Uncertainty in low-flow data from three streamflow-gaging stations on the upper Verde River, Arizona

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Introduction

Decreases in streamflow, particularly in the lower flow regime in perennial streams, are a significant concern to water-resource planners, especially in the Southwestern United States, where perennial streams are relatively few in number but provide valuable water supply, wildlife habitat, and recreational opportunities. Rapid population growth and the ensuing ground-water development have created the potential for a decrease in low flows in the upper Verde River Basin, Arizona. As a result, the performance of three U.S. Geological Survey streamflow-gaging stations at meeting low-flow monitoring objectives was evaluated on the basis of uncertainty in the streamflow data. In downstream order, the stations are Verde River near Paulden, Verde River near Clarkdale, and Verde River near Camp Verde.

Low-flow monitoring objectives

Four low-flow monitoring objectives were considered in the performance evaluation. The first monitoring objective was to characterize discharge of the lower flow regime through a variety of procedures such as frequency analysis and base-flow analysis. The second through fourth objectives were more specific and were related to detecting changes in the flow as a result of natural or human factors. The second objective was to detect differences between a low flow at a given time and a specified value of flow. The third

objective was to detect differences between low flows for two different times. The fourth objective was to detect linear trends in low flows over time.

Simple operational definitions of daily and annual low flows were made for the purpose of evaluating the performance of the streamflow-gaging stations at meeting the four low-flow monitoring objectives. The apex of a sharp bend in the streamflow-duration curve was considered to mark the division between low flows and moderate or high flows that result from runoff. These apexes, therefore, define the maximum values for low flows and occur at 0.85 m^3/s for Verde River near Paulden, 2.83 m^3/s for Verde River near Clarkdale, and 7.08 m^3/s for Verde River near Camp Verde. "Daily low flow" was defined as being equal to (1) the average instantaneous discharge for the day if this discharge is less than the maximum value of low flow, or (2) the maximum value of low flow if the average instantaneous discharge for the day exceeds the maximum value of low flow. This definition allows for computation of the annual low flow, which was defined as the mean of the daily low flows for a given year and is analogous to a coarse estimate of the annual base flow. Median daily low flows for the period of discharge record were 0.71 m^3/s for Verde River near Paulden, 2.27 m^3/s for Verde River near Clarkdale, and 3.96 m^3/s for Verde River near Camp Verde.

Methods of determining uncertainty in streamflow data

Standard errors of the streamflow data must be small enough so that the analyses required by the monitoring objectives are not unacceptably limited by uncertainty. Standard errors of daily and annual low-flow data were determined by using the Moss and Gilroy (1980) method. Their method is appropriate where the discharge rating is shifted to account for

small variations in the stage-discharge relation over time—a standard streamflow data collection procedure (Rantz and others, 1982). The Moss and Gilroy (1980) method considers uncertainty in the discharge-rating shift to be the main source of error in instantaneous and annual discharges, and that this uncertainty results from measurement error and from instability in the stage-discharge relation over time. Moss and Gilroy (1980) found that estimating the discharge-rating shift was analogous to Kalman filtering, a statistical procedure used to determine a minimum variance estimate for the state of a Markovian process over time, given periodic measurements that contain error. As a result, they developed a method of determining the standard error of daily and annual discharge data that is based on Kalman filtering.

The Moss and Gilroy (1980) method determines standard errors of daily and annual flows on the basis of four discharge-uncertainty parameters that reflect the measurement error and instability in the stage-discharge relation: measurement variance, process variance, 1-day serial correlation coefficient of the discharge-rating shift, and measurement frequency. Measurement variance reflects the average uncertainty in the individual discharge measurements used to calibrate and shift the discharge rating. The process variance and 1-day serial-correlation coefficient of the discharge-rating residuals reflect the stability of the stage-discharge relation over time. The process variance is a measure of the magnitude of variation in the discharge-rating shifts. A larger process variance represents a larger magnitude in physical changes to the channel geometry or vegetation conditions that affect the stage-discharge relation. The serial correlation coefficient represents the persistence of the discharge-rating shifts over time, and therefore reflects how fast the changes to the channel geometry or vegetation conditions occur over time.

Standard errors of daily and annual discharge decrease with a decrease in measurement variance, a decrease in process variance, or an increase in the serial correlation coefficient of the discharge-rating shifts. Standard errors of daily and annual discharge decrease with an increase in measurement frequency because the discharge rating is shifted on the basis of information gained from periodic discharge measurements made in the field. Methods described in Anning (2002) were used to calibrate the four discharge-uncertainty parameters.

Standard errors of daily and annual discharges

The discharge-uncertainty parameters at the three stations on the Verde River varied over time. For each station, the period of discharge record was subdivided into time intervals during which the four discharge-uncertainty parameters were relatively consistent compared to the variation of these parameters observed for the period of record. As a result of the variation, standard errors of daily and annual streamflow data varied over time at each station (fig. 1). Time-weighted mean standard errors of discharge data represent average conditions for the period of discharge record by accounting for the variation in the standard errors of the different length discharge-rating periods. Time-weighted mean standard errors of daily low flow for the period of discharge record, expressed as a percentage of the median daily low flow for the period of record, was 4.65 percent for Verde River near Paulden, 3.31 percent for Verde River near Clarkdale, and 5.99 percent for Verde River near Camp Verde. Time-weighted standard errors of annual low flows were 1.43 percent for Verde River near Paulden, 0.98 percent for Verde River near Clarkdale, and 1.80 percent for Verde River near Camp Verde.

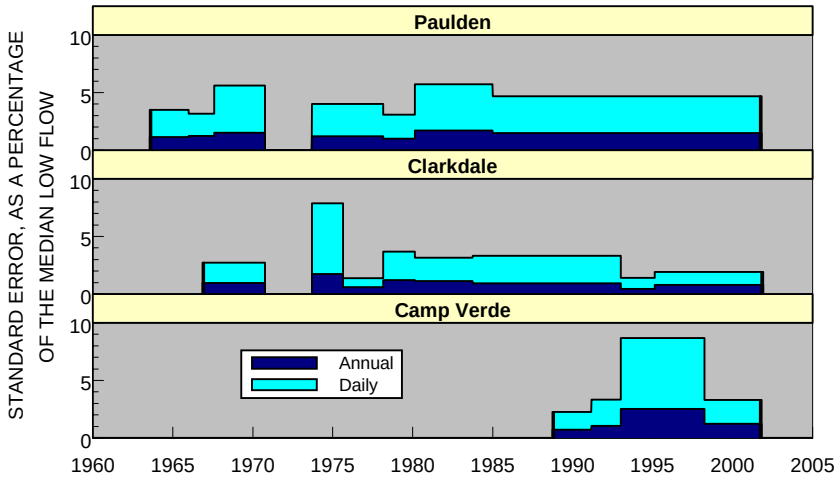

Figure 1. Standard errors of daily and annual low flows at streamflow-gaging stations on the Verde River, Arizona.

Evaluation of streamflow data uncertainty in terms of meeting low-flow monitoring objectives

The time-weighted standard errors of daily and annual discharges for the period of record at the three streamflow-gaging stations on the Verde River were used to generate statistics for each of the four monitoring objectives that were used to evaluate whether the uncertainty of the data was small enough to meet the objectives (table 1). Where the value of the statistic for a given station exceeds the targeted value for the statistic, the objective is not fully achieved (table 1). Appropriate target values for the objectives were determined using hydrologic judgment of the investigator.

The statistic used to evaluate the first objective, to characterize discharges of the lower flow regime, was the time-weighted standard error of the low-flow data expressed as a percentage of the median daily low flow for the period of record. The remaining three objectives involve hypothesis testing to detect particular effects, such as a difference in discharges or a slope (trend) in a time series of discharges. For these objectives, variation

in discharge data is considered to result in part from fluctuations in streamflow induced by natural or human factors, and also from uncertainty inherent in the data-collection process. Statistical hypothesis equations were used to determine the limitations that the uncertainty of the streamflow data will have on the size of the effect that is detectable. For example, the second objective of detecting differences between low flows for two different times was assessed on the basis of the uncertainty-limited minimum detectable difference between a low-flow value and a specified value. This quantity was calculated on the basis of the *Z*-test equation (Ott, 1993, p. 221). Similarly, the *t*-test equation for the slope of a linear regression (Ott, 1993, p. 492-505) was used to determine the uncertainty-limited minimum detectable slope of an annual series of low-flow data, and this slope in turn is used to evaluate objective 4 (table 1).

Time-weighted standard errors for annual low-flow data were small for all three stations, and as a result, the four monitoring objectives were achieved for annual low-flow data at each station (table 1). All four monitoring objectives were also achieved for daily low-flow data at Verde River near Clarkdale. The time-weighted mean standard errors of daily low flow at Verde River near Paulden, however, were not small enough to meet the third objective—the uncertainty of the streamflow data will limit analyses to detect only differences between daily low flows for two different times that are greater than 13.0 of the median daily low flow for the period of record (table 1). For Verde River near Camp Verde, only the first and fourth objectives will be fully achieved. The uncertainty of the low-flow data will limit analyses to detect only differences between a daily low flow and a specified value that are greater than 11.7 percent of the median daily low flow for the period of record. Similarly, only differences between daily low flows for two different

times that are greater than 16.0 percent of the median daily low flow for the period of record will be detected.

Table 1. Descriptions and values of statistics used to evaluate low-flow monitoring objectives of streamflow-gaging stations on the upper Verde River, Arizona. Statistics are expressed as a percentage of the median daily low flow for the period of record at each station. <, less than.

		Statistic used to evaluate objective				
				Time-weighted value of statistic		
Objective	**Description**	**Low-flow data**	**Targeted value for achieving objectives**	**Paulden**	**Clarkdale**	**Camp Verde**
1. Characterize discharge of the lower flow regime	Standard error of low flows	Daily	<10	4.65	3.31	5.99
		Annual	<5	1.43	0.98	1.80
2. Detect a difference between low flow and specified value	Uncertainty-limited minimum detectable difference between low flow and a specified value	Daily	<10	9.20	6.48	11.7
		Annual	<5	2.82	1.93	3.51
3. Detect a difference between low flow at two different times	Uncertainty-limited minimum detectable difference between low-flow at two different times	Daily	<10	13.0	9.16	16.6
		Annual	<5	3.99	2.72	4.97
4. Detect linear trend in annual series of data	Uncertainty-limited minimum detectable slope of a 25-year trend in an annual series of data, per year	Daily	<0.4	0.269	0.198	0.343
		Annual	<0.2	0.093	0.056	0.104

Reducing uncertainty in discharge data

For Verde River near Paulden and near Camp Verde, the uncertainty of daily low flows can be reduced to meet all monitoring objectives. This can be accomplished by decreasing the uncertainty of discharge measurements used to calibrate the stage-discharge rating, increasing the discharge-measurement frequency, or building an artificial control that would have a stable stage-discharge relation over time. The uncertainty of discharge measurements can be reduced by increasing the number of

subsections used in determination of velocity and area in the measurement, or by increasing the length of time for which velocity is measured. Alternatively, two discharge measurements could be made and the average used to determine the discharge-rating shift. Decreasing the uncertainty of discharge measurements or increasing the discharge-measurement frequency increases operational costs because more time is required to collect discharge measurements. In this approach, operational costs are incremented with each added or improved discharge measurement, but additional capital investment is not required. In contrast, building an artificial control requires a large capital investment, but operational costs would be reduced because less site visits would be required to verify the stage-discharge relation.

References:

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