IMPROVING ESTIMATES OF LOW-FLOW CHARACTERISTICS FOR STREAMFLOW STATIONS AFFECTED BY CLIMATIC CYCLES

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Introduction

Statistical techniques used to compute low-flow characteristics for streams assume that streamflow data are independent, random, and have no trend with time. The assumption that the data has no trend with time may not be valid if climatic cycles produce cycles in streamflow. This is especially true for streamflow stations with short periods of record where only part of the climatic cycle is represented.

Knowledge of the magnitude and frequency of low flows for streams is important for water-supply planning, waste-load allocation, storage-facility design, and maintenance of quantity and quality of water for irrigation, recreation, and wildlife conservation. A low-flow characteristic is defined as the minimum average discharge for a selected consecutive-day period for a given recurrence interval in years. For example, a 7-day, 10-year low flow (7Q10) of 12 ft3/s (cubic feet per second) for a site indicates that the minimum average discharge for 7-consecutive days is less than 12 ft3/s, on average, once in 10 years. Therefore, there is a 10-percent chance that the minimum average discharge for 7-consecutive days for any given year will be less than 12 ft3/s.

Fitting the Pearson Type III statistical distribution to the logarithms (base 10) of the annual series of the minimum average discharges for n-consecutive days (hereafter referred to as the annual low-flow series) for a streamflow gaging station is the method commonly used to compute low-flow characteristics. The computed log-Pearson Type III frequency curve is then evaluated by comparing it to Weibull plotting positions of the annual n-day low-flow series. The log-Pearson Type III frequency analysis of a hydrologic time series assumes that data are independent and random, and have no trend with time. Low-flow characteristics for selected recurrence intervals were computed using the log-Pearson Type III frequency equation as follows:

$$\log Q = \overline{X} + KS \qquad (1)$$

where:

Q is the computed n-day low-flow characteristic for the selected recurrence interval;

$\overline{X}$ is the mean of the logarithms of the annual n-day low-flow series;

K is a frequency factor and a function of the skew coefficient computed from the logarithms of the annual n-day low-flow series and the selected non-exceedance probability, which is the inverse of the recurrence interval [the K values were obtained from the Interagency Advisory Committee on Water Data (1982, Appendix 3)]; and

S is the standard deviation of the logarithms of the annual n-day low-flow series.

Background

In Mississippi, State water-management regulations governing the rate at which waste effluent can be discharged into a stream and the rate at which water can be withdrawn from a stream are based on the 7-day, 10-year low-flow characteristic for the stream. In a current (1989) study to update the 7-day low-flow characteristics for Mississippi streams, a trend analysis of the annual 7-day low-flow series for 103 continuous-record streamflow stations indicated a trend in low-flow data for some streams. Comparisons of the annual 7-day low-flow data for long periods of record at streamflow stations and the statewide rainfall data for the period 1900-86 show that cyclic patterns of streamflow correspond to cyclic patterns of rainfall. For most streamflow stations where a trend was indicated, the data did not cover a sufficient time period, and the apparent trend actually reflected part of a climatic cycle rather than a long-term trend.

Generally, rainfall in Mississippi for the mid-1950's was lower than average, which resulted in lower than average streamflow; rainfall in the mid-1970's was higher than average, which resulted in higher than average streamflow. A frequency analysis of the annual low-flow series for a station gaged only during the 1950's or 1970's will result in low-flow characteristics lower or higher, respectively, than a frequency analysis of data collected during a period that includes years with both extremely high and extremely low streamflow.

Purpose And Scope

This paper presents techniques for adjusting low-flow characteristics computed for annual low-flow data affected by climatic cycles. The development of these techniques involved the analysis of low-flow data for more than 100 streamflow stations on natural and unregulated streams in Mississippi and adjacent States.

Methods And Results

Low-flow characteristics for streamflow stations were computed based on the period of record and the observed climatic cycles. Stations having gaged records that included the years 1951-77 were considered long-term stations. Low-flow characteristics for these stations were not adjusted for climatic cycles because the period of record of streamflow data included the periods of both deficient and excessive rainfall. All other gaging stations were designated short-term stations. Low-flow characteristics for these stations were adjusted for cycles in rainfall based on correlation of low-flow data at the short-term station and at a selected long-term station. A statistically unbiased correlation method for estimating low-flow characteristics for ungaged streamflow sites, developed by Stedinger and Thomas (1985), was used to compute low-flow characteristics for short-term stations. This method provides improved estimates of the mean and standard deviation for the annual low-flow series at the short-term stations. The skew coefficient at a short-term station was assumed to equal the skew coefficient at the selected long-term station. Updated low-flow characteristics for short-term stations affected by climatic cycles were computed using the log-Pearson Type III frequency equation (eq. 1) based on these improved station statistics.

The correlation method developed by Stedinger and Thomas (1985) assumes a linear model (ordinary least-squares regression) between the logarithms of the annual low-flow series at the short-term station and the logarithms of concurrent annual low-flow series at the selected long-term station. Stedinger and Thomas recommend that the correlation coefficient of the ordinary least-squares regression should exceed about 0.70 to ensure that improved station statistics are obtained. A correlation of the annual low-flow series for the short-term station Black Creek near Brooklyn, MS with the concurrent annual data for the long-term station Bowie Creek near Hattiesburg, MS (correlation coefficient = 0.70) is shown as an example of the method in figure 1. Long-term stations were selected for correlation with short-term stations based on basin geology, drainage area, and distance between stations. To the extent possible, stations to be correlated were selected in adjacent basins with similar geology. Another selection criterion used was that the larger basin be less than 10 times the size of the smaller basin (W.O. Thomas, U.S. Geological Survey, oral commun. 1988). The effect of spatial variations in rainfall patterns is reduced by the distance between correlated basins.

Adjusted station statistics for the annual low-flow series at the short-term sites were computed based on correlations with similar long-term stations and equations from Stedinger and Thomas (1985, p. 4). The ordinary least-squares regression of the logarithms of annual low-flow series at a short-term station and those at a long-term station provide estimates of slope (a), intercept (b), and variance (Se2). Improved low-flow station statistics at a short-term station correlated with a long-term station were computed using the equations:

$$\overline{X}_{adj} = b + a\,M_{1t} \tag{2}$$

$$Var_{adj} = a^2 S_{1t}^2 + Se^2 \left[1 - \frac{\left(S_{1t}\right)^2}{(L-1)\left(S_{c1}\right)^2} \right] \tag{3}$$

where:

$\overline{X}_{adj}$ is the adjusted mean of the logarithms of the annual low-flow series at the short-term station;

Var_{adj} is the adjusted variance of the logarithms of the annual lowflow series at the short-term station;

a is the slope of the ordinary least-squares regression of the logarithms of the annual low-flow series at the short-term station and those at the long-term station;

b is the intercept of the ordinary least-squares regression of the logarithms of the annual low-flow series at the short-term station and those at the long-term station;

Se^2 is the variance of the ordinary least-squares regression of the logarithms of the annual low-flow series at the short-term station and those at the long-term station;

M_{lt} is the mean of the logarithms of the annual low-flow series for the full period of record at the long-term station;

S_{lt} is the standard deviation of the logarithms of the annual low-flow series for the full period of record at the long-term station;

S_{cl} is the standard deviation of the logarithms of the annual low-flow series for the concurrent period of record at the long-term station; and

L is the number of concurrent years of record for the short-term and long-term stations.

The adjusted standard deviation for the short-term station is the square root of the adjusted variance. This method for computing improved station statistics for short-term stations assumes that annual low-flow discharges occur concurrently at correlated stations, a reasonable assumption for Mississippi streams, and that the skews of the annual low-flow series for the two stations are approximately equal. Stedinger and Thomas (1985, p. 4) stated that skews for two stations "are approximately equal for watersheds in similar hydrologic environments."

The adjusted statistics for the short-term stations are estimates of the long-term statistics at those stations and reflect the range of the variance for a longer period of record than is available. For the example in figure 1, the 7-day 10-year low flow for the short-term station Black Creek at Brooklyn, MS, based on the log-Pearson Type III statistical distribution and unadjusted for climatic cycles in the station, data was computed to be 70 cubic feet per second for the period 1972-87. The time-sampling error of this 7-day, 10-year low flow is an estimate of the standard error of the low-flow characteristics and was computed to be 14 percent. When adjusted for climatic cycles using the correlation with the long-term station Bowie Creek near Hattiesburg, MS, the improved estimate of the 7-day, 10-year low flow at the Black Creek at Brooklyn, MS station was computed to be 57 cubic feet per second. The standard error of the improved low-flow characteristic was computed to be 1 percent from Stedinger and Thomas (1985, p. 8). The adjusted 7-day, 10-year low-flow characteristic at this station represents an estimate of the low-flow characteristic for a longer period of record that includes years with both extremely high and extremely low streamflow.

Summary

Comparisons of the annual 7-day low-flow series for long periods of record (1899-87) at streamflow gaging stations in Mississippi and the statewide rainfall data for the period 1900-86 show that cyclic patterns of streamflow correspond to cyclic patterns of rainfall. Generally, statewide rainfall for the mid-1950's was lower than average and rainfall in the mid-1970's was higher than average. A frequency analysis of the annual low-flow series for a station gaged only during the 1950's or 1970's will result in low-flow characteristics lower or higher, respectively, than a frequency analysis of data collected for a period that includes years with both extremely high and extremely low streamflow.

To adjust estimates of low-flow characteristics for streamflow stations affected by climatic cycles, streamflow stations were designated either a short-term station if the period of record did not include both climatic extremes, or a long-term station if the period of record included both climatic extremes. Low-flow characteristics for long-term stations were not adjusted, because the period of record of streamflow data included the periods of both excessive and deficient rainfall. Low-flow data for short-term stations were adjusted based on a correlation with low-flow data from long-term stations that have hydrologically similar watersheds. A statistically unbiased method for estimating low-flow characteristics was used to compute improved estimates of the mean and standard deviation of the annual low-flow series at the short-term station based on these correlations. Improved low-flow characteristics adjusted for climatic cycles in low-flow data were computed using the adjusted stations statistics and the log-Pearson Type III frequency equation. Improvement of estimates of low-flow characteristics for stations affected by climatic cycles is verified by a comparison of the standard errors of estimate of the low-flow characteristics computed with and without adjustments.

References

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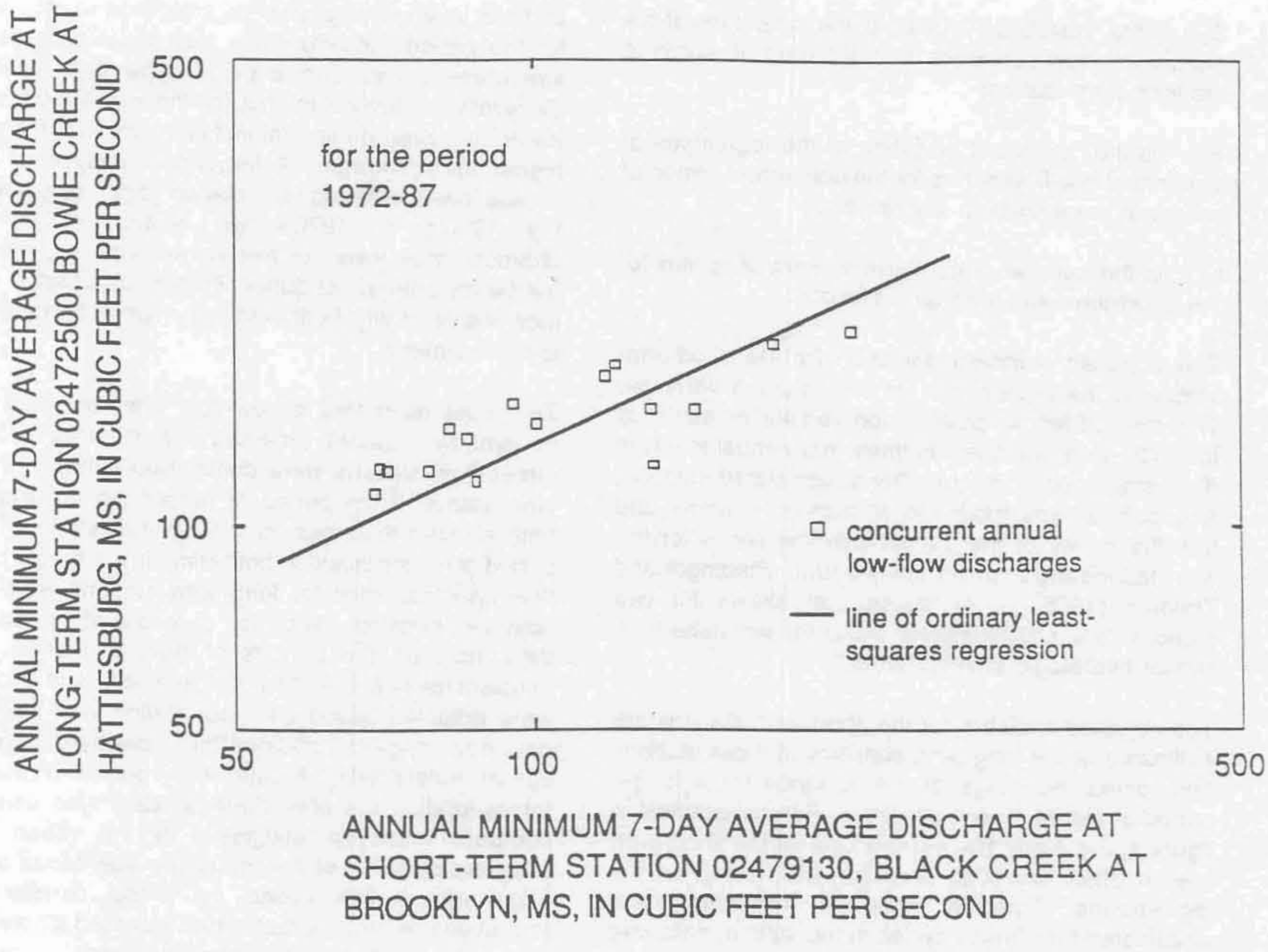

Figure 1. -- Correlation of annual 7-day low-flow series at a short-term station and at a long-term station in Mississippi