U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with
BUREAU OF RECLAMATION

Upper Klamath Lake Basin Nutrient-Loading Study—Assessment of Historic Flows in the Williamson and Sprague Rivers

Water-Resources Investigations Report 98–4198

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By JOHN C. RISLEY and ANTONIUS LAENEN

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Portland, Oregon
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U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS

Multiply	By	To obtain
acre	4,047	square meter (m^2)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
inch	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Celsius (°C) as follows:

$$°C = (°F-32)/1.8.$$

Sea level: In this report “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, called Mean Sea Level of 1929.

Upper Klamath Lake Basin Nutrient-Loading Study—Assessment of Historic Flows in the Williamson and Sprague Rivers

By John C. Risley *and* Antonius Laenen

Abstract

The Williamson River Basin, located in south-central Oregon, has a drainage area of approximately 3,000 square miles. The Sprague River, which flows into the Williamson River Basin, has a drainage area of 1,580 square miles. Together, the Williamson and Sprague Rivers supply about one-half of the inflow to Upper Klamath Lake. Various statistical techniques, which included trend tests, double-mass curves, and two-sample tests, were used to detect significant changes in the precipitation-runoff relation for the Williamson and Sprague River Basins. Flows from these two rivers were compared with the precipitation and air temperature records collected at Klamath Falls to assess the effect of climate on flow variations.

Most of the double-mass curves showed a major break in the slope of the curve occurring around 1950 and a smaller one near 1990. For the years 1930–50 and 1990–96, February through May flows were relatively lower in the Williamson River than in rivers in nearby basins, by an average of 25,000 acre-feet per year and 36,000 acre-feet per year, respectively, for the 4-month period. From 1950 through 1963, flows were generally higher in the Williamson River compared with the nearby rivers by an average of 38,000 acre-feet for the 4 months. In July through September of 1945–51, 1970–76, and 1992–96, flows were lower in the Williamson River than in the comparison rivers by an average of about 6,000 acre-feet for the 3-month period.

Two-sample statistical tests of the annual flow data sets for the Williamson and Sprague Rivers showed a significant increase in the estimated population mean for the period 1951–96 compared to the estimated population mean for the period 1922–50. However, climate data, which included annual precipitation data from Klamath Falls, Crater Lake, and Medford, and annual air temperature data from Klamath Falls, all showed no significant difference between the two periods.

During the past century, various human land-use activities, such as irrigation, grazing, drainage, and timber harvesting, may have had some impact on the hydrology within the Williamson River Basin. However, relating specific land-use activities to changes in flow is impossible to assess owing to the size and geologic complexity of the basin and to the paucity of historical land- and water-use data for local areas.

INTRODUCTION

Upper Klamath Lake was eutrophic when first discovered by non-Indian settlers in the 1800's; however, since the 1950's, the lake has progressed to a hypertrophic condition characterized by increases in algal abundance and changes in algal composition (Bortleson and Fretwell, 1993; Bureau of Reclamation, 1993). A possible cause for the increased abundance of algae is an increase of nitrogen and (or) phosphorus compounds in surface-water and ground-water inflows into the lake resulting from (1) the draining of marshland around the lake, (2) a decrease of forested area in the basin, and (3) an increase of agricultural land use. Die-off of massive blooms of the blue-green alga *Aphanizomenon flos-aquae* can temporarily produce dissolved oxygen concentrations of less than 2 mg/L (milligrams per liter) and also increase ammonia concentrations. The high productivity of algae produces pH levels of greater than 9.5 and increased turbidity (Bortleson and Fretwell, 1993), resulting in poor environmental conditions for resident fish populations (U.S. Fish and Wildlife Service, 1988).

The regulation of Upper Klamath Lake also may be affecting lake water quality. The lake is currently operated as a reservoir that provides irrigation water, minimum downstream flows for anadromous fish, and hydroelectric power. Flows into the lake determine, in part, the operation of the dam and carry nutrients from land-use activities within the basin. The dam, under standard operating procedures, allows lake elevations to fluctuate between 4,137 feet (Bureau of Reclamation datum; 3 feet below predam conditions) and 4,143 feet (historic high water). This regulation changes the flushing patterns and retention time of nutrients in the lake (Klamath River Basin Fisheries Task Force, 1991). Retention time can be a factor in defining and relating chemical and biological processes in the lake, especially in summer. Long-term changes in retention time could produce long-term changes in those processes.

In the late 1980's, the U.S. Fish and Wildlife Service, Bureau of Reclamation, University of California-Davis, Klamath Tribes, Pacific Power and Light, Oregon Department of Fish and Wildlife, and the U.S. Geological Survey (USGS) discussed research and reclamation options to improve water quality in the lake. In 1991, the USGS, in cooperation with the Bureau of Reclamation, began a study that would examine external sources of nutrients to the lake and analyze historic flows of major tributaries. Three previous reports by the USGS present results from that study: Laenen and LeTourneau (1996), Wood, Fuhrer, and Morace (1996), and Snyder and Morace (1997).

Purpose and Scope

The purpose of this report is to present the results of an analysis intended to determine whether streamflow characteristics have changed over time in the largest tributary basin of Upper Klamath Lake, the Williamson River Basin, and, if so, to identify possible sources of the change. The Williamson River Basin comprises the drainage basins of the Williamson and Sprague Rivers. The analyses herein is focused on the Williamson and Sprague Rivers for the period 1918–96. Long-term runoff data for other basins draining into the lake are unavailable. Also, no data are available for locations or periods of time when the Williamson and Sprague Rivers were not affected by human influences.

Study Area

The Upper Klamath Lake Basin (fig. 1), including the closed Crater Lake Basin, encompasses approximately 3,810 square miles. The basin is located in south-central Oregon, and most of the basin (3,400 square miles) is located in Klamath County, covering about one-half of the county. The Williamson River Basin (including the Sprague River Basin) has a drainage area of approximately 3,000 square miles and constitutes 79 percent of the total drainage area that contributes to Upper Klamath Lake. The Sprague River has a drainage area of 1,580 square miles—53 percent of the Williamson River Basin. Together, the Williamson and Sprague Rivers supply about one-half of the inflow to Upper Klamath Lake. The Klamath River flows out of the lower end of the lake and is a tributary to the Pacific Ocean in northern California.

Most of the Upper Klamath Lake Basin is located on the western fringe of the Basin and Range physiographic province (Dicken and Dicken, 1985), a region characterized by strong relief. The northern, eastern, and southern basin boundaries are formed by inactive volcanoes, rims, scarps, buttes, and fault-block mountains; the western boundary is formed by the Cascade Range, which is of volcanic origin. Elevations range from about 4,100 feet at Upper Klamath Lake to more than 9,000 feet in the Cascade Range. Extensive, broad, flat, poorly drained uplands, valleys, and marshlands are located throughout the province. The Upper Klamath Lake and Agency Lake beds are fault troughs, or graben valleys, formed by the uplifting of scarps and subsidence between these scarps and the Cascade Range (Gonthier, 1984).

In general, land use in the Williamson River Basin occurs in bands. At the lower elevations, adjacent to the major rivers, agricultural lands (primarily irrigated pasture) predominate. Rangelands are mainly on the tablelands, benches, and terraces, and forest is predominant on the slopes of the buttes and mountains. Livestock grazing can occur on irrigated pastureland, rangeland, and forestland throughout the basin. Timber harvesting has always been an important industry in the basin (Gearheart and others, 1995). Although forestland currently accounts for more than 81 percent of the basin, it is not homogeneous; second-growth stands are in varying stages of regeneration. Agricultural land currently accounts for slightly more than 6 percent of the basin. Agricultural diversity is discussed in more detail by Snyder and Morace (1997). Range, wetlands, water bodies, and urban areas compose the remaining 13 percent of basin land use.

The Cascade Range creates a rain shadow that affects the areal distribution of precipitation throughout the Upper Klamath Lake Basin (fig. 2). Annual precipitation in the basin ranges from lows of 15 inches at Upper Klamath Lake and along the Sprague River to highs reaching 90 inches at Crater Lake (Daly and others, 1994, 1997). The mean annual precipitation for the Upper Klamath Lake Basin is 27 inches. The mean annual precipitation is 23 inches in the Williamson River Basin upstream from the confluence with the Sprague River and 20 inches in the Sprague River Basin. Mean annual snow accumulation ranges from 15 inches in the valleys to more than 160 inches in the mountainous areas of the basin. Snowfall represents 30 percent of the annual precipitation in the valleys and more than 50 percent of the total at higher elevations.

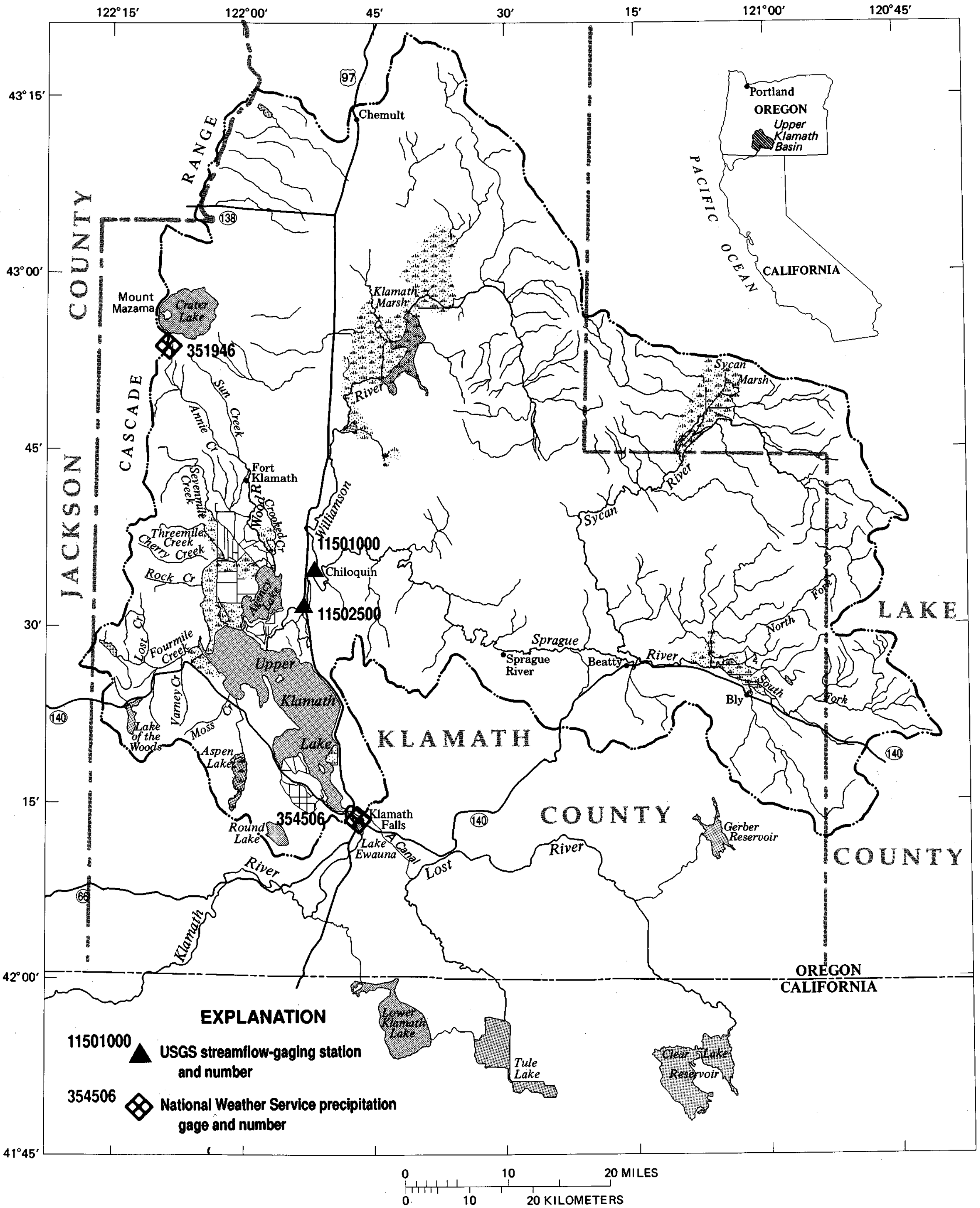


Figure 1. Location and extent of study area and locations of U.S. Geological Survey streamflow-gaging stations and National Weather Service precipitation gages, Upper Klamath Lake Basin, Oregon.

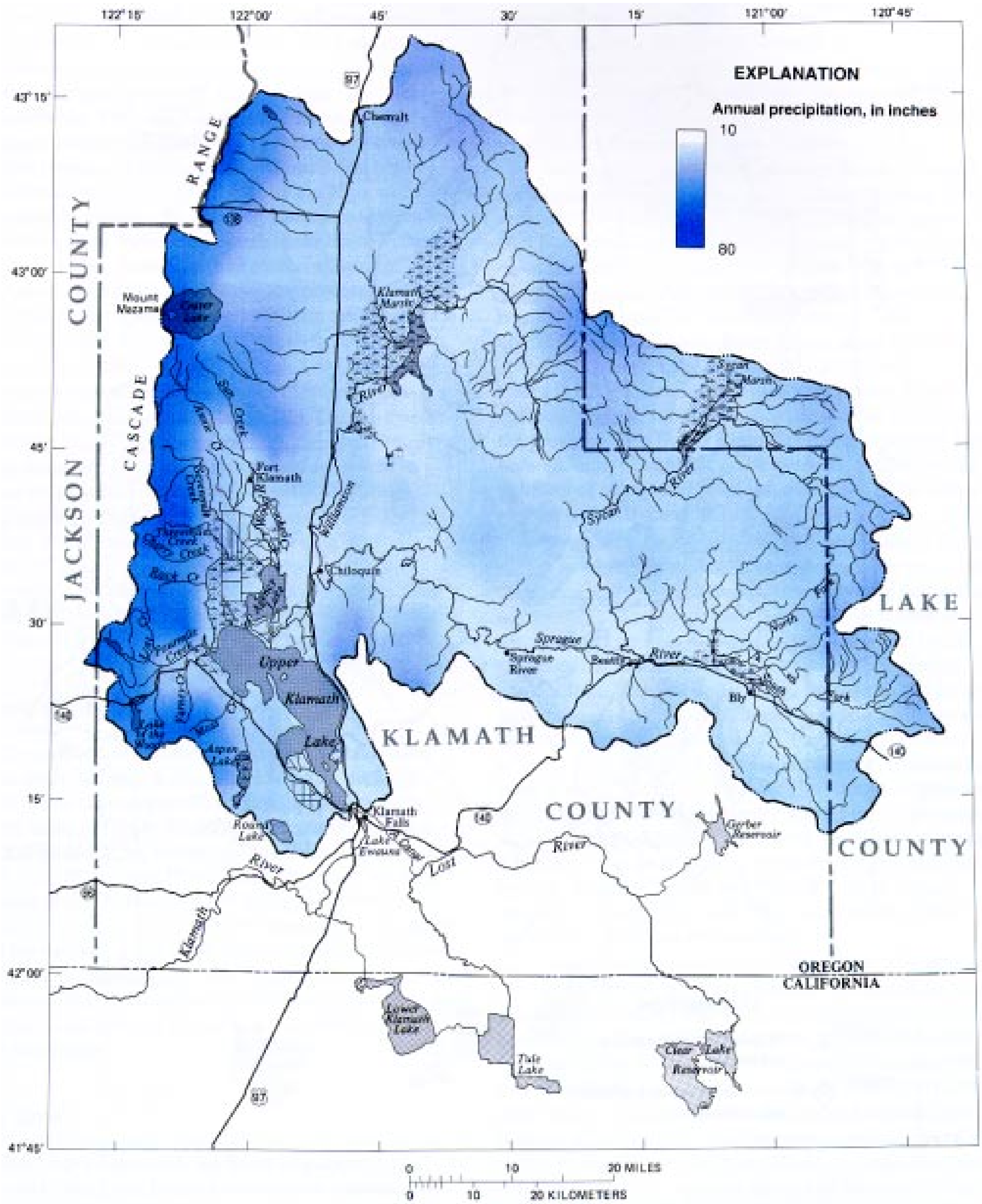


Figure 2. Mean annual precipitation in the Upper Klamath Lake Basin, Oregon (1961–90). (From Daly and others, 1994, 1997.)

The Upper Klamath Lake Basin has a poorly developed drainage system which includes many small streams that discharge into marshes and intermittent streams that disappear into pumice or porous lava. Hubbard (1970), in a water budget for the period 1964 through 1967 (a wetter than average period), estimated that total annual inflow to Upper Klamath and Agency Lakes from surface water, ground water, and precipitation averaged 1,846,000 acre-feet. Surface-water inflows represented 79 percent of this total (table 1). The Williamson River Basin and Wood River Basin collectively supplied 65 percent of the inflow. The Williamson River Basin, although constituting 79 percent of the total drainage area of the Upper Klamath Lake Basin, contributed only 49 percent of the total inflow.

Table 1. Inflow to Upper Klamath and Agency Lakes, Oregon, water years 1964–67 (Hubbard, 1970)

Source	Percent of budget
Williamson River (including Sprague and Sycan Rivers)	49
Wood River	16
Sevenmile, Fourmile, and Modoc Canals	8
Agricultural drainages	4
Intermittent creeks	2
Springs and seeps adjacent to lake	14
Direct precipitation	7
Total	100

Springtime flows can raise Upper Klamath Lake elevations as much as 3 feet above normal summertime lake operating levels. An analysis of long-term hydrologic data from streams and rivers draining into the lake is important to understanding its hydraulic retention time and water-quality problems. The retention time of Upper Klamath Lake varies throughout the year and is determined by inflows to the lake and lake volume, which is regulated by the dam at the lower end of the lake. Average retention time can be estimated by dividing the average annual (1921–96) lake volume (546,000 acre-feet) by the estimated average annual lake inflow (1,540,000 acre-feet), which results in a retention time of about 0.35 years (128 days).

Study Approach

Statistical techniques were used to analyze the Williamson and Sprague River streamflow data. Trend analysis was used to detect an increase or decrease in streamflow for the period of record as measured near the mouth of each river. Double-mass curve analysis (Searcy and Hardison, 1960) was used to detect possible changes in runoff patterns during the period of record that could indicate human influences in the basins. Long-term precipitation and air temperature data collected near the basins were used in these analyses to remove the influence of climate from the runoff data.

The theory behind double-mass curve analysis is that if data values for two variables change proportionally over time, a graph of the accumulation of one quantity against the accumulation of another quantity during the same time period will plot as a straight line. A break in the slope of the double-mass curve means that the proportionality has changed. For precipitation data, a change in proportionality (or change in slope) can occur if, for example, one of the gages was relocated during the period of record and the other gage was not moved. With runoff data, a change in slope can indicate flow diversion or augmentation, or alterations in basin land-use patterns in one of the basins, if it is known that the other basin was unchanged.

Precipitation, unlike streamflow, is less affected by local human influences and is an invaluable tool for identifying human-caused trends. Variation in climatic conditions among basins can be assessed by evaluating several precipitation records from different basins to look for differences among those records. Streamflow data from nearby basins also can be used to identify trends, but it is difficult to find streamflow data that have not been affected by human activities; only a small number of streamflow-gaging stations in the United States can be referenced for a natural response.

Although double-mass curve comparisons are useful in identifying departures, it is necessary to use two-sample statistical tests, such as the standard “t” and the non-parametric rank-sum, on both the streamflow and climate data to determine if the data before and after an identified departure year differ significantly. Evidence of human effects on runoff would exist if the two-sample tests showed significant changes in the runoff data for two periods of time, but not in the climate data for the same periods.

Historic land-use activities in the basin also can be analyzed or characterized to determine if there is an association between these activities and streamflow patterns over time. In the Williamson and Sprague River Basins, the most likely human activities that would have had an effect on basin hydrology during the period of flow data collection would be irrigation, grazing, wetland drainage, and timber harvesting.

Acknowledgments

The authors thank Elizabeth Budy and Greg McGranahan of the Winema National Forest, U.S. Forest Service, Klamath Falls, Oregon, for providing historical timber harvesting data, and Charles Collins, U.S. Geological Survey, Portland, Oregon, for assembling historical irrigation water rights data used in the study.

DATA ANALYSES

Various statistical techniques, which included trend tests, double-mass curves, and two-sample tests, were used to characterize and analyze the relationship between long-term streamflow data from the Williamson and Sprague Rivers, and the climate data from nearby locations.

Streamflow and Climate Data

Annual runoff in the Williamson River measured below the confluence with the Sprague River near Chiloquin (USGS streamflow-gaging station number 11502500; fig. 1) has ranged from a low of 350,000 acre-feet (1992) to a high of 1,600,000 acre-feet (1956). The mean annual runoff for the period of record (1918–96) is 753,000 acre-feet. Seasonal high flows occur from February through May; mean runoff for those 4 months for the period of record is 385,000 acre-feet. Low flows occur from July through September; mean runoff for those 3 months is 104,000 acre-feet. Variations in annual and monthly runoff in the Williamson River are shown in figures 3 and 4, respectively.

Variations in monthly runoff in the Sprague River during water years 1922–96 are shown in figure 5. During that period, annual runoff ranged from a low of 144,000 acre-feet (1992) to a high of 1,010,000 acre-feet (1956). The mean water year annual runoff was 418,000 acre-feet. The mean runoff of seasonally high flows, February through May, and low flows, July through September, were 239,000 and 44,500 acre-feet, respectively.

A computed streamflow record for the upper Williamson River was created by subtracting gaged Sprague River (11501000) monthly runoff from gaged Williamson River (11502500) monthly runoff. Because of the close proximity of the two gages to the confluence, the computed streamflow record is considered a reasonable representation of the Williamson River runoff from the basin above the Sprague River confluence. Figure 6 shows variations in the computed monthly runoff for the upper Williamson River above the Sprague River confluence for 1922–96.

Continuous precipitation data have been collected at Klamath Falls since 1904 and at Crater Lake by the National Park Service since 1931. At Klamath Falls, 70 percent of the annual precipitation falls between October and March. Continuous precipitation data have been collected since 1913 at Chiloquin, which is located within the Williamson River Basin and would have been more ideally suited for analyses. However, the Chiloquin record contained too many years of missing record.

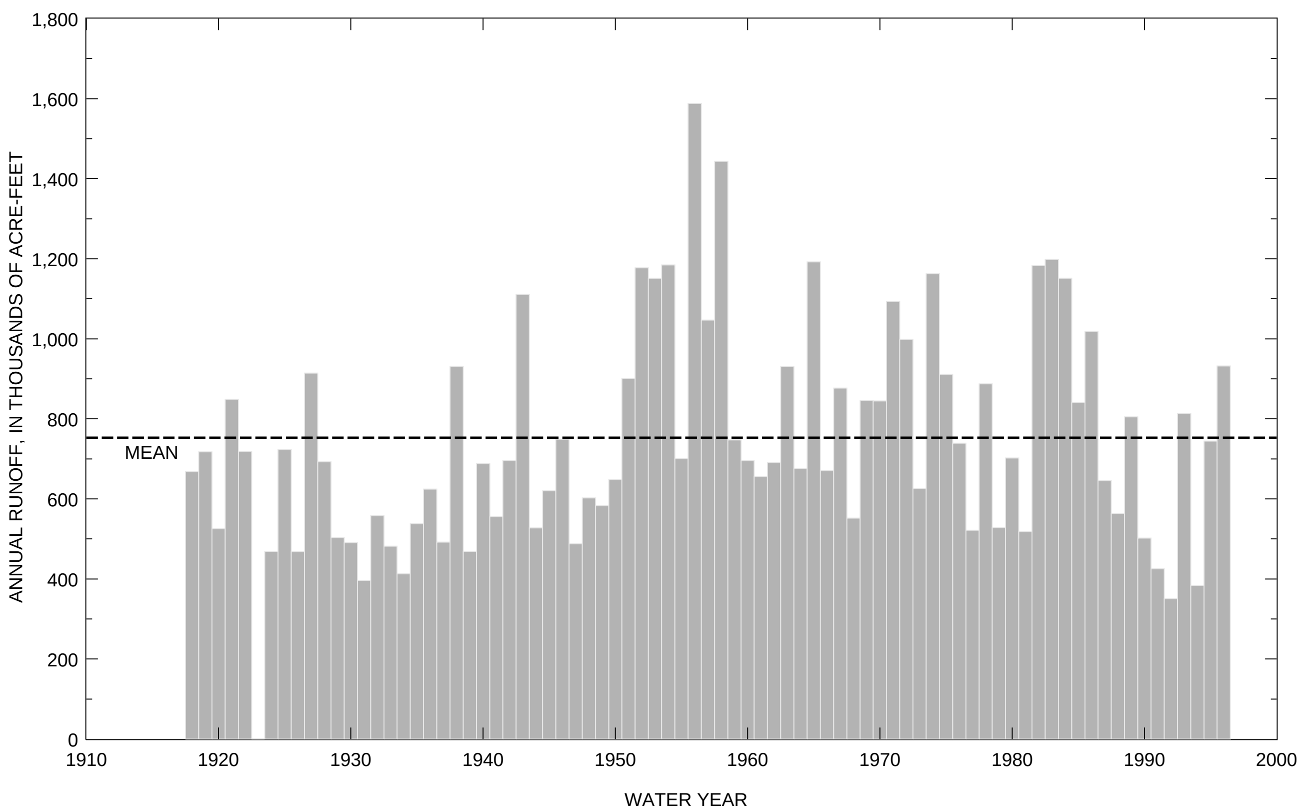


Figure 3. Annual runoff for the Williamson River below Sprague River, Oregon, water years 1918–96.

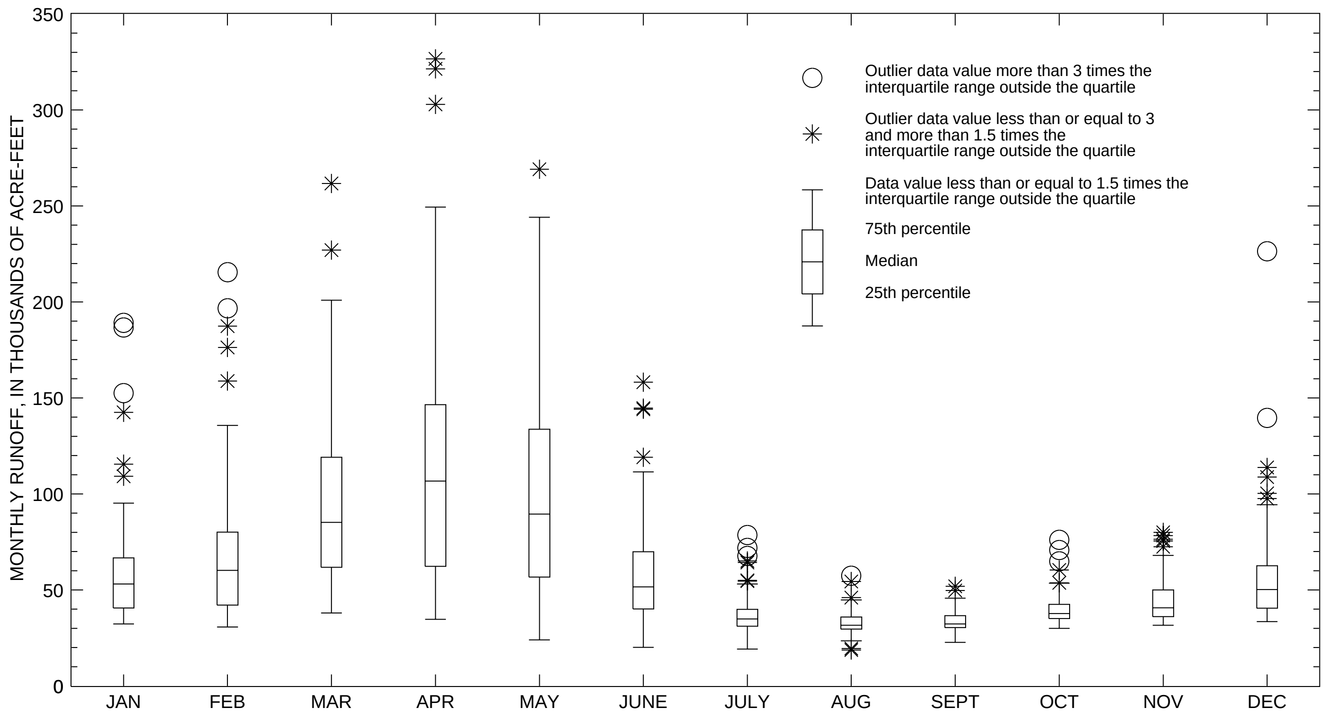


Figure 4. Monthly runoff statistics for the Williamson River below Sprague River, Oregon, water years 1918–96.

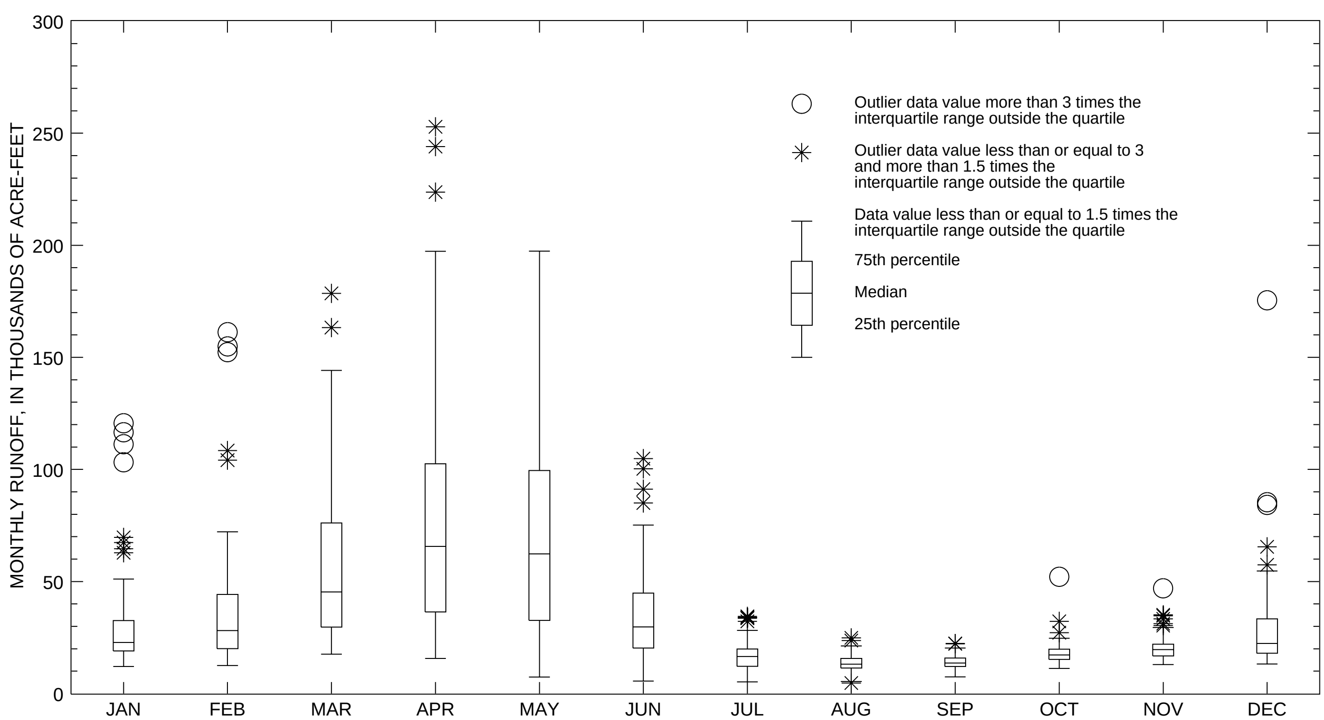


Figure 5. Monthly runoff statistics for the Sprague River, Oregon, water years 1922–96.

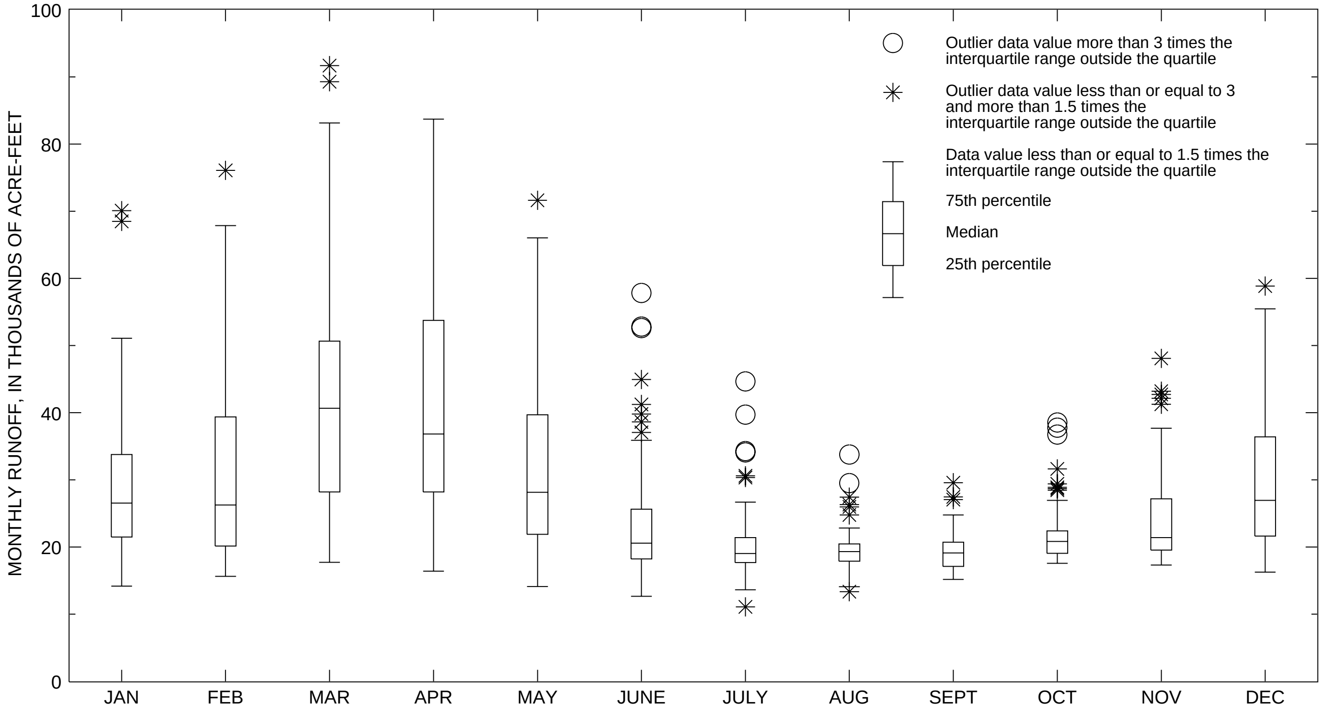


Figure 6. Monthly computed runoff statistics for the upper Williamson River above the Sprague River confluence, Oregon, water years 1922–96.

Annual precipitation at Klamath Falls for water years 1914–96 ranged from 6.61 inches in 1926 to 22.79 inches in 1956. The mean annual precipitation for this period was 13.4 inches. Precipitation was generally lower than normal from 1914 to about 1939, higher than normal from about 1940 to about 1958, and normal from about 1959 to 1996 (fig. 7).

Air temperature has been recorded at Klamath Falls since 1929 and at Crater Lake by the National Park Service since 1932. Snowpack data have been collected by the Natural Resources Conservation Service at a few locations within or near the Williamson River Basin during the last 20 years. Snowpack would have been a good climate indicator variable for these analyses, if not for its limited period of record.

The summary statistics of annual runoff, precipitation, and air temperature records used in the analyses are shown in table 2; summary statistics of seasonal (high and low flow) streamflow records are shown in table 3.

Trend Tests

Two statistical tests, linear regression (using year as an independent variable) and the Mann-Kendall test, were used on the long-term streamflow and climate data to determine if the records contained significant increasing or decreasing trends over time. The long-term streamflow data included annual runoff from the Williamson River (USGS station number 11502500), the Sprague River (USGS station number 11501000), and the upper Williamson River (computed). If the streamflow data show a significant trend and the climate data, collected in or nearby the basin, do not show a significant trend, the possibility of human-caused effects on the long-term streamflow characteristics of a basin exists. However, if both the streamflow and climate records are consistent, either both showing a trend or both showing no trend, it would be difficult to separate climatic and human influences in the streamflow record.

The results of the tests showed that none of the flow or climate records contain significant increasing or decreasing trends (table 4). The linear regressions had low R^2 values and p-values above 0.05 percent, indicating weak, nonsignificant correlation. The more statistically rigorous Mann-Kendall test, a nonparametric statistical test for trends, also detected no significant trend in the data sets. In this test, Kendall's tau correlation coefficient is analogous to the R^2 coefficient in the previous test, where 1 is a perfectly positive trend and -1 is a perfectly negative trend. The p-values were all above 0.05 percent, indicating that there was no trend of increasing or decreasing streamflow or climate values over time. However, the low detection levels of trends in the long-term records do not preclude the possibility that different time periods, within either the flow or climate records, could be statistically different from one another.

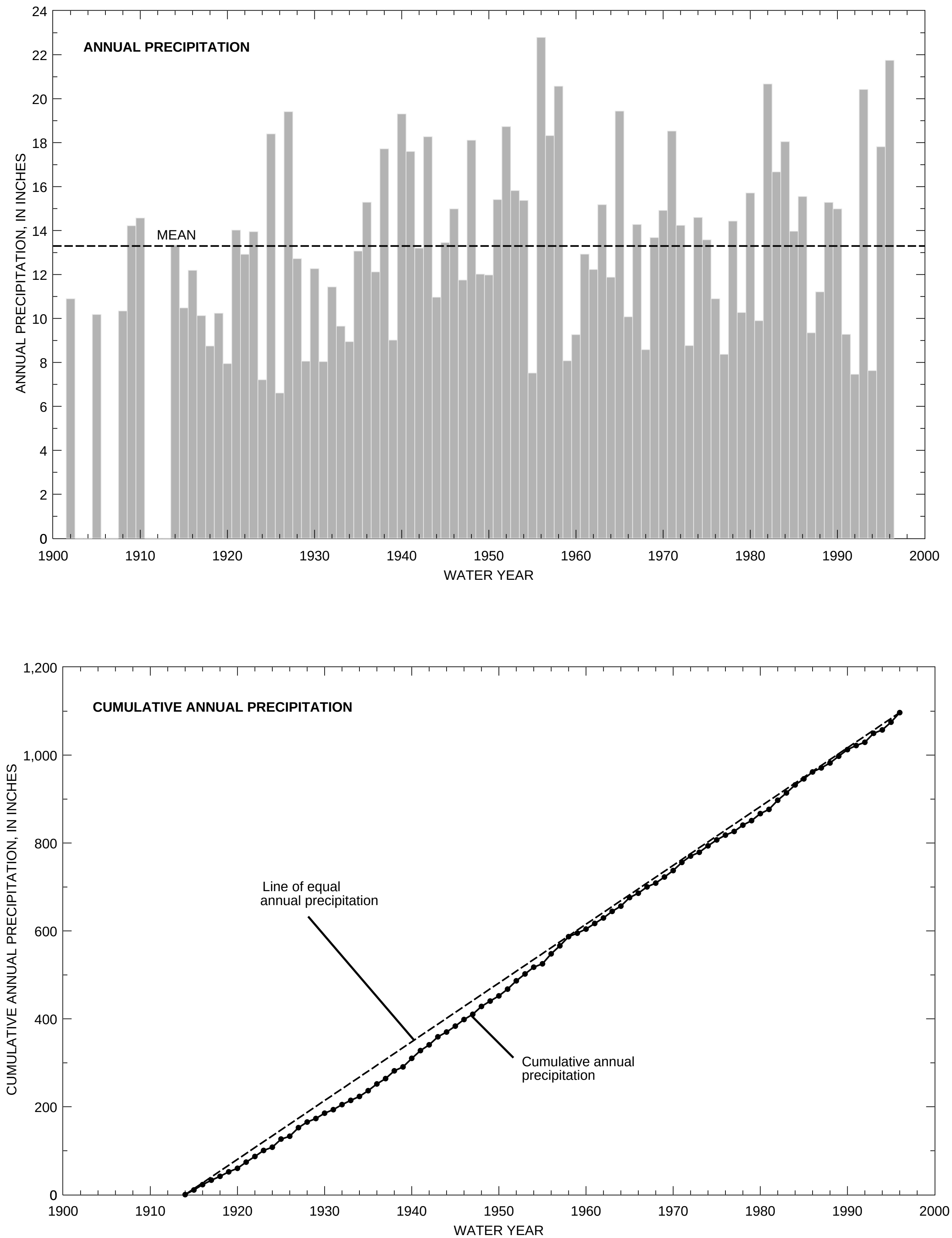


Figure 7. Annual precipitation, water years 1902–96, and cumulative annual precipitation, water years 1914–96, for Klamath Falls, Oregon. (Data from National Climatic Data Center, URL http://www.ncdc.noaa.gov/)

Table 2. Summary statistics of annual time-series data

Station and data type	Period of record (water year)	Mean	Standard deviation	Skewness
Williamson River (11502500) annual runoff (acre-feet)	1918–96	753,009	260,932	0.840
Sprague River (11501000) annual runoff (acre-feet)	1922–96	418,373	192,545	.750
Computed upper Williamson River annual runoff (acre-feet)	1922–96	336,103	93,059	.953
Klamath Falls annual precipitation (inches)	1902–96	13.3	3.91	.339
Crater Lake annual precipitation (inches)	1931–96	67.6	14.7	- .0919
Klamath Falls mean air annual temperature (degrees Celsius)	1929–96	8.97	.782	.953
Crater Lake mean annual air temperature (degrees Celsius)	1932–96	3.40	.858	.738

Table 3. Summary statistics of seasonal time-series data

Station and data type	Period of record (water year)	Mean	Standard deviation	Skewness
Williamson River Feb.–May (11502500) runoff (acre-feet)	1918–96	385,258	171,493	0.6579981
Williamson River July–Sept. (11502500) runoff (acre-feet)	1918–96	104,024	21,809	1.434522
Sprague River Feb.–May (11501000) runoff (acre-feet)	1922–96	238,762	133,712	.668142
Sprague River July–Sept. (11501000) runoff (acre-feet)	1922–96	44,511	12,921	.6118109
Computed upper Williamson River Feb.–May runoff (acre-feet)	1922–96	147,657	52,433	.6483126
Computed upper Williamson River July–Sept. runoff (acre-feet)	1922–96	59,262	11,054	2.011654

Table 4. Results of linear regressions using year as an independent variable, and Mann-Kendall trend tests on annual flow and climate data
[R^2, coefficient of determination; tau, analogous to the coefficient of determination]

Station and data type	Period of record	Linear regression		Mann-Kendall	
		R^2	p-value[a]	tau	p-value[b]
Williamson River (11502500) annual runoff	1918–96	0.0408	0.0761	0.152	0.151
Sprague River (11501000) annual runoff	1922–96	.0438	.0716	.132	.249
Computed upper Williamson River annual runoff	1922–96	.0235	.192	.107	.360
Klamath Falls annual precipitation	1902–96	.0431	.0523	.136	.0991
Crater Lake annual precipitation	1931–96	.000491	.860	.00699	.965
Klamath Falls mean annual air temperature	1929–96	.00334	.640	.0342	.807

[a] Level of significance of the regression “t” statistic test value for the independent variable.
[b] Level of significance of the Mann-Kendall “S” statistic test value.

Double-Mass Curve Comparisons

To detect possible changes in the precipitation-runoff relation, double-mass curve analyses were made by comparing observed Williamson and Sprague River streamflows with (1) basin precipitation, (2) flows in streams in nearby basins, and (3) computed Williamson and Sprague River flows (based on precipitation-runoff regressions).

Precipitation

Precipitation variability within the basin was assessed by comparing the only long-term precipitation records available in the Upper Klamath Lake Basin—from Klamath Falls and Crater Lake. Data in figure 8 show that variability exists on an annual basis, but that over time the relation between the two records appears fixed for the period of 1928 to 1996. In other words, the variations between wet and dry years are proportionally similar for both records. Because both records appear to have the same fixed relation, the longer Klamath Falls precipitation record is applicable for use in a double-mass curve analysis against other variables.

If the precipitation record at Klamath Falls is representative of natural precipitation conditions within the basin, then precipitation should be a good comparison parameter for detecting possible effects of human influences on flow. Using double-mass curve analyses, cumulative precipitation at Klamath Falls was compared to cumulative runoff in both the Williamson and Sprague Rivers (fig. 9).

Trends are noticeable in the double-mass curve analyses of annual runoff data from the Williamson River Basin and precipitation data from Klamath Falls. Flow departure trends at the Sprague River streamflow-gaging

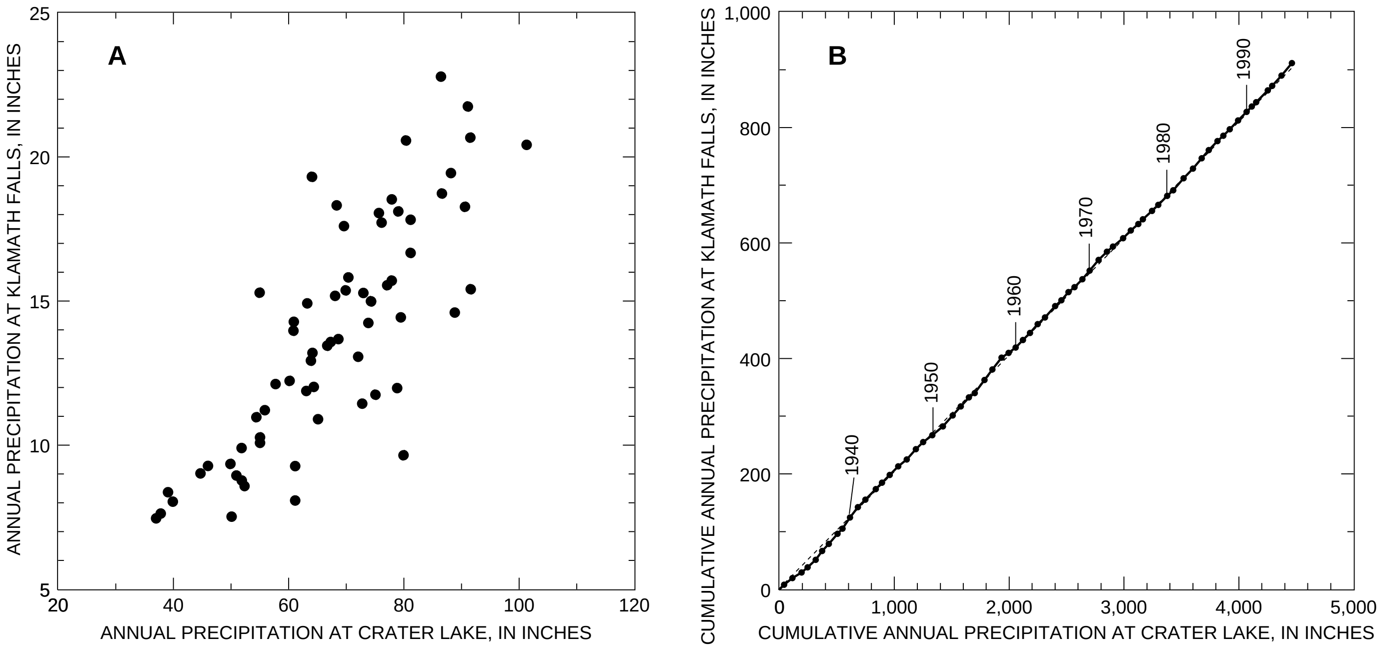


Figure 8. Comparison of (A) annual precipitation at Klamath Falls with annual precipitation at Crater Lake and (B) cumulative annual precipitation at Klamath Falls with cumulative annual precipitation at Crater Lake, Oregon, water years 1931–96.

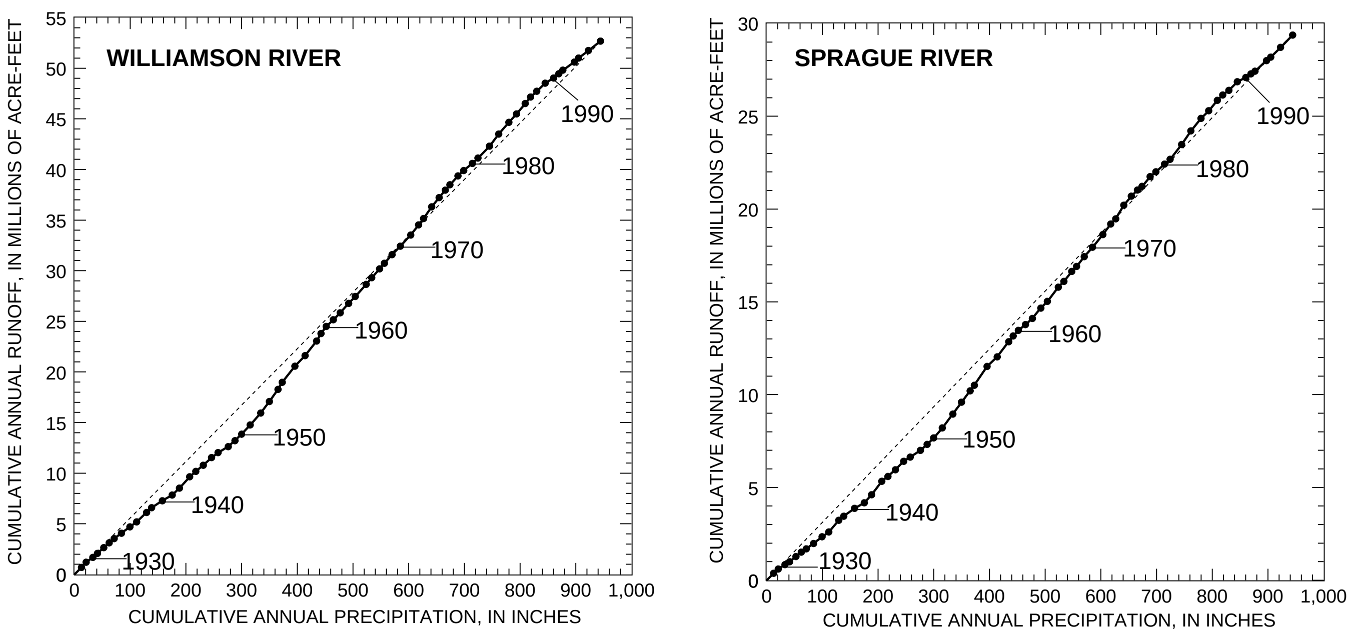


Figure 9. Comparison of Williamson River (11502500) cumulative annual runoff to Klamath Falls, Oregon, cumulative annual precipitation and Sprague River (11501000) cumulative annual runoff to Klamath Falls, Oregon, cumulative annual precipitation, water years 1928–96.

station (11501000) are similar to those at the Williamson River streamflow-gaging station (11502500) (fig. 9). Both graphs in figure 9 indicate that significant departures in the precipitation-runoff relations could have occurred in 1950 and in the late 1980’s.

Nearby-Basin Runoff

Trends observed in the double-mass analysis of cumulative runoff to cumulative precipitation (fig. 9) can be substantiated by additional analyses using streamflow data from nearby locations. One long-term and one short-term record were available for these comparisons. Figure 10 shows that a comparison of cumulative annual runoff in the Williamson River with cumulative annual runoff in streams from two adjacent basins reveals a similar trend as in the previous analysis using precipitation (fig. 9).

Big Marsh Creek is in the southern part of the Deschutes River Basin, just north of the Upper Klamath Lake Basin.

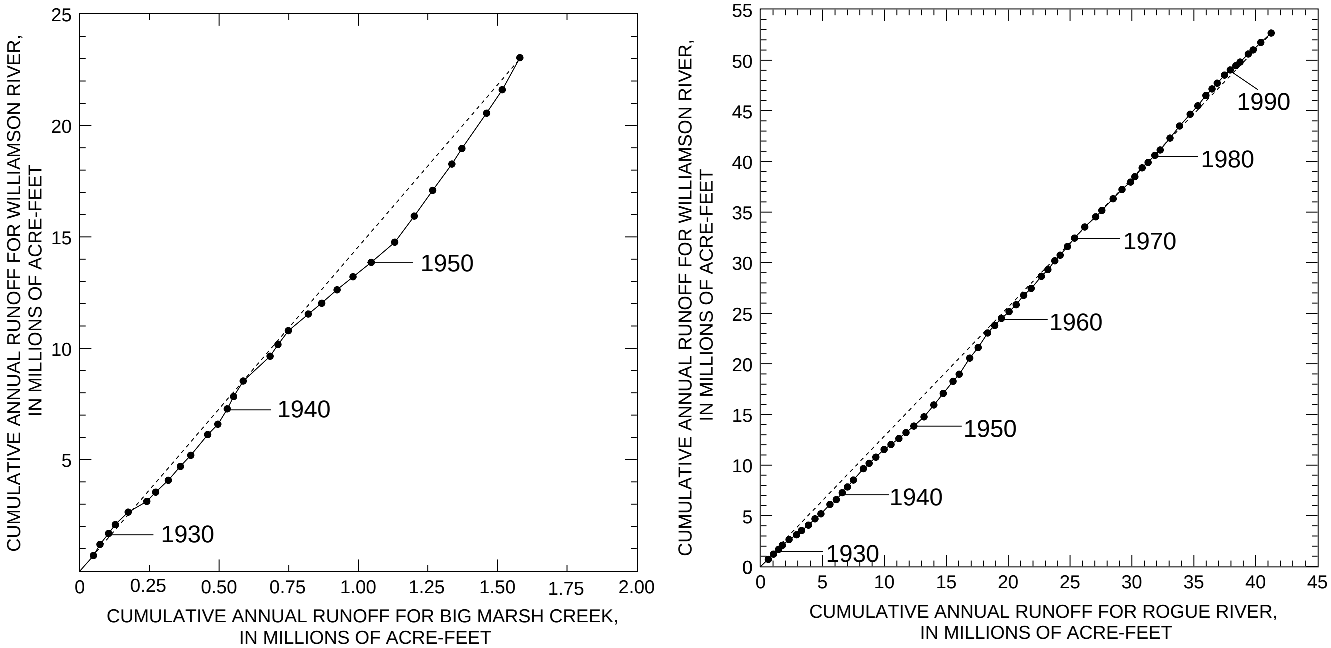


Figure 10. Comparison of cumulative annual runoff for the Williamson River, Oregon (11502500), with cumulative annual runoff for the Big Marsh Creek, Oregon (14061000), water years 1928–58, and cumulative annual runoff for the Rogue River, Oregon (14328000), water years 1928–96.

The stream is unregulated, and its basin has similar geology, topography, climate, and vegetation to Upper Klamath Lake Basin. No major timber harvesting was done in this basin prior to or during the period of streamflow-gaging station operation. The streamflow-gaging station at Hoey Ranch near Crescent, Oregon (14061000), was in operation from 1928 to 1958. A double-mass curve using this short-term record (fig. 10) indicates an increase in runoff in the Williamson River Basin in relation to the Big Marsh Creek Basin occurring in 1951. The precipitation double-mass curves for the Williamson River Basin showed a similar break occurring in 1950 (fig. 9).

The double-mass curve using the Rogue River above Prospect streamflow-gaging station (14328000) record (fig. 10) also shows a change in the relationship beginning in 1951. The streamflow-gaging station on the Rogue River monitors a basin on the western side of the Cascade Range that has had timber harvesting throughout the period of record—heaviest during the last 50 years (Jeff Lalan, Rogue River National Forest, Medford, Oregon, oral commun., April 1998). However, the relative increase in runoff in the Williamson River beginning in 1951 (fig. 10) could be an indication that Rogue River Basin logging had less significant effects on streamflow than did human activities in the Williamson River Basin.

To test the suitability of the Rogue River as a comparison site, a comparison was made between cumulative annual runoff in the Rogue River and cumulative annual runoff measured at the Salmon Creek near Oakridge streamflow-gaging station (14146500) (fig. 11), which monitors a stream basin in the Willamette National Forest. Major breaks in slope are not apparent in the double-mass curve even though the timber harvest in the Salmon Creek Basin has been considerably less than in the Rogue River Basin. Figure 11 shows a comparison of cumulative annual runoff in the Rogue River with cumulative annual runoff in Big Marsh Creek. Although this comparison shows some deviations, they are not as large as the deviations in figure 10, which compares Big Marsh Creek with the Williamson River.

Because of the fairly constant relationship over time (fig. 11) between the Rogue River Basin, in which timber harvests have occurred, and Salmon and Big Marsh Creek Basins, in which little or no timber harvests have occurred, the Rogue River can be considered suitable for comparison with the Williamson River. It is also the only nearby site with a long-term record. The breaks in slope shown in the Williamson River and Rogue River double-mass curve (fig. 10) cannot be attributed to differences in the precipitation regimes of the two basins. Although the precipitation gage closest to the Rogue River Basin is at Crater Lake, figure 8B shows a fairly consistent relation between data from the Crater Lake and Klamath Falls precipitation gages.

Double-mass curves using Williamson and Rogue River runoff were computed for high- and low-flow seasons (fig. 12). For the 4-month (February–May) high-flow season for the period 1930–50 (fig. 12), decreases in spring runoff in the Williamson River, relative to that in the Rogue River, averaged about 25,000 acre-feet; for the same months during the period 1990–96, the average decrease was about 36,000 acre-feet. Increases in spring runoff in the Williamson River, relative to Rogue River runoff, for the 1950–63 period averaged about 38,000 acre-feet.

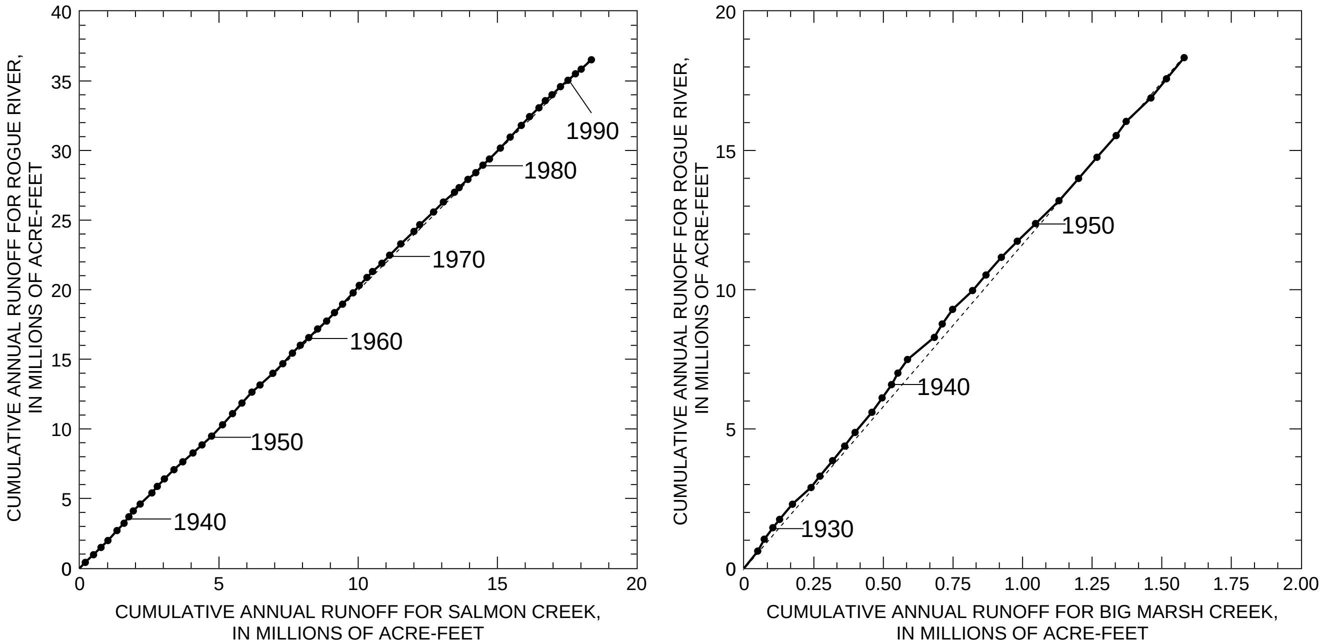


Figure 11. Comparison of cumulative annual runoff for the Rogue River, Oregon (14328000), with cumulative annual runoff for Salmon Creek, Oregon (14146500), water years 1934–93, and cumulative annual runoff for Big Marsh Creek, Oregon (14061000), water years 1928–58.

For the 3-month (July–September) low-flow season for the periods 1945–51, 1970–76, and 1992–96 (fig. 12), decreases in runoff in the Williamson River, relative to that in the Rogue River, averaged about 6,000 acre-feet.

Computed Runoff

To study possible changes in precipitation-runoff relations, Searcy and Hardison (1960) recommend using a double-mass curve of observed runoff against computed runoff. The computed runoff can be derived by using watershed models or simple regression equations, both of which use climate indicators such as precipitation, air temperature, and (or) snowpack data as input data. Using computed runoff reduces some of the variability in the observed runoff record that is caused by climatic variability. It is assumed that the remaining variability in a runoff record could then be associated with human activities such as timber harvesting, urbanization, or irrigation.

A series of linear regression trials were used to determine the best model for predicting annual and seasonal runoff in the Williamson and Sprague River Basins. Both Klamath Falls precipitation and air temperature data were tested as independent variables. The best regression models were found using Klamath Falls effective precipitation as a single independent variable. Searcy and Hardison (1960) explain:

> The effective precipitation (P_e) commonly used is that proportion of the current years's precipitation (P_o) and the proportion of the proceeding year's precipitation (P_1) that furnishes the current year's runoff.

This is shown as:

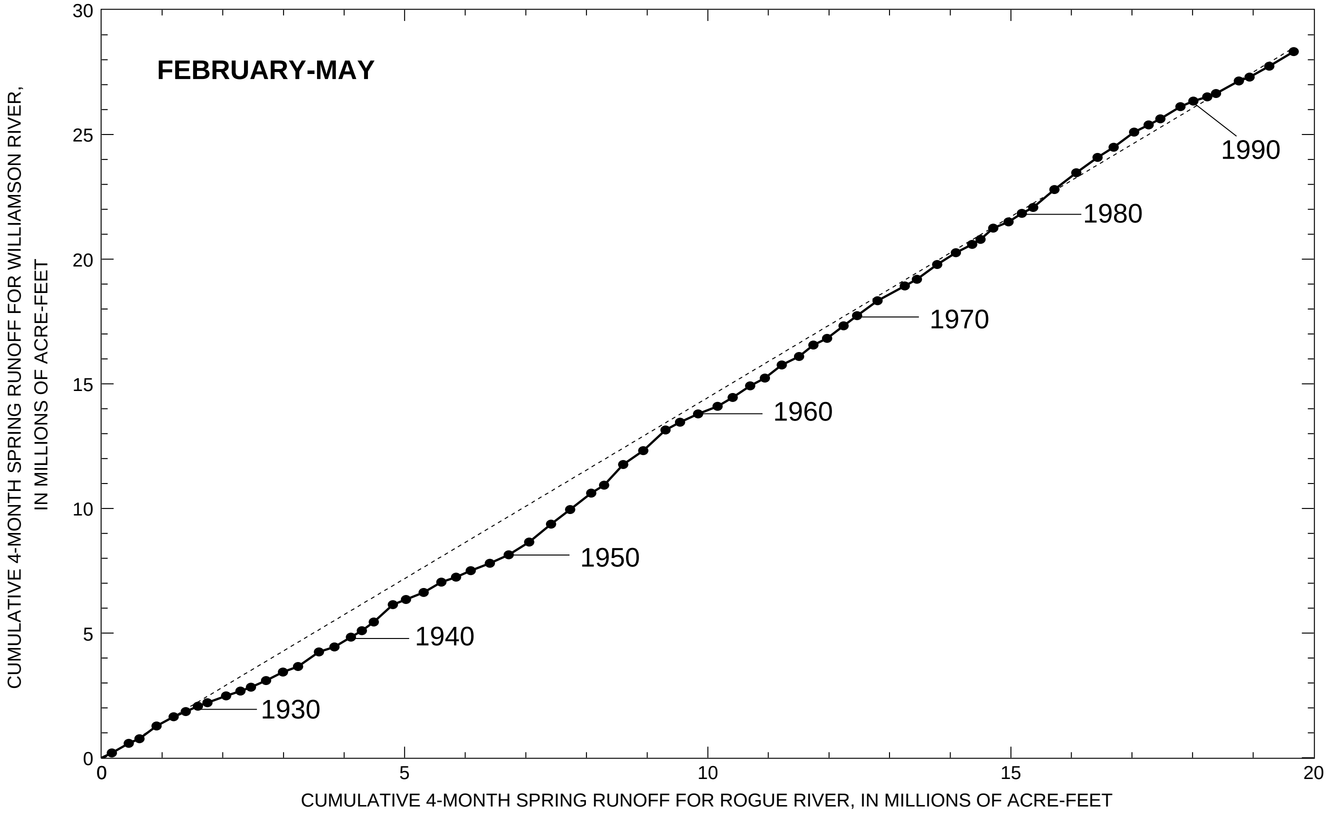
$$P_e = aP_o + bP_1 \qquad (1)$$

Various combinations of values for the weighting factors *"a"* and *"b"* are tested until the best model is determined. However, the sum of the weights must equal unity. For the Williamson and Sprague River regression models, it was necessary to use a third component in the equation to represent precipitation from the year before the preceding year—cP_2, yielding the equation:

$$P_e = aP_o + bP_1 + cP_2 \qquad (2)$$

The results of these regression models, which include annual and seasonal runoff, are shown in table 5. The R^2 values for the models, ranging from 0.242 to 0.717, are low and do not show close fits. The Klamath Falls precipitation record was the best long-term indicator of climate that was available. However, its gage is located outside of the Williamson River Basin and could not provide the best areal representation of climate for the basin. Thus, the influence of climate probably is not entirely removed from the observed-computed runoff double-mass curves calculated for these basins.

The effective precipitation equation for the upper Williamson River computed annual runoff (table 5, line 3) allocates more weight to precipitation falling in the preceding year than does the effective precipitation equation for the Sprague River annual runoff (table 5, line 2), thus indicating a difference in runoff timing between the two basins. The difference in runoff timing may be due, in part, to the different ground-water storage characteristics of the dominant rock types in each of the basins.



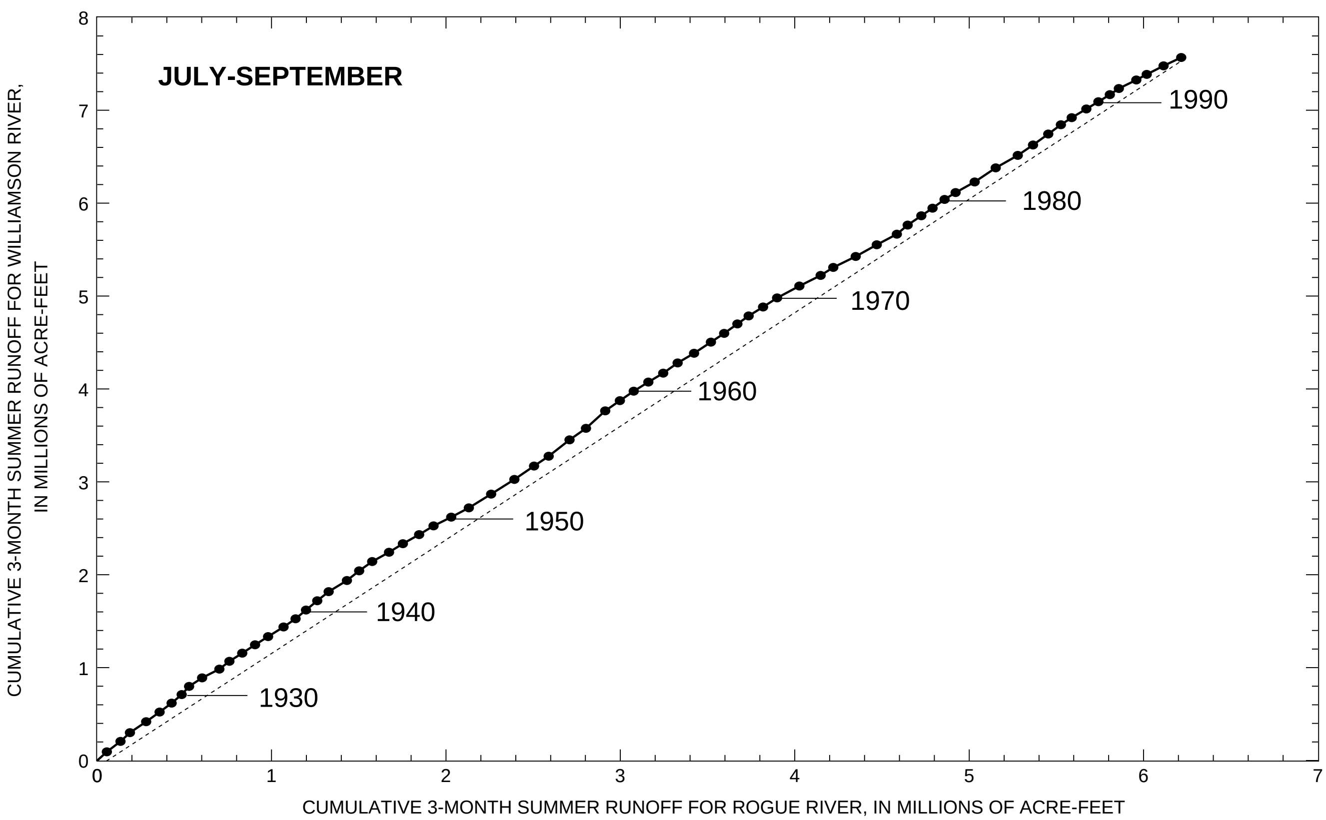


Figure 12. Comparison of cumulative runoff for the Williamson River, Oregon (11502500), with cumulative runoff for the Rogue River, Oregon (14328000), February–May and July–September, water years 1924–96.

Table 5. Results of linear regressions of annual and seasonal high and low flows for the Williamson, Sprague, and upper Williamson Rivers with Klamath Falls effective precipitation

[Annual values are for water years; R^2, coefficient of determination; Root MSE, standard error of the regression or the square root of the mean square error, in acre-feet; KFP, Klamath Falls annual precipitation, in inches; KFP1, preceding year's Klamath Falls annual precipitation; KFP2, year's precipitation preceding KFP1]

Dependent variable	Independent variable	R^2	Root MSE
Williamson River (11502500) annual runoff	0.7KFP+0.2KFP1+0.1KFP2	0.603	165,555
Sprague River (11501000) annual runoff	0.7KFP+0.2KFP1+0.1KFP2	.702	105,718
Computed upper Williamson River annual runoff	0.6KFP+0.3KFP1+0.1KFP2	.290	78,971
Williamson River (11502500) Feb.–May runoff	0.7KFP+0.2KFP1+0.1KFP2	.656	101,277
Sprague River (11501000) Feb.–May runoff	0.7KFP+0.2KFP1+0.1KFP2	.717	71,656
Computed upper Williamson River Feb.–May runoff	0.6KFP+0.3KFP1+0.1KFP2	.342	42,836
Williamson River (11502500) July–Sept. runoff	0.6KFP+0.3KFP1+0.1KFP2	.369	17,440
Sprague River (11501000) July–Sept. runoff	0.6KFP+0.3KFP1+0.1KFP2	.503	9,168
Computed upper Williamson River July–Sept. runoff	0.6KFP+0.3KFP1+0.1KFP2	.242	9,689

The upper Williamson River drainage basin consists largely of young (Quaternary) volcanic rocks, including large areas of ash and pumice from eruptions of Mount Mazama (Walker and MacLeod, 1991). In contrast, the Sprague River drainage basin is underlain by older (Tertiary) volcanic rocks consisting largely of basalt flows. It is likely that the more porous rock in the upper Williamson River Basin has more capability to store water than the lavas of the Sprague River Basin, thus resulting in higher and more sustained periods of baseflow in the upper Williamson River Basin than in the Sprague River Basin.

Another factor affecting runoff timing could be differences in the precipitation-recharge characteristics of the two basins. Because the upper Williamson River Basin is closer to the slopes of the Cascade Range, precipitation there is greater than that in the Sprague River Basin. More of its precipitation could be in the form of snow and, thus, would enter the ground-water system later in the season during snowmelt. Finally, Klamath Marsh, located in the upper Williamson River Basin, may provide additional storage capacity in the basin and, hence, increase runoff lag time.

Double-mass curves for the Williamson River Basin below the Sprague River confluence for computed annual runoff versus observed (1) annual runoff, (2) 4-month spring runoff, and (3) 3-month summer runoff are shown in figures 13–15. The lower part of each figure shows the cumulative residuals of the observed and computed runoff, plotted by year of occurrence. This graph is effectively a magnification of the double-mass curves. A break in slope of the double-mass curve corresponds to a maximum or a minimum point on the residual-mass curve. Figures 16 and 17 show double-mass curves that plot observed annual runoff versus computed annual runoff for the Sprague River and upper Williamson River Basins, above the Sprague River confluence.

The computed-runoff double-mass curves appear to show patterns similar to the patterns seen in the other double-mass curves for precipitation and nearby-basin runoff. A period of decreased runoff is evident in the 1930's and 1940's, with the exception of a minor increase in 1943. The precipitation-runoff relation appears to change in 1950 or 1951, which is the start of a period of increased runoff. A period of apparent decreased runoff begins in the late 1980's. The break in the slope of the curves around 1950 or 1951 might have been caused in part by higher than normal precipitation—Klamath Falls annual precipitation from 1951–54 was above normal—however, the break also could have been caused in part by human activities.

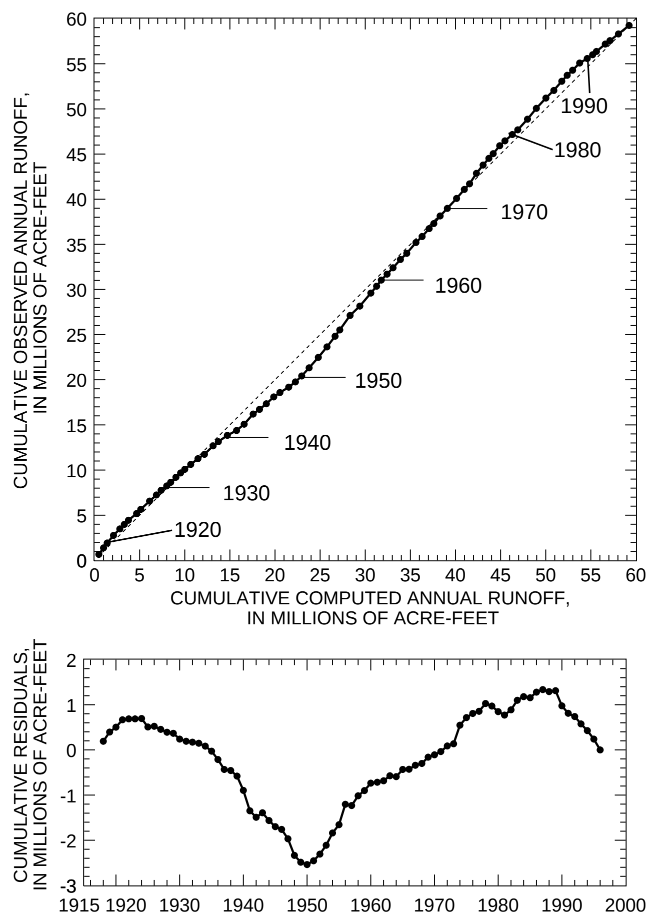


Figure 13. Comparison of cumulative observed annual runoff with cumulative computed annual runoff for the Williamson River, Oregon (11502500), and cumulative residuals, water years 1918–96.

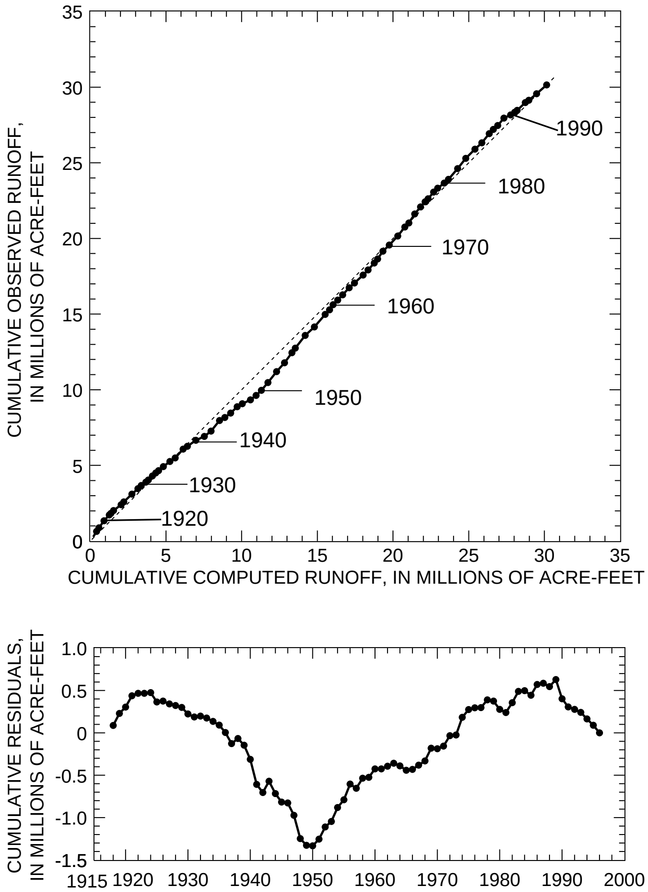


Figure 14. Comparison of February–May cumulative observed runoff with February–May cumulative computed runoff, Williamson River, Oregon (11502500), and cumulative residuals, water years 1918–96.

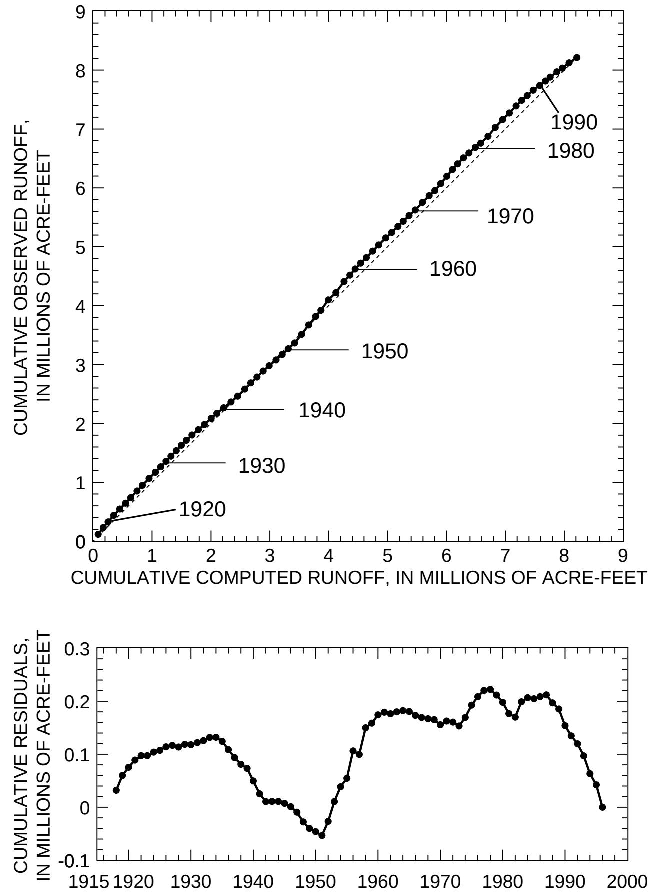


Figure 15. Comparison of the July–September cumulative observed runoff with July–September cumulative computed runoff, Williamson River, Oregon (11502500), and cumulative residuals, water years 1918–96.

Figures 13–17 also show a break occurring in the late 1980's, when runoff decreased. The same trend is also apparent in figures 9 and 10, which compare Williamson River runoff with precipitation and nearby-river runoff.

Two-Sample Tests

Two-sample statistical tests were used on the long-term flow and climate records to determine if there was a significant difference in runoff patterns during the periods 1922–50 and 1951–96. The year 1950 was chosen for the end of the first period because it appeared more often than other years as a break in slope on most of the double-mass curves. If the flow records show significant differences in runoff between the two periods but the precipitation and temperature records in the region do not, the possibility of human activity as a cause of the differences cannot be discounted.

Using the COMPARE option in STATIT statistical software, the appropriate t-test of the estimated population means was selected because of the lack of normality of the data sets. Most of the data sets were tested using a standard t-test on the log scale. However, some of the data sets required using a less sensitive test—the modified t-test based on Tukey's bi-weight estimator on the log scale or the unequal-variances t-test on the log scale. The annual runoff data sets for the Williamson, Sprague, and upper Williamson Rivers showed a significant difference in the estimated population means of the two periods, 1922–50 and 1951–96. However, the climate data, which included mean annual precipitation data from Klamath Falls, Crater Lake, and Medford, as well as mean annual air temperature data from Klamath Falls, all showed no significant statistical difference between the two periods (table 6). The 4-month spring high-flow (February through May) and the 3-month summer low-flow (July through September) seasonal data sets for the Williamson, Sprague, and upper Williamson Rivers also showed a significant difference in the estimated population means for the two periods, 1922–50 and 1951–96, with the exception of the upper Williamson River summer low-flow season (table 7). These results indicate the possibility that human activities in the past could have had an influence on streamflow characteristics in the Williamson and Sprague River Basins.

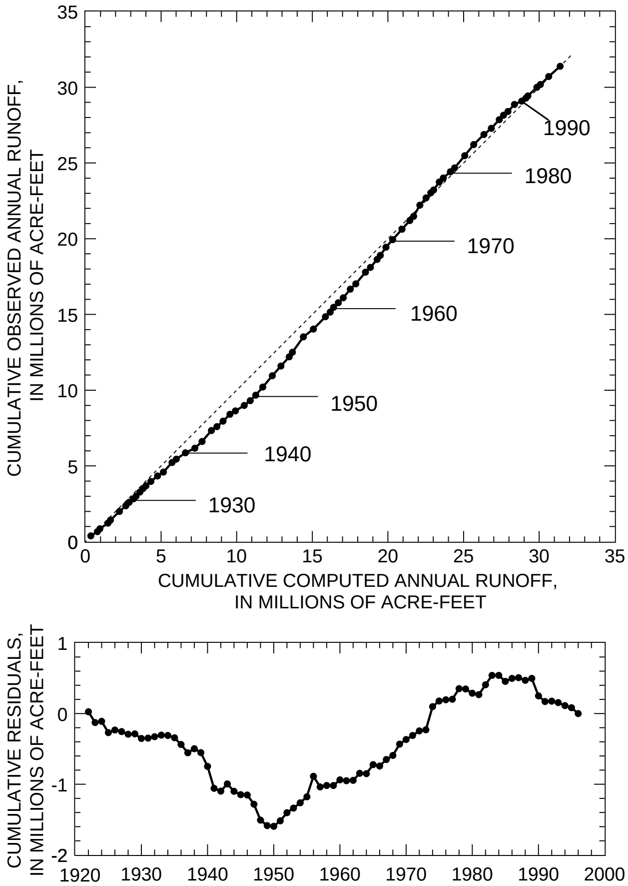


Figure 16. Comparison of cumulative observed annual runoff with cumulative computed annual runoff for the Sprague River, Oregon (11501000), and cumulative residuals, water years 1922–96.

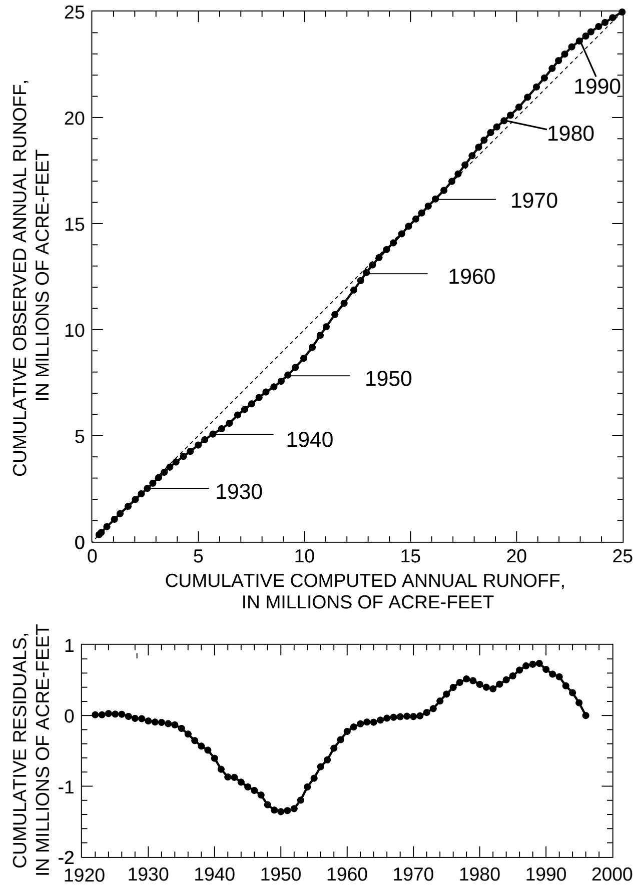


Figure 17. Comparison of cumulative observed annual runoff with cumulative computed annual runoff for the upper Williamson River, Oregon, and cumulative residuals, water years 1922–96. (The upper Williamson River is above the confluence of the Sprague River.)

These same annual and seasonal flow and climate data sets also were tested using the nonparametric rank-sum test for sample medians (tables 8 and 9). In terms of significant differences between the two time periods, the rank-sum results were identical to t-test results.

POTENTIAL EFFECTS OF LAND-USE ACTIVITIES ON STREAMFLOW

Forest, agriculture, and range are the three largest land-use activities in the basin upstream of the streamflow-gaging station on the Williamson River below the Sprague River confluence (table 10). During the past century, various human activities, such as irrigation, grazing, drainage, and timber harvesting, could have had some effect on the streamflow within the Williamson River Basin. However, because of the large area of Williamson River Basin above the USGS gage below the Sprague River confluence, approximately 3,000 square miles, caution must be used in drawing associations between flow departures and specific land-use activities. Further, the hydrologic effects of activities in the upper basin could cancel each either out and therefore be difficult to detect at locations downstream.

Irrigation and Drainage

Most of the irrigation in the upper Williamson and Sprague River Basins is for hay and native pasture (C.A. Collins, U.S. Geological Survey, Portland, Oregon, oral commun., 1998), because the climate is cooler, and the growing season shorter and less suitable for cash crop production than in the irrigated regions south of Klamath Falls. Nonetheless, irrigation has steadily grown over the past century, as reflected in the increasing amount of permitted irrigated land acreage in the basins (fig. 18; Oregon Water Resources Department, Water Rights Information System, URL http://www.wrd.state.or.us/waterrights/index.html). Figure 18 clearly shows that the period of greatest increase in irrigated acreage was from approximately 1950 to 1980.

In addition to irrigation, drainage of wetlands and increased grazing have changed the landscape, as described by the U.S. Forest Service (Elizabeth Budy, Winema National Forest, Klamath Falls, Oregon, written commun., 1998):

Table 6. Results of two-sample tests for differences in annual runoff, annual precipitation, and annual average air temperature for water years 1922–50 and 1951–96, Williamson River Basin, Oregon
[WY, water year]

Station and data type	Sample Means: First group WY 1922–50	Sample Means: Second group WY 1951–96	Type of two-sample test for population mean differences	One-sided p-value	Significant difference between the periods before and after 1950?
Williamson River (11502500) runoff, in acre-feet	612,590	843,940	Standard t-test on the log scale	0.0001	Yes
Sprague River (11501000) runoff, in acre-feet	333,403	471,940	Standard t-test on the log scale	.0015	Yes
Computed upper Williamson River runoff, in acre-feet	277,120	371,997	Modified t-test based on Tukey’s bi-weight estimator on the log scale	.0000	Yes
Klamath Falls precipitation, in inches	13.1	14.0	Standard t-test on the log scale	.1607	No
Crater Lake precipitation, in inches[a]	66.5	68.1	Standard t-test on the log scale	.3473	No
Medford precipitation, in inches	17.8	19.2	Standard t-test on the log scale	.1449	No
Klamath Falls air temperature, in degrees Celsius[b]	9.1	8.9	Modified t-test based on Tukey’s bi-weight estimator on the log scale	.1410	No

[a] Data available for 1931–96.
[b] Data available for 1929–96.

Table 7. Results of two-sample tests for differences in spring and summer runoff for water years 1922–50 and 1951–96, Williamson River Basin, Oregon
[WY, water year]

Station and data type	Sample Means: First group WY 1922–50	Sample Means: Second group WY 1951–96	Type of two-sample test for population mean differences	One-sided p-value	Significant difference between the periods before and after 1950?
Williamson River (11502500) Feb.–May runoff, in acre-feet	304,270	438,770	Standard t-test on the log scale	0.0005	Yes
Williamson River (11502500) July–Sept. runoff, in acre-feet	97,448	107,570	Unequal-variances t-test on the log scale	.0311	Yes
Sprague River (11501000) Feb.–May runoff, in acre-feet	188,923	270,182	Standard t-test on the log scale	.0072	Yes
Sprague River (11501000) July–Sept. runoff, in acre-feet	39,718	47,533	Standard t-test on the log scale	.0049	Yes
Computed upper Williamson River Feb.–May runoff, in acre-feet	113,269	168,589	Standard t-test on the log scale	.0000	Yes
Computed upper Williamson River July–Sept. runoff, in acre-feet	57,986	60,038	Modified t-test based on Tukey’s bi-weight estimator on the log scale	.1786	No

“The historical effects of grazing throughout the Williamson River watershed are apparent today. Grazing has reduced or eliminated hardwood communities that are associated with live water sources, either developed or natural. Water diversions, to both drain wetlands and irrigate pastures, have contributed to lowering of water tables, changing plant communities, and reducing the extent of riparian plants and natural wetlands.”

An increase in irrigation use often can cause a decrease in streamflow during the low-flow season. Although the greatest rate of irrigation expansion occurred between 1950 and 1980, the t-test and rank-sum test results do not show a significant decrease in streamflow during that period relative to climate. In fact, the tests showed significant flow increase during the low-flow season in the Sprague River.

Table 8. Results of rank-sum two-sample tests for differences in annual runoff, annual precipitation, and annual average air temperature for water years 1922–50 and 1951–96, Williamson River Basin, Oregon
[WY, water year]

Time series data	First group WY 1922–50		Second group WY 1951–96		One-sided p-value	Significant difference between the periods before and after 1950?
	Median	Standard error	Median	Standard error		
Williamson River (11502500) annual runoff, in acre-feet	592,180	39,150	82,770	59,753	0.0001	Yes
Sprague River (11501000) annual runoff, in acre-feet	304,490	28,204	495,060	48,139	.0022	Yes
Computed upper Williamson River annual runoff, in acre-feet	264,830	8,516	360,280	18,079	.000	Yes
Klamath Falls annual precipitation, in inches	12.7	1.1392	14.4	1.0207	.134	No
Crater Lake annual precipitation, in inches [a]	68.2	4.518	68.2	3.543	.379	No
Medford annual precipitation, in inches	16.91	1.4243	19.1	1.3609	.1584	No
Klamath Falls annual average air temperature, in degrees Celsius [b]	9.09	.1954	8.78	.1001	.176	No

[a] Data available for 1931–96.
[b] Data available for 1929–96.

Table 9. Results of rank-sum two-sample tests for differences in spring and summer runoff for water years 1922–50 and 1951–96, Williamson River Basin, Oregon
[WY, water year]

Time series data	First group WY 1922–50		Second group WY 1951–96		One-sided p-value	Significant difference between the periods before and after 1950?
	Median	Standard error	Median	Standard error		
Williamson River (11502500) Feb.–May runoff, in acre-feet	279,160	30,422	441,990	42,512	0.0006	Yes
Williamson River (11502500) July–Sept. runoff, in acre-feet	95,683	2,217	100,470	3,914	.0942	Yes
Sprague River (11501000) Feb.–May runoff, in acre-feet	169,790	23,626	282,480	36,553	.0075	Yes
Sprague River (11501000) July–Sept. runoff, in acre-feet	36,721	2,118	47,597	2,634	.0030	Yes
Computed upper Williamson River Feb.–May runoff, in acre-feet	104,710	7,879	163,450	11,308	.0000	Yes
Computed upper Williamson River July–Sept. runoff, in acre-feet	58,077	1,014	56,058	2,116	.2774	No

Table 10. Land use in the Williamson River Basin, Oregon
[Data derived from 1:24,000-scale U.S. Geological Survey orthophotoquads produced between 1975 and 1987, and categorized using Anderson and others (1976) level 1 classification scheme]

	Forest	Agriculture	Range	Urban	Water	Wetland	Bare	Tundra	Glacier	Total
Upper Williamson River Basin (above Sprague River confluence)										
Square miles	1,222	91.5	22.9	6.1	24.6	40.0	11.0	1.7	0.2	1,420
Percentage	86.1	6.4	1.6	.4	1.7	2.8	.8	.1	<.1	100.0
Sprague River Basin										
Square miles	1,209	90.1	252.3	1.6	2.2	22.0	2.8	.0	.0	1,580
Percentage	76.5	5.7	16.0	.1	.1	1.4	.2	.0	.0	100.0
Williamson River Basin (including Sprague River Basin)										
Square miles	2431	181.6	275.2	7.7	26.8	62.0	13.8	1.7	.2	3,000
Percentage	81.0	6.1	9.2	.3	.9	2.1	.5	<.1	<.1	100.0

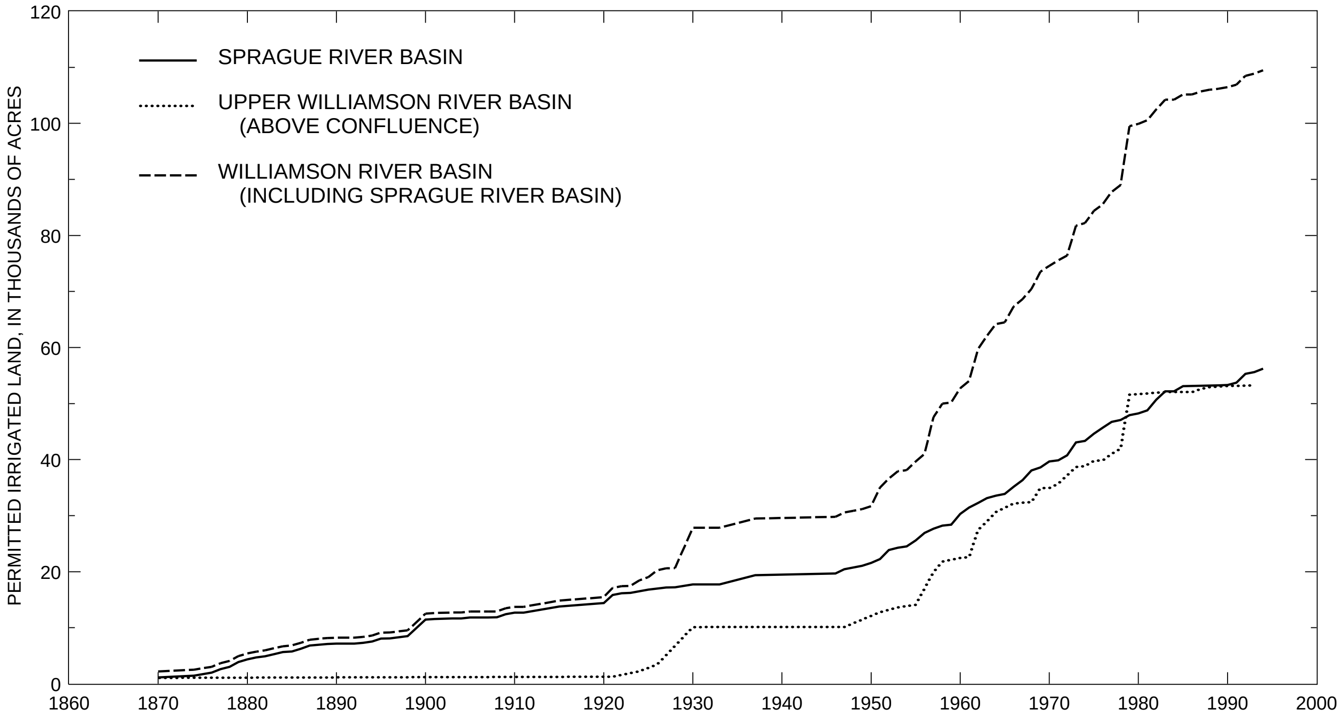


Figure 18. Annual permitted irrigated land acreage in the Williamson River Basin, Oregon, 1870–1994. (Data from Oregon Water Resources Department, Water Rights Information System, URL http://www.wrd.state.or.us/waterrights/index.html)

It is, however, possible that the post-1950 increase in runoff during spring could be related to decreased evapotranspiration due to riparian vegetation removal and wetland drainage in the basin during summer for farming and ranching. Historically, the lower reaches of the rivers were once thickly lined with cottonwoods, which have high water-consumption rates. The drainage of thousands of acres of wetlands also could have significantly affected the hydrology by increasing the time of travel of runoff to the river while decreasing evapotranspiration losses.

Timber Harvest

About 81 percent of Upper Klamath Lake Basin is forested (Gearheart and others, 1995), and logging might affect runoff in the Williamson River Basin. Prior to this century, the basin forest was generally composed of large old-growth ponderosa pines. (An exception is the Cascade Range high elevation regions, which is populated with red Shasta fir). Understory growth was minimized by frequent low intensity fires, which did not harm the ponderosa pines. However, logging and fire suppression over the past 100 years have substantially changed the forest. The present-day forest is composed of ponderosa pine, almost entirely second or third growth, and lodge-pole pine. The thicker understory is populated with white and grand firs (Paul Bakke, U.S. Forest Service, Winema National Forest, Klamath Falls, Oregon, oral commun., 1998).

In the Klamath Basin, as with other basins on the eastern side of the Cascade Range, ponderosa pine historically have been favored trees for timber harvest. Ponderosa pines are generally spread apart and separated by less favored understory trees. Cutting patterns can include both selective and clear-cutting. With clear-cutting, new areas of snow are opened up, causing an acceleration of snowmelt (Harr and Coffin, 1992) and a decrease in evapotranspiration (Rothacher, 1970), resulting in an increase in both annual and spring runoff. A decrease in clear-cutting could yield the opposite response. However, with selective cutting patterns, analyzing the hydrologic effects of logging is more complicated. For example, the thriving replacement species could have higher or lower evapotranspiration rates than the tree that was removed and, subsequently, alter annual flows.

Figure 19 shows the record of timber harvested in Klamath County (approximately twice the size of the Williamson River Basin) for the period of 1925–92 (Bourhill, 1994). Timber production peaked in 1943 during World War II at greater than 700-million board feet. The lower plot shows timber production in the preexisting Klamath Indian Reservation—whose boundaries coincided with much of the Williamson River Basin and the current Winema National Forest. In spite of the postwar housing boom during the 1950's and 1960's, timber harvest production tapered off in the Williamson River Basin because most of the virgin timber stands had been harvested.
The next significant period of harvest started in the late 1970's and extended through the mid-1980's (Elizabeth Budy, Winema National Forest, oral commun., 1998).

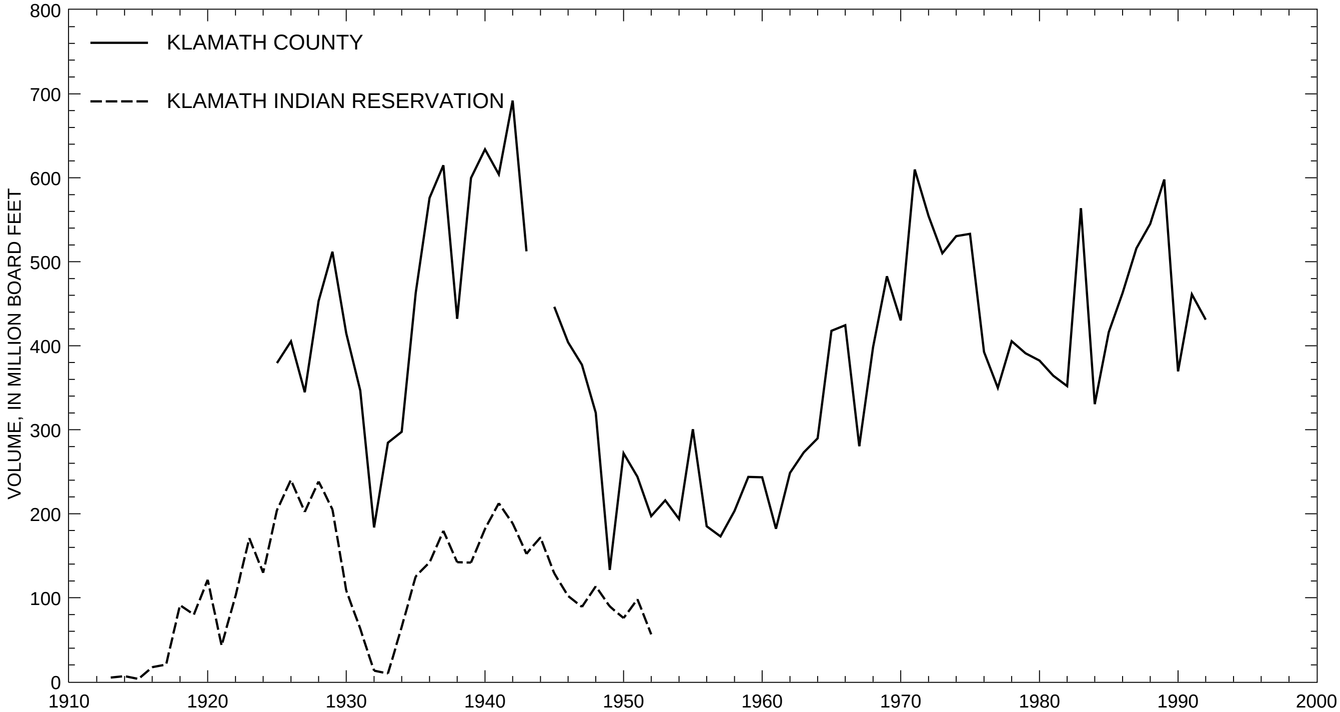


Figure 19. Annual timber harvest totals for Klamath County and Klamath Indian Reservation, Oregon, 1913–92.

Unfortunately, the volume of board feet of timber harvested is not a consistent indicator of land-surface disturbance. The selective cutting of a few large trees might have less hydrologic impact than an equal volume of smaller trees spread out over a larger area.

Although the hydrologic effects of logging could have been significant in the Williamson River Basin, the net effect on the streamflow regime at the USGS gages near the Sprague River confluence is difficult to assess due to sparse historical logging data. The t-test and rank-sum test results showed a significant increase in runoff (relative to climate) during the high-flow season for the post-1950 period for both the upper Williamson and Sprague River Basins, which might imply an increase in land-surface disturbance due to logging; however, the data in figure 19 do not support that hypothesis.

SUMMARY

The Williamson River Basin has a drainage area of approximately 3,000 square miles, comprises 79 percent of the total drainage area of the Upper Klamath Lake Basin (3,810 square miles), and covers about one-half of Klamath County, Oregon. The Sprague River, which flows into the Williamson River Basin, has a drainage area of 1,580 square miles and comprises 53 percent of the Williamson River Basin. Flow from the Williamson River Basin constitutes about one-half of the inflow for Upper Klamath Lake. Runoff volume in the spring affects the retention time of Upper Klamath Lake, which in turn could affect water quality and biological conditions in the summer. Long-term changes in runoff characteristics might, therefore, affect long-term conditions in the lake.

During the period 1918 through 1996, annual runoff in the Williamson River—measured just below the confluence with the Sprague River near Chiloquin at U.S. Geological Survey streamflow-gaging station 11502500—ranged from a low of 350,000 acre-feet (1992) to a high of 1,600,000 acre-feet (1956). The mean water year annual runoff was 753,000 acre-feet. Seasonally high flows occur from February through May, during which the mean runoff for the period of record was 385,000 acre-feet. Low flows occur from July through September, when the mean runoff for the period of record was 104,000 acre-feet.

During the period 1922 through 1996, annual runoff in the Sprague River—measured just above the confluence with the Williamson River near Chiloquin at U.S. Geological Survey streamflow-gaging station 11501000—ranged from a low of 144,000 acre-feet (1992) to a high of 1,010,000 acre-feet (1956). The mean water year annual runoff was 418,000 acre-feet. The mean runoff of seasonally high flows, February through May, and low flows, July through September, were 239,000 and 44,500 acre-feet, respectively.

Double-mass curve analyses were used to detect significant changes in the precipitation-runoff relation for the Williamson and Sprague River Basins. Runoff from these two rivers was compared with the precipitation record collected at the city of Klamath Falls, with runoff measured at

streamflow-gaging stations on the nearby Rogue River (to the west) and Big Marsh Creek (to the north), and with computed flows from the Williamson and Sprague Rivers (based on a precipitation-runoff regression). Most of the double-mass curves showed a major break in the slope of the curve occurring around 1950.

For the periods 1930–50 and 1990–96, February through May runoff was relatively lower in the Williamson River than in the Rogue River and Big Marsh Creek by an average of 25,000 acre-feet and 36,000 acre-feet per year, respectively, for the 4-month period. From 1950–63, runoff was generally higher in the Williamson River compared with the nearby rivers by an average of 38,000 acre-feet for the 4 months. In July through September of 1945–51, 1970–76, and 1992–96, flows were lower in the Williamson River than in the comparison rivers by an average of about 6,000 acre-feet for the 3-month period.

Two-sample statistical tests of the annual streamflow data sets for the Williamson and Sprague Rivers showed a significant increase in runoff for the period 1951–96 compared to the period 1922–50. Climate data, which included annual precipitation data from Klamath Falls, Crater Lake, and Medford, as well as annual average air temperature data from Klamath Falls, showed no significant difference between the two periods, suggesting the possibility of human activities as a cause of the difference in runoff between the two periods. The seasonally high (February through May) and low (July through September) flows for the Williamson River, Sprague River, and upper Williamson River (above the Sprague River confluence) also all were significantly different before and after 1950, with the exception of the upper Williamson River low-flow season, according to the results of the statistical test.

During the past century, various land-use activities, such as irrigation, grazing, drainage, and timber harvesting, could have resulted in the observed changes in streamflow characteristics in the Williamson River Basin. However, relating specific land-use activities to changes in runoff is impossible to assess using available data owing to the size and geologic complexity of the basin and to the paucity of historical land- and water-use data for local areas.

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