
Prepared in cooperation with the
BUREAU OF LAND MANAGEMENT

# Trends in Streamflow of the San Pedro River, Southeastern Arizona


**Figure 1.** Location of study area.

## Introduction

Total annual streamflow of the San Pedro River at Charleston in southeastern Arizona (fig. 1) decreased by about 66 percent from 1913 to 2002 (fig. 2). The San Pedro River is one of the few remaining free-flowing perennial streams in the arid Southwestern United States, and the riparian forest along the river supports several endangered species and is an important habitat for migratory birds. The decreasing trend in streamflow has led to concerns that riparian habitat may be damaged and that overall long-term water supply for a growing population may be threatened. Resource managers and the public have an interest in learning more about the trend and the possible causes of the trend.

Thomas and Pool (2006) investigated the decreasing trends in streamflow of the San Pedro River. Their study evaluated trends in seasonal streamflows and trends in the relation between precipitation and streamflow. The purpose of this fact sheet is to summarize results of the detailed study by Thomas and Pool (2006).

Changes in total annual streamflow of the San Pedro River at Charleston, Arizona, were greater than changes in annual precipitation at Tombstone, Arizona, for the same period (1913–2002; figs. 2 and 3). Annual precipitation decreased by 13 percent, and annual streamflow decreased by 66 percent. Winter precipitation and streamflow changed by a small amount, but summer precipitation decreased by 26 percent, and summer streamflow decreased by 85 percent.

Possible factors that could have caused the decreasing trends in streamflow were trends in precipitation, changes in watershed characteristics, and human activities. The variation in streamflow caused by variation in precipitation was statistically removed. Thus, the remaining variation or trend in streamflow can be attributed to factors other than precipitation.

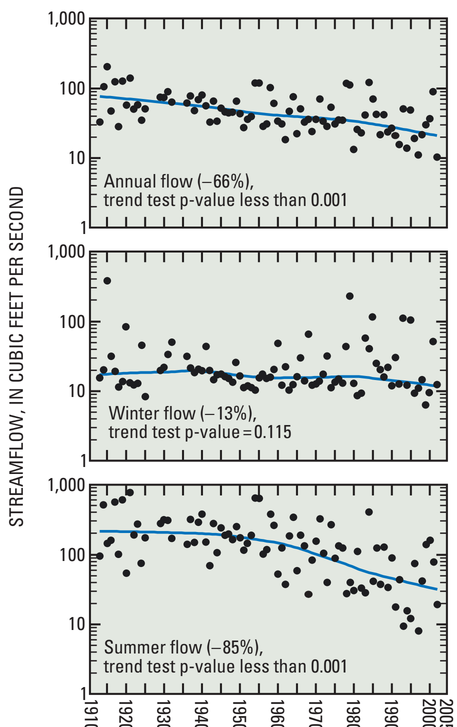


**Figure 2. Trends in annual and seasonal streamflow of San Pedro River at Charleston, Arizona. Lines are LOWESS fit to data.**

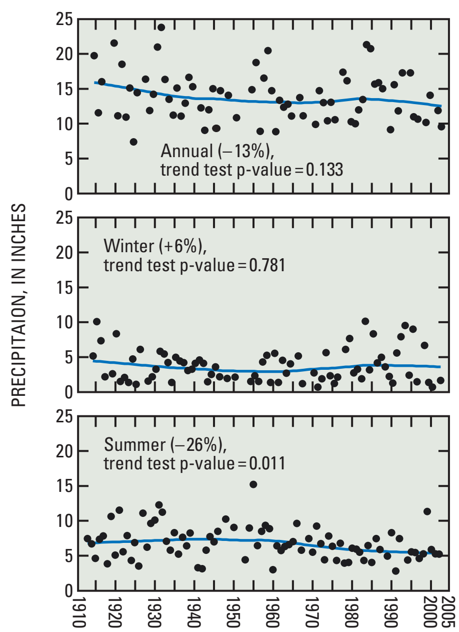


**Figure 3. Trends in annual and seasonal precipitation at Tombstone, Arizona. Lines are LOWESS fit to data.**

## Methods

Two methods were used to partition the variation in streamflow and to determine trends in the partitioned variation: (1) regression analysis between precipitation and streamflow and statistical tests of time trends in regression residuals, and (2) development of regression equations between precipitation and streamflow for three time periods (early, middle, and late parts of the record) and testing to determine if the three regression equations (rainfall-runoff relations) are significantly different. Method 1 was applied to monthly values of total flow (average flow) and low flow (3-day low flow), and method 2 was applied to total flows. The low flows are roughly analogous to base flow, which is ground-water discharge to the river.

An important feature of the statistical analysis in the study is that it provides objective criteria for making decisions and interpretations about the data The statistical tests for trends result in a p-value. The p-value is a measure of the strength of evidence (data) for determining if the change in flow over time is a random occurrence or if it is a significant trend that did not occur by chance. As the p-value decreases, the evidence to support a conclusion for a trend becomes stronger. A threshold significance level of 0.05 was used in the study; a p-value of less than 0.05 means that the trend is considered significant. A p-value of 0.05 means that there is a 5-percent probability that the conclusion for a trend is incorrect.

The regression analysis between precipitation and streamflow (method 1) was done by using a regression-smoothing technique called locally weighted scatterplot smoothing (LOWESS) (Cleveland, 1979; Insightful, 2001). This nonlinear technique was used because the relation between precipitation and streamflow is not linear. Examples of the nonlinear relations are shown for February and July in figure 4.

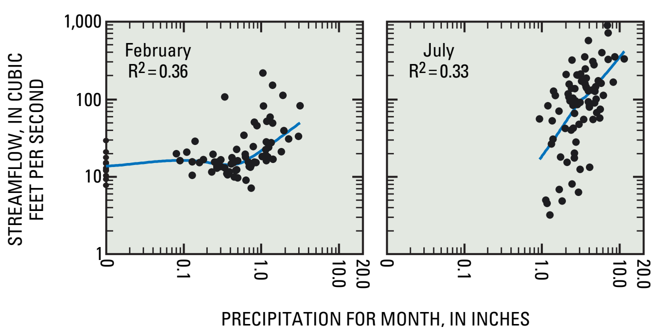


**Figure 4.** Examples of LOWESS fits to precipitation at Tombstone and streamflow of the San Pedro River at Charleston, Arizona, February and July.

## Results of Regressions and Trend Tests

The LOWESS analyses were successful in explaining much of the variation in streamflow (tables 1 and 2). Generally, precipitation for the same month as streamflow and precipitation for several preceding months were used in the LOWESS equations. The $R^2$ values shown in tables 1 and 2 represent the amount of variation in streamflow that is explained by precipitation. Thus, precipitation in December, January, and February explained 80 percent of the variation in total streamflow for February. The advantage of using several months of precipitation instead of just one month of precipitation is evident in the comparison of the $R^2$ values of single-variable LOWESS equations to the $R^2$ values of multivariable equations. For February, the $R^2$ value was 0.36 for a single-variable equation and 0.80 for a multivariable equation; for July, the $R^2$ value was 0.33 for one variable and 0.70 for multiple variables (table 1 and fig. 4).

**Table 1.** Results of LOWESS regression analyses between monthly precipitation at Tombstone, Arizona, and monthly total streamflow for the San Pedro River at Charleston, Arizona

[$R^2$, coefficient of multiple determination]

| Month of total streamflow[1] | Months of precipitation used in LOWESS regression equation[2] | $R^2$ for regression equation |
|---|---|---|
| Jan. | Oct., Nov., Dec., Jan. | 0.81 |
| Feb. | Dec., Jan., Feb. | .80 |
| Mar. | Jan., Feb., Mar. | .66 |
| Apr. | Jan., Feb., Mar. | .50 |
| May | Jan., Feb., Mar. | .52 |
| June | Dec., Jan., Mar., June | .73 |
| July | Jan., May., June, July | .70 |
| Aug. | Feb., July, Aug. | .64 |
| Sept. | May, Aug., Sept. | .62 |
| Oct. | May, Sept., Oct. | .77 |
| Nov. | June, Oct., Nov. | .74 |
| Dec. | Oct., Nov., Dec. | .78 |

[1]Time period for analysis was 1913–2002.

[2]LOWESS regression model: $\log Q_n = \log P_1 + \log P_2 + \log P_n$, where $Q_n$ is average streamflow for month n, in cubic feet per second, and $P_n$ is precipitation for month n, in inches.

**Table 2.** Results of LOWESS regression analyses between monthly precipitation at Tombstone, Arizona, and monthly low flow for the San Pedro River at Charleston, Arizona

[$R^2$, coefficient of multiple determination]

| Month of low flow[1] | Months of precipitation used in LOWESS regression equation[2] | $R^2$ for regression equation |
|---|---|---|
| Jan. | Oct., Nov., Dec., Jan. | 0.80 |
| Feb. | Nov., Dec., Jan. | .82 |
| Mar. | Jan., Feb., Mar. | .58 |
| April | Jan., Feb., Mar. | .60 |
| May | Nov., Dec., Jan., Mar. | .75 |
| June | Dec., Jan., June | .57 |
| July | Apr., May, June, July | .81 |
| Aug. | Dec., July, Aug. | .67 |
| Sept. | Jan., Aug., Sept. | .60 |
| Oct. | May, Aug., Sept. | .66 |
| Nov. | Aug. and Oct. | .65 |
| Dec. | Aug., Oct., Nov. | .59 |

[1]Time period for analysis was 1931–2002.

[2]LOWESS regression model: $\log Q_n = \log P_1 + \log P_2 + \log P_n$, where $Q_n$ is 3-day low flow for month n, in cubic feet per second, and $P_n$ is precipitation for month n, in inches.

To determine if factors other than precipitation caused trends in total flows and low flows, the residuals from the LOWESS multivariable analyses were tested for trends using a Kendall tau statistical test (Helsel and Hirsch, 1992). The LOWESS residual (measured minus predicted value) represents streamflow with the variability caused by precipitation removed. Trends in the residuals are trends caused by factors other than variation in precipitation. Residual trends are also trends in the relation between precipitation and streamflow.

Factors other than precipitation caused significant trends in total flows for June-December and did not cause significant trends for January-May (table 3). For low flows, factors other than precipitation caused significant trends for May, June,

**Table 3.** Trends in monthly total streamflow and monthly total streamflow adjusted for variation in precipitation, San Pedro River at Charleston, Arizona, 1913–2002

[<, less than]

| Month | Total streamflow, 1913–2002 | | | |
|---|---|---|---|---|
| | Kendall tau trend test | | | |
| | Streamflow and time | | Adjusted streamflow and time[1] | |
| | Slope[2] | p-value | Slope[2] | p-value |
| Jan. | n | 0.017 | n | 0.208 |
| Feb. | n | .930 | p | .428 |
| Mar. | n | .996 | p | .487 |
| Apr. | p | .542 | p | .638 |
| May | n | .081 | n | .449 |
| June | n | .001 | n | <.001 |
| July | n | <.001 | n | .007 |
| Aug. | n | <.001 | n | .001 |
| Sept. | n | <.001 | n | <.001 |
| Oct. | n | .029 | n | <.001 |
| Nov. | n | <.001 | n | <.001 |
| Dec. | n | .018 | n | <.001 |

[1]Variation in streamflow that was caused by variation in precipitation was removed by LOWESS regression analysis.

[2]Slope of trend: n is negative and p is positive.

| | | p-value |
|---|---|---|
| n or p | not significant | 0.05 to 1.00 |
| n | significant | <0.05 |

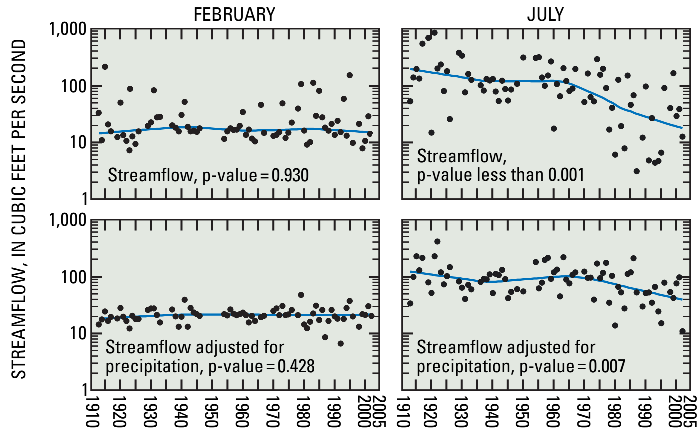


**Figure 5.** Trends in streamflow and adjusted streamflow for February and July, San Pedro River at Charleston, Arizona. Lines are LOWESS fit to data.

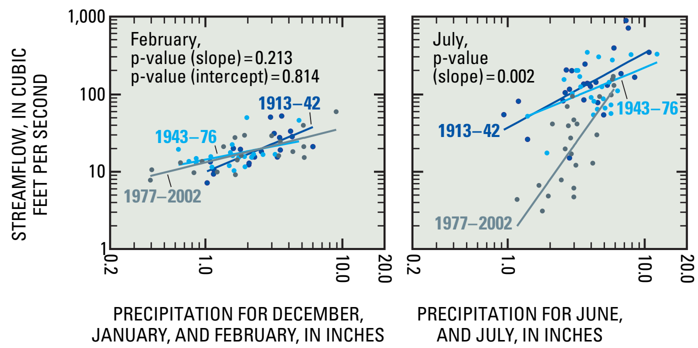


**Figure 6.** Trends in rainfall-runoff relations for February and July, San Pedro River at Charleston, Arizona, 1913 to 2002.

and August-December and did not cause significant trends for January-April and July (table 4). Thus, a seasonal pattern was determined with significant trends in summer, fall, and early winter flows, and no significant trends in late winter and spring flows. Examples of trends in streamflow and trends in streamflow adjusted for variation in precipitation (LOWESS residuals) are shown for February and July in figure 5.

Trends in rainfall-runoff relations for three time periods were evaluated by comparing regression relations between precipitation and streamflow for 1913–42, 1943–76, and 1977–02. The difference among regression relations was determined with a nested F-test (Helsel and Hirsch, 1992). The results of the nested F-tests were similar to results of the LOWESS residual tests—trends in summer, fall, and late winter flows were significant, and trends in other parts of the year were not significant (table 5). Examples of trends in rainfall-runoff relations for February and July are shown in figure 6.

## Factors Affecting Trends

The primary factors that could have caused decreasing streamflow trends and changes in rainfall-runoff relations are decreases in precipitation, natural or human-induced changes in watershed characteristics, and increases in ground-water pumping. Examples of watershed characteristics that can change over time are riparian vegetation, upland vegetation, and stream-channel morphology. Annual precipitation decreased by 13 percent from 1913 to 2002, and the decrease likely resulted in some of the decrease in streamflow; however, statistical analyses provide strong evidence that other factors also contributed to the decrease in streamflow.

**Table 4.** Trends in monthly low flow and monthly low flow adjusted for variation in precipitation, San Pedro River at Charleston, Arizona, 1931–2002

[<, less than]

| Month | Low flow, 1931–2002 | | | |
|---|---|---|---|---|
| | Kendall tau trend test | | | |
| | Streamflow and time | | Adjusted streamflow and time[1] | |
| | Slope[2] | p-value | Slope[2] | p-value |
| Jan. | n | 0.014 | n | 0.089 |
| Feb. | n | .292 | n | .965 |
| Mar. | p | .527 | p | .342 |
| Apr. | n | .139 | n | .293 |
| May | n | <.001 | n | .007 |
| June | n | <.001 | n | .002 |
| July | n | <.001 | n | .073 |
| Aug. | n | <.001 | n | .002 |
| Sept. | n | <.001 | n | <.001 |
| Oct. | n | <.001 | n | .003 |
| Nov. | n | .007 | n | <.001 |
| Dec. | n | .003 | n | <.001 |

[1]Variation in low flow that was caused by variation in precipitation was removed by LOWESS regression analysis.

[2]Slope of trend: n is negative and p is positive

| | | p-value |
|---|---|---|
| n or p | not significant | 0.05 to 1.00 |
| n | significant | <0.05 |

Changes in upland and riparian vegetation were likely major factors in the decreasing trends in total streamflows and low flows. Factors other than precipitation caused significant trends in total flows and low flows in the summer and fall, but those factors did not cause significant trends in late winter flows. The significant trends coincide with high rates of transpiration from vegetation in the summer, and the nonsignificant trends coincide with low rates of transpiration in the late winter. Another piece of evidence that implicates vegetation as a cause of decreased flows is that the upland and riparian vegetation of the San Pedro River Basin changed during the 20th century. The relative proportions of different species changed in upland vegetation (woody plants increased and grasses decreased), and the areal extent and density of riparian vegetation increased substantially (Rojo and others, 1999; Kepner and Edmonds, 2002; as referenced in Thomas and Pool, 2006).

Ground-water pumping in the upper San Pedro watershed in Mexico and the United States had a mixed influence on streamflow trends at Charleston. Pumping increased from less than 2,500 acre-ft/yr before 1940 to about 53,000 acre-ft/yr in 2002 (Thomas and Pool, 2006). Statistical analyses indicate that seasonal pumping from wells near the river for irrigation in the spring and summer was a major factor in the decrease in low flows. The analyses also indicate that year-round pumping from wells in the regional aquifer away from the river was not a major factor in the decrease in low flows. If regional pumping had caused a trend, the pumping should have affected low flows for all months of the year, but factors other than precipitation did not cause significant trends in low flows for January, February, March, and April (table 4). These conclusions are for trends from 1913–2002, and regional pumping in the United States and Mexico could affect streamflow at Charleston in the future, because regional ground-water pumping can have a delayed effect on streamflows (Alley and others, 1999).

*—Blakemore E. Thomas*

**Table 5.** Results of significance tests for differences among regression relations between precipitation at Tombstone, Arizona, and monthly total streamflow for the San Pedro River at Charleston, Arizona, for three time periods

[---, no data; <, less than]

| Month | Months of cumulative precipitation used for explantory variable[1] | p-values for significance tests of difference among regression relations for three time periods[2] | |
|---|---|---|---|
| | | Slope[3] | Intercept[4] |
| Jan.[5] | --- | --- | --- |
| Feb. | 3 | 0.213 | 0.814 |
| Mar. | 3 | 0.663 | 0.961 |
| Apr. | [6]3 | 0.302 | 0.810 |
| May | [6]3 | 0.188 | 0.198 |
| June | 1 | 0.451 | 0.008 |
| July | 2 | 0.002 | ([7]) |
| Aug. | 1 | 0.239 | <0.001 |
| Sept. | 2 | 0.889 | <0.001 |
| Oct. | 2 | 0.014 | ([7]) |
| Nov. | 3 | 0.731 | 0.002 |
| Dec. | 3 | <0.001 | ([7]) |

[1]Precipitation for same month as streamflow and indicated number of previous months (2 months is the same month and the previous month)

[2]Data were grouped into three time periods (1913–42, 1943–76, and 1977–2002). For each time period, a linear regression analysis was made between precipitation and monthly average streamflow. The difference among regression relations was tested with a nested F-test.

[3]Slope of regression relations.

[4]Intercept of regression relations.

[5]Linear regression relations could not be fit.

[6]Months of cumulative precipitation are January, February, and March.

[7]Significance test for difference among regression intercepts is not valid when the slopes are significantly different.

| | | p-value |
|---|---|---|
| (shaded) | not significant | 0.05 to 1.00 |
| (unshaded) | significant | <0.05 |

## References


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*Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: New York, Elesevier Science Publishing Company, Inc., 522 p.*

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