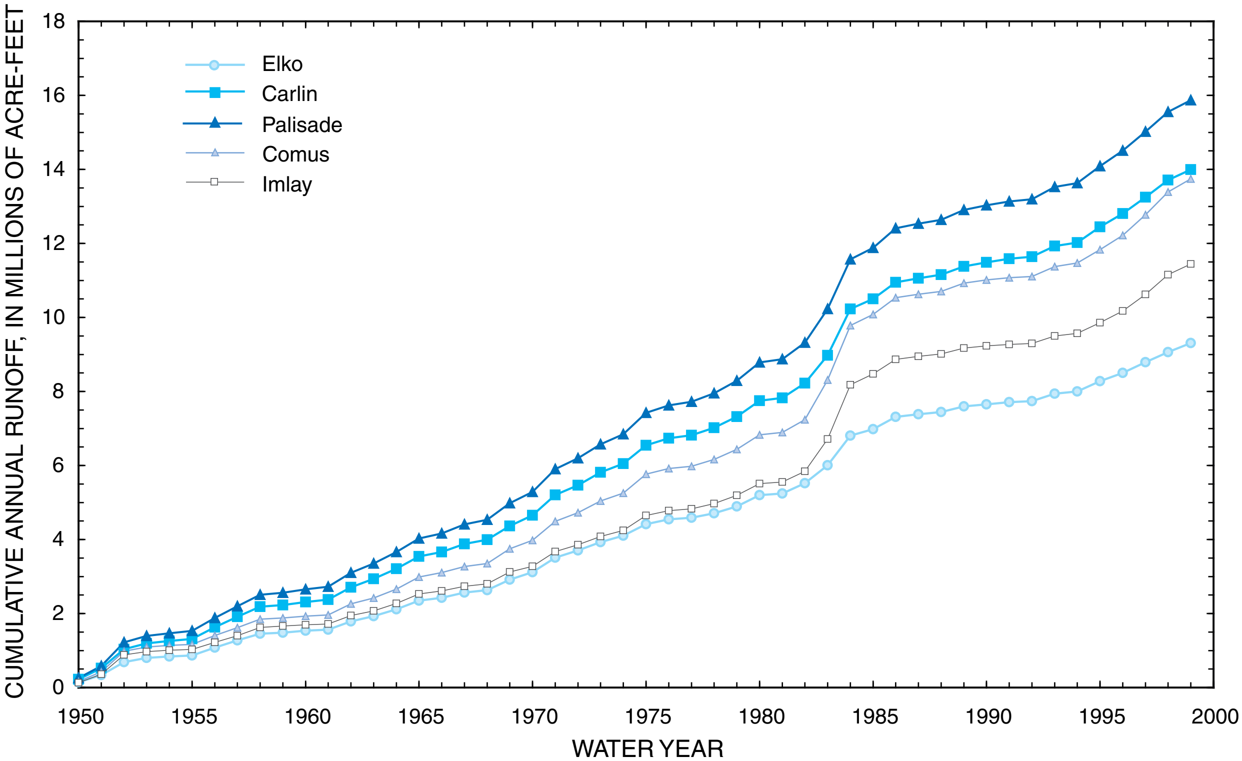


Figure 14. Cumulative annual runoff at selected streamflow gages on Humboldt River, water years 1950–99. Locations of streamflow gages are shown in figure 2.

The cumulative annual runoff at all five streamflow gages showed a dramatic increase in 1983 and 1984. The abrupt increase in slope of each curve represents the highest annual runoff recorded on the Humboldt River. Runoff in 1983 and 1984 was the result of low-altitude snowmelt during late winter and early spring of both years followed by a prolonged high-altitude snowmelt. Annual runoff at Comus and Imlay showed the greatest change during 1983 and 1984 because large accumulations of snow over much of the drainage area, especially lowland areas (fig. 3), resulted in a much larger part of the drainage area that contributed flow to the river.

Relative changes in annual runoff between an upstream and downstream gage on the Humboldt River were analyzed by plotting differences in cumulative annual flow over time. Differences in cumulative annual flow between streamflow gages Elko and Carlin, Carlin and Palisade, Palisade and Comus, and Comus and Imlay are shown in figure 15. Upward sloping curves indicate a gaining reach, whereas downward sloping curves indicate a losing reach. The reach of the Humboldt River between Elko and Carlin showed the greatest gain in annual runoff. This mostly was the result of tributary inflow, especially from the South Fork of the Humboldt River. The reach of the Humboldt River between Carlin and Palisade showed a gain in annual runoff because of tributary flow from Maggie, Susie, and Marys Creeks and ground-water discharge. The slopes of the cumulative difference curves between Elko and Carlin and between Carlin and Palisade, steepened during 1982–84 and during 1994–98 in response to above mean annual precipitation.

The Humboldt River below Palisade almost always lost flow to irrigation diversions, infiltration of streamflow into the alluvium, and evapotranspiration because the cumulative difference in annual runoff between Palisade and Comus and Comus and Imlay was negative (fig. 15). The greatest annual loss was generally between Palisade and Comus, although the greatest cumulative loss from 1950 to 1999 was between Comus and Imlay because annual runoff at Comus exceeded that at Palisade in 1983–84 and again from 1997 to 1999 (cumulative difference in runoff between Palisade and Comus became less negative). Annual runoff along the Humboldt River downstream of Palisade was influenced by the effects of infrequent accumulation of snow over large areas of lower

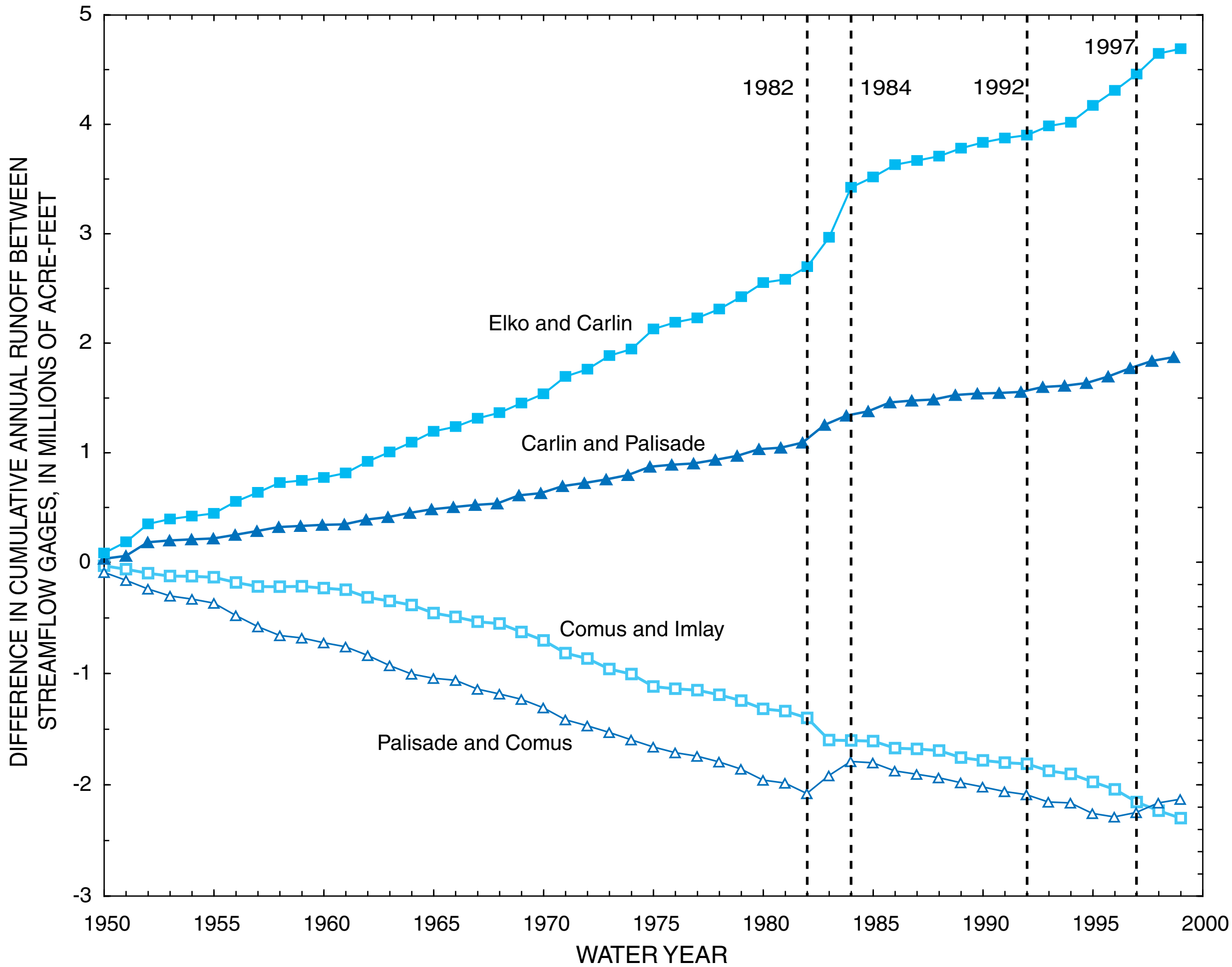


Figure 15. Differences in cumulative annual runoff between selected streamflow gages on Humboldt River, water years 1950–99. Locations of streamflow gages are shown in figure 2.

altitudes, whereby annual runoff can occasionally increase downstream of Palisade. Thus, variations in annual runoff increased below Palisade because of the combined effects of annual runoff above Palisade, infrequent accumulation of snow at lower altitudes, and increased ground-water storage capacity below Palisade.

The discharge of water to the Humboldt River from the Betze Mine by way of the T-S Ranch Reservoir from 1997 to 1999 and the Lone Tree Mine by way of the Lone Tree cooling ponds from 1992 to 1999 also contributed to increased runoff at Comus (fig. 5; location of cooling ponds shown in fig. 4), which when combined with above mean annual precipitation and runoff resulted in greater annual runoff at Comus than at Palisade from 1997 to 1999. However, the discharge of water from the Lone Tree cooling ponds from 1992 to 1996 was insufficient to alter the slope of the cumulative difference in annual runoff between Palisade and Comus because the slope remained unchanged from 1985 to 1996 (fig. 15).

The annual runoff at the streamflow gage near Imlay was less than annual runoff at Comus in 1983 and was about the same as that at Comus in 1984 and 1985. Some of the loss in 1983 was probably caused by ungaged diversions to the Upper and Lower Pitt-Taylor Reservoirs upstream of Imlay (a streamflow gage recorded diversions from 1947 to 1977; Berris and others, 2003, p. XV) and some may have been caused by greater infiltration into the alluvium during high flow.

The slope of the cumulative difference in annual runoff between Comus and Imlay increased downward after 1961 and then was nearly constant until 1982. The increased downward slope suggests that more water was lost along the reach from 1962 to 1982 than was lost from 1950 to 1961. The reason for the change in slope after 1961 is not known but the change cannot be explained by increased diversions to the Pitt-Taylor Reservoirs (diversion is above the Imlay streamflow gage; fig. 4) as diversions were recorded during 1947; 1951–53; 1958; 1965–66; and 1969–75 but not during 1961–64. Another possibility for the change in slope after 1961 is that alluvial aquifers along the Humboldt River floodplain between Comus and Imlay slowly released ground water that had been stored during a period of above mean annual precipitation from the late 1930's into the 1940's (Eakin and Lamke, 1966, p. 19). A similar trend was observed following the wet years of 1982–84, in which the slope from 1985–95 was about the same as that from 1950–61 and the slope from 1996–1999 was about the same as that from 1962–82.

Differences in cumulative annual flow for the reaches between Elko and Carlin and Carlin and Palisade form straight lines when plotted against the cumulative annual flow of the streamflow gage at Palisade (fig. 16). The straight lines indicate that any changes in annual runoff were less than what could be discerned from the graph or that any change affected annual runoff above Palisade equally. The discharge of water from Maggie Creek Reservoir (location shown in fig. 4) into Maggie Creek had little effect on the difference in annual runoff between Carlin and Palisade. If there had been an effect, the difference in annual runoff between Carlin and Palisade would have shown an increased slope after 1994.

The cumulative difference in annual flow between Palisade and Comus and between Comus and Imlay did not form straight lines (fig. 16), which indicates that both reaches were affected differently than reaches between Elko and Carlin and Carlin and Palisade. The slope of the curve for the reach between Palisade and Comus increased downward after 1952 indicating that annual runoff at Comus was less after 1952 relative to the annual runoff at Palisade. Annual runoff at Palisade and Comus in 1952 was about twice the mean annual runoff from 1950 to 1999 (fig. 13), and annual runoff in 1952 followed a period from the late 1930's into the 1940's of above mean annual precipitation (Eakin and Lamke, 1966, p. 19). The general downward slope of the cumulative difference in annual runoff between Palisade and Comus reversed during

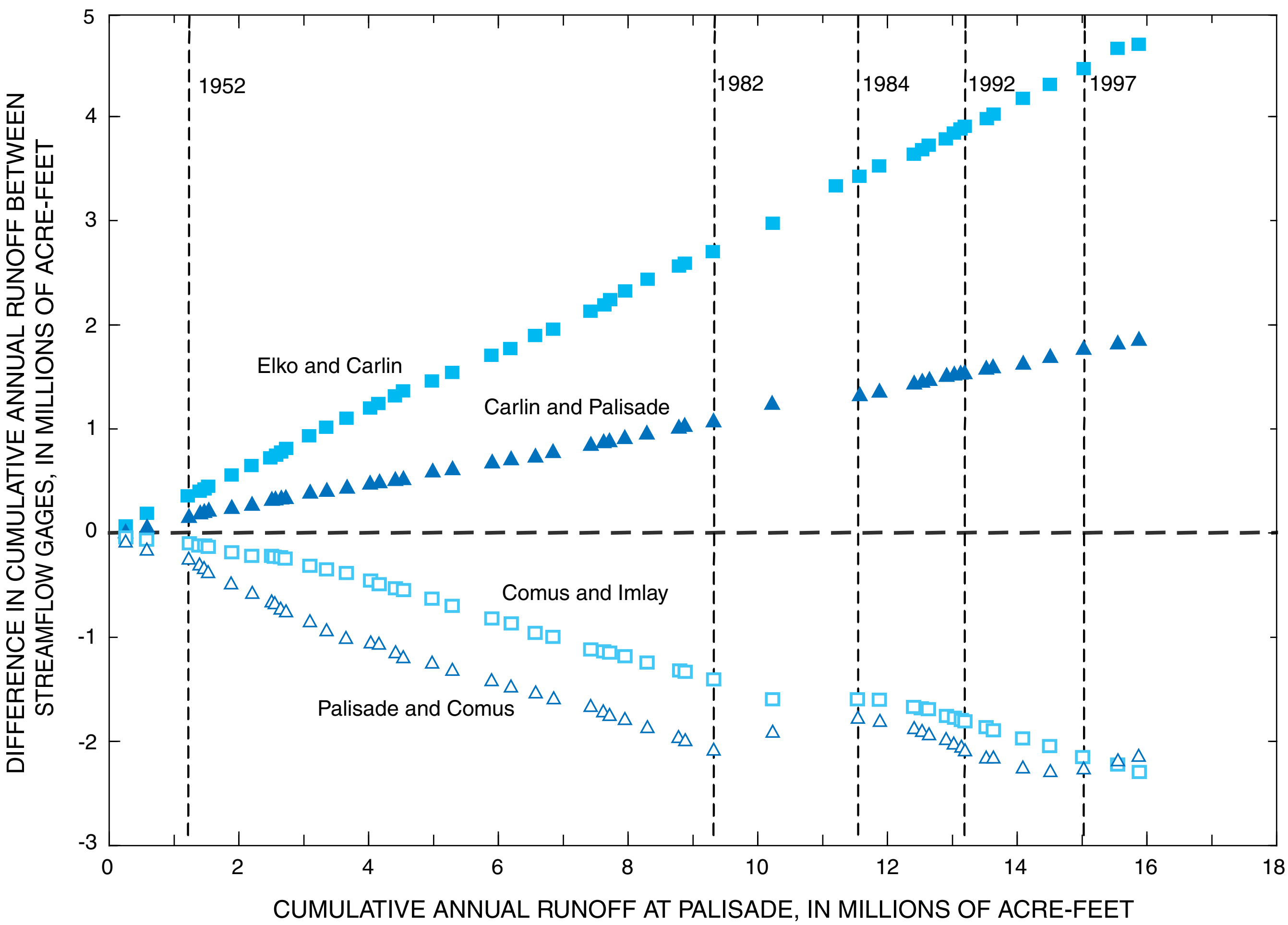


Figure 16. Differences in cumulative annual runoff between selected streamflow gages on Humboldt River compared with cumulative annual runoff at Palisade, Nevada, water years 1950–99. Locations of streamflow gages are shown in figure 2.

1983–84 and again during 1997–99, both of which correspond to periods of above mean annual precipitation and runoff. The slope in the cumulative difference in annual runoff between Palisade and Comus when compared with cumulative annual runoff at Palisade decreased slightly after 1992 (fig. 16). This is different from the slope of the difference in cumulative runoff shown in figure 15, and suggests that the discharge of water from the Lone Tree Mine by way of the Lone Tree cooling ponds from 1992 to 1996 had a small effect on the difference in annual runoff between the Palisade and Comus streamflow gages that could not be discerned in figure 15. The most likely explanation for the reach to switch between losing and gaining is that much of the area along the reach only contributes sufficient runoff to the Humboldt River during infrequent periods of well above the mean annual precipitation (both high and low altitude) that are capable of overcoming losses due to diversions for irrigation, evapotranspiration, and infiltration into the alluvium.

The cumulative difference in annual runoff between Comus and Imlay also showed variations in its slope (fig. 16). However, changes in the slope were more gradual compared with the reach between Palisade and Comus, suggesting less contribution from tributary streams during periods of above mean annual precipitation, diversions to the Pitt-Taylor Reservoirs, and a greater capacity for ground-water storage. The lack of a reversal in the slope and an extended period of a flatter slope in the early 1950's that followed a period of above mean annual precipitation during the late 1930's into the 1940's (Eakin and Lamke, 1966, p. 19) and during 1982–84 suggests that ground-water storage in this reach may be an important factor affecting the shape of the curve.

Mean monthly discharge during 1950–70 was less than either of the two later periods (fig. 17). Mean annual discharge during 1971–91 was greater than during 1950–70 and during 1992–99 at all streamflow gages. The monthly distribution of runoff was the same for all three reference periods. Lowest mean monthly discharge was in September at all streamflow gages and highest discharge was in June. The pattern is consistent with snowmelt-dominated runoff in which precipitation that accumulated as snow during the winter months in the mountains became runoff during the spring and early summer, and once most of the accumulated snow had melted, runoff declined rapidly during late summer.

The mean monthly discharge during 1992–99 had two differences when compared with the two earlier periods. First, mean monthly discharge in June and July was highest during 1992–99 at all streamflow gages (fig. 17). The reason for increased discharge in June and July during 1992–99 in relation to the two earlier periods is unknown but may be caused by releases from the South Fork Reservoir, which began operation in 1987. Second, mean monthly discharge from August through February was also higher during 1992–99 at Comus, and the mean monthly discharge at Comus exceeded that at Palisade for the same months (fig. 17). The higher mean monthly discharges at Comus during what was historically the low-flow months can only be attributed to discharge of water to the Humboldt River from the Lone Tree and Betze Mines (fig. 5).

Flow duration for the three reference periods at each streamflow gage on the Humboldt River show a decrease in the slope of the curves at high discharge (fig. 18; less than 10 percent of time that discharge was equaled or exceeded) and was similar to the tributary streams (fig. 12). The decrease in slope of the flow-duration curves during the low-flow sections of the curves (greater than 90 percent of time that discharge was equaled or exceeded) at Elko, Carlin, and Palisade indicates that discharge during low flow prior to and after the South Fork Reservoir was likely sustained by tributary inflow and ground-water discharge and operations of the South Fork Reservoir had little effect on low flow.

The low-flow section of the flow duration curves at the Elko, Carlin, and Palisade streamflow gages during 1950–70 were consistently lower than those during 1971–91 and during 1992–99. The slightly higher discharge per drainage area of the low-flow section of the flow-duration curve during 1992–99 compared with 1971–91 at Palisade may be caused by increased tributary flow from Maggie Creek because water from Gold Quarry Mine was discharged into Maggie Creek from Maggie Creek Reservoir beginning in 1994 (fig. 5).

The much lower discharge per drainage area and the greatly increased slope of the low-flow section of the flow-duration curves at Comus suggests that the discharge during low flow was not maintained by tributary inflow or ground-water discharge. The higher discharge for much of the flow-duration curve during 1992–99 when compared with 1971–91 was likely caused by, or at least affected by, discharge of water from the Betze and Lone Tree Mines (fig. 5). However, much of the increased discharge at Comus during 1992–99 did not reach Imlay because the low-flow section of the flow-duration curve during 1992–99 was less than that during 1950–70 and 1971–91 (fig. 18). The higher percentage of time that low flow occurred during 1992–99 may have been caused by the extended drought from 1986 to 1994. The extended drought may have caused increased infiltration between Comus and Imlay such that much of the water discharged to the Humboldt River above Comus was lost prior to reaching the Imlay gage, particularly during 1992–94.

The mean daily discharge for the three reference periods shows a detailed pattern of runoff at each of the five streamflow gages on the Humboldt River (fig. 19). Mean daily discharges were computed from the daily mean discharges for each day of the year during each reference period. The general pattern of higher discharge from March through July and lower discharge from August through February is the same as the distribution of mean monthly discharge (fig. 17). Two distinct periods of increased discharge are shown in the mean daily discharge during 1950–70 and 1992–99 that is not discernable with the mean monthly discharge. The two peaks suggest an earlier low-altitude snowmelt followed by a later high-altitude snowmelt. An initial peak discharge occurred in early April at Elko and late April at Carlin and Palisade

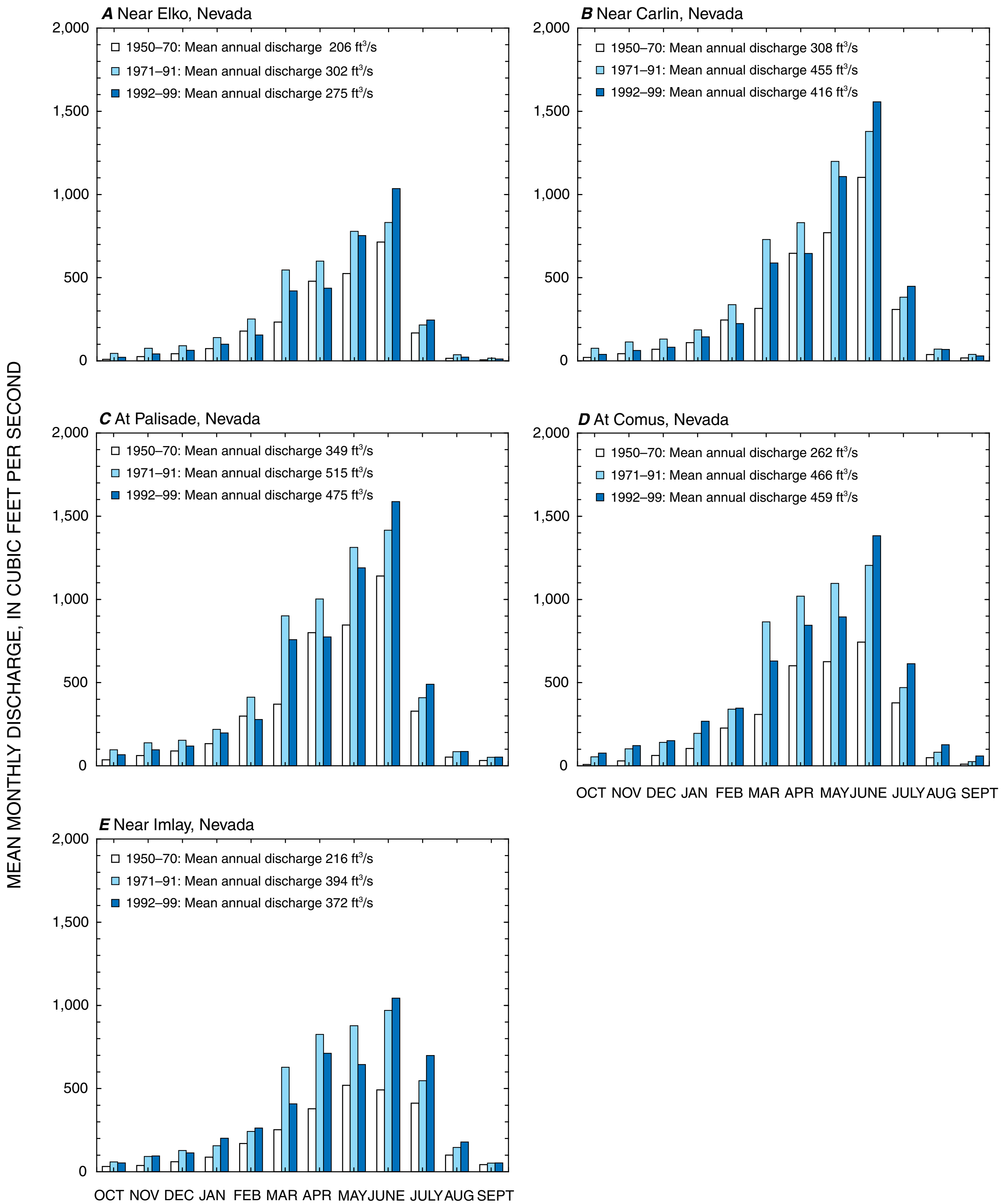


Figure 17. Mean monthly discharges at streamflow gages on Humboldt River *A*, near Elko; *B*, near Carlin; *C*, at Palisade; *D*, at Comus; and *E*, near Imlay, Nevada, water years 1950–70, 1971–91, and 1992–99. Locations of streamflow gages are shown in figure 2.

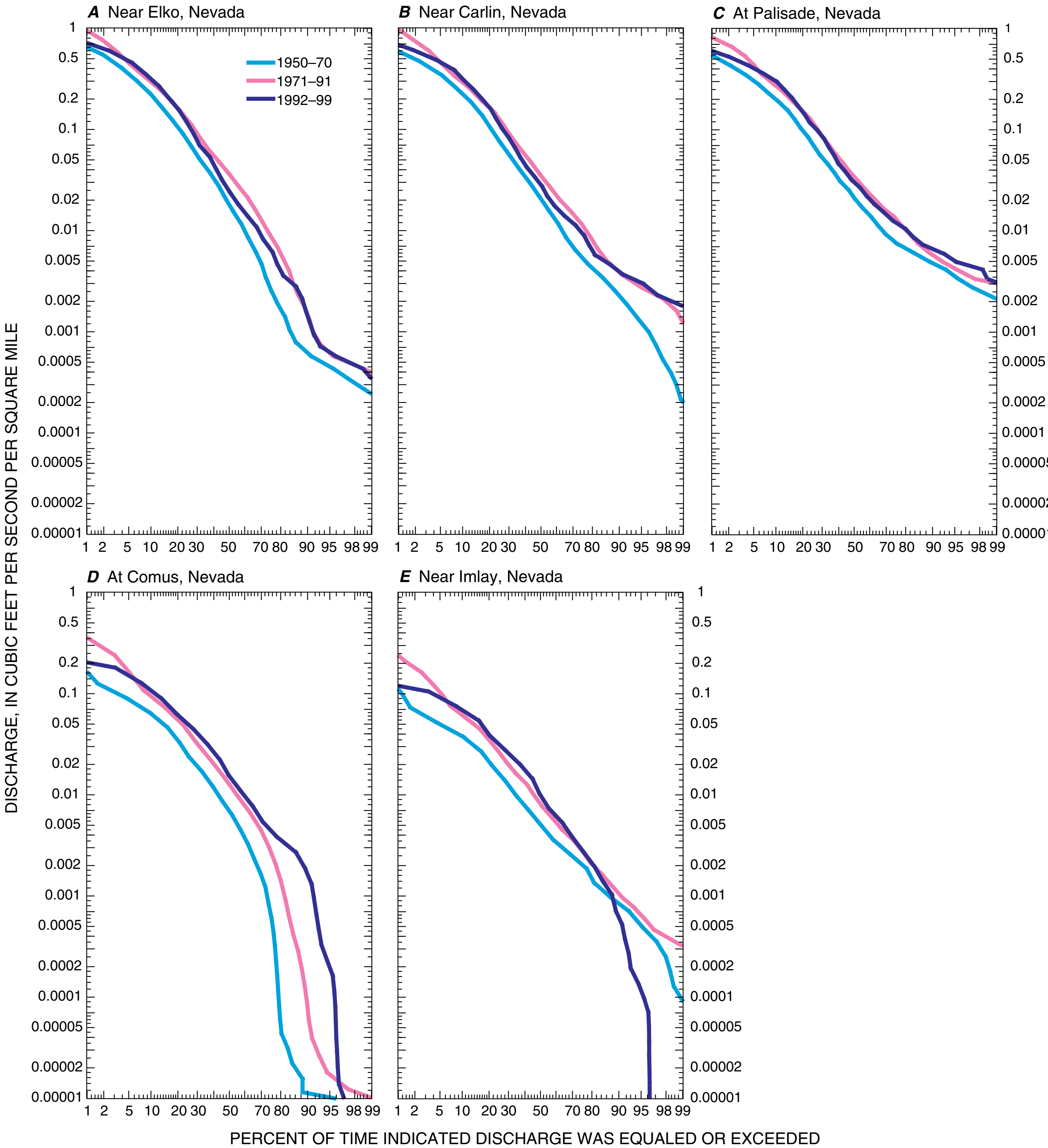


Figure 18. Flow duration at streamflow gages on Humboldt River *A*, near Elko; *B*, near Carlin; *C*, at Palisade; *D*, at Comus; and *E*, near Imlay, Nevada, water years 1950–70, 1971–91, and 1992–99. Locations of streamflow gages are shown in figure 2.

during 1950–70 whereas a second and larger peak occurred in early June. The initial peak discharge at Comus and Imlay during 1950–70 occurred in late April and early May and was higher than the later second peak in late June and early July (fig. 19).

The initial peak discharge during 1992–99 was earlier at all five streamflow gages with the initial peak occurring in late March at Elko, Carlin, and Palisade and late March to early April at Comus and Imlay. However, the discharge for the initial peak at Comus and Imlay was less than the later peak in June and July, which differs from the two earlier reference periods. This suggests a changing pattern in the low-altitude snowmelt that results in an earlier but diminished runoff, particularly at Comus and Imlay. Two earlier peaks during 1971–91 generally correspond to the initial peaks during 1950–70 and 1992–99 suggesting that the middle reference period includes the transition from a later to earlier low-altitude snowmelt.

The dramatic increase in peak flow between Elko and Carlin for all reference periods was caused by tributary inflow from the South Fork of the Humboldt River, which drains much of the western Ruby Mountains (fig. 1). The dramatic decrease in peak flow between Palisade and Comus indicates considerable loss between the two streamflow gages as a result of diversions and from infiltration into the alluvium.

Differences in mean daily discharge for the three reference periods during low flow are not readily discernable in figure 19 and consequently the period from September 1 to December 30 is shown for the five streamflow gages in figure 20. The mean daily discharge from September 1 to December 30 during 1950–70 increased from Elko to Carlin and from Carlin to Palisade, whereas the mean daily discharge

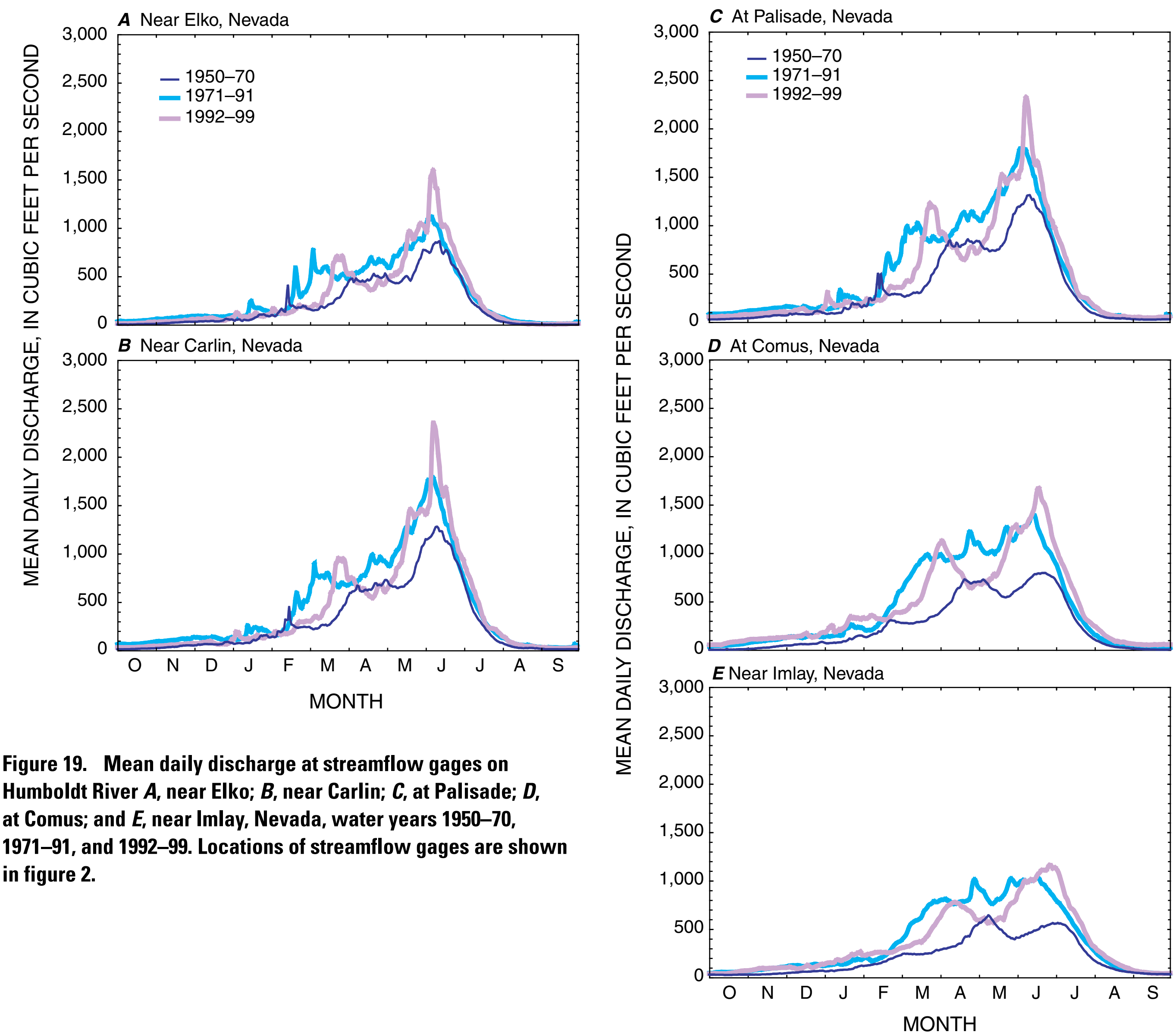


Figure 19. Mean daily discharge at streamflow gages on Humboldt River *A*, near Elko; *B*, near Carlin; *C*, at Palisade; *D*, at Comus; and *E*, near Imlay, Nevada, water years 1950–70, 1971–91, and 1992–99. Locations of streamflow gages are shown in figure 2.

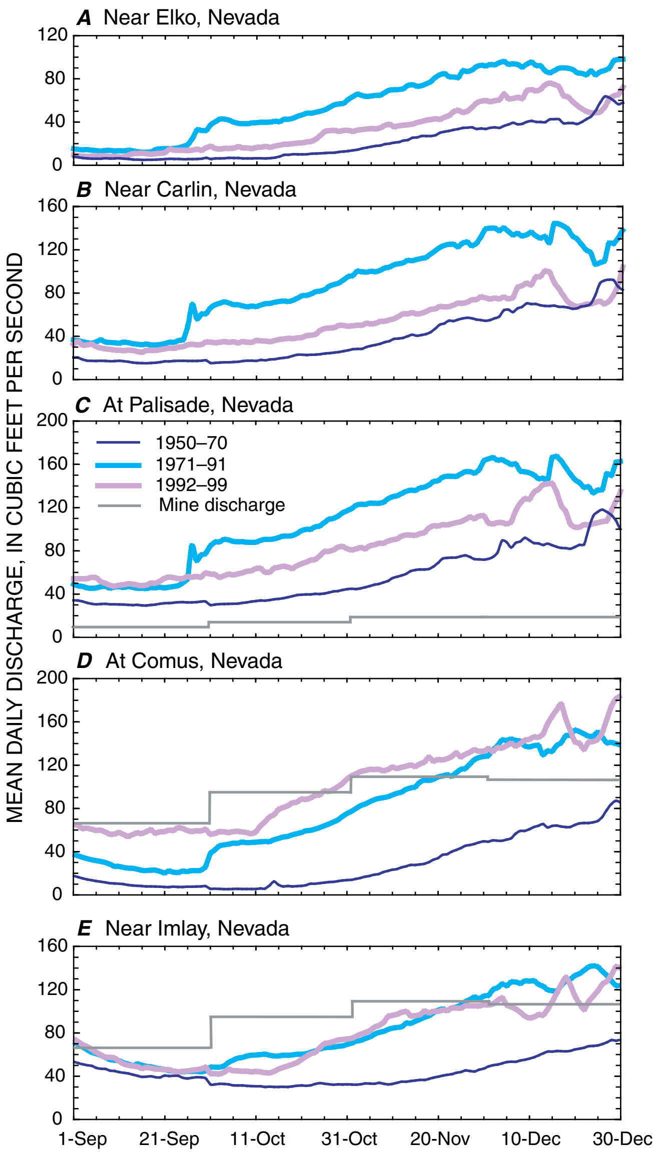


Figure 20. Mean daily discharges from September through December at streamflow gages on the Humboldt River *A*, near Elko; *B*, near Carlin; *C*, at Palisade; *D*, at Comus; and *E*, near Imlay, Nevada, water years 1950–70, 1971–91, and 1992–99. Mean monthly discharges of water to Humboldt River or tributary from mining operations included for streamflow gages downstream of Carlin. Locations of streamflow gages are shown in figure 2.

decreased markedly from Palisade to Comus, a pattern consistent with mean daily discharge during peak flow (fig. 19). However, the mean daily discharge from September 1 until the end of December during 1950–70 at Imlay was greater than that at Comus. Because little tributary inflow from intermittent streams occurred during late summer and fall, much of the increase in low flow along the reach between Comus and Imlay likely was from ground-water discharge to the river. Increases in ground-water discharge between Comus and Imlay during this period were documented by Cohen and others (1965) and Eakin and Lamke (1966).

Mean daily flow from September 1 through December 30 during 1971–91 was consistently greater than during 1950–70 and resulted from greater precipitation. Although mean daily discharge was greater, the overall pattern of increased discharge from Elko to Carlin and Carlin to Palisade, decreased discharge from Palisade to Comus, and increased discharge from Comus to Imlay was the same as during 1950–70 (fig. 20).

The pattern changed from Palisade to Comus and Comus to Imlay during 1992–99 when mean daily discharge was greater at Comus than either Palisade or Imlay. Additionally, mean daily discharge during 1992–99 was less than that during 1971–91 at Elko and Carlin and most of the time at Palisade, whereas the mean daily discharge was mostly greater than that during 1971–91 at Comus and about the same at Imlay. The marked increase in mean daily discharge during 1992–99 at Comus with respect to the mean daily discharge at Palisade was caused by the discharge of water from the Betze and Lone Tree Mines. The decrease in mean daily discharge between Comus and Imlay indicates that part of the water discharged to the Humboldt River either was diverted or infiltrated into alluvium prior to reaching the streamflow gage near Imlay.

Annual Precipitation Volume

Annual precipitation volume in the drainage area above a streamflow gage is difficult to estimate because it requires integrating annual precipitation measured at a few locations over the entire drainage area, which is different than a streamflow gage that normally represents all runoff from the drainage area above the gage. The uncertainty in estimates of annual precipitation volume depends on how well the few measured locations of precipitation represent the distribution precipitation over the entire drainage area.

Method Used

The method devised to estimate precipitation volumes above each streamflow gage was an attempt to account for the natural variability in precipitation using the limited number of weather stations shown in figure 2 and listed in table 2. The natural variability in precipitation results from two principal factors. The first factor is how storms generally track across the Humboldt River Basin (Houghton and others, 1975). The basin upstream of the streamflow gage near Imlay encompasses an area of about 15,500 mi^2 (table 3). The second factor is the large differences in altitude among the many mountain ranges and adjacent valleys. Because of the way storms generally track across Nevada, mean annual precipitation is more at the north and east ends of the Humboldt River Basin (fig. 21). For example, the Toiyabe Range in the southern part of the basin has less mean annual precipitation at similar altitude than the Santa Rosa Range and the Independence and Jarbidge Mountains to the north. The effect of altitude results in precipitation ranging from about 9 in. in the valley lowland near Elko, Nevada to more than 36 in. at the highest altitudes in the nearby Ruby Mountains (fig. 21).

The mean annual precipitation was used as a basis for estimating annual precipitation in the drainage areas above each streamflow gage. The distribution of mean annual precipitation was developed by Daly and others (1994) using mean-annual precipitation data from 1960 to 1991 and their propriety computer model named Precipitation-Elevation Regressions on Independent Slopes Model (PRISM). Estimates of mean annual precipitation from PRISM were provided by G.H. Taylor (Oregon Climate Service, Oregon State University, written commun., 1997) for a 2.4 mi^2 (2.5 km by 2.5 km) grid.

Because the relation between precipitation and altitude was not the same throughout the basin, 21 transects were drawn across all major mountain ranges and adjacent valleys (fig. 21) and precipitation was compared with altitude to determine regions that had similar characteristics. Four transects were drawn across the Ruby Mountains and East Humboldt Range because the mountains have the greatest mean annual precipitation (fig. 2). The mean altitude for each 2.4 mi^2 grid along transects was determined from 2 acre (90 m by 90 m) digital elevation model (DEM) data (1-degree DEM data; U.S. Geological Survey, 2000). Mean annual precipitation for each PRISM grid along all transects (the dependent variable) was plotted against its corresponding altitude (the independent variable).

The data were grouped into seven regions on the basis of similar distributions between precipitation and altitude (fig. 21). For example, regions 3 and 7 were divided along the Humboldt River between Winnemucca and the streamflow gage at Palisade because there was more precipitation in region 3 at a similar altitude than in region 7. Region 2 was used to relate precipitation and altitude for the Ruby Mountains, East Humboldt Range, Jarbidge Mountains, and the highest part of the Independence Mountains, whereas three regions (regions 4, 5, and 6) were used for the Toiyabe Range in the southernmost part of the basin. The seven regions sufficiently captured the variation in mean annual precipitation from north to south and from west to east. The different regions also allowed for annual variations in precipitation across the basin to be incorporated into the estimates of annual precipitation volumes.

Equations that relate mean annual precipitation from the PRISM data to a corresponding altitude were calculated for each region using several types of regression equations (linear, natural log, power, and polynomial). The regression equation used for each region was chosen by comparing residuals to predicted precipitation (Helsel and Hirsch, 1992) and from the coefficient of determination or R^2 (fig. 22). Equations for areas with higher precipitation in the mountain regions (regions 1 and 2) were represented by a natural log equation, whereas the other regions were represented by a linear equation (regions 3 and 6), an exponential function (region 4), or by a second order polynomial (regions 5 and 7).

Annual precipitation was estimated by adjusting the regression equations that relate mean annual precipitation to altitude for each of the 7 regions (fig. 22). Each regression equation was adjusted for each water year by fitting the equation (without changing its shape) to best fit precipitation that had been recorded at all active precipitation stations in each region. Thus, a value dependent on annual precipitation at precipitation stations was added to the regression equation of each region for years where precipitation was greater than the mean and a value was subtracted from the regression equation for years where precipitation was less than the mean.

Precipitation recorded at all active stations for a water year was determined from monthly precipitation totals for all precipitation stations except for the high-altitude bulk-storage gages operated by NDWR. The bulk-storage gages typically were measured in April and October of each year. Not all precipitation stations were operational during the entire period (table 2). Many of the high-altitude bulk-storage gages operated by NDWR began in water year 1953. Because there was little information on high-altitude precipitation prior to water year 1953, precipitation volumes for water years 1950–52 were not estimated. Also, many of the high-altitude SNOTEL stations operated by the NRCS of the U.S. Department of Agriculture began during water year 1981 (table 2); consequently, estimates of annual precipitation volume for water years prior to 1981 were limited mostly to the high-altitude bulk-storage gages operated by NDWR. Annual water-year adjustments that were either added to (for above mean annual precipitation) or subtracted from (for below mean annual precipitation) each regression equation for water years 1953–99 are listed in table 4.

Annual precipitation volume for each region above the three tributary and five Humboldt River streamflow gages was estimated by multiplying the annual precipitation estimated from the regression equations with an area of a selected altitude range in each region. The area in acres for an altitude interval of 1,000 ft was determined for each region starting at a base altitude of 4,000 ft (table 5). An average precipitation across the selected altitude ranges for each water year was determined from the adjusted regression equation. The annual precipitation volume in each region was estimated by summing over all altitude intervals.

Annual precipitation volume above each streamflow gage was estimated by summing precipitation volumes in each region within the drainage area above the gage for water years 1953–99 (table 6). The lack of measured precipitation in many parts of the Humboldt River Basin does not justify a more sophisticated approach in estimating precipitation volumes. The method used provides an estimate of annual precipitation volumes that is consistent with measured precipitation in the basin. Although the absolute volumes may be more or less than what actually occurred in the basin, a more sophisticated approach would suffer from the same lack of data. A more sophisticated approach could perhaps provide for a better estimate of method uncertainty.

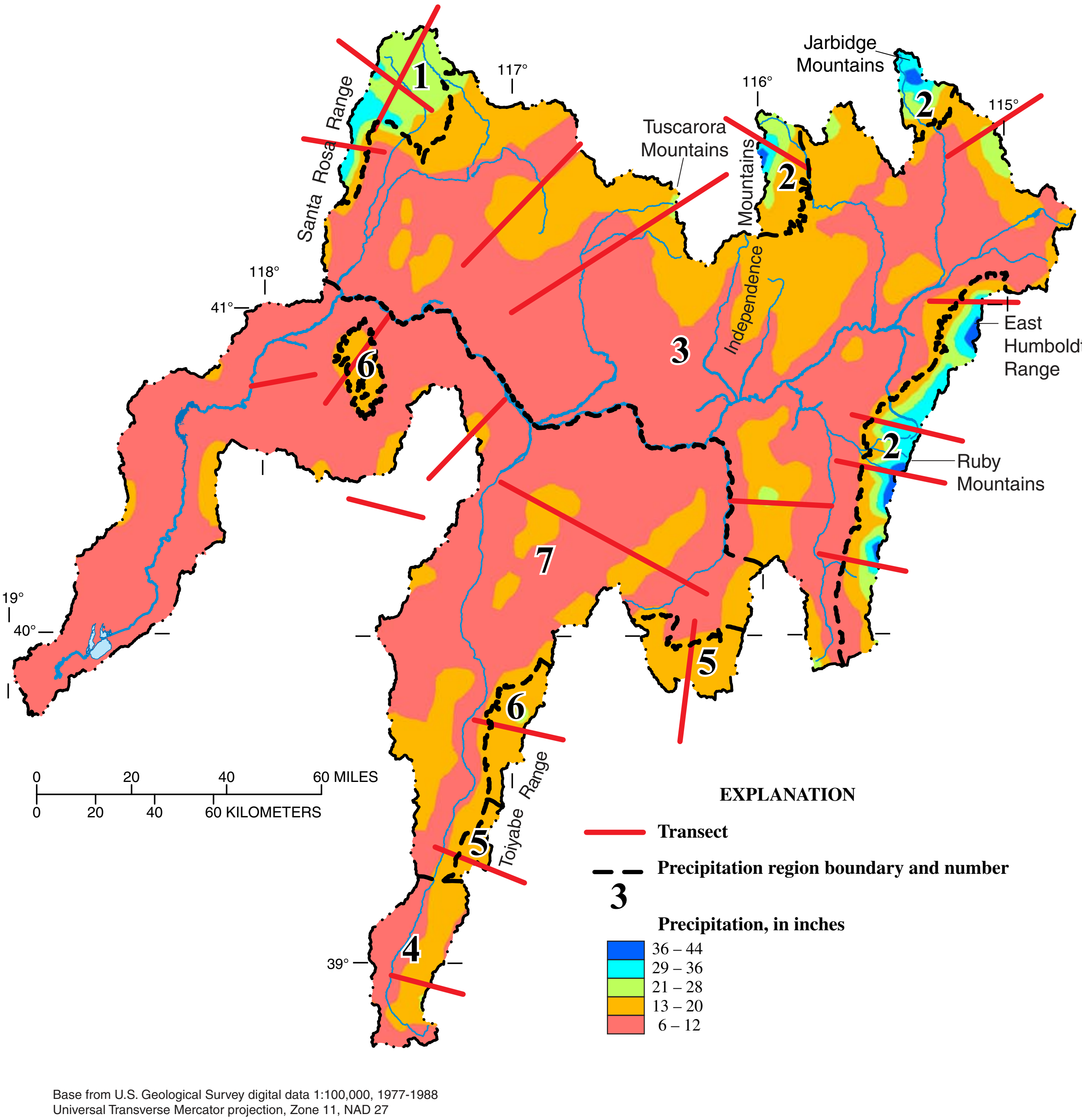


Figure 21. Distribution of mean annual precipitation and transects used to determine regions of different mean annual precipitation with respect to land-surface altitude. Mean annual precipitation was estimated for 1960–91 by Daly and others (1994) for all of Nevada. Estimates of mean annual precipitation for a 2.4 square mile grid were provided by G.H. Taylor (Oregon Climate Service, Oregon State University, written commun., 1997).

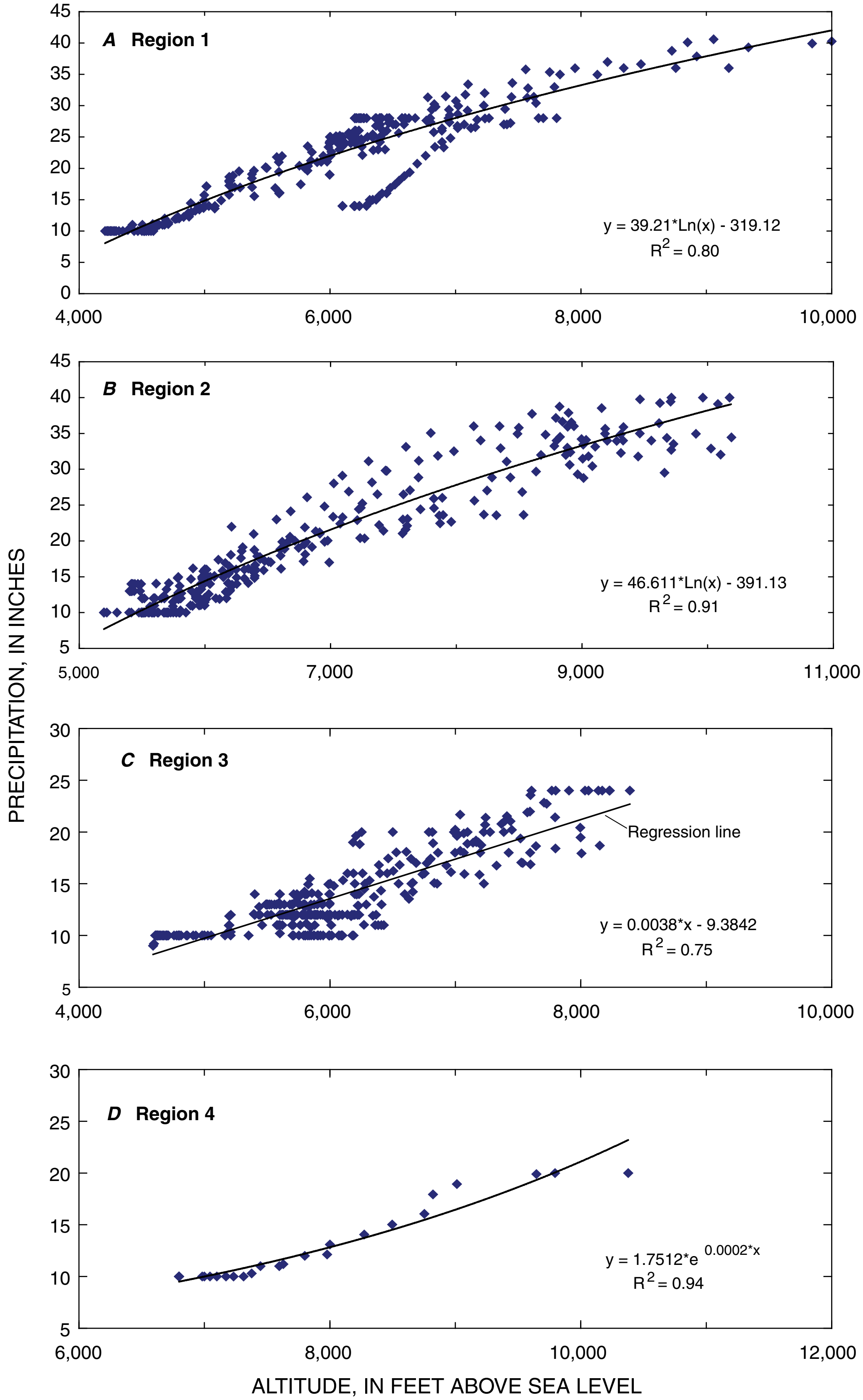


Figure 22. Relation of mean annual precipitation to land-surface altitude by region in the Humboldt River Basin. Locations of regions are shown in figure 21.

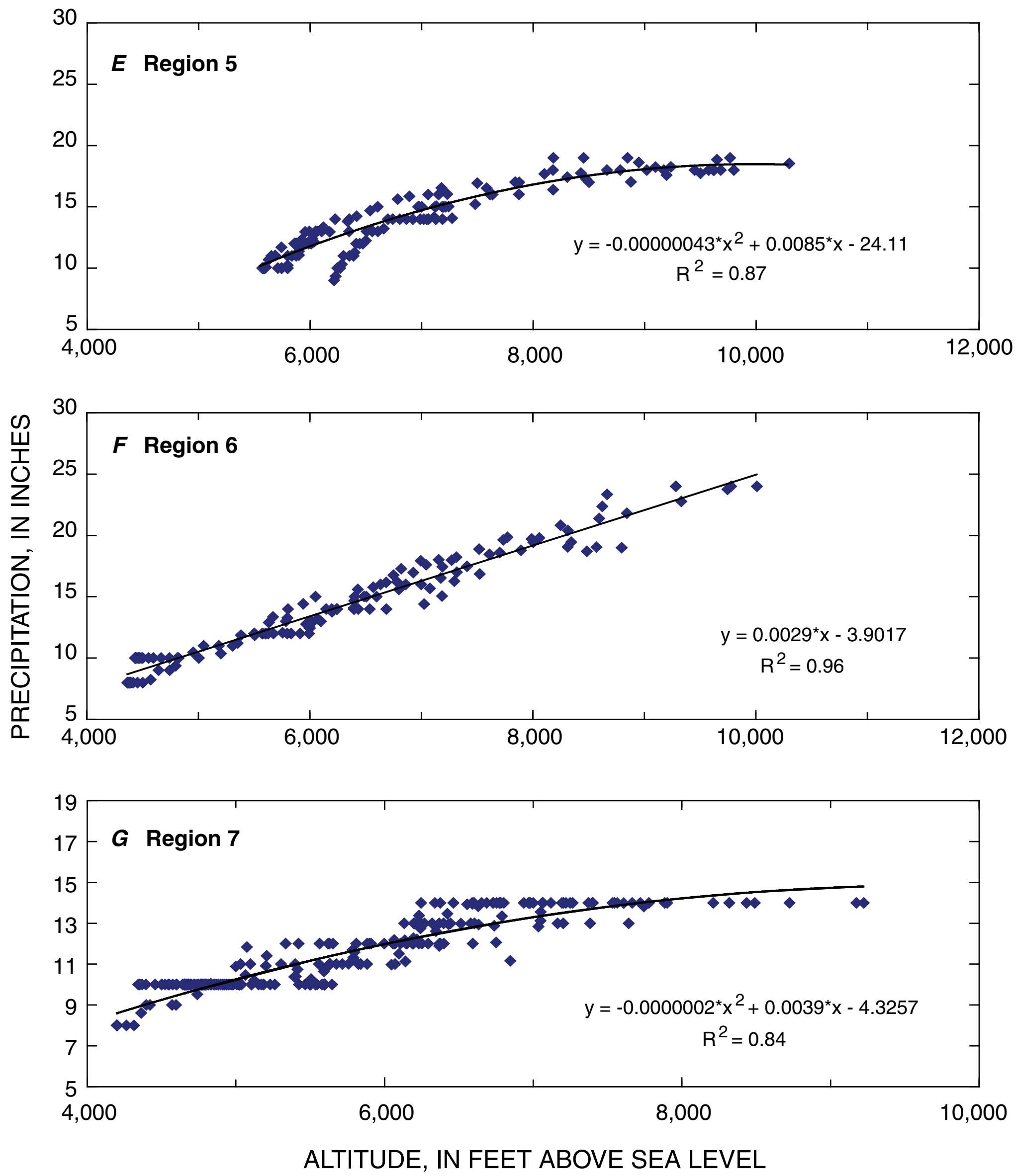


Figure 22. Continued.

Table 4. Annual adjustments to the regression equations of mean annual precipitation and land-surface altitude by region in the Humboldt River Basin, north-central Nevada for water years 1953–99

[All values are in inches. Locations of regions are shown in figure 21]

Year	Region							
	1	2	3		4	5	6	7
			Below 6,000 feet	Above 6,000 feet				
1953	-6.79	-2.21	-4.40	-6.82	-3.61	-7.85	-5.98	-4.67
1954	-6.48	-2.82	-2.41	-6.83	-2.96	-3.25	-4.76	-4.22
1955	-6.08	-2.71	-3.59	-6.84	1.88	-3.19	-4.58	-4.65
1956	-0.99	1.66	1.00	-3.56	8.77	1.04	0.08	-4.65
1957	-2.33	2.07	-0.32	-3.33	4.18	-4.49	-4.72	-1.30
1958	2.21	1.64	-1.48	-3.53	3.98	0.38	0.62	-0.09
1959	-5.15	-2.26	-3.62	-4.49	-0.17	-7.95	-6.32	-4.56
1960	-4.76	-0.30	-4.80	-4.22	0.08	-6.25	-5.57	-4.23
1961	-4.34	-0.95	-2.84	-7.06	9.68	-3.20	-2.23	-1.95
1962	-4.40	1.06	-0.29	-2.33	7.73	-4.11	-2.80	-0.07
1963	-4.10	3.60	0.73	0.33	1.18	1.30	0.53	0.29
1964	-4.59	1.24	0.71	-5.23	4.33	1.68	0.72	0.72
1965	-2.58	4.22	4.52	1.36	3.38	7.18	3.60	1.69
1966	-7.85	-4.53	-2.85	-6.64	0.43	-5.08	-6.20	-4.38
1967	-1.49	0.87	0.69	-4.21	6.13	-1.15	-0.91	-1.44
1968	-4.82	-0.91	0.31	-3.29	6.23	-3.94	-5.17	-2.56
1969	-0.43	3.07	0.56	-0.17	7.28	2.43	1.43	0.46
1970	1.41	3.10	2.23	-0.39	4.53	0.87	0.60	0.30
1971	-1.15	4.59	2.25	-1.87	3.63	3.72	0.77	-1.47
1972	-4.40	0.84	-1.55	-4.36	-0.27	-0.02	-2.62	-3.66
1973	-1.24	-0.15	1.94	-3.18	3.99	3.98	1.59	0.32
1974	-4.28	-0.90	-2.30	-6.24	-3.46	-3.52	-4.06	-2.48
1975	-1.18	1.14	3.12	-2.91	5.55	8.13	3.23	0.65
1976	-2.53	-0.34	1.54	-5.09	3.38	3.24	0.73	0.49
1977	-4.53	-2.53	-3.60	-4.83	3.17	-2.23	-2.92	-2.94
1978	-0.06	2.33	2.92	2.05	3.81	6.13	2.37	2.57
1979	-4.21	0.09	-0.44	-2.09	3.08	0.35	-1.30	0.03
1980	1.33	4.84	1.34	1.25	4.92	-0.16	-1.80	0.56
1981	-6.19	-2.28	-3.04	-6.79	0.09	-2.44	-3.70	-2.79
1982	11.20	4.33	1.90	2.34	1.60	2.58	1.24	0.13
1983	8.00	6.57	3.28	0.21	6.06	5.04	3.52	2.67
1984	12.30	10.68	3.97	3.85	6.38	12.43	6.26	3.46
1985	-2.82	0.97	-1.15	-3.03	5.02	0.84	-1.47	-1.59
1986	3.80	1.08	0.18	-1.49	1.37	-1.85	-1.83	-1.00
1987	-4.35	-1.06	-1.75	-5.02	3.83	0.28	-1.68	-0.47
1988	-7.82	-3.85	-0.68	-5.43	3.90	3.94	-1.82	-1.01
1989	5.64	-1.76	-2.10	-2.15	2.06	1.45	-2.23	-0.73
1990	-6.49	-1.62	-0.17	-5.86	1.53	-0.13	-1.99	-0.86
1991	-2.30	-1.98	-0.92	-4.82	1.35	0.65	-1.93	-1.74
1992	-9.65	-2.74	-2.23	-4.89	0.79	-3.00	-4.38	-2.72
1993	6.14	2.56	2.14	-0.20	0.42	-2.45	-3.08	0.20
1994	-8.45	-1.26	-0.35	-6.93	-0.99	-1.83	-3.69	-2.30
1995	7.63	4.15	4.58	1.84	5.47	3.38	1.52	0.81
1996	1.68	3.52	0.86	-2.69	0.39	1.28	-2.12	-0.44
1997	3.71	10.14	2.57	-0.15	3.60	-3.15	0.05	2.37
1998	8.00	4.37	5.41	-0.27	5.64	8.37	5.97	6.29
1999	-1.87	3.74	-0.08	-3.31	2.79	-3.99	-3.58	-0.94

Table 5. Areas of land-surface altitude intervals used to estimate precipitation volumes in drainage areas above selected streamflow gages on Lamoille, Rock, and Martin Creeks, and on Humboldt River, north-central Nevada

[All areas are in acres. Symbol: --, interval does not exist. Locations of streamflow gages and regions are shown in figures 2 and 21, respectively]

Region	Land-surface altitude interval, in feet above sea level								Total Area
	4,000-4,999	5,000-5,999	6,000-6,999	7,000-7,999	8,000-8,999	9,000-9,999	10,000-10,999	>11,000	
				Lamoille Creek					
2	--	--	612	2,461	4,281	5,878	2,651	56	15,938
				Rock Creek					
3	36,339	376,711	119,654	17,964	2,130	--	--	--	552,798
				Martin Creek					
1	1,555	47,128	45,764	15,545	2,107	57	--	--	112,157
				Humboldt River near Elko					
2	--	252	206,130	86,240	50,553	30,156	8,623	185	382,139
3	--	782,288	532,017	75,300	6,855	--	--	--	1,396,460
Combined	--	782,540	738,147	161,540	57,408	30,156	8,623	185	1,778,599
				Humboldt River near Carlin					
2	--	263	320,568	143,344	85,796	54,508	16,258	215	620,952
3	3,633	1,333,571	710,189	98,973	10,119	13	--	--	2,156,498
Combined	3,633	1,333,834	1,030,757	242,317	95,915	54,521	16,258	215	2,777,450
				Humbold River at Palisade					
2	--	263	320,568	143,344	85,796	54,508	16,258	215	620,952
3	18,511	1,577,938	879,648	125,628	11,628	13	--	--	2,613,366
Combined	18,511	1,578,201	1,200,216	268,972	97,424	54,521	16,258	215	3,234,318
				Humboldt River at Comus					
2	--	263	320,568	143,344	85,796	54,508	16,258	215	620,952
3	507,795	2,266,369	1,133,157	180,738	16,903	13	--	--	4,104,975
4	--	216	97,681	94,853	73,229	25,578	6,064	220	297,841
5	--	--	122,882	52,520	16,459	3,715	390	--	195,966
6	--	95	77,143	40,114	7,876	1,655	65	--	126,948
7	573,098	1,230,076	531,905	125,972	12,810	455	--	--	2,474,316
Combined	1,080,893	3,497,019	2,283,336	637,541	213,073	85,924	22,777	435	7,820,998
				Humboldt River near Imlay					
1	1,796	94,258	125,299	36,321	6,719	247	--	--	264,640
2	--	263	320,568	143,344	85,796	54,508	16,258	215	620,952
3	1,040,771	2,660,747	1,208,241	194,422	17,549	13	--	--	5,121,743
4	--	216	97,681	94,853	73,229	25,578	6,064	220	297,841
5	--	--	122,882	52,520	16,459	3,715	390	--	195,966
6	--	145	115,963	56,791	12,384	1,844	65	--	187,192
7	1,101,578	1,407,637	581,661	129,938	12,889	455	--	--	3,234,158
Combined	2,144,145	4,163,266	2,572,295	708,189	225,025	86,360	22,777	435	9,922,492

Table 6. Precipitation volumes estimated for water years 1953–99 in drainage areas above selected streamflow gages on Lamoille, Rock, and Martin Creeks, and on Humboldt River, north-central Nevada

[Volumes are in millions of acre-feet. Locations of streamflow gages are shown in figure 2]

Year	Lamoille Creek	Rock Creek	Martin Creek	Humboldt River near Elko	Humboldt River near Carlin	Humboldt River at Palisade	Humboldt River at Comus	Humboldt River near Imlay
1953	0.041	0.346	0.153	1.611	2.537	2.841	5.388	6.480
1954	0.040	0.414	0.156	1.720	2.726	3.072	6.029	7.295
1955	0.040	0.373	0.160	1.646	2.599	2.919	5.781	6.951
1956	0.046	0.569	0.207	2.253	3.561	4.035	7.759	9.408
1957	0.046	0.527	0.195	2.192	3.451	3.901	7.957	9.646
1958	0.046	0.485	0.237	2.092	3.286	3.707	8.026	9.826
1959	0.041	0.399	0.168	1.778	2.779	3.137	5.931	7.133
1960	0.043	0.362	0.172	1.778	2.768	3.106	5.895	7.048
1961	0.042	0.396	0.176	1.740	2.758	3.092	6.826	8.244
1962	0.045	0.539	0.175	2.213	3.471	3.937	8.402	10.131
1963	0.048	0.605	0.178	2.495	3.896	4.429	9.109	10.971
1964	0.045	0.540	0.174	2.134	3.392	3.833	8.544	10.377
1965	0.049	0.748	0.192	2.815	4.422	5.053	10.646	12.906
1966	0.038	0.401	0.143	1.647	2.602	2.942	5.862	7.053
1967	0.045	0.551	0.203	2.173	3.441	3.897	8.150	9.932
1968	0.042	0.549	0.171	2.139	3.370	3.833	7.741	9.348
1969	0.048	0.594	0.212	2.442	3.816	4.337	9.201	11.143
1970	0.048	0.649	0.230	2.541	3.989	4.542	9.441	11.526
1971	0.050	0.632	0.206	2.513	3.967	4.495	9.003	10.925
1972	0.045	0.473	0.175	2.020	3.180	3.586	6.962	8.394
1973	0.043	0.606	0.205	2.275	3.598	4.098	8.944	10.935
1974	0.042	0.425	0.176	1.819	2.878	3.236	6.585	8.010
1975	0.045	0.650	0.205	2.407	3.815	4.345	9.520	11.623
1976	0.043	0.570	0.193	2.146	3.413	3.874	8.629	10.554
1977	0.040	0.396	0.174	1.754	2.745	3.099	6.447	7.767
1978	0.047	0.701	0.216	2.686	4.192	4.800	10.410	12.661
1979	0.044	0.537	0.177	2.183	3.419	3.886	8.334	10.071
1980	0.050	0.637	0.229	2.621	4.091	4.651	9.521	11.556
1981	0.041	0.393	0.159	1.699	2.687	3.021	6.320	7.632
1982	0.049	0.669	0.321	2.698	4.202	4.792	9.652	11.943
1983	0.052	0.692	0.291	2.750	4.326	4.911	10.582	13.033
1984	0.058	0.758	0.331	3.113	4.865	5.525	11.693	14.371
1985	0.045	0.502	0.190	2.117	3.322	3.758	7.814	9.437
1986	0.045	0.565	0.252	2.286	3.581	4.071	8.296	10.199
1987	0.042	0.458	0.176	1.912	3.014	3.404	7.544	9.137
1988	0.038	0.490	0.143	1.871	2.960	3.367	7.552	9.109
1989	0.041	0.479	0.269	2.014	3.135	3.565	7.656	9.450
1990	0.041	0.502	0.156	1.954	3.103	3.514	7.648	9.274
1991	0.041	0.489	0.195	1.947	3.073	3.485	7.385	9.012
1992	0.040	0.443	0.126	1.834	2.883	3.265	6.717	8.025
1993	0.047	0.648	0.274	2.527	3.964	4.518	9.195	11.355
1994	0.042	0.484	0.137	1.899	3.029	3.418	7.087	8.563
1995	0.049	0.755	0.288	2.841	4.457	5.097	10.486	12.919
1996	0.048	0.575	0.232	2.347	3.701	4.186	8.595	10.519
1997	0.057	0.663	0.251	2.799	4.407	4.971	10.261	12.531
1998	0.049	0.760	0.291	2.795	4.418	5.042	11.776	14.582
1999	0.049	0.535	0.199	2.261	3.565	4.020	8.165	9.907

Trends

Water-year precipitation volumes varied among the three tributary streamflow gages on Lamoille, Rock, and Martin Creeks and from year to year as shown by departures from mean annual precipitation volumes (fig. 23). The drainage area of Lamoille Creek produced the least precipitation volume because it has the smallest area (25 mi^2 compared with 175 mi^2 for Martin Creek and 864 mi^2 for Rock Creek) even though it has the highest annual rate (33.9 in. for Lamoille Creek compared with 21.7 in. for Martin Creek, and 12 in. for Rock Creek). The coefficient of variation for Lamoille Creek was much less than that for Rock and Martin Creeks (0.10 compared with 0.21 percent for Rock Creek and 0.24 percent for Martin Creek) suggesting that precipitation in the higher elevations of the Ruby Mountains varies less from year to year than in drainages that include large areas of lower altitude. Although not entirely consistent, the three drainages generally were below mean annual precipitation volume during 1953–61 and during 1985–92, and were above the mean annual precipitation volume during 1969–71, 1982–84, and 1993–98. Water years 1963 and 1965 were above mean annual precipitation volume for Lamoille and Rock Creeks but below the mean annual precipitation volume for Martin Creek suggesting that precipitation was greater towards the east side of the Humboldt River Basin during those years. The highest annual precipitation volume was in 1984 for both Lamoille and Martin Creeks, whereas annual precipitation volumes during 1965, 1995, and 1998 nearly equaled 1984 in the Rock Creek drainage.

The departures from mean annual precipitation volume for water years 1953–99 in the drainage areas above streamflow gages along the Humboldt River near Elko, Carlin, and at Palisade showed a greater annual variation than the annual precipitation volume for Lamoille Creek but less than that for Rock Creek (figs. 23 and 24). The 1950's generally had less annual precipitation volume than during 1985–92. Highest annual precipitation was in 1984 and the lowest was in 1953. The coefficient of variation was nearly the same for all three drainage areas (0.17 to 0.18).

The mean annual precipitation volume in the drainage area above Comus (8.2 million acre-ft) was about double the mean annual precipitation volume above the Palisade gage (3.9 million acre-ft), and the increase in the corresponding drainage areas was about 2.5 times. The mean annual precipitation in the drainage areas above Palisade and Comus for water years 1953–99 was about 14.6 in. and 12.3 in., respectively. The decrease in mean annual precipitation along with an increase in the percent of drainage area below an altitude of 6,000 ft (table 3) in the corresponding drainage areas above Comus and Imlay compared with the drainage areas above Palisade, Carlin, and Elko indicate that a greater percentage of precipitation was from lower elevations. The overall pattern of above and below mean annual precipitation volume in the drainage areas above Comus and Imlay was most similar to that for Rock Creek (fig. 23).

Relation of Annual Runoff to Precipitation

The effect of climate on annual runoff of the Humboldt River was evaluated by comparing estimates of annual runoff at each streamflow gage with annual precipitation volume in the drainage area above the respective gage. Annual runoff of the Humboldt River and its tributaries is affected not only by precipitation that falls during the same year as the runoff, but also from precipitation that fell in previous years because of water stored in impoundments and in aquifers. The effect of storage retained from year to year was accounted for in the analysis by minimizing the sum of the squares of the difference in rank between an effective precipitation volume and annual runoff.

The effective annual precipitation volume (P_e) was estimated by taking fractions of annual precipitation volume (P_0) for the year of runoff and from successive years prior to year of runoff ($P_1, P_2 \ldots P_n$) as described by Searcy and Hardison (1960, p. 44), where

$$P_e = aP_0 + bP_1 + cP_2 + \ldots zP_n, \qquad (1)$$

and the sum of the fractions ($a, b, c \ldots z$) must equal unity. Annual runoff was assigned a number according to rank starting with the year of highest runoff as 1. The same procedure was used to determine rank of annual precipitation volume. The difference in rank between annual precipitation volume and runoff was squared and summed and provided a basis for comparing estimates of effective precipitation volume using a fraction of annual precipitation volume from each successive year prior to runoff. Effective precipitation volume was calculated by assigning a fraction to the year of runoff and to successive years prior to the year of runoff, and the square of the difference in rank was then calculated and summed for the effective precipitation volume. Different percentages were used until a minimum value of the sum of the squares between effective precipitation volume and runoff was determined. If fractions from prior years precipitation volumes decreased the sum of the squares then the precipitation volume from the prior years had an effect on annual runoff. The sum of the squares increased when the percentage of prior years precipitation volume was too large, thus an optimum number of years and percentages for each year was obtained using this method.

Minimum sum of the squares of the difference in rank between effective annual precipitation volume and runoff were calculated when fractions of precipitation volumes for the year of runoff (P_0) plus two years prior the year of runoff (P_1, P_2) were used to estimate the effective annual precipitation volume (table 7). Effective annual precipitation volume for Lamoille and Martin Creeks included small fractions (less than 0.05) for each of two years prior to the year of runoff suggesting little effect from storage changes in the drainage areas above the streamflow gages, whereas the streamflow gage on

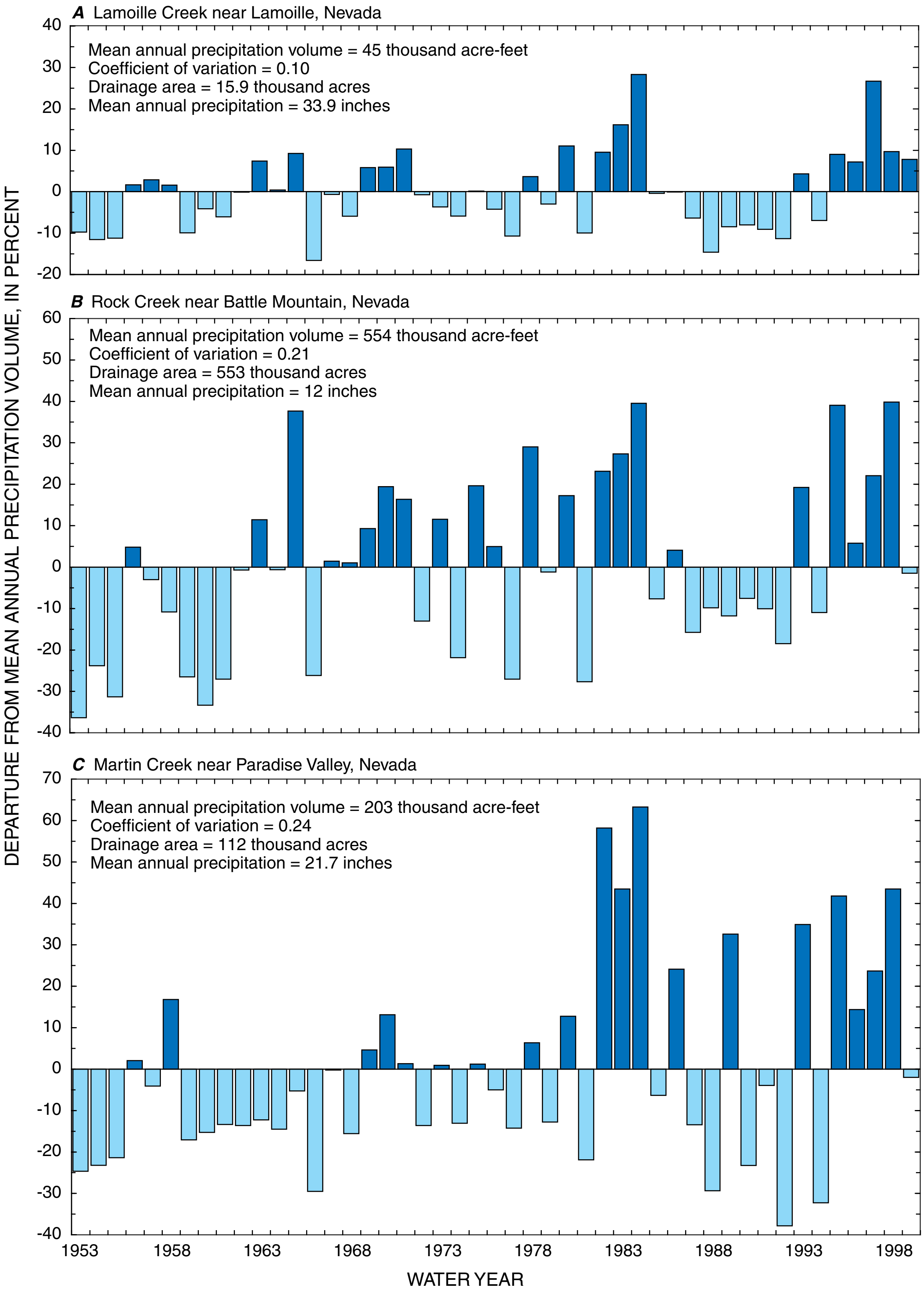


Figure 23. Departures from mean annual precipitation volume in drainage area above streamflow gages on *A*, Lamoille; *B*, Rock; and *C*, Martin Creeks, water years 1953–99. Locations of streamflow gages are shown in figure 2.

Rock Creek had much higher fractions of annual precipitation volumes from the two years prior to runoff suggesting changes in storage affected annual runoff (either in aquifers or in Willow Creek Reservoir; fig. 4). Effective annual precipitation volume for streamflow gages along the Humboldt River also included fractions of the precipitation volume from two years prior to the year of runoff (table 7).

The least effect of prior years precipitation volumes for streamflow gages on the Humboldt River was estimated from the streamflow gage near Carlin, which is the first downstream gage from the South Fork of the Humboldt River. The South Fork and its tributaries drain most of the west side of the Ruby Mountains and even though a reservoir was built at the base of the Ruby Mountains (fig. 4), the higher percentage of precipitation for the same year as runoff suggests smaller changes in storage than for the other streamflow gages along the Humboldt River. The higher percentage for the same year of runoff at the Carlin gage is consistent with the Lamoille Creek gage. The gradually decreasing fraction in annual precipitation volume for the year of runoff at streamflow gages downstream of Carlin suggests that changes in storage (mostly in aquifers) are more important further downstream.

The effect of annual precipitation volume for years prior to the year of runoff on the relation of annual runoff to annual precipitation volume was tested in multiple-linear regression models whereby annual precipitation volume was separated into the year of runoff and successive years prior to the year of runoff. The models assumed both untransformed and transformed values for runoff and precipitation volume that were in the form of:

$$\hat{R} = \beta_0 + \beta_1(P_0) + \beta_2(P_1) + \beta_3(P_2) + \beta_4(P_3), \text{ and} \qquad (2)$$

$$\ln \hat{R} = \beta_0 + \beta_1 \ln(P_0) + \beta_2 \ln(P_1) + \beta_3 \ln(P_2) + \beta_4 \ln(P_3) \qquad (3)$$

where $\hat{R}$ is estimated annual runoff (response variable);

$\beta_0, \beta_1, \beta_2, \beta_3, \beta_4$ are regression coefficients;

P_0, P_1, P_2, P_3 are annual precipitation volume for year of runoff and successive years prior to year of runoff (explanatory variables); and

$\ln$ is natural log or $\log_e$.

A stepwise regression was done with both models in which annual precipitation volume for successive years prior to the year of runoff (P_1, P_2, P_3) were added to the regression equation until the coefficient of the earliest year did not improve the regression equation and was not significant to a P-value (probability) of 0.05. The log transformed values resulted in a better regression model for all streamflow gages except for that on Lamoille Creek where untransformed data resulted in a better regression model. The selection of the proper model was made by plotting residual runoff (both transformed and untransformed) to the predicted runoff for possible trends and by plotting predicted runoff to actual runoff to be certain that the relation was generally linear with homogeneous variance (Helsel and Hirsch, 1992, p. 258).

Table 7. Fractions used to estimate effective precipitation volumes on basis of partitioning precipitation over three-year periods from 1953 through 1999 in drainage areas above streamflow gages on Lamoille, Rock, and Martin Creeks, and above streamflow gages on Humboldt River near Elko, near Carlin, at Palisade, at Comus, and near Imlay, Nevada

[Locations of streamflow gages are shown in figure 2]

Streamflow gage	Factor applied to annual precipitation[1]		
	Two years previous	Previous year	Year of runoff
Tributary streamflow gages			
Lamoille Creek	0.01	0.01	0.98
Rock Creek	.11	.11	.78
Martin Creek	.01	.03	.96
Humboldt River streamflow gages			
Near Elko	.15	.21	.64
Near Carlin	.03	.17	.80
At Palisade	.14	.15	.71
At Comus	.15	.23	.62
Near Imlay	.16	.26	.58

[1] The first three-year period of effective precipitation volume corresponded to water years 1953–55; the year of annual runoff was 1955; the previous year was 1954 and two years' previous was 1953. Subsequent effective precipitation volumes were estimated by incrementing each year in the three-year period by one year. The percentage of precipitation for the year of runoff, previous year, and two years' previous was estimated using a method to minimize the square of the difference in rank of effective precipitation to annual runoff as described by Searcy and Hardison (1960).

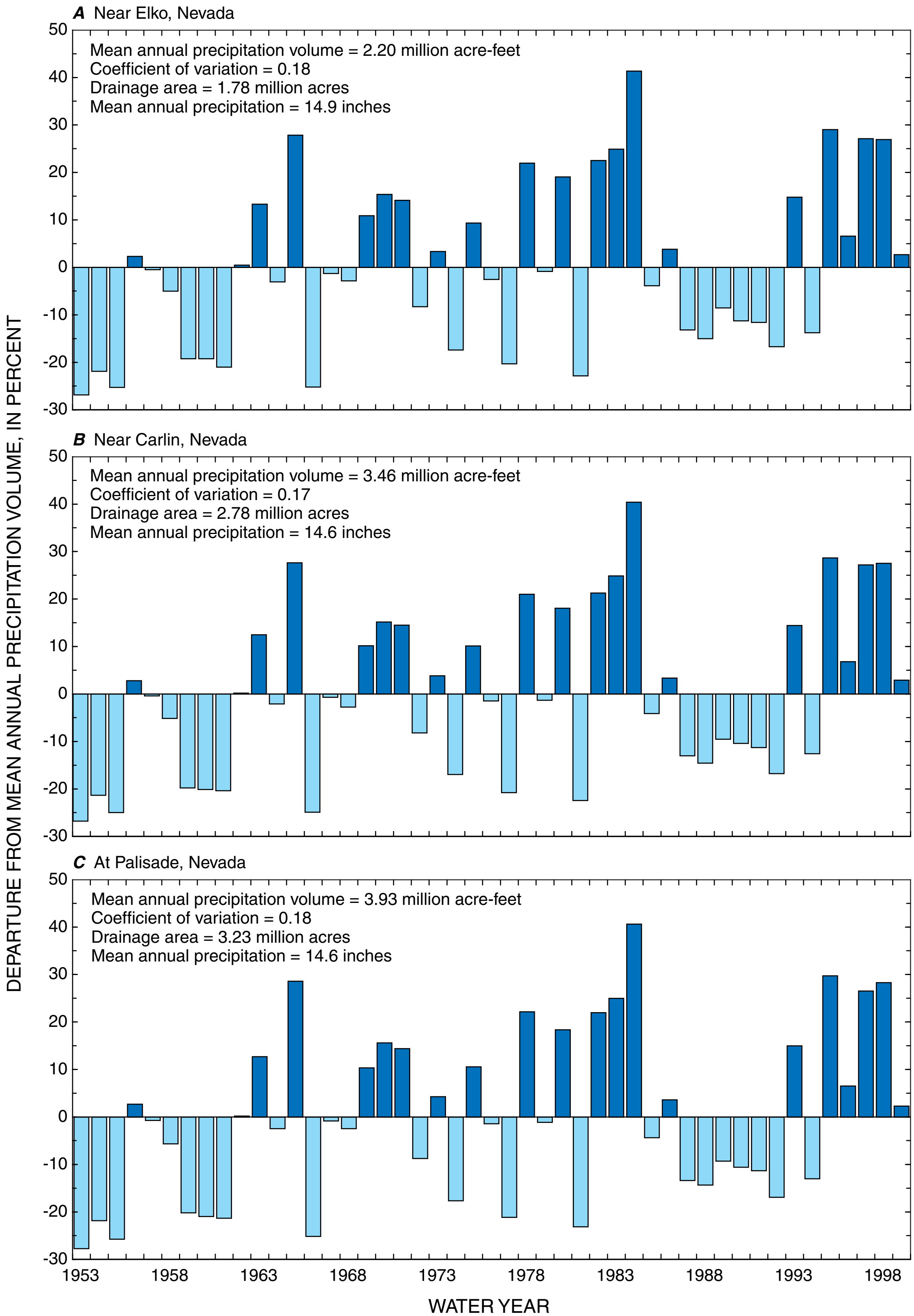


Figure 24. Departures from mean annual precipitation volume in drainage area above streamflow gages on the Humboldt River *A*, near Elko; *B*, near Carlin; *C*, at Palisade; *D*, at Comus; and *E*, near Imlay, Nevada, water years 1953–99. Locations of streamflow gages are shown in figure 2.

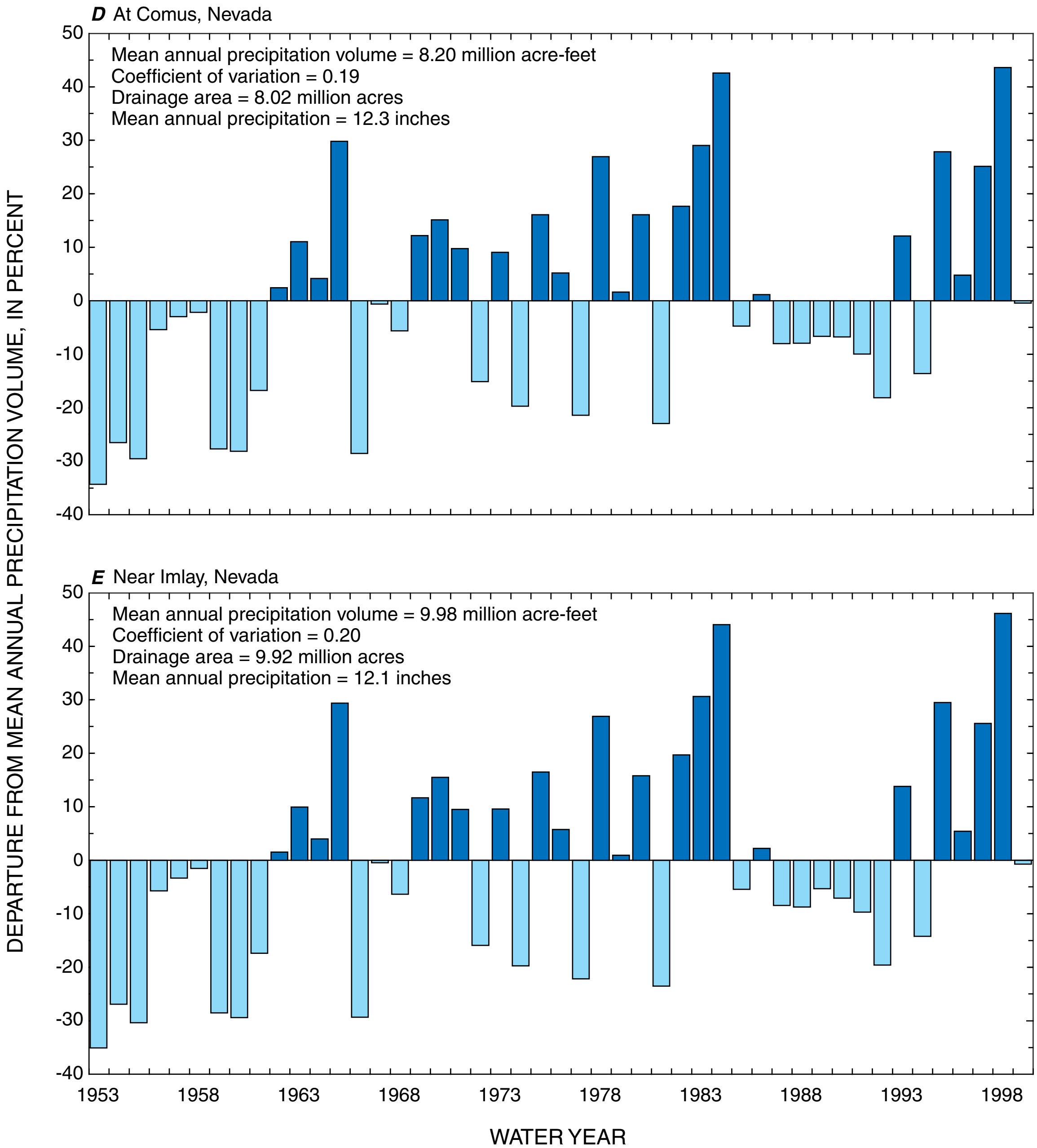


Figure 24. Continued.

Precipitation volume during the year of runoff was the only significant explanatory variable (P-value of less than 0.05) for the tributary streamflow gages on Lamoille, Rock, and Martin Creeks, whereas precipitation volume during the previous year was also significant for all streamflow gages on the Humboldt River. These results, although less sensitive to prior years annual precipitation volume, are generally consistent with the method of minimizing the sum of squares of the difference in rank between precipitation volume and runoff summarized in table 8. The only exception was the Rock Creek gage where the multiple-linear regression model indicated that only the precipitation volume for the year of runoff was significant, whereas minimizing the sum of the squares of the difference in rank indicated fractions of the precipitation volume from the previous two prior years were important. Regression models of the runoff using the effective precipitation volume were the same to slightly better than those from the multiple linear regression. Thus, effective precipitation volumes determined by minimizing the sum of squares of the difference in rank was used in the analyses of trends.

Tributaries

The relation of annual runoff to effective precipitation volume for the streamflow gages on Lamoille, Rock, and Martin Creeks is shown in figure 25. The nearly linear relation between annual runoff and effective precipitation volume for Lamoille Creek indicates that sufficient precipitation occurs each year such that there are only minor year to year changes in storage, evapotranspiration, and in the percentage of the drainage area that contributes runoff, whereas the nonlinear power relation for the Martin Creek and Rock Creek gages indicates that there are much larger year to year changes in storage, evapotranspiration, and in the percentage of the drainage area that contributes runoff.

The streamflow gage on Rock Creek shows greater variability than the streamflow gage on Martin Creek such that there is much scatter in annual runoff to effective precipitation volume (fig. 25). The equations used to predict annual runoff and the coefficient of determination also are listed in the graph for each streamflow gage. The equations for streamflow gages on Martin Creek and Rock Creek include an additional term that is the bias correction factor because transforming a log-regression equation back into its original form results in a median estimate for the predicted value and not the mean (Helsel and Hirsch, 1992). The bias correction factor (BCF) was estimated using a smearing estimate (Duan, 1983) that is equal to the mean of the individually transformed log residuals or

$$BCF = \frac{\sum_{i=1}^{n} \exp(e_i)}{n}, \qquad (4)$$

where e_i is the difference of the predicted runoff minus runoff and n is the number of years used in the regression.

The greater variability between annual runoff and the effective precipitation volume from Lamoille Creek to Rock Creek corresponds to progressively larger percentages of land-surface altitudes less than 6,000 ft in the drainages (table 3). Annual precipitation in the area below 6,000 ft is normally less than the annual evapotranspiration demand (Houghton and others, 1975, p. 62–64). Only occasionally is there sufficient precipitation during the winter months that produce runoff from the lower altitudes in the Martin Creek and Rock Creek drainages and from large areas in the Humboldt River drainage.

The considerable scatter among the individual estimates for Rock Creek is attributed to variations of when and where precipitation occurred in the drainage area during the year and the quantity of water in storage at the beginning of each year, and perhaps to the change in operation of the Willow Creek Reservoir as suggested by a change in mean monthly runoff after 1971 (fig. 11). The effect of antecedent conditions in the Rock Creek drainage is shown by nearly the same effective precipitation volume for 1965, 1984, 1995, and 1998, yet discharge was 38,000 acre-ft in 1965; 170,000 acre-ft in 1984; 24,000 acre-ft in 1995; and 60,000 acre-ft in 1998. The higher than average precipitation years in 1965 and 1995 followed relatively long periods of generally below average precipitation whereas 1984 was at the end of a relatively long period of above average precipitation (11 of 16 years from 1969–84 were above average) and followed two consecutive years of above average precipitation (fig. 23).

Humboldt River

The relation between annual runoff and the effective precipitation volume at streamflow gages on the Humboldt River are similar in form to those for Rock and Martin Creeks (fig. 26), although the coefficient of determination (R^2 between 0.73 and 0.75) suggests similar variation as Martin Creek and much less variation than Rock Creek. However, antecedent conditions similar to that of Rock Creek also affect annual runoff along the Humboldt River. Annual runoff was consistently greater along the river in 1983 and 1984 than in 1965, 1995, and 1998. Annual runoff in 1984 was more than double that in 1998 at the five streamflow gages on the Humboldt River, even though effective precipitation volume in 1984 was only about 10 percent more than in 1998 in the drainages above Elko, Carlin, and Palisade (fig. 26*A–C*) and were nearly equal at Comus and Imlay (fig. 26*D–E*). Water years 1965, 1995, and 1998 all were followed by relatively long periods of below mean annual precipitation and consequently, much of the effective precipitation volume during 1965, 1995, and 1998 may have gone to replenishing ground-water storage. Although the effective precipitation volume was greatest in 1984 for the five streamflow gages, the year culminated a 16-year period (1969–84) of generally above mean annual precipitation (fig. 24) in which much of the available ground-water storage may have been filled.

Table 8. Effective precipitation volumes estimated for water years 1955–99 in drainage areas above streamflow gages on Lamoille, Rock, and Martin Creeks, and on Humboldt River near Elko, near Carlin, at Palisade, at Comus, and near Imlay, Nevada

[Volumes are in millions of acre-feet. Locations of streamflow gages are shown in figure 2. Shaded areas for streamflow gages on Humboldt River for 1984 and 1998 are used to show differences in annual precipitation during two periods of above mean precipitation]

Year	Lamoille Creek	Rock Creek	Martin Creek	Humboldt River				
				near Elko	near Carlin	at Palisade	at Comus	near Imlay
1955	0.0445	0.375	0.159	1.652	2.618	2.931	5.779	6.965
1956	0.0407	0.531	0.205	2.087	3.372	3.733	7.044	8.431
1957	0.0399	0.515	0.195	2.124	3.444	3.784	7.585	9.153
1958	0.0400	0.499	0.236	2.129	3.322	3.782	7.970	9.712
1959	0.0457	0.423	0.171	1.883	2.885	3.330	6.717	8.235
1960	0.0463	0.380	0.172	1.822	2.785	3.195	6.223	7.514
1961	0.0458	0.393	0.176	1.751	2.761	3.100	6.477	7.755
1962	0.0407	0.504	0.175	2.081	3.328	3.694	7.663	9.147
1963	0.0432	0.575	0.178	2.347	3.790	4.168	8.604	10.317
1964	0.0423	0.547	0.174	2.200	3.480	3.937	8.652	10.492
1965	0.0449	0.709	0.192	2.668	4.231	4.783	9.932	11.939
1966	0.0483	0.455	0.145	1.891	2.935	3.383	7.365	9.106
1967	0.0452	0.556	0.201	2.184	3.327	3.916	7.998	9.659
1968	0.0491	0.533	0.172	2.076	3.359	3.718	7.553	9.132
1969	0.0378	0.584	0.211	2.359	3.729	4.200	8.708	10.483
1970	0.0447	0.632	0.229	2.470	3.941	4.412	9.131	11.078
1971	0.0423	0.630	0.206	2.508	3.966	4.480	9.134	11.116
1972	0.0476	0.509	0.177	2.167	3.338	3.856	7.803	9.553
1973	0.0476	0.594	0.204	2.270	3.538	4.077	8.497	10.273
1974	0.0496	0.450	0.177	1.915	3.009	3.414	7.184	8.832
1975	0.0448	0.620	0.205	2.301	3.649	4.144	8.759	10.573
1976	0.0435	0.563	0.193	2.139	3.465	3.855	8.527	10.425
1977	0.0424	0.443	0.175	1.905	2.891	3.390	7.410	9.109
1978	0.0450	0.653	0.214	2.470	3.923	4.415	9.231	11.051
1979	0.0431	0.539	0.178	2.199	3.530	3.913	8.528	10.376
1980	0.0403	0.633	0.227	2.565	3.980	4.557	9.381	11.346
1981	0.0466	0.436	0.161	1.905	2.948	3.386	7.358	9.043
1982	0.0437	0.635	0.315	2.537	3.941	4.507	8.866	10.760
1983	0.0499	0.656	0.291	2.595	4.256	4.629	9.729	11.885
1984	0.0407	0.741	0.330	3.000	4.753	5.330	11.131	13.635
1985	0.0492	0.551	0.195	2.355	3.614	4.184	9.121	11.295
1986	0.0522	0.580	0.251	2.377	3.575	4.228	8.695	10.668
1987	0.0422	0.474	0.178	1.997	3.119	3.554	7.758	9.461
1988	0.0386	0.495	0.145	1.936	2.988	3.471	7.662	9.291
1989	0.0412	0.478	0.264	1.978	3.102	3.513	7.616	9.311
1990	0.0414	0.498	0.159	1.951	3.104	3.501	7.635	9.293
1991	0.0410	0.489	0.195	1.957	3.080	3.500	7.486	9.150
1992	0.0400	0.455	0.129	1.868	2.922	3.333	7.010	8.481
1993	0.0468	0.608	0.269	2.342	3.753	4.185	8.354	10.114
1994	0.0419	0.497	0.141	1.984	3.183	3.562	7.516	9.202
1995	0.0490	0.714	0.283	2.656	4.199	4.764	9.511	11.536
1996	0.0482	0.585	0.233	2.358	3.809	4.215	8.804	10.830
1997	0.0569	0.664	0.251	2.737	4.288	4.871	9.912	12.070
1998	0.0494	0.729	0.289	2.733	4.395	4.911	10.950	13.399
1999	0.0486	0.574	0.202	2.416	3.736	4.307	9.310	11.542

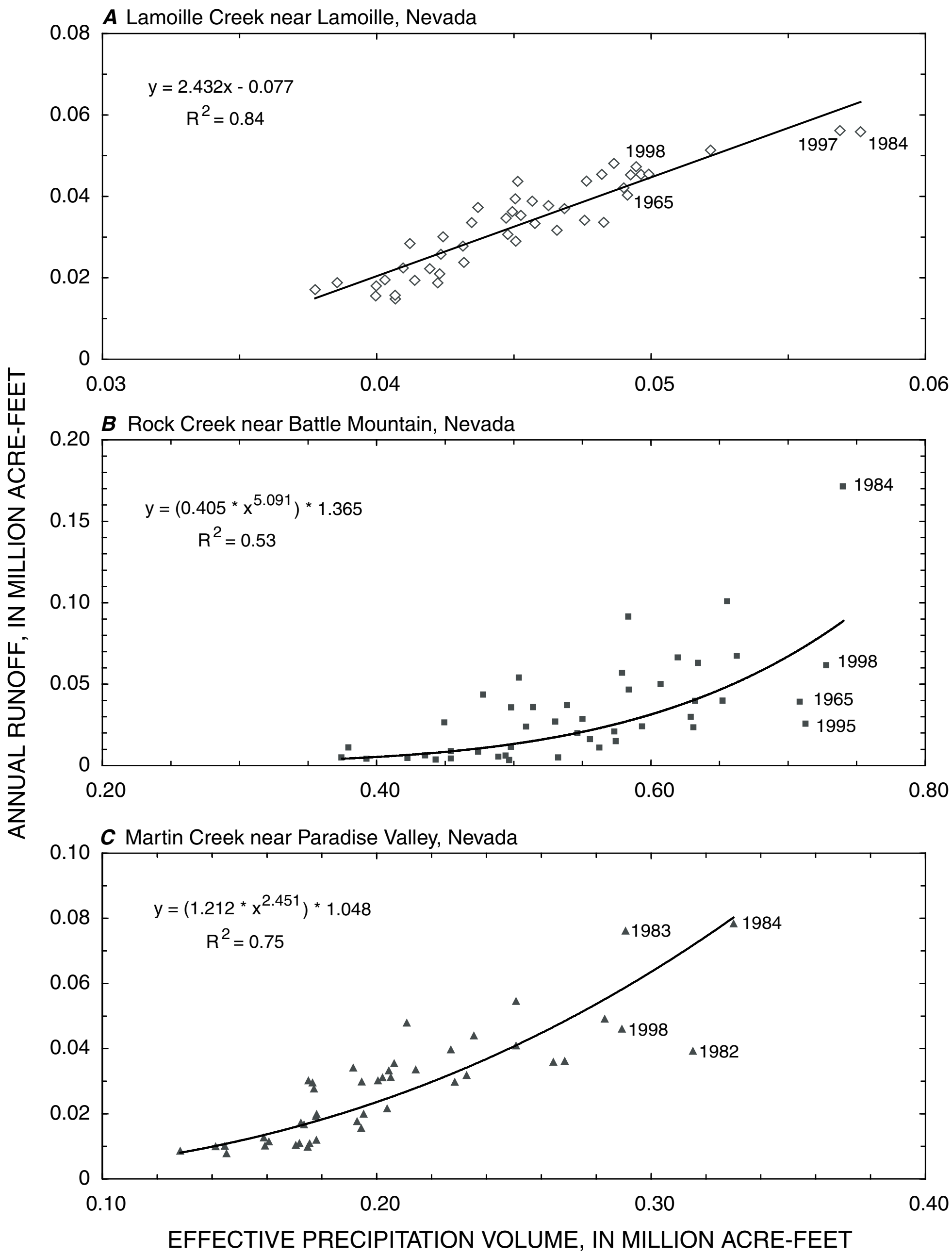


Figure 25. Relation between annual runoff and effective precipitation volume at streamflow gages on *A,* Lamoille; *B*, Rock; and *C*, Martin Creeks, water years 1955–99. Location of streamflow gages is shown in figure 2.

Perhaps another reason for the lack of annual runoff in response to precipitation in 1998 is that a large percentage of the increased precipitation was in the lower-altitude areas and less in the higher Ruby Mountains and Eastern Humboldt Range. This is supported by the greater positive departures in annual precipitation for the stations at Beowawe, Battle Mountain, and Winnemucca compared with stations at Lamoille and Arthur 4NW (fig. 3), and by the greater positive offsets used to compute annual precipitation for the lower-altitude areas of region 3 and all of region 7 in 1998 compared with 1984 (table 5). Thus, estimated annual precipitation in 1998 was about 10 percent less than in 1984 for the streamflow gages at Palisade, near Carlin, and near Elko, whereas annual precipitation in 1998 was about 1 percent more than in 1984 for the streamflow gages at Comus and near Imlay (table 6). Much of the precipitation in the lower-altitude areas likely contributed little runoff to the Humboldt River; rather much of this precipitation was lost to evapotranspiration or infiltrated to ground water.

Trends in the ratio of annual runoff to effective precipitation volume during 1955–99 show a cyclical pattern related to the effective precipitation volume (fig. 27). The ratio of runoff to effective precipitation volume for the Lamoille Creek gage ranged from 0.35 in 1959 to 0.99 in 1999 and the mean was 0.7. The mean ratio indicates that about 70 percent of the effective precipitation became runoff. Ratios approaching 1 for the streamflow gage on Lamoille Creek indicate that either there was little evapotranspiration relative to the increased precipitation or more likely that precipitation was underestimated. A possible reason for decreased evapotranspiration during years of above mean annual precipitation is that the heavy snowpack in the drainage may result from cooler temperatures caused by a prolonged melt. The ratio of annual runoff to the effective precipitation volume was directly affected by the volume being well below or above the mean. Higher ratios were calculated during years when the effective precipitation volume was above the mean and lower ratios were calculated during years below the mean (fig. 27).

A similar pattern is shown for the streamflow gages on Rock and Martin Creeks except the ratio of annual runoff to effective precipitation volume is much lower (fig. 27). The ratio for Rock Creek ranged from about 0.01 in several years to 0.2 in 1984 and the mean was 0.05. This is much lower than either of the streamflow gages on Lamoille and Martin Creeks, and suggests that only 5 percent of the total precipitation in the basin became runoff at the streamflow gage on Rock Creek. The remaining 95 percent was either lost to evapotranspiration or became ground water that did not return to Rock Creek.

The inability to correctly estimate the actual volume of precipitation that had fallen in the drainage area above each gage results in some variability in the ratio of runoff to precipitation that can not be explained by an increase or a decrease in effective precipitation volume. For example, the ratio of runoff to effective precipitation volume for the streamflow gage on Martin Creek increased in 1962 yet the estimated effective precipitation volume was nearly the same during 1960–63 (fig. 27). Similarly, the ratio of runoff to effective precipitation volume for the streamflow gage on Rock Creek increased in 1989, even though the effective precipitation volume remained well below the mean during 1987–89. These variations in the ratio of runoff to effective precipitation volume are likely caused by errors inherent in estimating annual precipitation volumes in drainages with sparse measurements of precipitation, although some of the variations may be the result of changes in storage of water in snow, surface reservoirs, and ground water.

The ratio of annual runoff to effective precipitation volume during 1955–99 at the five streamflow gages on the Humboldt River show trends similar to those for Lamoille, Rock, and Martin Creeks (fig. 28). The ratio of runoff to the effective precipitation volume for Elko, Carlin, and Palisade was nearly the same for all three streamflow gages. The ratios range from about 0.02 in 1955, 1959, 1961, and 1992 to as much as 0.27 in 1984. High ratios generally correspond with periods of above mean effective precipitation volume and low ratios generally correspond with periods of below mean effective precipitation volume (fig. 28) The ratios are consistent with the power-law equations (fig. 26) in which the ratio of runoff to effective precipitation volume remains a power-law with a positive exponent. The mean ratio was 0.08 for the three streamflow gages and indicates that on average about 8 percent of the effective precipitation volume became runoff and that 92 percent was lost to evapotranspiration or to ground water. Although streamflow is lost to ground water along much of the Humboldt River, ground-water discharge during the late summer is sufficient to maintain flow at Elko, Carlin, and Palisade (fig. 18). Mean annual ground-water discharge to the Humboldt River between Carlin and Palisade was estimated at 12,000 acre-ft during 1946–81 (Maurer and others, 1996, p. 28).

The streamflow gages at Comus and near Imlay have similar patterns in the ratio of annual runoff to effective precipitation volume to the three upstream gages, although the ratios are much lower (fig. 28). The mean ratio was 0.03 for Comus and the mean ratio was 0.02 for Imlay. These low ratios suggest that almost all of the precipitation in the drainage areas above the two streamflow gages was lost to evapotranspiration or to ground water. Finally, the pattern of generally higher ratios of runoff during periods when the effective precipitation volume was above the mean effective precipitation volume and decreasing ratios during periods of below the mean (fig. 28) for Comus and Imlay was nearly the same as the pattern for the upstream gages. The rapid rise in the ratio from 1982 to 1984 is consistent with consecutive years where effective precipitation volume was above the mean effective precipitation volume, whereas the rapid fall following 1984 is consistent with a marked decline in the effective precipitation volume.

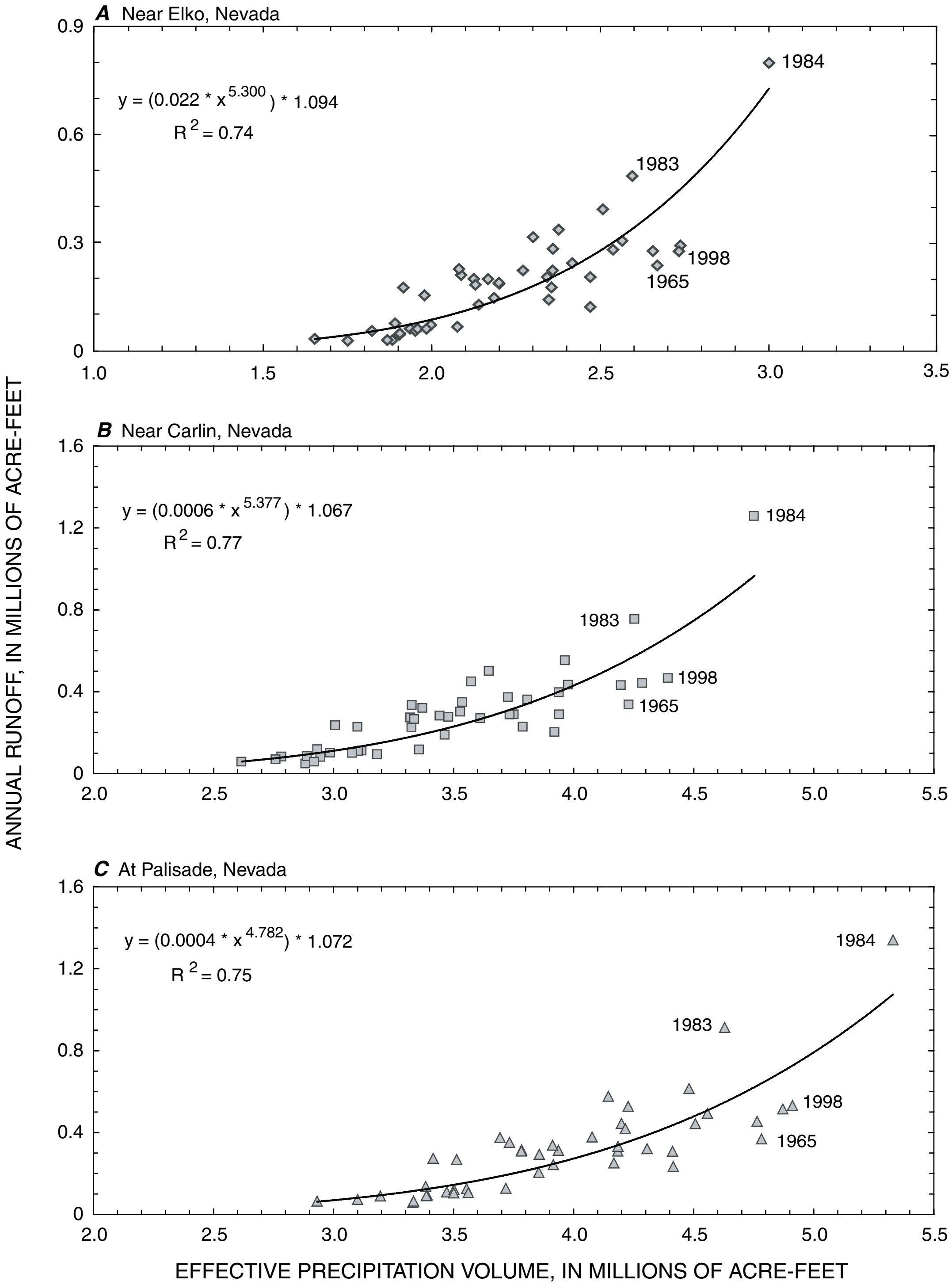


Figure 26. Relation between annual runoff and effective precipitation volume at streamflow gages on Humboldt River *A*, near Elko; *B*, near Carlin; *C*, at Palisade; *D*, at Comus; and *E*, near Imlay, Nevada, water years 1955–99. Locations of streamflow gages are shown in figure 2.

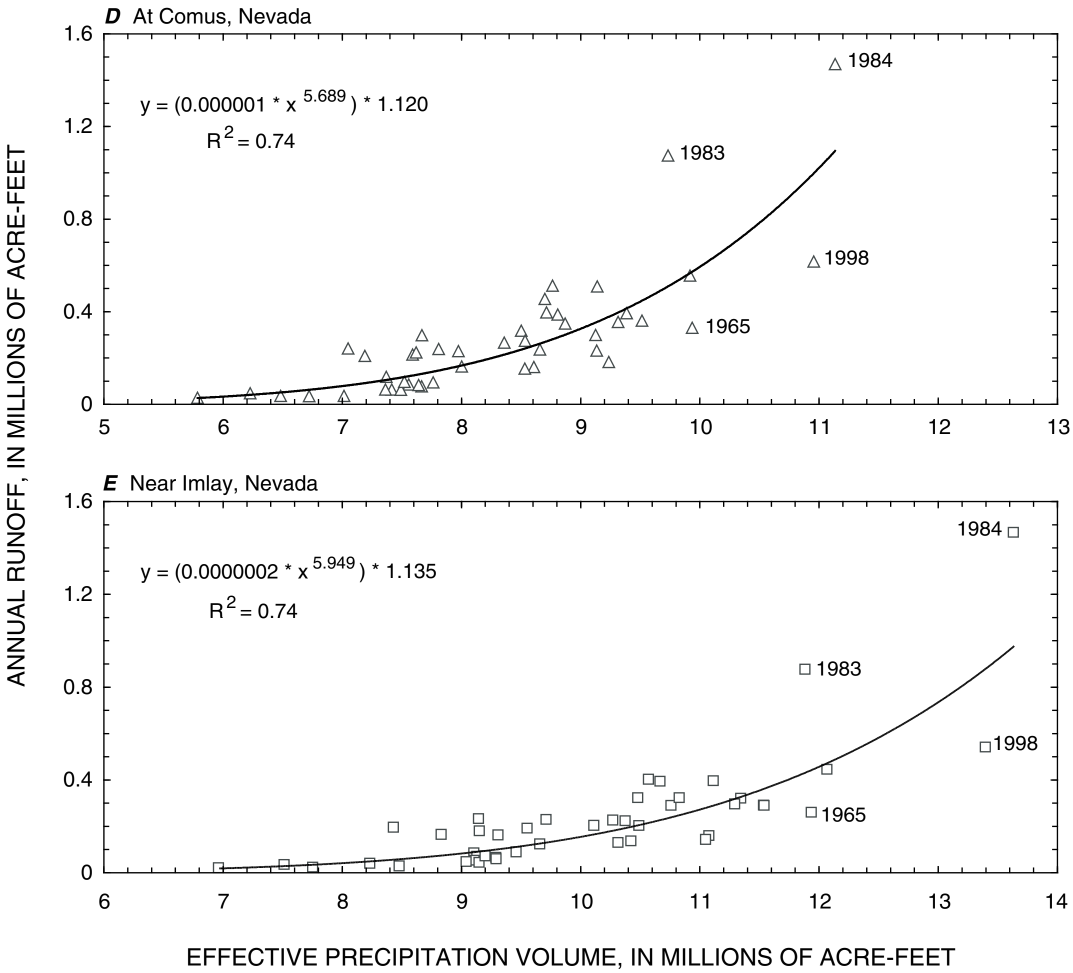


Figure 26. Continued.

Effects of Ground-Water Withdrawals on Annual Runoff

Ground-water withdrawals in the Humboldt River Basin have the potential for decreasing annual runoff in the Humboldt River. The effect is dependent on the quantity and proximity of the ground-water withdrawals to the river (Glover and Balmer, 1954; Heath, 1987; Winter and others, 1998). The withdrawal of large quantities of ground water in areas distant from the Humboldt River or the withdrawal of small quantities near it may have no measurable effect on runoff. However, if withdrawals of large quantities of ground water are sustained over time, runoff may eventually be reduced. Reduction in streamflow has been attributed to ground-water withdrawals in many parts of the country (Glennon, 2002). Some of the more significant reductions in streamflow have occurred along the Arkansas River in western Kansas as a result of agricultural withdrawals (Sophocleous, 2000) and in the loss of sustained baseflow during the fall that once supported Salmon on the Cosumnes River, near Sacramento, California (Fleckenstein and others, 2004).

Unlike the reductions determined from the marked differences in runoff and baseflow between gages for the Arkansas and Cosumnes Rivers, reductions in annual runoff and baseflow along the Humboldt River from 1950–99 were not obvious (figs. 15–20). Thus, multiple linear-regression analyses were done using annual runoff at streamflow gages on the Humboldt River to assess the effects of ground-water withdrawals. The analyses were done by converting all volumes to millions of acre-feet (to be consistent with the effective precipitation volumes) and then taking the log transform of annual runoff of the upstream gage, and the effective precipitation volume, ground-water withdrawals, and mine discharges in the drainage area between gages. The general form of the equation used is:

$$\ln \hat{R}_{dn} = \beta_0 + \beta_1 \ln(R_{up}) + \beta_2 \ln(P_{ef}) + \beta_3 \ln(W_{gw}) + \beta_4 \ln(D_m), \qquad (5)$$

where $\hat{R}_{dn}$ is estimated annual runoff at downstream gage (response variable);

$\beta_0, \beta_1, \beta_2, \beta_3, \beta_4$ are regression coefficients;

R_{up} is annual runoff at upstream gage, millions of acre-feet;

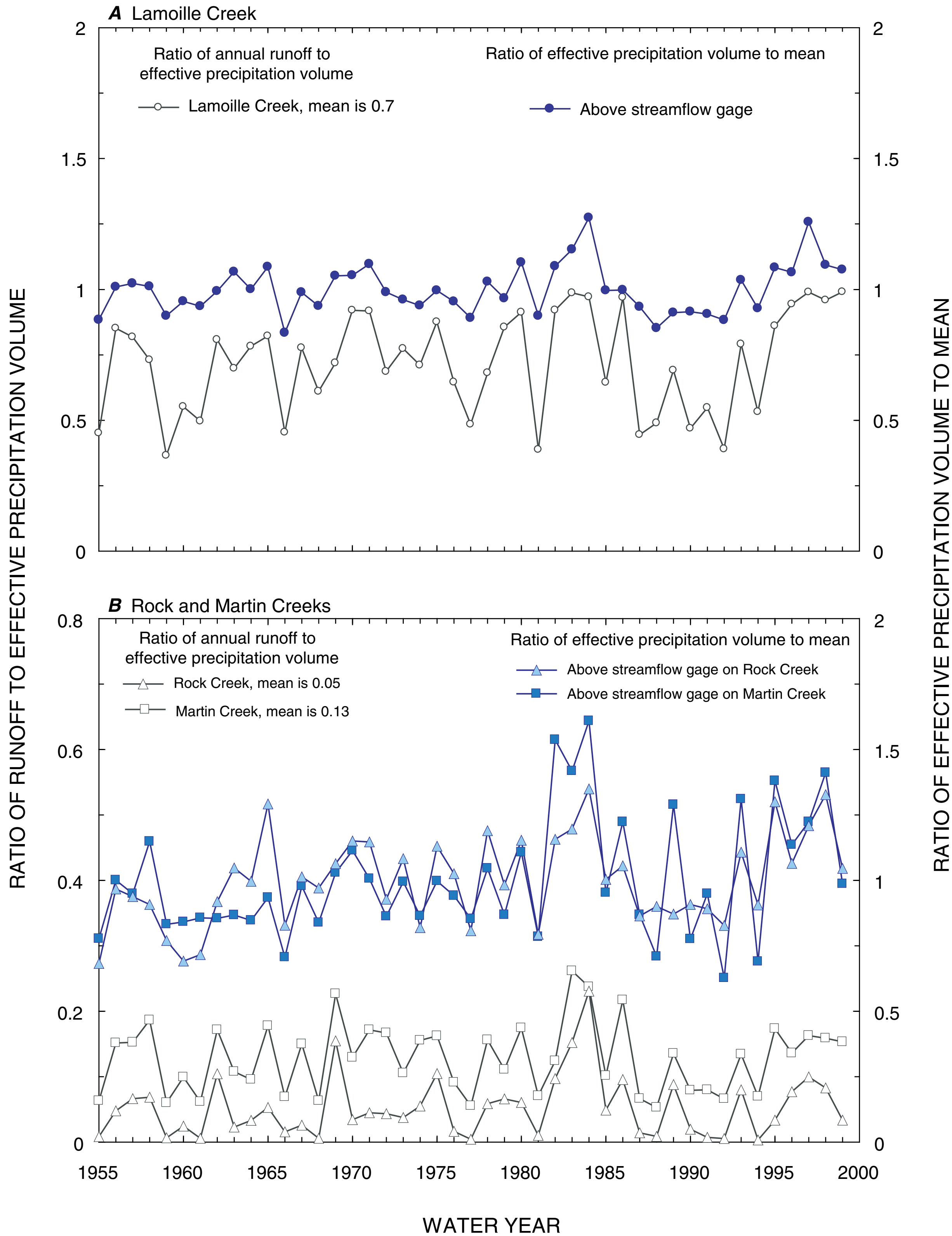


Figure 27. Ratios of annual runoff to effective precipitation volume at streamflow gages on *A*, Lamoille Creek; and *B*, Rock and Martin Creeks, and effective precipitation volume to mean effective precipitation volume above each streamflow gage, water years 1955–99. Locations of streamflow gages are shown in figure 2.

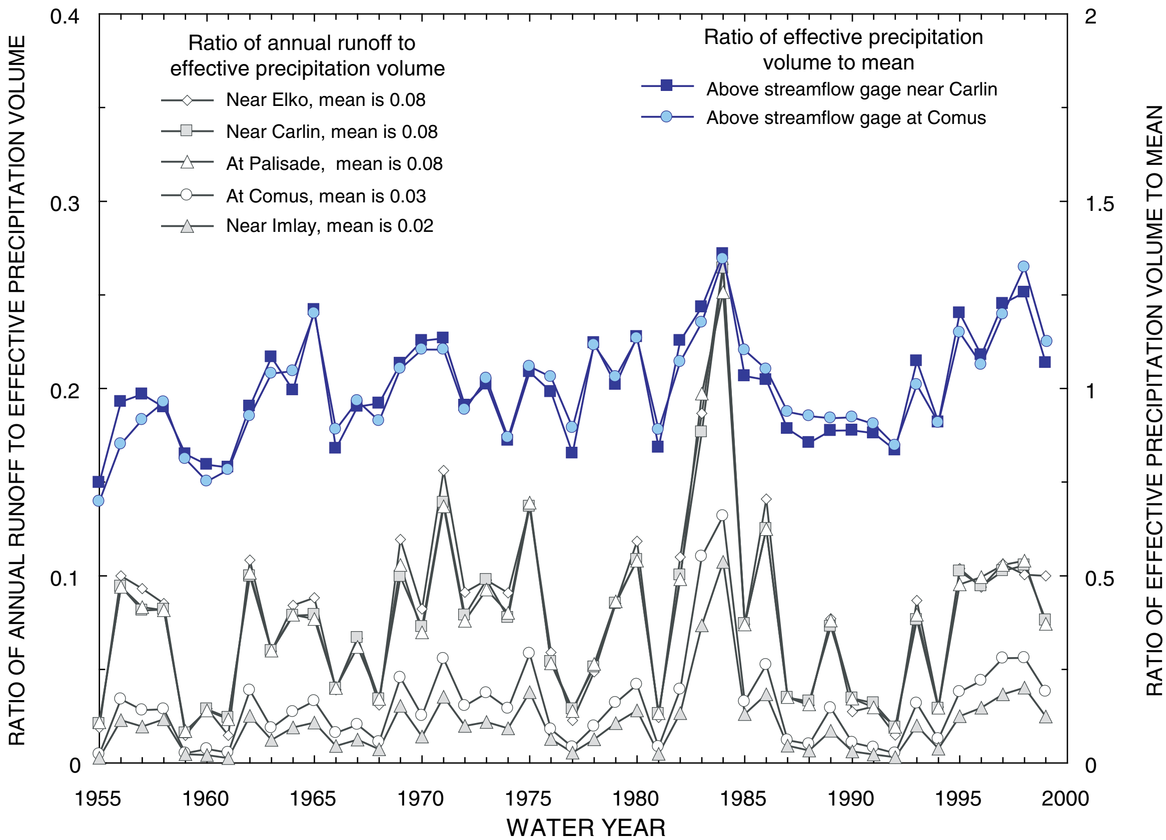


Figure 28. Ratios of annual runoff to effective precipitation volume at streamflow gages on Humboldt River, and ratios of effective precipitation volume to mean effective precipitation volume above streamflow gages near Carlin and at Comus. Locations of streamflow gages are shown in figure 2.

P_{ef} is effective precipitation volume between streamflow gages, millions of acre-feet;

W_{gw} is annual ground-water withdrawals between streamflow gages, millions of acre-feet;

D_m is annual mine discharge to Humboldt River or a tributary stream between streamflow gages, millions of acre-feet; and

$\ln$ is natural log or $\log_e$.

The analyses for the uppermost streamflow gage near Elko did not include an upstream gage and thus, all precipitation and ground-water withdrawals in the drainage area above the gage was included in the stepwise regression. The models used the log transformed values because they were found to have a more constant variance throughout the range of the explanatory variables ($R_{up}, P_{ef}, W_{gw}, D_m$). Also, the use of log transformed values was consistent with the results of the regression models used to predict runoff from the effective precipitation volume for each of the streamflow gages, and was consistent with the findings that channel infiltration losses can be estimated from streamflow using a power-law equation (Burkham, 1970, p. D271).

Annual ground-water withdrawals estimated during 1955–99 (fig. 8) were partitioned into each of the drainage areas between streamflow gages except for the streamflow gage near Elko, which included the entire drainage area above the gage (table 9). Only the regression equations that were used to predict runoff at the streamflow gages at Palisade and Comus included mine discharge to the Humboldt River. Mine discharge was assumed to be a small volume (1 acre-ft) for years in which no water was discharged to the river to allow for transformation to a natural log. Not included in the models were estimates of annual evapotranspiration in the drainage areas between gages. Also, annual diversions for irrigation along the river and to the Pitt-Taylor Reservoirs were not included in the models because data were not available for all years.

The inclusion of ground-water withdrawals into the regression equations for the streamflow gages near Elko and Carlin did not substantially improve the regression equation nor was the P-value (significance level attained by the data; Helsel and Hirsch, 1992, p. 108–109) less than a probability of 0.05 (or 5 percent chance that it should have been accepted) as listed in table 10. Only the effective precipitation volume was significant in the regression equation for the streamflow

Table 9. Annual ground-water withdrawals estimated for water years 1955–99 in drainage areas above streamflow gage on Humboldt River near Elko, and between selected streamflow gages from Elko to Imlay, Nevada

[Volumes are in acre-feet, rounded to two significant figures. Locations of streamflow gages are shown in figure 2]

Year	Ground-water withdrawals				
	Upstream of streamflow gage near Elko	Between streamflow gages			
		near Elko and near Carlin	near Carlin and at Palisade	at Palisade and at Comus	at Comus and near Imlay
1955	690	2,600	10	5,500	5,700
1956	700	2,600	10	6,000	6,600
1957	750	2,700	10	6,400	7,000
1958	760	2,700	10	9,000	7,700
1959	770	2,900	10	9,600	8,900
1960	870	3,200	10	12,000	9,100
1961	870	3,300	10	15,000	9,900
1962	880	3,300	110	15,000	14,000
1963	980	3,400	140	19,000	14,000
1964	980	3,500	140	23,000	15,000
1965	980	3,500	140	26,000	16,000
1966	980	3,600	140	27,000	18,000
1967	1,100	3,700	140	30,000	20,000
1968	1,100	3,800	140	33,000	13,000
1969	1,200	3,900	140	34,000	16,000
1970	1,300	4,000	140	34,000	18,000
1971	1,400	4,200	140	39,000	21,000
1972	1,400	4,400	140	40,000	27,000
1973	1,400	4,600	140	40,000	39,000
1974	1,500	4,700	140	40,000	51,000
1975	1,600	4,900	140	41,000	53,000
1976	1,600	5,000	140	46,000	60,000
1977	1,600	5,300	140	55,000	65,000
1978	1,900	5,400	140	67,000	72,000
1979	1,900	5,600	140	73,000	75,000
1980	2,000	5,800	150	81,000	73,000
1981	2,100	6,000	150	89,000	78,000
1982	2,300	6,200	150	79,000	74,000
1983	2,300	6,100	150	66,000	58,000
1984	2,300	6,300	160	64,000	62,000
1985	2,300	6,800	170	63,000	63,000
1986	2,400	6,800	180	55,000	62,000
1987	2,400	7,500	360	57,000	64,000
1988	2,400	8,800	2,300	61,000	69,000
1989	2,500	9,800	5,400	60,000	72,000
1990	2,500	10,000	6,200	83,000	74,000
1991	2,500	9,900	6,600	61,000	72,000
1992	2,500	12,000	6,900	170,000	79,000
1993	2,500	12,000	12,000	200,000	86,000
1994	2,600	13,000	23,000	190,000	110,000
1995	2,700	13,000	25,000	200,000	100,000
1996	2,700	14,000	26,000	140,000	110,000
1997	2,900	13,000	29,000	180,000	120,000
1998	2,900	14,000	27,000	260,000	120,000
1999	2,900	15,000	17,000	260,000	77,000

gage near Elko, whereas both the annual runoff near Elko and the effective precipitation volume were significant for the streamflow gage near Carlin. However, neither precipitation nor ground-water withdrawals were significant explanatory variables in the regression equation for the streamflow gage at Palisade even though runoff from Maggie, Susie, and Marys Creeks and ground-water discharge contribute additional flow to the Humboldt River between Carlin and Palisade. Perhaps ground-water discharge and runoff from the tributary streams had similar variation to the annual runoff at Carlin such that all the variability at Palisade was explained by the variability in annual runoff at Carlin.

The regression analysis at Palisade was divided into two periods (1955–91 and 1992–99; table 10) because ground-water withdrawals were correlated to mine discharge. The expectation was for ground-water withdrawals to decrease runoff and mine discharge to increase runoff, which could affect the regression equation for the longer period. Neither ground-water withdrawals during 1955–91 nor mine discharge during 1992–99 were significant to a probability value of 0.05 indicating that these variables had no effect on annual runoff at Palisade. The analysis is consistent with the results that the difference in runoff at Carlin and Palisade did not change during 1950–99 (fig. 16).

The regression equations for the streamflow gage at Comus showed that either ground-water withdrawals or mine discharge was significant to runoff but not both (table 10). The coefficient for ground-water withdrawals was positive and thus, its effect was to increase runoff at Comus. Because of the effect of discharge of water from Betze and Lone Tree Mines, the regression analysis was divided into the same two periods as was done for the streamflow gage at Palisade. Ground-water withdrawals during 1955–91 were not significant to a probability of 0.05, whereas mine discharge during 1992–99 was significant to a probability of 0.01 and resulted in an overall increase in annual runoff during 1992–99 that was not explained by effective precipitation. Runoff into the Humboldt River from ungaged tributaries between Palisade and Comus undoubtedly contributed annual runoff to the river during 1992–99 but the contribution could not be distinguished from annual runoff at Palisade and the discharge of water directly to the river from the mines. Thus, the coefficients for annual runoff at Palisade and for mine discharge between Palisade and Comus listed in table 10 likely incorporate runoff from tributary streams.

Ground-water withdrawals in the reach between Comus and Imlay was significant in the regression analysis (table 10), although the effect is small and the P-value of 0.04 is close to the 0.05 probability used to reject coefficients of explanatory variables. Nonetheless, the negative coefficient along with an overall regression equation that improved the R^2 and lowered the standard error (table 10) suggests that ground-water withdrawals in the reach between Comus and Imlay may have caused a decrease in annual runoff at Imlay. Much of decrease was between 1970 and 1998 when ground-water withdrawals increased six fold (table 9). The results are reasonable because considerable ground-water withdrawals for irrigation occurred near the Humboldt River between Golconda and Imlay (fig. 4). A numerical model simulation of ground-water withdrawals at the southern end of Paradise Valley and in the Humboldt River Valley north of Golconda resulted in a net increase in ground-water flow from Humboldt River Valley to Paradise Valley (Prudic and Herman, 1996). Prior to the ground-water withdrawals in Paradise Valley, ground-water flow from Paradise Valley contributed baseflow to the river (Cohen and others, 1965). Although unknown, similar effects may have occurred west of Winnemucca where ground-water flow from Grass Valley increased flow along the river between Winnemucca and the Imlay streamflow gage during the early 1960's (Cohen and others, 1965).

Another possibility for the significance of ground-water withdrawals in the reach between the Comus and Imlay streamflow gages is that the ground-water withdrawals acted as a surrogate to diversions along the Humboldt River, either for irrigation along the river or to temporarily store excess streamflow in the Pitt-Taylor Reservoirs (fig. 4). However, the trend in ground-water withdrawals likely was different than the trend in surface-water diversions. Diversions along the Humboldt River between Comus and Imlay have not changed since adjudication of the Humboldt River in the 1930's and diversions to the Pitt-Taylor Reservoirs only occur during years when Rye Patch Reservoir is at its maximum storage capacity such that the diversion of water into the Pitt-Taylor Reservoirs follows the pattern on annual runoff at the Comus streamflow gage and not that from ground-water withdrawals.

Summary and Conclusions

Since 1990, ground-water withdrawals in the Humboldt River Basin have increased as a result of a general increase in population and development of large gold mines. Trends in streamflow at five long-term streamflow gages on the Humboldt River between Elko and Imlay, Nevada and at three streamflow gages on tributary streams were analyzed to evaluate effects of climate variability and ground-water withdrawals on flows along the Humboldt River. The study is part of the Humboldt River Basin Assessment by the USGS in cooperation with the NDCNR. The study is based on daily mean discharge at each of the streamflow gages and precipitation measured at 36 stations in or adjacent to the Humboldt River Basin from 1950 through 1999.

Ground water is, and historically has been, pumped in the Humboldt River Basin for municipal, domestic, power generation, irrigation, mining, and stock purposes. Ground-water withdrawals for these purposes were estimated annually from 1950–99. Ground-water withdrawals were less than 10,000 acre-feet in the basin upstream of Rye Patch Reservoir in 1950, increased to more than 160,000 acre-feet by 1981 as a result of pumping for irrigation, and increased to more than 420,000 acre-feet in 1998 because of the need to dewater gold

Table 10. Results of multiple linear regression models to estimate runoff at streamflow gages along the Humboldt River from Elko to Imlay, Nevada

[Locations of streamflow gages are shown in figure 2. Symbols: --, explanatory variable was not included in regression model. Abbreviation, P-value is probability value. Shaded lines represent the best regression model for each gage and period]

	Natural log of explanatory variables[a]											
			Runoff at upstream gage		Precipitation		Ground-water withdrawals		Mine water discharged to Humboldt River			
Period	Intercept[b]	P-value	Slope[b]	P-value	Slope[b]	P-value	Slope[b]	P-value	Slope[b]	P-value	Coefficient of determination (R^2)	Standard error
Humboldt River near Elko												
1955–99	-6.14	<0.01	--	--	5.30	<0.01	--	--	--	--	0.740	0.432
1955–99	-7.90	<0.01	--	--	5.60	<0.01	-0.23	0.19	--	--	0.754	0.425
Humboldt River near Carlin												
1955–99	-0.009	<0.01	0.825	<0.01	0.469	<0.01	--	--	--	--	0.986	0.090
1955–99	-0.009	<0.01	0.825	<0.01	0.469	<0.01	-0.008	0.77	--	--	0.986	0.091
Humboldt River at Palisade												
1955–99	0.118	<0.01	0.996	<0.01	--	--	--	--	--	--	0.998	0.035
1955–99	0.111	<0.01	0.997	<0.01	-0.011	0.74	--	--	--	--	0.998	0.035
1955–99	0.118	<0.01	0.996	<0.01	--	--	<-0.001	0.99	--	--	0.998	0.035
1955–99	0.118	<0.01	0.996	<0.01	--	--	--	--	<0.001	0.90	0.998	0.035
1955–91	0.118	<0.01	0.996	<0.01	--	--	--	--	--	--	0.998	0.036
1955–91	0.115	<0.01	0.997	<0.01	-0.004	0.93	--	--	--	--	0.998	0.036
1955–91	0.111	<0.01	0.997	<0.01	--	--	<-0.002	0.53	--	--	0.998	0.036
1992–99	0.117	<0.01	0.991	<0.01	--	--	--	--	--	--	0.998	0.035
1992–99	0.072	<0.01	1.003	<0.01	-0.083	0.45	--	--	--	--	0.999	0.036
1992–99	0.117	<0.01	0.997	<0.01	--	--	--	--	<0.001	0.61	0.998	0.037
Humboldt River at Comus[c]												
1955–99	-1.095	<0.01	1.101	<0.01	0.74	<0.01	--	--	0.004	0.03	0.988	0.105
1955–99[c]	-0.676	<0.01	1.122	<0.01	0.519	0.01	0.053	0.01	--	--	0.988	0.105
1955–91	-1.116	<0.01	1.112	<0.01	0.687	<0.01	--	--	--	--	0.990	0.096
1955–91	-0.577	0.16	1.134	<0.01	0.445	0.04	0.047	0.10	--	--	0.990	0.094
1992–99	-1.855	0.18	1.018	<0.01	1.159	0.15	--	--	--	--	0.980	0.163
1992–99	2.661	0.07	0.912	<0.01	-0.630	0.27	--	--	0.575	<0.01	0.997	0.071
1992–99	1.263	<0.01	0.942	<0.01	--	--	--	--	0.451	<0.01	0.996	0.076
Humboldt River near Imlay												
1955–99	-0.155	<0.01	1.050	<0.01	--	--	--	--	--	--	0.987	0.111
1955–99	-0.425	<0.01	1.003	<0.01	0.341	0.06	--	--	--	--	0.989	0.108
1955–99	-0.768	<0.01	0.981	<0.01	0.609	<0.01	-0.046	0.04	--	--	0.990	0.104

[a]Natural log values were calculated from volumes for each explanatory variable reported in millions of acre-feet. Explanatory variables include annual runoff from upstream gage, and effective precipitation volumes, ground-water withdrawals, and water discharged to Humboldt River or tributary from mining operations, except for streamflow gage near Elko, which included effective precipitation volumes and ground-water withdrawals in drainage area above the gage. Time periods were divided into two intervals for the streamflow gages at Palisade and Comus because of the correlation between ground-water withdrawals and mine discharge.

[b]Intercept and slope are coefficients determined from multiple linear regressions using equation 5.

[c]Positive coefficient for ground-water withdrawals is opposite in sign from expected as it should lower the natural log value of the predicted runoff, thus the model was rejected in favor of the one that used mine discharge.

mines that were below the water table. Part of the ground-water withdrawals for mining operations was discharged back to the Humboldt River or to Maggie Creek, a tributary of the Humboldt River. The maximum annual volume of water discharged to the Humboldt River or to Maggie Creek was 96,700 acre-ft in 1998.

Annual runoff along the Humboldt River and its tributaries is highly variable. Runoff in the basin above Palisade is dominated by snowmelt mostly from high altitude in the Ruby Mountains, East Humboldt Range, and Jarbidge and Independence Mountains. Annual runoff generally increases from Elko to the Palisade gages because of tributary inflow and ground-water discharge. Ground-water discharge during late summer into winter maintains a baseflow in the Humboldt River upstream of Palisade. Annual runoff generally decreases downstream of Palisade because of irrigation diversions, infiltration of streamflow into alluvium, and evapotranspiration. However, annual runoff at Comus downstream of Palisade exceeded the annual runoff at Palisade during 1983–84 and again during 1996–99. Greater annual runoff at Comus than Palisade during 1983–84 resulted from well above annual mean precipitation and accumulation of snow at lower altitudes throughout much of the drainage basin, whereas greater annual runoff during 1996–99 was a result of above annual mean precipitation combined with the discharge of water from mining operations into the Humboldt River.

The daily discharge at Comus prior to the discharge of water directly into the river from mining operations was minimal during late summer to early winter because of insufficient baseflow from ground-water discharge. Beginning in 1992, daily discharge at Comus and Imlay increased markedly during the late summer to early winter as a result of added flow from the mining operations. However, the marked increase was much less at Imlay indicating that part of the water discharged to the river by the mines either infiltrated into the alluvium or was diverted prior to reaching the streamflow gage near Imlay.

The effect of climate on annual runoff of the Humboldt River was evaluated by comparing annual runoff at each streamflow gage with estimates of the annual precipitation volume in the drainage area above each gage. Precipitation generally is greater in the mountains than in the adjacent valleys, and is generally greater at the same altitude in the northern half of basin than in the southern half because of how storms track across the basin. Consequently, the basin was divided into seven regions to account for the variability in precipitation and a relation between mean annual precipitation and altitude was determined for each region. The relation that was developed for each region was then adjusted upward or downward on the basis of annual precipitation measured at stations in or near each of the regions. The annual precipitation volume was then estimated on the basis of the volume of precipitation within 1,000-ft altitude intervals in each region.

Because both surface and ground water storage within the drainage area above each streamflow gage has an effect on runoff, an effective precipitation volume was estimated by minimizing the square of the difference in rank of annual precipitation and runoff. The lowest square of the difference in rank was estimated when the effective precipitation included a fraction of precipitation from each of two years previous to the year of runoff. Even though the effective precipitation volume was an attempt to account for changes in storage, there was considerable variation between annual runoff and effective precipitation volume at all streamflow gages. Linear regression models were used to determine the relation between annual runoff and effective precipitation volume. Overall variations were reduced when the annual runoff and effective precipitation volumes were transformed into log values at all streamflow gages except those for Lamoille Creek. The log-transformation results in a power-law equation whereby runoff increased exponentially with increased precipitation.

Although there was considerable annual variation between annual runoff and the effective precipitation volume, the ratio of annual runoff to the effective precipitation volume was generally higher during periods when the effective precipitation volume was greater than the mean effective precipitation volume and was lower during periods that were below the mean effective precipitation volume. Highest ratios were estimated for Lamoille Creek. Annual runoff at Lamoille Creek increased linearly with increased precipitation, and on average about 70 percent of the effective precipitation volume became runoff. This indicates that on average about 30 percent of the effective precipitation volume was lost to evapotranspiration or to ground water that did not discharge back to the creek upstream of the gage.

Lowest ratios of runoff to effective precipitation volume were estimated on the Humboldt River at the streamflow gage near Imlay, just upstream from Rye Patch Reservoir. The ratio of annual runoff to effective precipitation volume at this gage ranged from less than 0.01 to 0.11 and had a mean of 0.02. The low ratio indicates that most of the precipitation in the drainage above Imlay was lost to evapotranspiration, either from natural vegetation or from irrigated crops or infiltrated into the alluvium. The pattern of generally higher ratios of runoff to effective precipitation volume during periods of above the mean effective precipitation volume and lower ratios during periods of below the mean effective precipitation volume was similar to that estimated for the tributary streams.

The effects of ground-water withdrawals on annual runoff along the Humboldt River were evaluated using multiple linear regressions. Ground-water withdrawals upstream of Palisade were not significant to a probability of 0.05 in explaining annual runoff at streamflow gages near Carlin or Elko indicating that ground-water withdrawals had little to no effect on annual runoff upstream of Carlin. Only annual runoff at the streamflow gage near Carlin was significant in predicting annual runoff at Palisade. This indicates that ground-water withdrawals and mine discharge to Maggie Creek had no effect on runoff at Palisade, which is consistent with graphical methods that indicated no change in the difference in annual runoff between the Carlin and Palisade streamflow gages during 1950–99.

The reach between Palisade and Comus was divided into two periods (1955–91 and 1992–99) because ground-water withdrawals from two mines discharged directly into the river beginning in 1992 and the discharge to the river was correlated to the increase in ground-water withdrawals. Ground-water withdrawals during 1955–91 had little to no effect on annual runoff at Comus; however, the discharge of water to the river by the mines during 1992–99 was significant to a probability of less than 0.01 indicating that the discharges from the mines had the effect of increasing annual runoff at Comus.

Finally, ground-water withdrawals in the reach between Comus and Imlay were significant to a probability of 0.04 for the 1955–99 period. The negative coefficient suggests that ground-water withdrawals may have caused a decrease in the annual runoff at Imlay, particularly between 1970 and 1998 when withdrawals increased six fold. Most of the ground-water withdrawals in the reach between Comus and Imlay were for agricultural irrigation located either near the mouths of alluvial valleys adjacent to the Humboldt River Valley or they were within the valley proper. This contrasts with ground-water withdrawals upstream of the Comus gage where most of the ground-water withdrawals were in alluvial basins or mountains distant from the river.

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BACK COVER: Photographs of Humboldt River at T-S Ranch bridge near Argenta, Nevada, downstream of streamflow gage at Palisade. Top photograph is from the bridge looking downstream on June 8, 1999 during high flow. Bottom photograph is from the bridge looking downstream on October 19, 1992 during a period of no flow. Top photograph taken by D.E. Prudic, and bottom photograph taken by D.K. Maurer, U.S. Geological Survey.

Prudic and others—Trends in Streamflow on the Humboldt River between Elko and Imlay, Nevada, 1950–99—USGS SIR 2005-5199