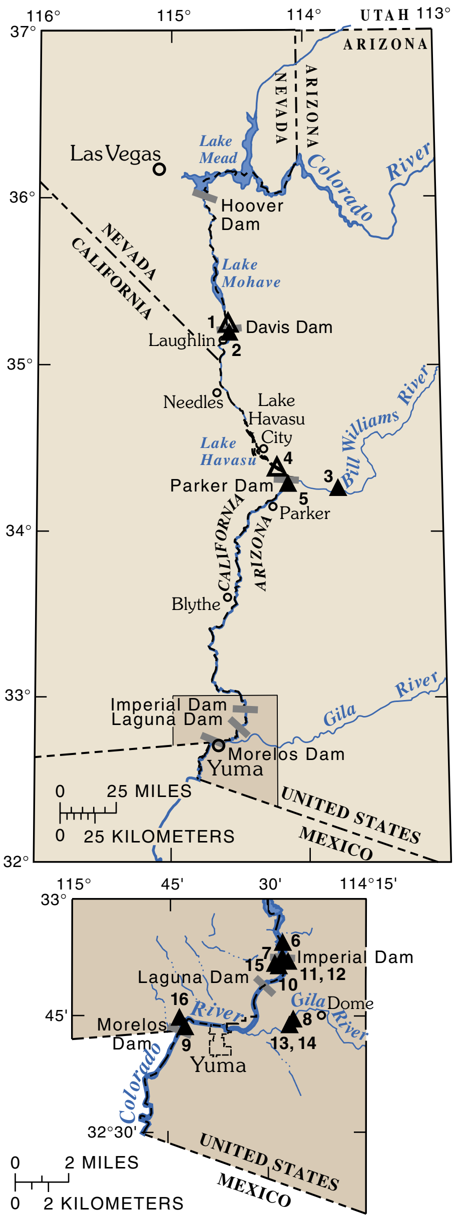
Prepared in cooperation with the
BUREAU OF RECLAMATION

Uncertainty in Annual Streamflow and Change in Reservoir Content Data from Selected Surface-Water Gaging Stations on the Lower Colorado River



EXPLANATION

1△ CONTINUOUS-RECORD RESERVOIR-CONTENTS GAGING STATION—Number corresponds to site number in table 1

▲6 CONTINUOUS-RECORD STREAMFLOW-GAGING STATION—Number corresponds to site number in table 1

Figure 1. Location of streamflow and reservoir-contents gaging stations.

The lower Colorado River is an important water resource for metropolitan populations, agriculture, and industry in California, Arizona, and Nevada. The Bureau of Reclamation (BOR) manages the river, releasing water stored in Lakes Mead, Mohave, and Havasu, and in other smaller reservoirs as needed so that it can be used by diverters. To help guide river management, streamflow and reservoir content are monitored at strategically located gaging stations along the lower Colorado River, its tributaries, and its diversions. The data obtained from these gaging stations, however, contain uncertainty and are only estimates of the "true" streamflow and reservoir content. As part of a cooperative project with the BOR, the U.S. Geological Survey (USGS) estimated the standard error of the annual discharge for calendar years 1995–99 at 14 streamflow-gaging stations and the standard error of the change in reservoir content at 2 reservoir-content gaging stations (table 1 and fig.1; Anning, 2002). These standard error estimates provide a measure of the random uncertainty for the annual data.

Table 1. Site numbers and names.

1.	Lake Mohave at Davis Dam
2.	Colorado River below Davis Dam
3.	Bill Williams River below Alamo Dam
4.	Lake Havasu near Parker Dam
5.	Colorado River below Parker Dam
6.	Colorado River above Imperial Dam
7.	Colorado River below Imperial Dam
8.	Gila River near Dome
9.	Colorado River at the northerly international boundary
10.	Mittry Lake Diversions at Imperial Dam
11.	Gila Gravity Main Canal at Imperial Dam (stilling well gage operated by the USGS)
12.	Gila Gravity Main Canal at Imperial Dam (acoustic velocity meter gage operated by the BOR)
13.	Welton-Mohawk Canal (radial-gates gage operated by the USGS)
14.	Welton-Mohawk Canal (acoustic velocity meter gage operated by the BOR)
15.	All-American Canal near Imperial Dam
16.	All-American Canal below Pilot Knob wasteway

Why Quantify Uncertainty?

In the United States, water from the main stem in the lower Colorado River is apportioned among the States of California, Arizona, and Nevada by the Boulder Canyon Project Act of December 21, 1928, and confirmed by the U.S. Supreme Court decree, 1964, *Arizona v. California*, in terms of consumptive use (U.S. Congress, 1948). The decree is specific about the responsibility of the Secretary of the Interior to account for consumptive use of water from the mainstem. Accounting for the use of Colorado River water is required by the 1964 decree (U.S. Supreme Court, 1964); a report that contains records of diversions, returns, and consumptive use of water is published annually by the BOR (Bureau of Reclamation, 1965–2000).

The USGS, in cooperation with the BOR, developed the Lower Colorado River Accounting System (LCRAS; Owen-Joyce and Raymond, 1996) as a method to determine the annual consumptive use of Colorado River water by diverters from Hoover Dam to Mexico. The LCRAS is being tested by the BOR to calculate the consumptive use of Colorado River water. The LCRAS is based on a water balance that is applied to four reaches of the lower Colorado River: Hoover Dam to Davis Dam, Davis Dam to Parker Dam, Parker Dam to Imperial Dam, and Imperial Dam to Morelos Dam (fig. 1).

The water balance equation used by the BOR and its components are (Bureau of Reclamation, 2000):

$$Q_{res}=Q_{diff}+T_{rm}+T_{rum}-Q_{ex}-E \\ -CU_d-ET_{pht}-ET_{crop}-\Delta S_r-\Delta S_a-$$

where

Q_{res} = Residual (algebraic sum of errors);

$Q_{diff}=Q_{us}-Q_{ds}$;

Q_{us} = Flow entering the reach at the upstream boundary;

Q_{ds} = Flow exiting the reach at the upstream boundary;

T_{rm} = Measured tributary inflow to the reach;

T_{rum} = Unmeasured tributary inflow to the reach;

Q_{ex} = Water exported out of the basin;

E = Open-water evaporation;

CU_d = Domestic, municipal, and industrial use;

ET_{pht} = Total estimated phreatophyte evapotranspiration;

ET_{crop} = Total estimated crop evapotranspiration;

ΔS_r = Change in reservoir storage; and,

ΔS_a = Change in storage of the alluvial aquifer.

The components of the water balance are measured where possible and estimated otherwise. Many of the components are measured by streamflow or reservoir-contents gaging stations. The sum of the water-balance components typically does not equal zero because each component contains some uncerainty. To force the sum of the components of the water balance to equal zero, a portion of Q_{res} is distributed to each component on the basis of the variance of estimate (squared standard error) for that component. Therefore, methods were established for determining the standard error of the components in the water balance that are defined by streamflow or reservoir-contents-gaging stations (Anning, 2002).

Sources of Error

The techniques of computing the annual discharge at streamflow-gaging stations of the lower Colorado River network generally involve continuously recording a correlative variable as a surrogate for discharge, such as river stage, and then applying a discharge rating (a curve relating discharge to stage) to the correlative data to compute a continuous record of discharge.

U.S. Geological Survey hydrographer measuring discharge from a cableway at the Gila Main Canal at Imperial Dam using a vertical-axis current meter. Stage is recorded continuously inside the stilling well seen in the background.

The annual discharge is computed by integrating the discharge record over the year. The discharge rating changes over time in response to changes in channel geometry, vegetation conditions, and other factors. As a result, periodic discharge measurements are collected with vertical-axis type current meters or with acoustic doppler current profile meters to recalibrate the discharge rating. The recalibration consists of shifting the rating such that at the time of a discharge measurement, the rated discharge agrees with the measured discharge. For times in between discharge measurements, the shift is interpolated. The uncertainty of the shift is the major source of uncertainty for the computed discharge data (Moss and Gilroy, 1980). The uncertainty of the shift changes over time; it is smallest at the time of a discharge measurement. The uncertainty of the shift increases with time after the discharge measurement because channel conditions change, and the "true" shift may not change over time as does the shift that is estimated by interpolation. Discharge measurements provide information about the shift for times before and after the measurement is collected, so the error of the shift is largest midway between discharge measurements (fig. 2). The uncertainty of computed discharge data can be reduced by decreasing the error of discharge measurements or by increasing the frequency of the discharge measurements. Annual change in reservoir content is measured as the difference between the reservoir content on December 31 of one year and the reservoir content on December 31 of the previous year. Reservoir content is determined using a stage reading and a stage-contents rating table. Assuming that the stage-contents table is without error, the major source of error for reservoir content data is the misrepresentation of the reservoir stage. Reservoir stage at the upstream end may differ from that at the downstream end where the gaging station is located because of unsteady reservoir inflows and outflows, or from sustained winds that shift the mass of the reservoir in the direction of the wind. Other factors, such as drawdown from withdrawal intakes for downstream releases or wind generated waves, may affect the reservoir stage near the recording instruments.

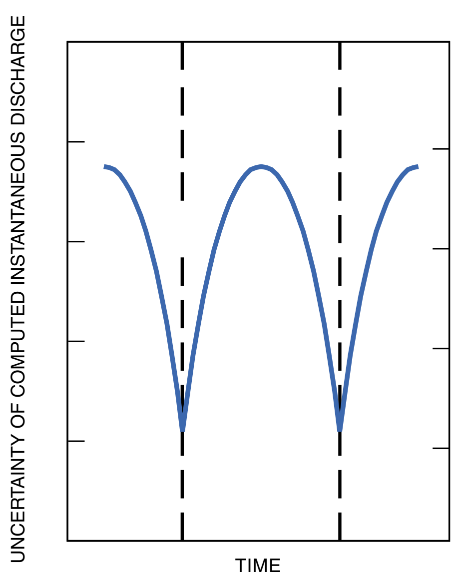


Figure 2. Uncertainty of computed instantaneous discharge. Dashed lines indicate time of discharge measurements.

Standard Error of the Annual Discharge and Change in Reservoir Content

The standard error of the annual discharge and change in reservoir content was determined for 14 streamflow- and 2 reservoir-content gaging stations,l respectively (fig. 3). The methods used to estimate the standard errors were developed to quantify the random component of the uncertainty and may underestimate the bias component of the uncertainty; therefore, the values for the standard errors may actually be somewhat larger than those presented if bias errors are present.

The standard error of the annual discharge, as a percentage, was generally small at most stations for calendar years 1995–99 and ranged from 0.11 percent for the All-American Canal near Imperial Dam in 1998 to 12.26 percent for the Colorado River below Imperial Dam in 1996 (fig. 3A). In general, the standard error of the annual discharge, as a percentage, was smallest at streamflow-gaging stations on the main stem of the Colorado River; however, the standard error, in acre-feet, was largest at these stations because of the large annual discharge on the main stem. The standard error of the annual discharge was less than 2 percent with the exceptions of Bill Williams River below Alamo Dam, Gila River near Dome, and the Colorado River below Imperial Dam. The variation of percent errors of the annual discharge for different stations reflects the differences in the uncertainty of the discharge measurements used to determine the shifts, the frequency of these discharge measurements, and the change of the discharge rating over time in response to changes in channel geometry, vegetation conditions, and other factors.

The standard error for the annual change in content for the two reservoirs ranged from 1,590 acre-feet for Lake Havasu in 1996 to 2,790 acre-feet for Lake Mohave in 1995 (fig. 3B). The standard error, in acre-feet, for the annual change in content for the two reservoir-content gaging stations was smaller than the standard error for the annual discharge for streamflow-gaging stations on the main stem of the Colorado River and on the major diversions from the Colorado River; however, it was generally larger than the standard error of the annual discharge for most of the tributary inflows to the Colorado River.

The small standard errors quantitatively indicate that much of the streamflow and reservoir content data used to estimate and distribute the consumptive use of Colorado River water among users are of high quality. The standard errors can be used by the BOR and USGS to evaluate whether the operation of individual gaging stations needs to be changed so that the uncertainty of the data collected can be reduced. In addition, the standard errors can be used to distribute the residual of the LCRAS water balance (page 2) to each of the water balance components.

—David W. Anning

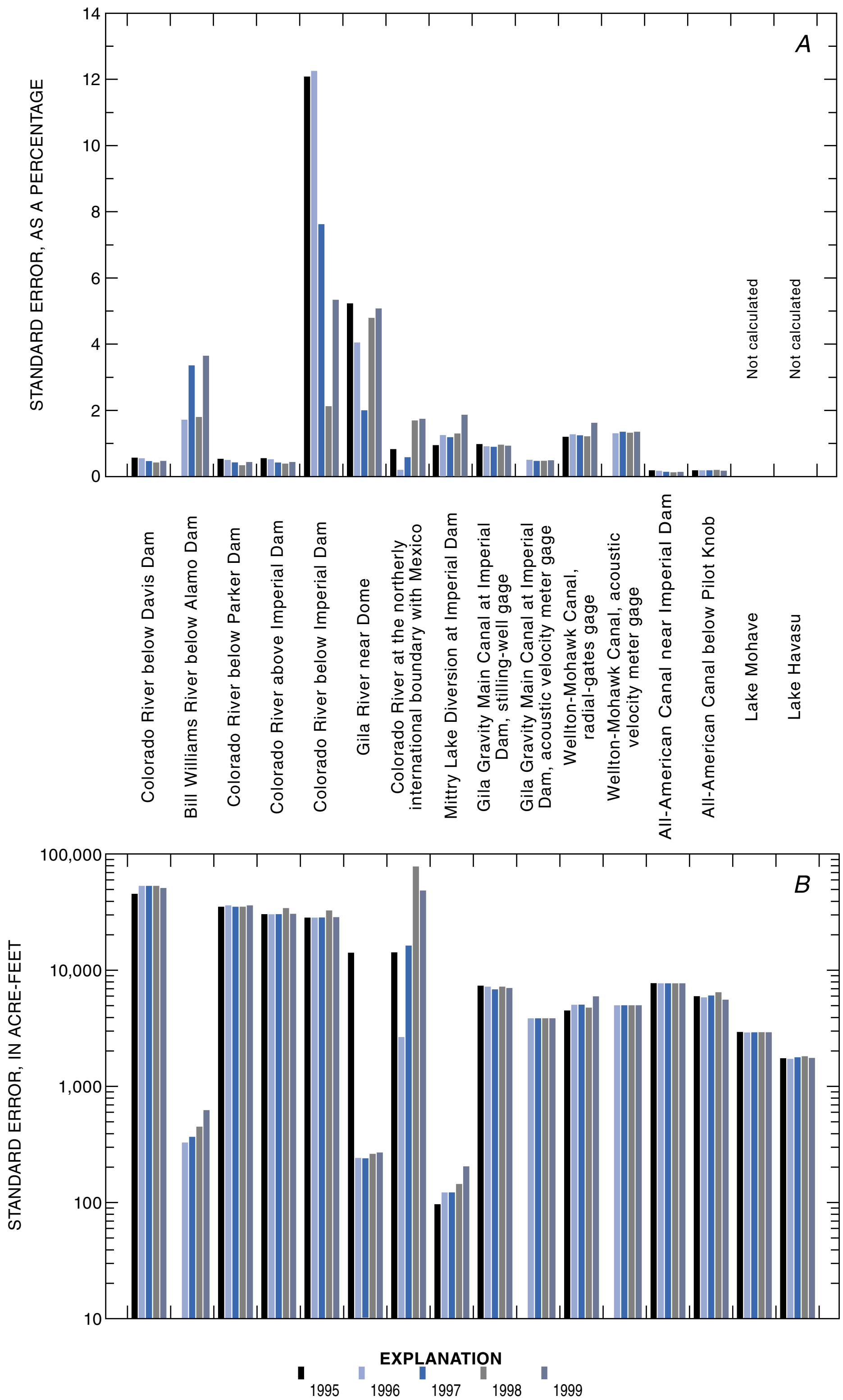


Figure 3. Standard error of estimate of the annual discharge at surface-water gaging stations, 1995–99 (A) as a percentage, and (B) in acre-feet.

Bureau of Reclamation hydrographers measuring discharge using an acoustic doppler profiler from a boat on the Gila Gravity Main Canal at Imperial Dam.

U.S. Geological Survey hydrographer making a wading discharge measurement at Bill Williams River below Alamo Dam using a vertical-axis current meter.

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