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

Potential Errors Associated with Stage-Discharge Relations for Selected Streamflow-Gaging Stations, Maricopa County, Arizona

Water-Resources
Investigations Report 00—4224

Prepared in cooperation with the
FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

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Tucson, Arizona
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U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
Water Resources Division
520 N. Park Avenue, Suite 221
Tucson, AZ 85719–5035

Copies of this report can be purchased from:

U.S. Geological Survey
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CONVERSION FACTORS

Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

VERTICAL DATUM

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 the United States and Canada, formerly called “Sea Level Datum of 1929”. Elevation, as used in this report, refers to distance above or below sea level.

Potential Errors Associated with Stage-Discharge Relations for Selected Streamflow-Gaging Stations, Maricopa County, Arizona

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Abstract

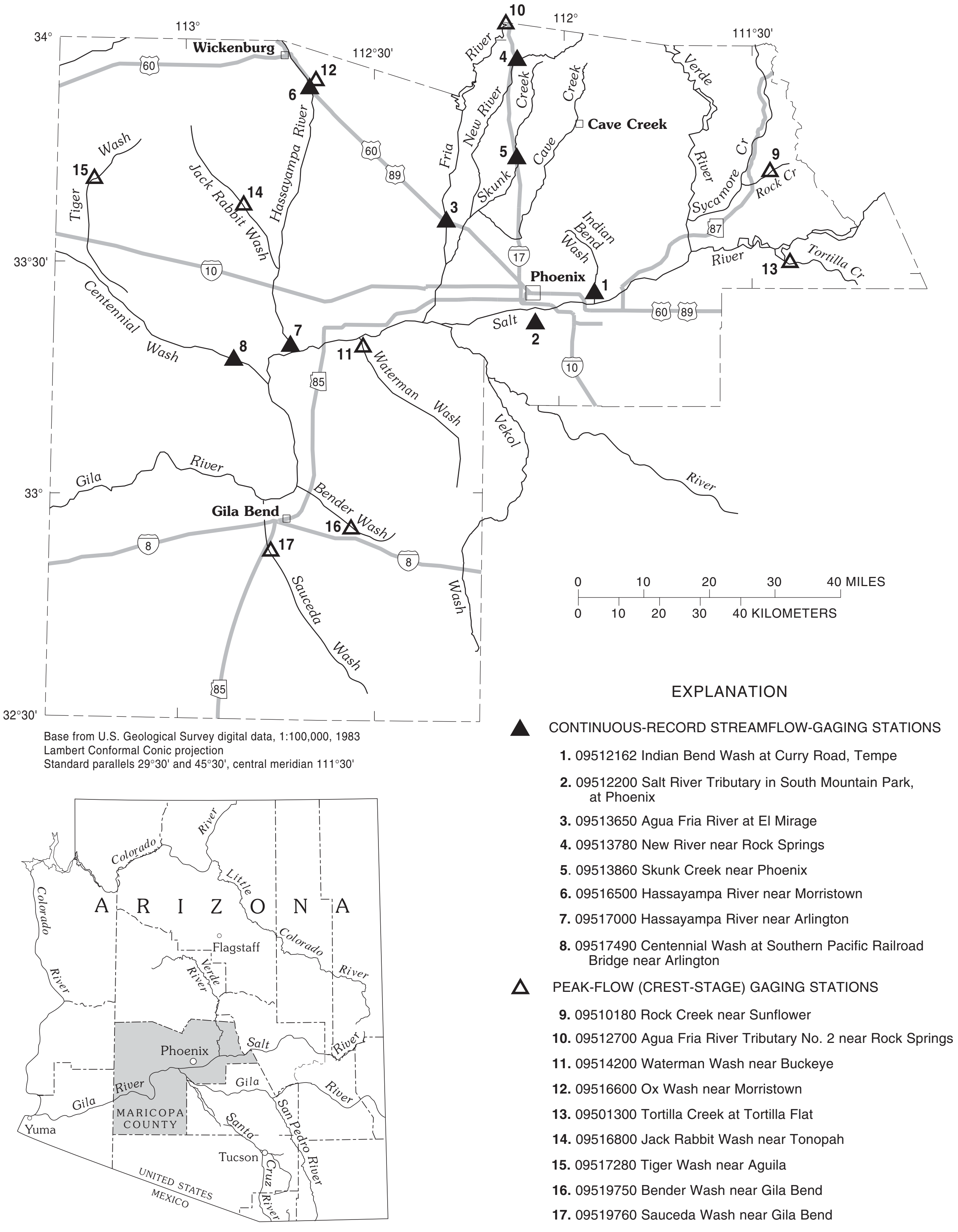
Potential errors were derived for individual discharge measurements and stage-discharge relations for 17 streamflow-gaging stations in Maricopa County. Information presented primarily consists of stage and discharge data that were used to develop the stage-discharge relations that were in effect for water year 1998. Accuracy of the discharge measurements directly relate to accuracy of the stage-discharge relation developed for each site. Stage-discharge relations generally are developed using direct measurements of stage and discharge, indirect measurements of peak discharge, and theoretical weir and culvert computations. Accuracy of current-meter measurements of discharge (direct measurements) depends on factors such as the number of subsections in the measurement, stability of the channel, changes in flow conditions, and accuracy of the equipment. Accuracy of indirect measurements of peak discharge is determined by the accuracy of discharge coefficients and flow type selected for the computations. The accuracy of indirect peak-discharge computations generally is less than the accuracy associated with current-meter measurements.

Current-meter measurements, indirect measurements of discharge, weir and culvert computations, and step-backwater computations are graphically represented on plots of the stage-discharge relations. Potential errors associated with the discharge measurements at selected sites are depicted as error bars on the plots.

Potential errors derived for discharge measurements at 17 sites range from 5 to 25 percent. Errors generally are greater for measurements of large flows in channels having unstable controls using indirect methods.

INTRODUCTION

The U.S. Geological Survey (USGS), in cooperation with the Flood Control District of Maricopa County (FCDMC), operates a network of continuous and peak-flow (crest-stage) gaging stations throughout Maricopa County, Arizona (**fig. 1**). Discharge records for these stations generally are computed by applying a record of stage to a site-specific stage-discharge relation. Development of stage-discharge relations, often called rating curves, generally consists of plotting discharge measurements against the corresponding stage, and fitting a line or curve to these plotted points. Periodic measurements of discharge typically are made using a current meter. The error associated with current-meter measurements depends on factors that include the number of subsections in the measurement, stability of the channel, changes in flow conditions, and accuracy of the equipment (Rantz and others, 1982).



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Lambert Conformal Conic projection
Standard parallels 29°30' and 45°30', central meridian 111°30'

Figure 1. Study area and locations of selected continuous-record streamflow-gaging stations and peak-flow (crest-stage) gaging stations, Maricopa County, Arizona.

When the direct measurement of discharge is not possible, peak discharge may be computed using hydraulic equations that incorporate elevations of debris marks deposited by floodwaters, channel geometry, and estimates of channel roughness. This method is known as an indirect computation of peak discharge. When stage-discharge relations are needed for a site near hydraulic structures, such as culverts and weirs, discharge is determined not only using high-water marks and geometry but also using selected discharge coefficients and previously derived equations for flow at these types of structures (Bodhaine, 1968). Accuracy of stage-discharge relations developed for sites near hydraulic structures primarily depends on the accuracy of the selected discharge coefficients and, for culvert computations, accurate determination of flow type. The accuracy of indirect computations of peak discharge generally is less than the accuracy associated with current-meter measurements.

When new rating curves are developed, and current-meter measurements are not available to define the relation between stage and discharge, the USGS generally will develop the relation on the basis of theoretical computations using the channel configuration, estimates of channel roughness, and assigned discharges. If only one cross section is surveyed, slope-conveyance techniques are used. If multiple cross sections are used, a step-backwater computation is used to determine discharge. These computations generally supply a range of values for definition of stage-discharge relations. When hydraulic structures, such as weirs and culverts, control stage at the streamflow-gaging stations, equations for computing discharge at these types of structures also may be used to compute discharges for a range of stage values.

The relation of stage to discharge usually is controlled by a reach or section of channel below the gaging station, known as the station control (Kennedy, 1984). The control is assumed to eliminate the effect of all other downstream conditions, such as channel geometry and vegetation conditions, on the velocity of flow at the gaging station. Controls are classified as section controls and channel controls and are further divided into natural and artificial. Section controls generally are only effective at low discharges and may be completely submerged at moderate to high discharges when channel control is in effect. Channel control includes all the channel features that determine the stage of the river for a certain discharge. The channel control generally consists of the size, slope, roughness (frictional resistance), alignment, constrictions and expansions, and shape of the channel (Kennedy, 1984). The reach acting as the channel control may increase in length at higher discharges; therefore, at higher discharges, the stage-discharge relation may be affected by additional channel features. Natural section controls may consist of a bedrock protrusion across the channel, a cobble- or boulder-dominated riffle, or other naturally occurring physical features that may result in a fairly stable relation between stage and discharge. Artificial controls may consist of hydraulic structures such as culverts, weirs, and diversion dams.

For many streamflow-gaging stations throughout the United States, controls usually are stable and the procedure for developing stage-discharge relations is fairly straightforward. Development of relations between stage and discharge for ephemeral streams, however, can be difficult. The control for gaging stations on wide, flat, and unconsolidated alluvial channels, which are predominant in the semiarid to arid southwestern United States, may be unstable at all discharges. When flows occur in these channels, sediment and other material eroded from or deposited on the streambed or banks can alter the cross-sectional area of the stream at a given stage and time. Additionally, the flow velocities may be impeded by the variable growth and alteration of vegetation along channel margins (Phillips and Ingersoll, 1998; Phillips and others, 1998). The forces of flow may even result in removal of vegetation and subsequent buildup of debris on downstream trees and structures. Processes like these can significantly alter the stage-discharge relation during a single flow. Finally, difficulties associated with developing stage-discharge relations for ephemeral streams are compounded by the fact that flows in these channels are typically flashy (sharp rises and declines in discharge), and hydrographers may not have adequate warning and time to make current-meter measurements and, therefore, may have to rely on indirect-discharge measurements.

Purpose and Scope

This report describes and illustrates potential errors and uncertainties associated with stage-discharge relations developed for selected streamflow-gaging stations in Maricopa County, Arizona. The information is presented to help water-resource managers and engineers better assess uncertainties of discharge values published for the selected sites. These potential errors are depicted as error bars for selected sites. Current-meter measurements, indirect measurements of discharge, weir and culvert computations, and step-backwater computations are graphically represented on plots of the stage-discharge relations. Information presented in this report primarily consists of stage and discharge data that were used to develop the stage-discharge relations that were in effect for water year 1998.

Description of Study Area

The basin-and-range topography of central Arizona, including Maricopa County, is characterized by steep block-faulted mountains separated by gently sloping valleys composed of material eroded from the mountains. Consequently, alluvial channels are predominant throughout the study area. These channels typically are ephemeral, and the bed material is such that substantial geomorphologic changes in geometry can occur during flows (Glancy and Williams, 1994). Although not as common as alluvial channels, gravel-bed streams also are found in the study area, and several are presented in this report. Channel boundaries of gravel-bed streams tend to be fairly stable during low to moderate flows in central Arizona; however, during large flows, large amounts of bed material may be displaced. The study area also includes bedrock channels that are considered stable at all discharges. Of the 17 sites used in this report, 11 of the channels are predominately composed of sand- and gravel-sized material, 4 of the channels are predominately composed of cobble and boulder material, and 2 of the channels are predominantly composed of exposed bedrock. Eight of the 17 sites have some type of artificial control downstream from the streamflow-gaging station.

Precipitation in central Arizona generally occurs in summer (June through October) and winter (December through March), and the amount of rainfall for those seasons is about equal (Sabol and others, 1990). Summer precipitation normally is produced by convective thunderstorms. Precipitation from these storms usually is of short duration and high intensity. These storms frequently produce flash floods that primarily occur in urban areas and small natural basins. Winter precipitation normally is produced by regional-frontal systems. Storms from these systems typically are of long duration, low intensity, and cover large areas. These storms can result in substantial runoff volumes and peak flows for large streams in the study area. A third storm type, dissipating-tropical cyclones, occurs primarily in September and October (Hirschboeck, 1985; Webb and Betancourt, 1992). Although less frequent than the other types of storms, dissipating-tropical cyclones can cause considerable flooding (Aldridge and Eychaner, 1984; Roeske and others, 1989).

The type, distribution, and density of vegetation near streams in the study area are highly variable and are subject to change seasonally as well as during flows. The variable condition of vegetation in streams in the study area can result in changes to roughness characteristics of the channel and, therefore, temporal changes to the stage-discharge relation (Phillips and others, 1998). Periodic alteration of vegetation conditions, either artificial or natural, in the control reach of streamflow-gaging stations in arid to semiarid regions can be the primary source of error and uncertainty for stage-discharge relations.

POTENTIAL ERRORS ASSOCIATED WITH MEASUREMENTS USED TO DEVELOP STAGE-DISCHARGE RELATIONS

Potential Errors Associated with Current-Meter Discharge Measurements

The USGS uses standardized methods for determining discharge by current-meter measurements (Rantz and others, 1982). Measurements of width, depth, and velocity are made at intervals across a section of the stream. These measurements generally are made by wading or from a bridge or cableway suspended above the stream. The current meter is used to measure velocity at discrete depths and locations along the chosen section of stream. Total discharge past the section is computed as the summation of the products of the subsection areas of the stream section and their respective velocities. A full discussion of techniques employed by the USGS for current-meter measurements can be found in Rantz and others (1982). The error associated with discharge determinations from current-meter measurements depends on many factors ranging from accuracy of equipment to rapid changes in flow conditions (Rantz and others, 1982). The USGS rates current-meter measurements as excellent, good, fair, or poor, which correspond to potential errors of less than 2, 5, 8, and greater than 8 percent, respectively.

When base-flow conditions occur in streams in Maricopa County, changes in stage over the period of time needed to make a current-meter measurement generally are minimal, and other proper standardized measurement procedures can be employed. Because of the flashy nature and general instability of streams in central Arizona, these channels are subject to changing bedform conditions, and rapid changes in stage (during moderate to large flows). Varying velocity, changing bedform conditions, and rapid changes in stage, therefore, can be the primary sources of current-meter measurement error during floodflows in these stream types. When adverse flow and channel conditions persist, the hydrographer may choose to streamline current-meter measurement procedures. Modifying the standard-measurement procedure may reduce the time needed to make a discharge measurement and result in a more accurate representation of channel geometry, control conditions, and the stage that correspond to the discharge measurement. This modification can include reducing the number of subsections in the measurement section, reducing the amount of velocity observation time, and reducing the number of point-velocity measurements in each subsection. More accurate measurements can be made when stage is changing rapidly by reducing the length of time for the measurement. Current-meter measurements made during these adverse conditions generally are rated no better than fair but can be rated poor depending on the severity of the hydraulic conditions and difficulties in obtaining accurate channel-geometry, stage, and velocity data.

Potential Errors Associated with Indirect Measurements of Discharge

Indirect measurements of peak discharge are made when it is impractical to measure flow using a current meter. When hydraulic structures, such as weirs and culverts, control the flow, indirect measurements generally are made using discharge coefficients defined by laboratory study and previously derived equations (Bodhaine, 1968). In the absence of hydraulic structures that act as flow controls, indirect determination of peak discharge is based on hydraulic equations that relate the discharge to the water-surface profile and the geometry of the channel (Benson and Dalrymple, 1967).

Slope-Area and Slope-Conveyance Computations

At gaging stations where hydraulic structures are not present, the two methods used to define stage-discharge relations in Maricopa County are slope-area and slope-conveyance computations. Slope-area computations involve (1) a field survey of the reach following flow in order to obtain the elevation and location of high-water marks corresponding to the peak stage, (2) cross-section geometry of selected cross sections in the reach, and (3) selection of roughness coefficients. The Manning equation, continuity equation, and energy equation are used to compute the final peak discharge. A full description of proper field and office procedures required to compute peak discharge using slope-area computations can be found in Benson and Dalrymple (1967) and Dalrymple and Benson (1967). Indirect measurements derived using slope-area computations generally are rated as either good, fair, or poor, which correspond to errors of less than 10, 15, or 25 percent or greater than the actual discharge, respectively.

Slope-conveyance computations are similar to slope-area computations of discharge in that the computation incorporates channel geometry, estimates of frictional resistance, and, in most cases, high-water marks formed during peak flows. The accuracy of indirect measurements derived from slope-conveyance computations, however, can be considerably less than the accuracy associated with slope-area computations, and generally would not be rated better than fair (within 15 percent of actual discharge). Slope-area computations of discharge generally use the geometry of an entire reach of channel. Energy losses associated with expansion or contraction of the reach between cross sections is considered, and the energy gradient is used in the Manning equation. For slope-conveyance computations of discharge, however, only one cross section of the reach is used, which negates the ability to account for expansion or contraction losses, and the bed slope or slope of the water-surface profile is used instead of the slope of the energy gradient. Because expansion or contraction losses may be substantial, the slope of the energy gradient may not coincide with the slope of the bed or water-surface profile, and substantial computational errors may result for a nonuniform reach. The selected reach must be uniform for a moderate distance upstream and downstream from the surveyed cross section to decrease errors associated with discharge computations using slope conveyance.

A major assumption used in computing indirect measurements of discharge is that the channel geometry and frictional characteristics are no different following flow, when the reach is surveyed and documented, than they were at the time of peak flow. For ephemeral sand channels in arid to semiarid environments, however, this assumption may lead to large errors. The power and force of flow may be such that substantial movement and degradation of the channel substrate occur before and during peak flow. Following the peak, channel-bed configuration may change dramatically as a result of scour in particular sections of the channel, or sediment that is suspended by the flow may settle out and deposit along the channel bed and margins. Consequently, survey of channel configuration (and subsequent computed cross-sectional areas) following the flow may not accurately reflect the geometry at peak discharge (Jarrett, 1987; Kirby, 1987; Quick, 1991; Sauer and Meyer, 1992; Glancy and Williams, 1994). The result may be erroneous computations of peak discharge.

Bedforms that change during flows in alluvial channels also may add to the uncertainty of postflow computations of peak discharge. Flow in alluvial channels can be classified as either lower-regime or upper-regime flow separated by a transition zone (Simons and Richardson, 1966). Roughness coefficients for indirect measurements in sand channels generally are selected following flow on the basis of the median diameter of bed material and the assumption that upper-regime flow and plane-bed conditions persist at the time the high-water marks are formed. According to eyewitness accounts and photographs documenting flow in sand channels, however, large antidunes are common and may result in increased turbulence and energy losses (Karim, 1995). Additionally, the antidunes may collapse resulting in a surge of the water surface along the channel margins. The surge may cause super elevation of the high-water marks that would be surveyed following flow (Phillips and Ingersoll, 1998). The result would be an erroneously large area of flow and, therefore, erroneously large estimates of peak discharge.

The roughness characteristics of the channel also must be selected for indirect measurement of peak discharge and may be another potential source of error in these computations. Manning's roughness coefficient, n, usually is used to represent flow resistance. The procedure for selecting n values, however, is subjective and requires judgement and skill that is developed primarily through experience. The required experience can be augmented with photographs and channel descriptions where roughness of the channel is considered verified. Several publications are available to aid in the selection of n values in arid to semiarid environments (Aldridge and Garrett, 1973; Thomsen and Hjalmarson, 1991; Phillips and Ingersoll, 1998). In spite of availability of these guides, inaccuracies in selection of n values for indirect measurements are possible and may result in direct errors in the computed channel conveyance and peak discharge (Kirby, 1987; Quick, 1991). Potential inaccuracies accompanying selection of n values are considered when accuracy ratings are assigned to individual indirect measurements.

Finally, ephemeral streams in desert environments also may contain substantial amounts of vegetation throughout the main channel. Vegetation conditions may be altered by the power of flow as indicated by several previous investigations (Burkham, 1976; Phillips and Hjalmarson, 1994; Phillips and others, 1998). The effect of vegetation conditions on total-flow retardance during peak flow may not be accurately represented by postflow-vegetation conditions and could potentially result in erroneous assumptions of friction characteristics for peak-flow computations.

Changing vegetation conditions, along with uncertainties of channel geometry and the likelihood of changing bedforms, increase the uncertainty of indirect measurements of flow in alluvial ephemeral streams. Accuracy of indirect measurements made in these channel types, therefore, often is downgraded to fair or poor to account for these errors. Because errors associated with the above-mentioned problems may be lessened for an ephemeral cobble-bed channel, indirect measurements made for these channel types may be rated as good.

Measurements of Discharge at Weirs by Indirect Methods

For computation of peak discharge at stations where a weir is used to control the flow, equations can be used to develop the stage-discharge relation. For computation of flow over a weir structure that spans the channel, the equations most commonly used to compute discharge require values for the width of the weir, either the static head or the total energy head in reference to the crest of the weir, and a discharge coefficient.

In most cases, values for width of the weir crest and head on a weir can be measured directly; however, discharge-coefficient values must be selected from tables developed by previous investigators (Bureau of Reclamation, 1948; Kindsvater and Carter, 1959). These investigators indicate that the coefficient is a function of specific dimensionless ratios that describe the geometry of the channel and the weir. Because of the endless variety of weir shapes and sizes, selection of a weir coefficient can be difficult. One method is the use of established tables, and another method is computation of discharge coefficients using known discharges at lower stages and extrapolating to the stage or discharge in question. Regardless of the weir equations used to define stage-discharge relations in Maricopa County, selection of a proper discharge coefficient is considered the main source of error and uncertainty. Weir measurements are rated using the same rating system that is used for slope-conveyance and slope-area measurements.

Measurements of Discharge at Culverts by Indirect Methods

Peak discharge through culverts can be determined from water-surface elevations that define the headwater and tailwater elevations (Bodhaine, 1968) and is the primary method for developing and maintaining stage-discharge relations for 5 of the 17 streamflow-gaging stations in this report. In general, either continuous-record or peak-flow (crest-stage) gaging stations are placed on the upstream and downstream wingwall of culverts to ensure water-surface elevations are recorded properly.

Culverts placed under roadways tend to cause an abrupt change in the characteristics of flow. The flow in the approach of the culvert usually is considered tranquil and fairly uniform (Rantz and others, 1982). As flow proceeds through the culvert, however, tranquil, critical, or rapid conditions may exist if the culvert is partially filled. This transition of flow results in rapidly varying flow conditions in which acceleration plays the primary role (rather than boundary friction). The culvert also may flow full under pressure conditions (Rantz and others, 1982).

Flow through culverts is classified into six types on the basis of the relative heights of the headwater and tailwater elevations and the location of the control section. Bodhaine (1968) presents a full discussion of the six types of culvert flow, as well as procedures used to determine peak discharge at culverts. In order to use procedures outlined by Bodhaine (1968), discharge coefficients must be selected for the culvert geometry and flow type. Selection of discharge coefficients can be somewhat subjective and may be the primary source of uncertainty associated with culvert-discharge computations.

Because the ephemeral streamflow sites in Maricopa County typically are visited only after flow occurs, determining the flow type can be difficult at best. Stage gages at the upstream and downstream ends of the culvert may assist in flow-type determination; however, the selection of flow type may require a certain amount of interpretation of flow and field conditions long after the flow has ended.

Finally, sediment and debris carried downstream by moderate to large flows in Maricopa County have been known to fill culverts and catch on culvert walls, thereby decreasing the conveyance of the culvert. Accurate representation of culvert geometry, or area of flow inside the culvert, is required for indirect computation of discharge at these structures; however, when sediment or debris, such as vegetation, decrease the effective flow area, the timing of the clogging effect during the flow is unknown. The assumption, however, often is made that sediment is deposited following peak flow during the flow recession, and that debris is carried on the rising stage of flow. These assumptions may be erroneous and could lead to large errors for culvert peak-flow computations. The accuracy of discharge measurements made using hydraulic equations for culvert flow also is rated similar to the accuracy of slope-area and slope-conveyance measurements.

Potential Errors Associated with Step-Backwater Computations

Because of the ephemeral nature of most of the selected streams in this report and the episodic nature of runoff, high-flow current-meter or indirect measurements may not be available for rating-curve development. The rating curves may be extrapolated to higher stages using step-backwater computations. In calculating step-backwater computations, water-surface profiles for selected discharges are computed by successive approximations (Rantz and others, 1982). A full discussion of the collection and analysis of information required for rating-curve development using step-backwater computations is presented by Bailey and Ray (1966) and Davidian (1984). Errors associated with step-backwater computations are similar to errors associated with indirect measurements of peak discharge. For instance, roughness coefficients also must be selected for these computations, and the bed configuration and vegetation conditions during peak flow may be considerably different than conditions when step-backwater surveys are made. The rating system for the accuracy of step-backwater computations is similar to the rating system for accuracy of slope-area and slope-conveyance indirect measurements; however, step-backwater computations used to define stage-discharge relations generally are considered by many to contain the largest degree of error compared with all previously described methods.

PRESENTATION OF SITE INFORMATION

The previous sections of this report focus primarily on errors associated with discharge measurements utilizing standard methodologies that are employed by the USGS. These measurements are the fundamental component for the development of stage-discharge relations. Stage data that are recorded in the field are applied to these relations, and the relations subsequently are utilized to compute discharge data. For continuously recording stations, stage data generally are acquired at 15-minute intervals. Utilizing the stage-discharge relation, a discrete discharge value is computed for each stage reading, and ultimately mean daily discharges, mean annual discharges, peak flow, total volume of flow for specified time periods, and other components are derived and reported and are utilized by end users of the data. For peak-flow (crest-stage) gaging stations, peak stage is acquired in the field and then applied to the site-specific stage-discharge relation. Peak flow or discharge is computed using the relation and is the discrete data value reported for these types of stations.

In subsequent sections of this report, the derived stage-discharge relations are displayed for 17 selected streamflow-gaging stations in Maricopa County, Arizona. The discharge measurements used to develop the relations, as well as potential error bars, also are displayed. By examining these illustrations, users of streamflow data can acquire a better understanding of potential errors associated with the stage-discharge relations as well as potential errors associated with discharge data derived from those relations.

Reach and control descriptions, measurements used to define the stage-discharge relation, and a graphical representation of the stage-discharge relation along with error or uncertainty bars are presented for selected streamflow-gaging stations. For seven of the selected sites, the stage-discharge relation was defined primarily by using weir and culvert equations. For the other 10 stage-discharge relations presented in this report, a combination of current-meter measurements and other methods for determining discharge for free-surface open-channel flow situations, such as the indirect or step-backwater methods, were used to derive the relations.

The potential error, in percent of discharge, associated with individual measurements used to define the stage-discharge relations, as well as measurements made subsequent to rating development, are shown in the tables and illustrated in the figures. The error corresponding to each measurement is illustrated using error bars (**table 1**). The error associated with current-meter measurements, indirect measurements of peak discharge, and measurements obtained from weir and culvert computations are reflected only in discharge values. Gage height is considered the known variable for these measurements. Any error associated with gage height (rapidly rising or falling stage, for example) is incorporated in the overall measurement rating. Because discharge is considered the known variable for step-backwater computations, however, errors associated with these computations are reflected only in gage-height values.

A control-stability rating is assigned to each site (**tables 2** and **3**). The ratings are based on a scale of 1 to 5 and are a function of the stability of the low- and high-water controls. Consequently, control-stability ratings are intended to reflect the amount of error associated with developed stage-discharge relations for each site presented in this report. Rating values are defined in the following manner.

1. The low- and high-water controls are considered extremely unstable at all flows. Only alluvial channels may be assigned a value of 1.
2. The control is considered extremely unstable for a small range of flows. An example may be an alluvial channel with stable banks.
3. The control is considered moderately stable for most flows. An example may be gravel-bed streams where channel banks are subject to erosion by high-flow conditions.
4. The control is considered stable for most flows. An example may include gravel-bed streams with stable banks. Other examples include streamflow-gaging stations at weirs and culverts where the channel upstream or downstream from the structure is susceptible to aggradation or degradation.
5. The low- and high-water controls are considered extremely stable at all flows. Examples include a concrete-control section across the width of the channel downstream from the gaging station as well as concrete-lined banks, or weirs and culverts where the channel upstream and downstream from the structure is stable.

Table 1. Measurement types and associated potential errors

Rating	Potential errors, in percent	Rating	Potential errors, in percent
Current-meter method		**Indirect methods**	
Good	≤ 5	Good	±10
Fair	≤ 8	Fair	±15
Poor	[1] > 8	Poor	±25

[1] An error greater than 8 percent is displayed as 10 percent in the graphical representation of the error bars.

Table 2. Selected continuous-record streamflow-gaging stations, Maricopa County, Arizona

Station number	Station name	Type of control	Control-stability rating
09512162	Indian Bend Wash at Curry Road, Tempe	Culvert	4
09512200	Salt River Tributary in South Mountain Park, at Phoenix.	Culvert	4
09513650	Agua Fria River at El Mirage	Gravel riffle[1]	3
09513780	New River near Rock Springs	Gravel riffle[1]	3
09513860	Skunk Creek near Phoenix	Concrete apron	4
09516500	Hassayampa River near Morristown	Shifting sand at low flows[1]	2
09517000	Hassayampa River near Arlington	Gravel riffle (low-flow channel)[1]	2
09517490	Centennial Wash at Southern Pacific Railroad Bridge near Arlington.	Gravel riffle[1]	3

[1] Channel control at high flows.

Table 3. Selected peak-flow (crest-stage) gaging stations, Maricopa County, Arizona

Station number	Station name	Type of control	Control-stability rating
09510180	Rock Creek near Sunflower	Concrete weir[1]	3
09512700	Agua Fria River Tributary No. 2 near Rock Springs	Culvert	4
09514200	Waterman Wash near Buckeye	Channel control	2
09516600	Ox Wash near Morristown	Culvert	4
09501300	Tortilla Creek at Tortilla Flat	Irregular-shaped concrete weir	4
09516800	Jack Rabbit Wash near Tonopah	Channel control	2
09517280	Tiger Wash near Aguila	Shifting sand and gravel at low flows[2]	2
09519750	Bender Wash near Gila Bend	Bedrock outcrop[2]	3
09519760	Sauceda Wash near Gila Bend	Culvert	4

[1] Channel control when weir is buried by sand.
[2] Channel control at high flows.

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SITE INFORMATION FOR SELECTED CONTINUOUS-RECORD STREAMFLOW-GAGING STATIONS, MARICOPA COUNTY, ARIZONA

09512162 Indian Bend Wash at Curry Road, Tempe, Arizona

Description of channel conditions.—The low-flow control at the Curry Road site is the upstream invert of the series of culverts. Two additional cemented boulder weirs are about 400 ft and 800 ft upstream, and a golf-cart path is 100 ft upstream from the gaging station. The channel is nearly straight for 0.75 mi upstream from the gaging station. The channel has boulders and cobbles for 100 ft upstream and 300 ft downstream from the gaging station. The grass-lined channel, which is upstream from the boulders and cobbles, is mowed periodically (public golf course). The amount and height of grass and weeds present in the cobble channel near the gaging station, however, varies and probably influences the stage-discharge relation for low to moderate flows.

Table 4. Data from discharge measurements, Indian Bend Wash at Curry Road, Tempe, Arizona

Date	Gage height, in feet	Discharge, in cubic feet per second	Method	Measurement rating	Potential error, in percent
Measurements used to define rating 3					
07–24–92	2.20	803	Current meter	Good	5
10–06–93	6.00	6,040	Current meter	Poor	15
02–26–96	.89	4.17	Current meter	Fair	8
07–26–96	.84	1.34	Current meter	Poor	15
07–26–96	.82	.55	Current meter	Poor	15
08–19–96	1.05	18.3	Current meter	Fair	8
09–02–96	1.52	180	Current meter	Fair	8
01–14–97	1.06	22.1	Current meter	Good	5
08–26–97	1.32	103	Current meter	Fair	8
08–26–97	1.37	123	Current meter	Fair	8
Measurements made since rating 3 was developed					
02–05–98	1.38	133	Current meter	Fair	8
02–25–98	1.28	107	Current meter	Fair	8

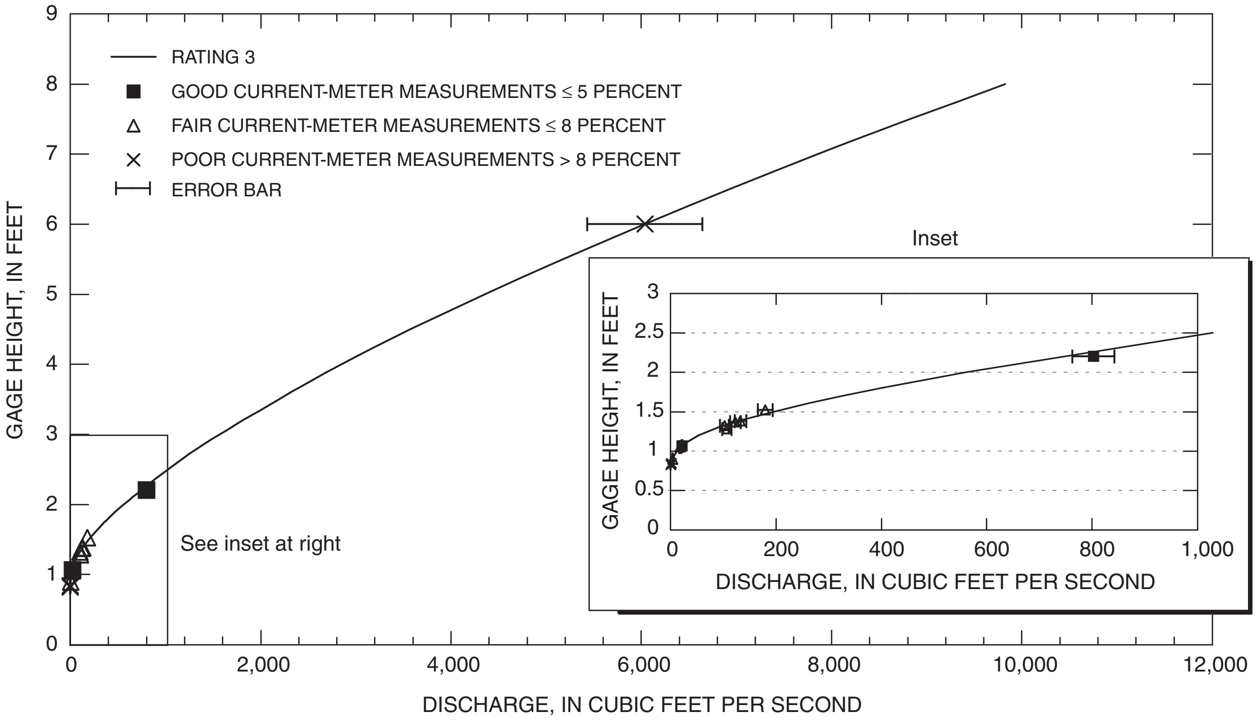

Figure 2. Graph showing stage-discharge relation, Indian Bend Wash at Curry Road, Tempe, Arizona.

Figure 3. View looking downstream at gaging station from right bank, Indian Bend Wash at Curry Road, Tempe, Arizona.

09512200 Salt River Tributary in South Mountain Park, at Phoenix, Arizona

Description of channel conditions.—The low-flow control is the upstream invert of the culvert, which is susceptible to fill of sand- and gravel-sized material including angular cobbles. At this location, however, the channel alluvium is shallow and is not subject to considerable shifting. The medium-flow control is the culvert. The sensitivity of the rating decreases greatly when water overflows the left bank. This decrease in sensitivity has caused the rating to be changed several times during the period of record. Upstream from the gaging station, the channel is straight for about 500 ft and is between 15 to 40 ft wide. The channel banks generally are covered with vegetation and mesquite trees. Downstream from the culvert, the channel is straight for about 150 ft and is between 10 and 25 ft wide. The vegetation becomes thicker in the downstream reach of the channel.

Table 5. Data from discharge measurements, Salt River Tributary in South Mountain Park, at Phoenix, Arizona

[Method from Kennedy (1984)]

Date	Gage height, in feet	Discharge, in cubic feet per second	Method	Measurement rating	Potential error, in percent
			Measurements used to define rating 2		
07–22–61	9.09	370	Type I culvert computation	Fair	15
07–22–61	1.26	.34	Current meter	Good	5
10–19–63	9.52	530	Type V flow through culvert and overflow computation	Fair	15
08–26–64	5.8	161	Type I culvert computation	Fair	15
08–26–64	3.01	31.0	Current meter	Poor	15
08–26–64	2.20	7.94	Current meter	Poor	15
			Measurements made since rating 2 was developed		
01–11–92	1.48	1.19	Current meter	Fair	8

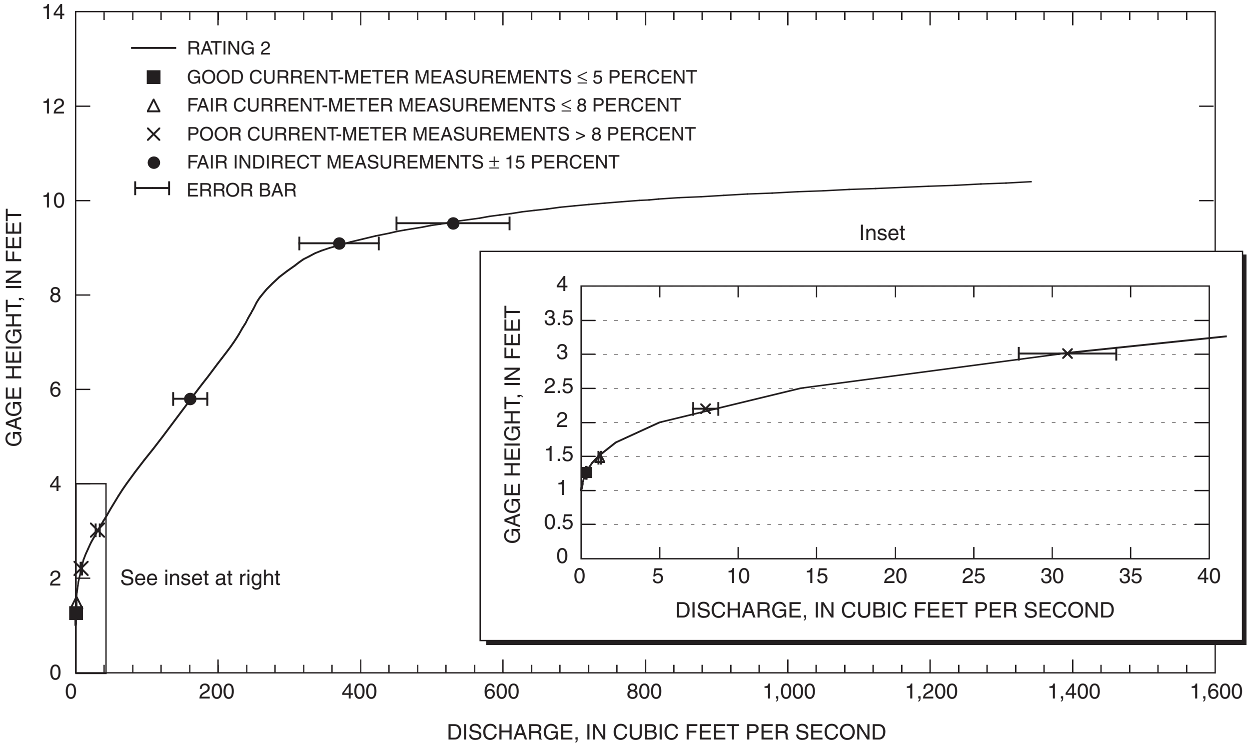

Figure 4. Stage-discharge relation, Salt River Tributary in South Mountain Park, at Phoenix, Arizona.

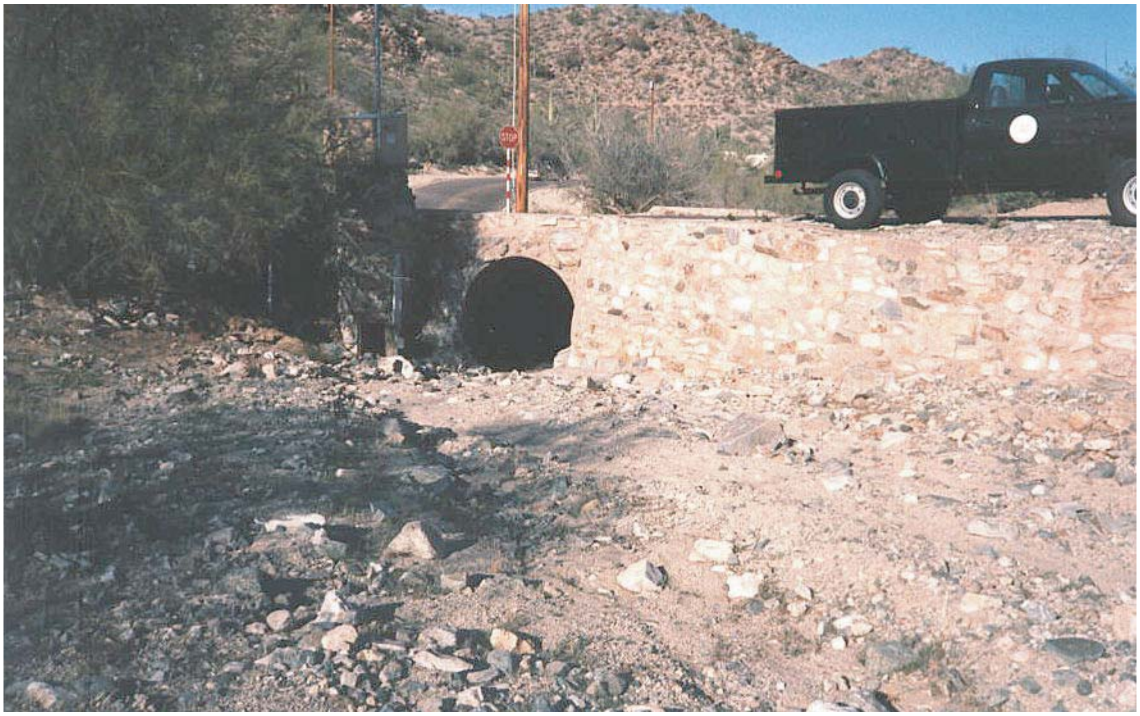

Figure 5. View looking downstream at gaging station, Salt River Tributary in South Mountain Park at Phoenix, Arizona.

09513650 Agua Fria River at El Mirage, Arizona

Description of channel conditions.—The low-water control is a cobble riffle about 100 ft downstream from the gaging station. The channel is fairly straight for about 800 ft upstream and 1,200 ft downstream from the gaging station. The channel is rectangular in shape and is composed primarily of coarse gravel. The main channel is about 600 ft wide at the gaging station, but widens slightly above and below the gaging station. Channel banks are shaped and lined with rocks to minimize erosion at high flow. The high-flow control is the channel.

Table 6. Data from discharge measurements, Agua Fria River at El Mirage, Arizona

Date	Gage height, in feet	Discharge, in cubic feet per second	Method	Measurement rating	Potential error, in percent
Measurements used to define rating 5					
03–06–78	7.95	9,870	Slope area	Poor	25
12–19–78	16.74	58,400	Slope area	Good	10
01–05–95	3.09	40.4	Current meter	Fair	8
Measurements made since rating 5 was developed					
03–14–98	2.83	6.84	Current meter	Good	5
02–04–98	2.43	.22	Current meter	Poor	15
02–18–98	2.91	17.7	Current meter	Poor	15

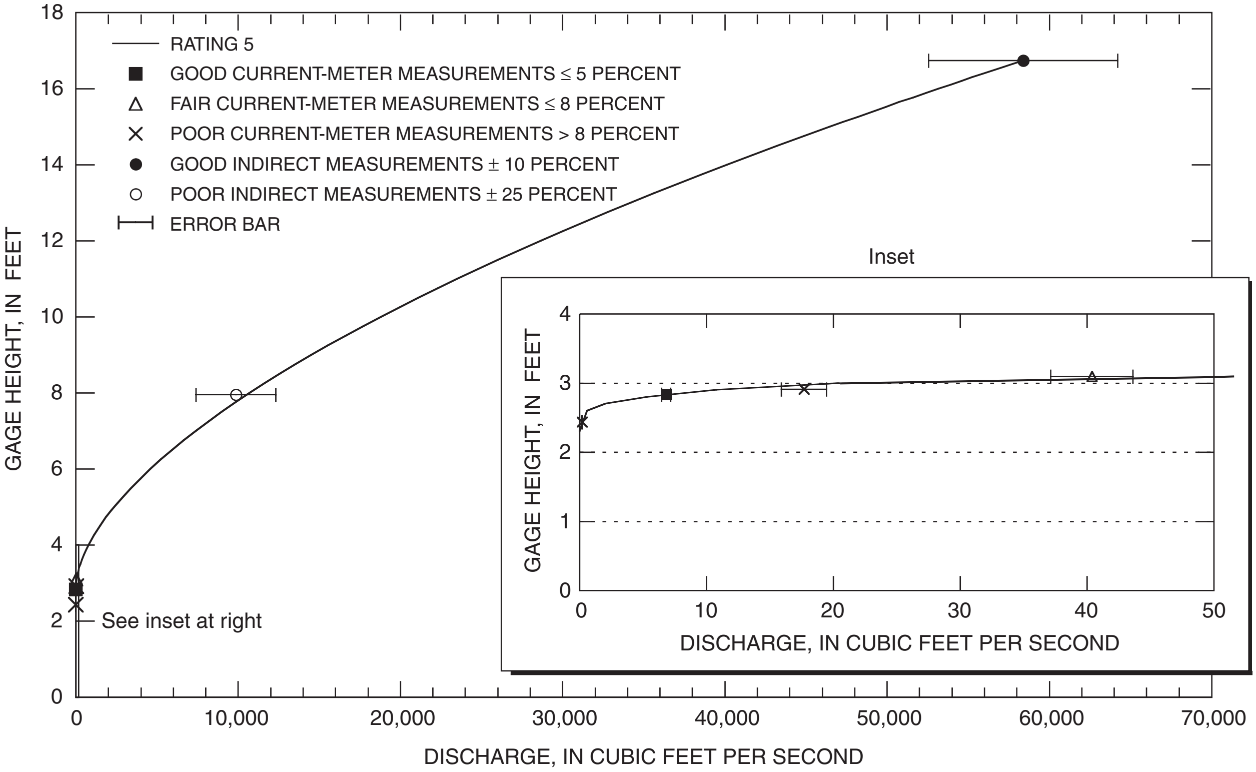

Figure 6. Stage-discharge relation, Agua Fria River at El Mirage, Arizona.

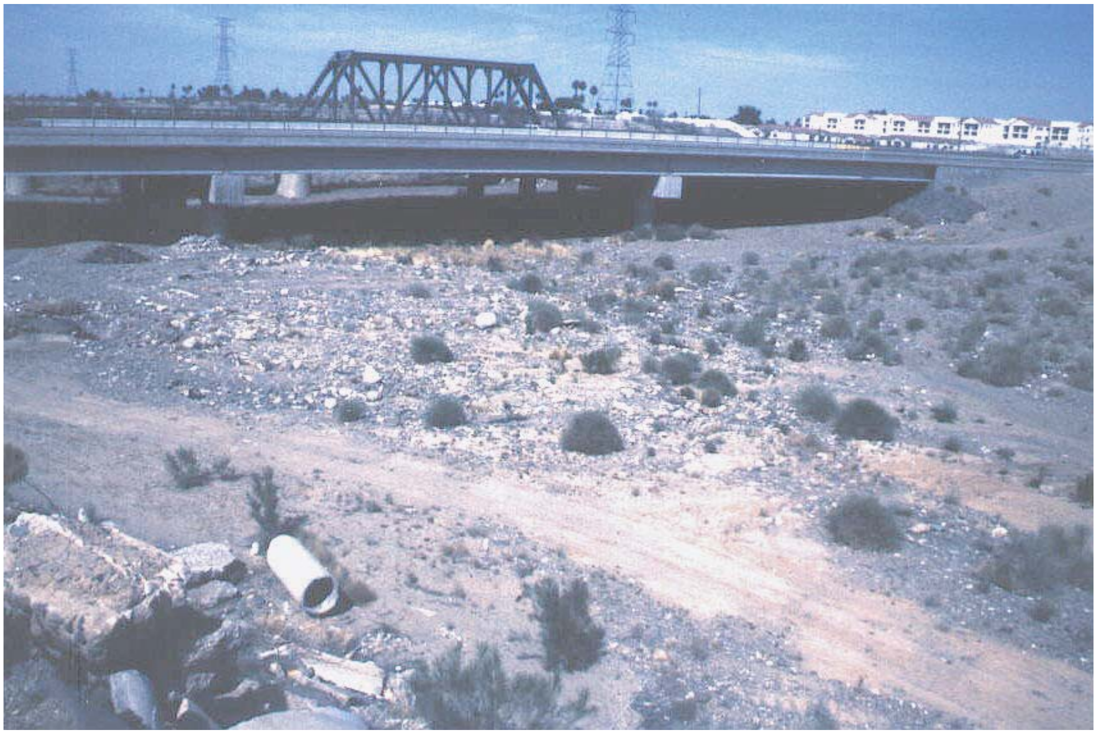

Figure 7. View looking upstream toward gaging station from right bank, Agua Fria River at El Mirage, Arizona.

09513780 New River near Rock Springs, Arizona

Description of channel conditions.—The low- and medium-flow control is the sand-and-gravel riffle that begins about 25 ft below the gaging station and extends to a graded road crossing about 200 ft downstream from the gaging station. The road crossing is susceptible to scour and fill because of automobile traffic, flooding, and road-grading activities. The high-flow control is the channel. The site has an overflow channel to the left of the main channel at a gage height of about 9 ft. The left bank has sparse vegetation, and the right bank consists of steep bedrock near the gaging station with sparse vegetation downstream.

Table 7. Data from discharge measurements, New River near Rock Springs, Arizona

Date	Gage height, in feet	Discharge, in cubic feet per second	Method	Measurement rating	Potential error, in percent
Measurements used to define rating 9					
01–08–93	10.80	12,600	Slope area	Fair	15
01–13–93	2.70	180	Current meter	Fair	8
01–28–93	1.96	39.6	Current meter	Fair	8
03–03–93	2.04	50.4	Current meter	Fair	8
05–14–93	1.37	4.56	Current meter	Fair	8
09–16–93	1.13	.52	Current meter	Fair	8
12–02–93	1.32	2.74	Current meter	Good	5
Measurements made since rating 9 was developed					
02–16–94	1.33	3.07	Current meter	Fair	8
04–28–94	1.17	.45	Current meter	Poor	15
05–19–94	1.17	.07	Current meter	Fair	8
01–09–95	1.84	31.9	Current meter	Fair	8
03–03–95	1.65	11.7	Current meter	Fair	8
04–04–95	1.38	8.23	Current meter	Good	5
04–27–95	1.27	3.68	Current meter	Fair	8
03–06–96	1.00	.49	Current meter	Poor	15
09–13–96	.96	.89	Current meter	Poor	15
01–14–97	2.40	110	Current meter	Poor	15
01–15–97	1.76	28.3	Current meter	Good	5
02–04–97	1.12	2.16	Current meter	Poor	15
02–25–97	1.01	.69	Current meter	Good	5
03–10–97	1.14	2.42	Current meter	Fair	8
04–01–97	.94	.72	Current meter	Poor	15
04–29–97	.94	.17	Current meter	Poor	15
09–12–97	1.29	6.03	Current meter	Fair	8
02–04–98	3.58	532	Current meter	Fair	8
02–05–98	2.14	67.9	Current meter	Good	5
02–12–98	1.76	25.3	Current meter	Fair	8
02–25–98	2.57	153	Current meter	Fair	8
03–02–98	1.79	22.1	Current meter	Good	5
03–16–98	1.43	5.80	Current meter	Fair	8
03–27–98	2.48	126	Current meter	Fair	8
03–30–98	2.50	161	Current meter	Good	5
04–17–98	1.40	11.7	Current meter	Fair	8
05–15–98	1.06	1.88	Current meter	Poor	15

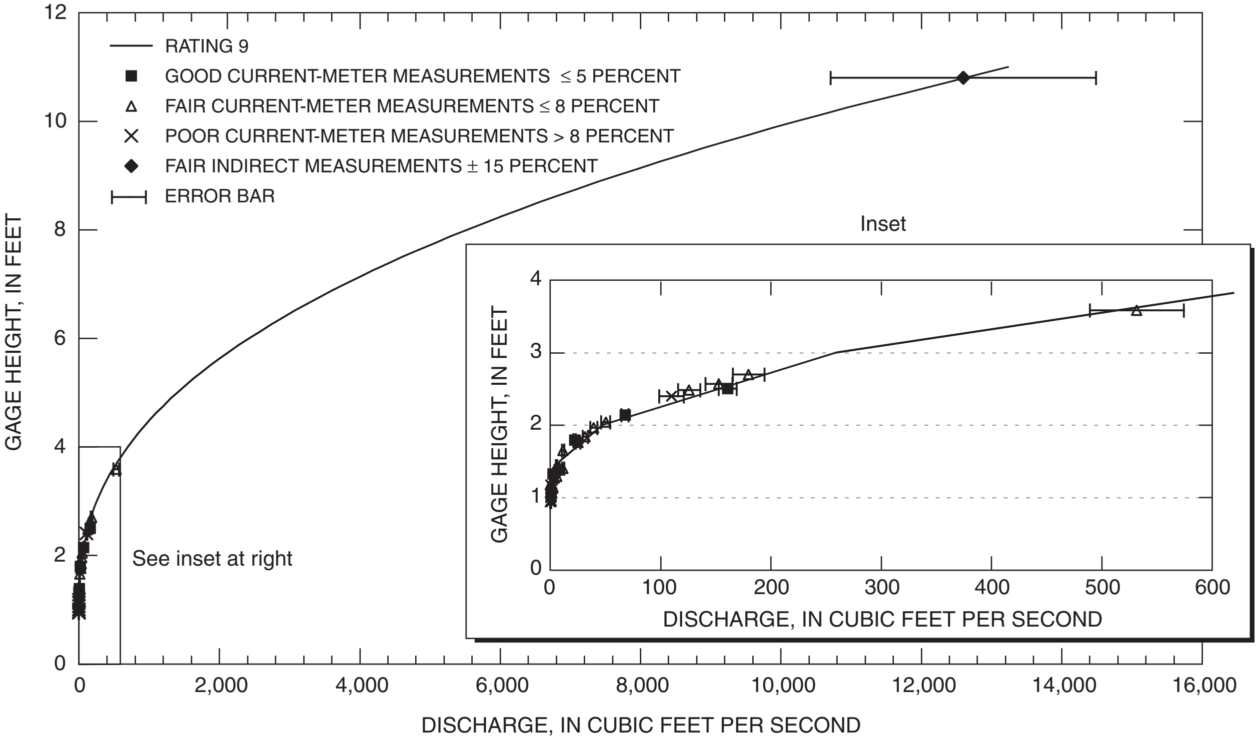

Figure 8. Stage-discharge relation, New River near Rock Springs, Arizona.

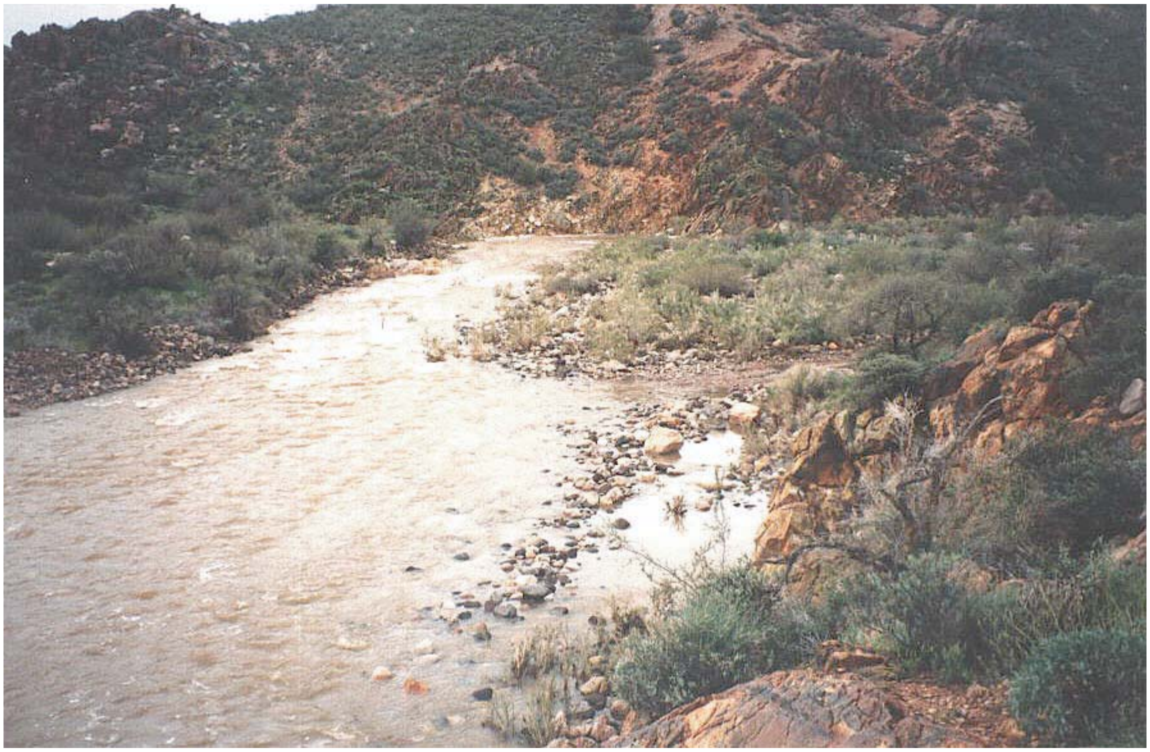

Figure 9. View looking downstream from control on right bank, New River near Rock Springs, Arizona.

09513860 Skunk Creek near Phoenix, Arizona

Description of channel conditions.—The watercourse is channelized above and below the present streamflow-gaging station by sloped earthen-dike walls covered with large angular boulders. The channel bottom has coarse sand and gravel and a cover of sparse vegetation. A concrete apron that is the control at all stages extends the entire width of the channel. The apron begins about 85 ft below the station and extends 240 ft to eight box culverts that run beneath Interstate 17 and Frontage Road. Vegetation in the channel is razed periodically by the Flood Control District of Maricopa County.

Table 8. Data from discharge measurements, Skunk Creek near Phoenix, Arizona

Date	Gage height, in feet	Discharge, in cubic feet per second	Method	Measurement rating	Potential error, in percent
Measurements used to define rating 10					
07–22–86	2.59	1,040	Slope conveyance	Poor	25
11–01–87	1.52	43.2	Current meter	Fair	8
07–24–90	1.52	40	Current meter	Fair	8
08–12–90	5.45	8,160	Slope area	Fair	15
03–01–91	2.32	618	Current meter	Good	5
Measurements made since rating 10 was developed					
01–08–93	2.16	483	Current meter	Fair	8
01–05–95	1.70	168	Current meter	Fair	8
01–06–95	1.62	120	Current meter	Fair	8
12–22–97	1.39	16.5	Current meter	Fair	8
02–04–98	2.02	285	Current meter	Fair	8
02–04–98	2.17	371	Current meter	Fair	8

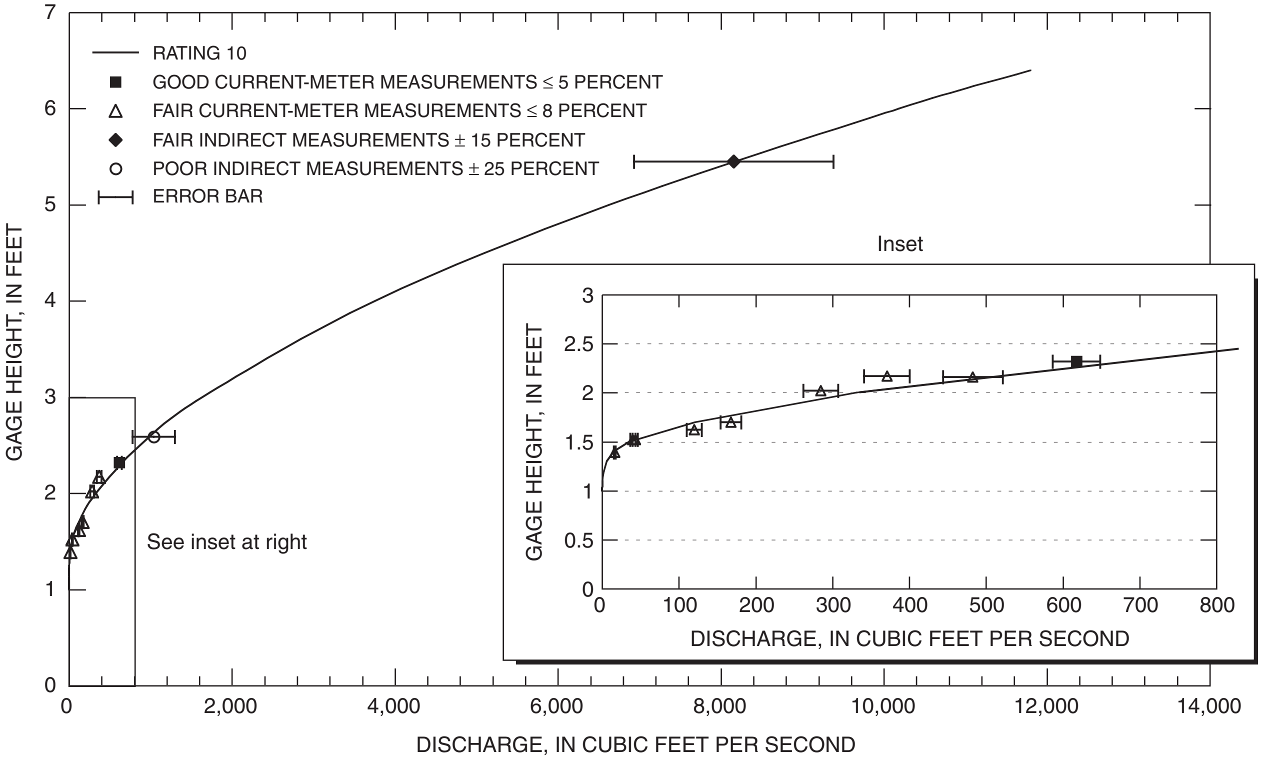

Figure 10. Stage-discharge relation, Skunk Creek near Phoenix, Arizona.

Figure 11. View looking downstream at gaging station from left bank, Skunk Creek near Phoenix, Arizona.

09516500 Hassayampa River near Morristown, Arizona

Description of channel conditions.—The low- and medium-flow control is a 200-foot wide sand channel that is straight for 1,000 ft above and below the streamflow-gaging station. The channel-bed material is a coarse sand-and-gravel mix that is subject to considerable shifting at all stages. The left bank is a near-vertical bedrock cliff. The right bank is a bedrock outcrop that slopes away from the channel floor. A railroad track right-of-way is adjacent to the right bank of the channel. Mesquite trees line the right bank below the terrace. A sharp right bend in the channel and a railroad-bridge abutment 1,000 ft downstream acts as the control during high flows.

Table 9. Data from discharge measurements, Hassayampa River near Morristown, Arizona

Date	Gage height, in feet	Discharge, in cubic feet per second	Method	Measurement rating	Potential error, in percent
Measurements used to define rating 6					
09–05–74[1]	19.05	47,500	Slope area	Poor	25
02–20–80	14.32	17,000	Slope area	Poor	25
01–08–93	15.91	26,300	Slope conveyance	Poor	25
02–17–95	8.25	850	Current meter	Poor	15
03–14–95	7.93	323	Current meter	Good	5
04–13–95	7.36	23.0	Current meter	Poor	15
Measurements made since rating 6 was developed					
04–27–96	7.32	37.7	Current meter	Poor	15
05–16–95	7.14	7.35	Current meter	Poor	15
06–26–95	7.05	.07	Current meter	Poor	15
08–29–95	6.76	2.28	Current meter	Poor	15
09–18–95	6.71	1.25	Current meter	Poor	15
10–11–95	6.18	.23	Current meter	Poor	15
01–13–97	6.94	9.92	Current meter	Poor	15
09–26–97	9.61	3,796	Current meter	Fair	8
09–26–97	8.65	879	Current meter	Fair	8
01–09–98	7.5	1.02	Current meter	Poor	15
01–28–98	7.45	.96	Current meter	Poor	15
02–18–98	7.64	35.6	Current meter	Poor	15
02–25–98	7.76	156	Current meter	Poor	15
04–01–98	7.63	157	Current meter	Fair	8
04–16–98	7.63	146	Current meter	Fair	8
04–30–98	7.3	38	Current meter	Fair	15

[1] The original measurement is missing; therefore, a poor rating is assumed.

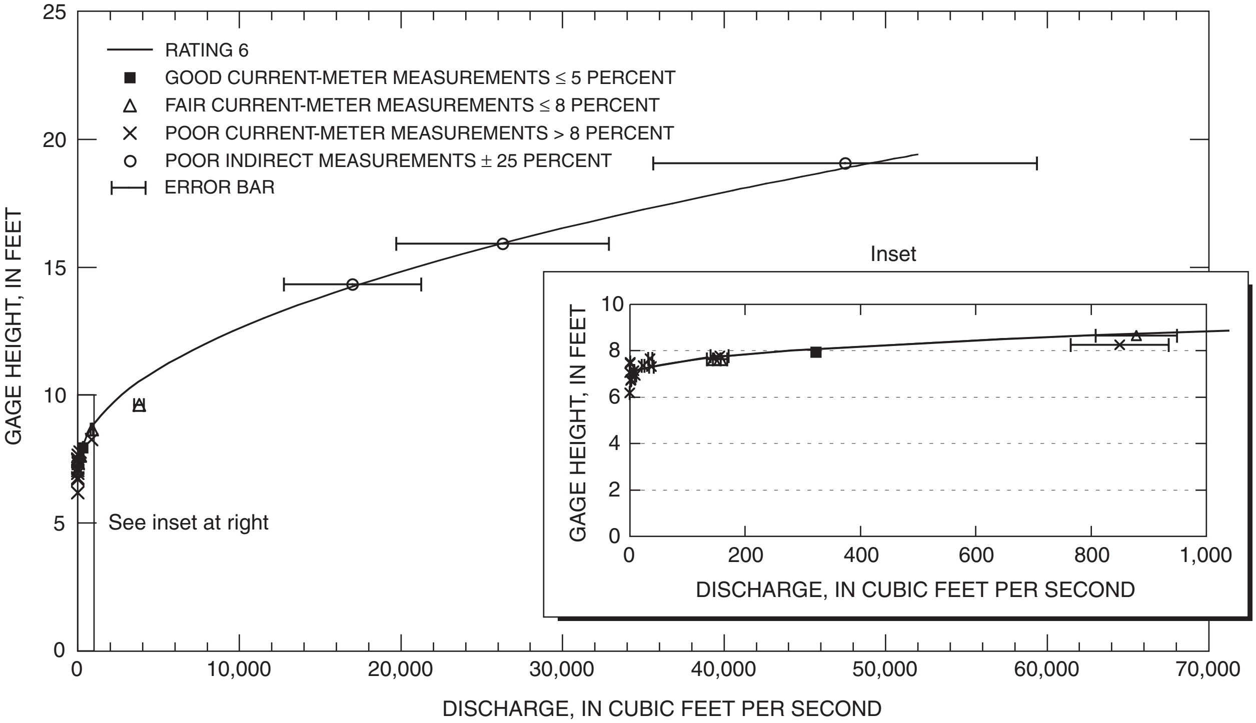

Figure 12. Stage-discharge relation, Hassayampa River near Morristown, Arizona.

Figure 13. View looking downstream at gaging station from midchannel, Hassayampa River near Morristown, Arizona.

09517000 Hassayampa River near Arlington, Arizona

Description of channel conditions.—The low-flow channel is the control most of the time; a gravel riffle downstream from the gage becomes effective at extremely low flows (less than 5 ft^3/s). The channel is subject to scour and fill at all stages. The channel is fairly straight for 750 ft above and about 1,000 ft below the gaging station but does slightly turn toward the right bank 75 ft upstream from the bridge. The channel is trapezoidal in shape and is unstable at high flows. Substantial amounts of vegetation (saltcedar, willow, mesquite, and palo verde) may grow along the edge of the low-flow channel during sustained periods of low flow. Vegetation is more sparsely distributed throughout the main channel. Higher flows have a tendency to scour and uproot the vegetation downstream from the station. Scour of as much as 8 ft has been measured by depth-sounding methods from the bridge during floods. The average low-flow channel width is about 30 ft, and the high-flow channel width is about 250–300 ft. Flow is primarily irrigation return flow most of the year.

Table 10. Data from discharge measurements, Hassayampa River near Arlington, Arizona

Date	Gage height, in feet	Discharge, in cubic feet per second	Method	Measurement rating	Potential error, in percent
Measurements used to define rating 7					
02–15–95	10.60	3,900	Slope area	Fair	15
03–06–95	9.90	3,300	Slope area	Fair	15
06–20–95	5.35	55.4	Current meter	Good	5
07–19–95	5.17	31.7	Current meter	Fair	8
08–21–95	5.76	131	Current meter	Good	5
Measurements made since rating 7 was developed					
11–07–96	4.90	14.2	Current meter	Good	5
02–13–97	5.00	33.5	Current meter	Poor	15
04–08–97	4.84	26.8	Current meter	Good	5
04–08–97	4.85	24.7	Current meter	Good	5
05–28–97	5.04	47.6	Current meter	Fair	8
07–09–97	5.02	40.6	Current meter	Fair	8
08–09–97	5.77	165	Current meter	Fair	8
08–11–97	5.48	64.9	Current meter	Fair	8
08–14–97	9.45	2,550	Slope area	Poor	25
09–26–97	8.40	851	Current meter	Poor	15
09–26–97	9.05	1,613	Current meter	Poor	15
10–15–97	4.85	53.1	Current meter	Fair	8
10–17–97	4.63	51.3	Current meter	Fair	8
11–26–97	4.70	56.2	Current meter	Fair	8
01–09–98	4.58	50.6	Current meter	Fair	8
02–04–98	5.20	103	Current meter	Fair	8
02–09–98	5.50	158	Current meter	Good	5
03–10–98	4.67	56.8	Current meter	Fair	8
04–24–98	4.39	44.3	Current meter	Good	5
05–08–98	4.54	53.1	Current meter	Fair	8

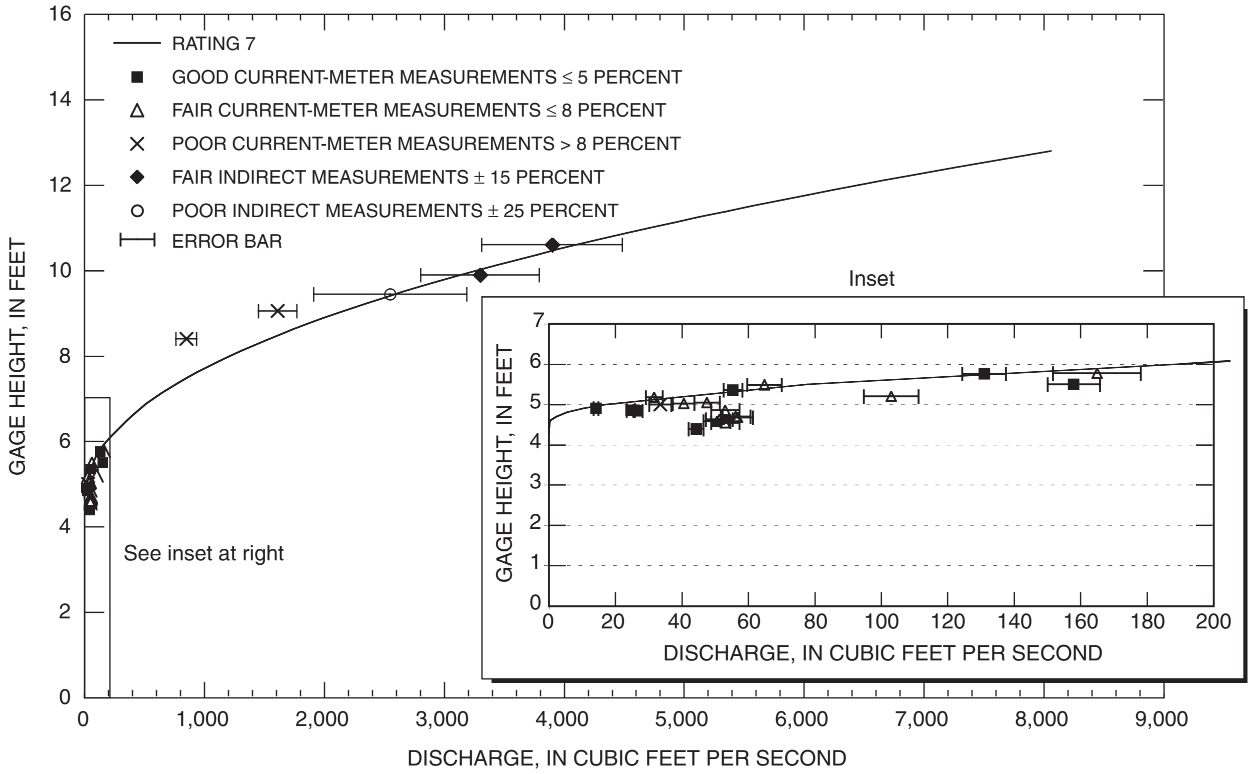

Figure 14. Stage-discharge relation, Hassayampa River near Arlington, Arizona.

Figure 15. View looking downstream from bridge, Hassayampa River near Arlington, Arizona.

09517490 Centennial Wash at Southern Pacific Railroad Bridge near Arlington, Arizona

Description of channel conditions.—The location of the low-flow control, a gravel riffle downstream from the gaging station, varies for each flow. The machine-graded channel banks become the control during medium and high flows. The wash upstream from the railroad bridge approaches the bridge from a northwestern direction. At the bridge, the wash abruptly turns to the south. Winters Wash joins Centennial Wash from the northeast just north of the bridge. The channel is fairly straight for about 2,000 ft downstream from the railroad bridge and gradually expands and then bends to the southeast. The channel shape is fairly trapezoidal, about 300 ft wide, and composed of sand and clay with gravel deposits in places. Brush and small trees grow in the channel above the gaging station, but the channel is clear below the gaging station. The banks and channel are maintained by frequent bulldozing. The low-flow channel, which is about 10 ft wide, meanders downstream from the bridge adjacent to the right bank. The stream is ephemeral and is dry most of the year.

Table 11. Data from discharge measurements, Centennial Wash at Southern Pacific Railroad Bridge near Arlington, Arizona

Date	Gage height, in feet	Discharge, in cubic feet per second	Method	Measurement rating	Potential error, in percent
Measurements used to define rating 6					
07–15–96	4.05	822	Current meter	Fair	8
07–15–96	3.73	643	Current meter	Fair	8
Measurements made since rating 6 was developed					
08–12–97	5.20	1,796	Slope conveyance	Poor	25

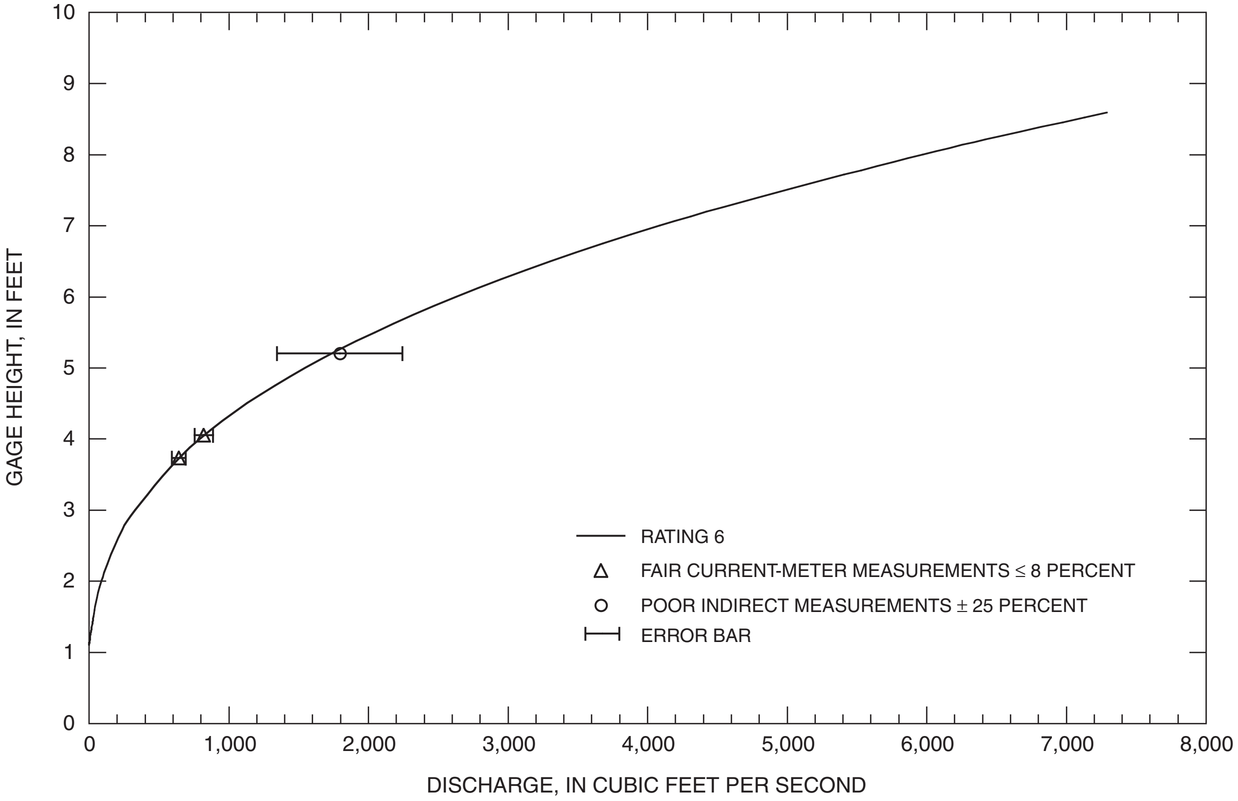

Figure 16. Stage-discharge relation, Centennial Wash at Southern Pacific Railroad Bridge near Arlington, Arizona.

Figure 17. View looking upstream at gaging station from left bank, Centennial Wash at Southern Pacific Railroad Bridge near Arlington, Arizona.

SITE INFORMATION FOR SELECTED PEAK-FLOW (CREST-STAGE) GAGING STATIONS, MARICOPA COUNTY, ARIZONA

09510180 Rock Creek near Sunflower, Arizona

Description of channel conditions.—The low-water control is a concrete weir 50 ft long with a small v-notch that controls stage for extremely low flows. The medium control is the concrete weir. At higher stages, the channel may control flow. The weir is often covered with sand, and its effectiveness during moderate to large flows is unknown. The channel is straight 75 ft upstream and 300 ft downstream from the gaging station. The left bank is a 10-foot high rocky bank with scattered trees and brush. The slope varies from vertical to 1 to 1, and the right bank is a fairly flat flood plain with many trees, scattered rocks, and brush. The streambed is composed of loose sand with scattered grass and brush below the control.

Table 12. Data from discharge measurements, Rock Creek near Sunflower, Arizona

Date	Gage height, in feet	Discharge, in cubic feet per second	Method	Measurement rating	Potential error, in percent
Measurements used to define rating 5					
12–22–65	6.88	1,900	Slope area	Poor	25
01–05–95	4.59	151	Current meter	Good	5
01–27–97	3.64	6.31	Current meter	Fair	8
03–03–97	3.83	8.69	Current meter	Fair	8
Measurements made since rating 5 was developed					
01–08–98	3.69	.72	Current meter	Fair	8
02–06–98	3.87	11.2	Current meter	Fair	8
02–09–98	4.62	155	Current meter	Fair	8

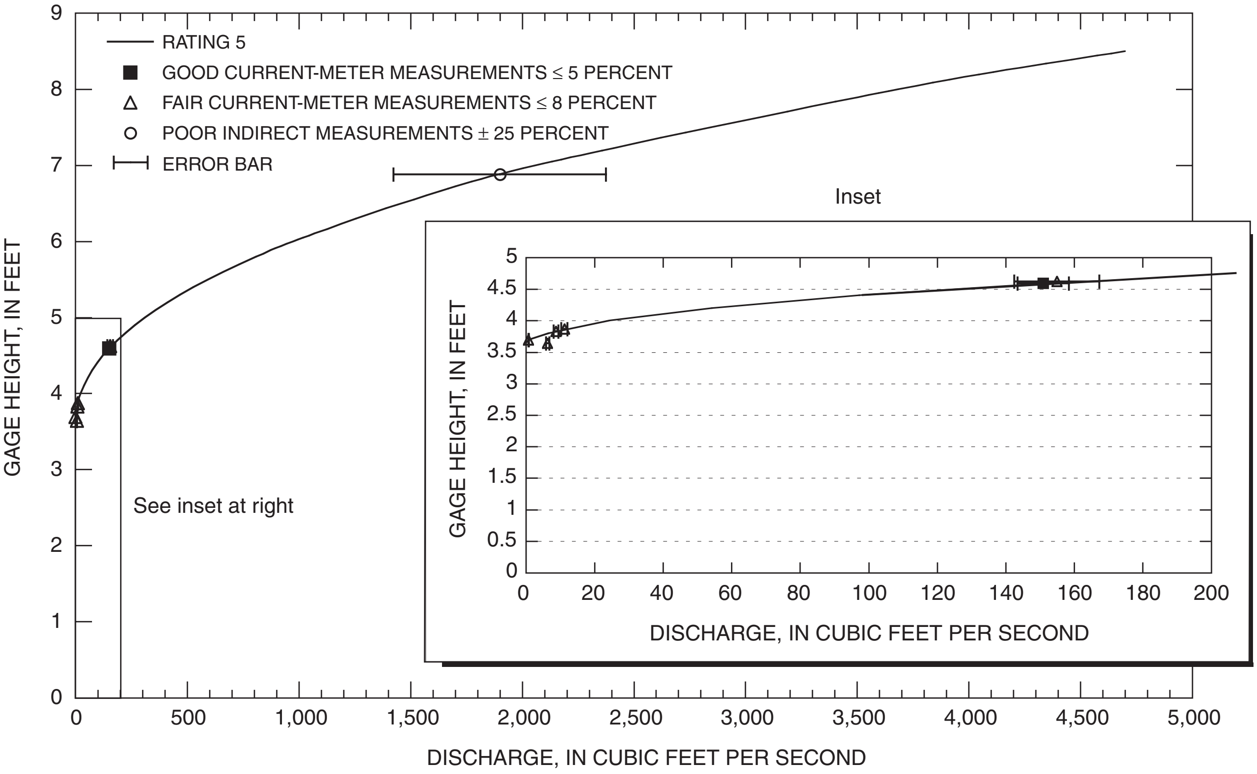

Figure 18. Stage-discharge relation, Rock Creek near Sunflower, Arizona.

Figure 19. View looking upstream at gaging station, Rock Creek near Sunflower, Arizona.

09512700 Agua Fria River Tributary No. 2 near Rock Springs, Arizona

Description of channel conditions.—The control of flows less than about 30 ft^3/s is a riffle formed by fill on the apron between the crest-stage gaging station and the culvert entrance. This sediment is subject to shifting during flow. The box culvert forms the control for higher flows with Type I flow below about a 7.2-foot gage height and Type 5 at higher stages (Bodhaine, 1968). The highway embankment and pavement also form the control for road overflow at extremely high stages.

Table 13. Data from discharge measurements, Agua Fria River Tributary No. 2 near Rock Springs, Arizona

Date	Gage height, in feet	Discharge, in cubic feet per second	Method	Measurement rating	Potential error, in percent
Measurements used to define rating 2					
08–16–63	6.28	411	Culvert	Good	10
08–22–63	5.06	292	Culvert	Good	10
08–02–64	19.54	1,200	Culvert	Good	10
Measurements made since rating 2 was developed					
08–02–74	10.4	721	Culvert	Fair	15
02–04–98	1.06	14.8	Current meter	Poor	15

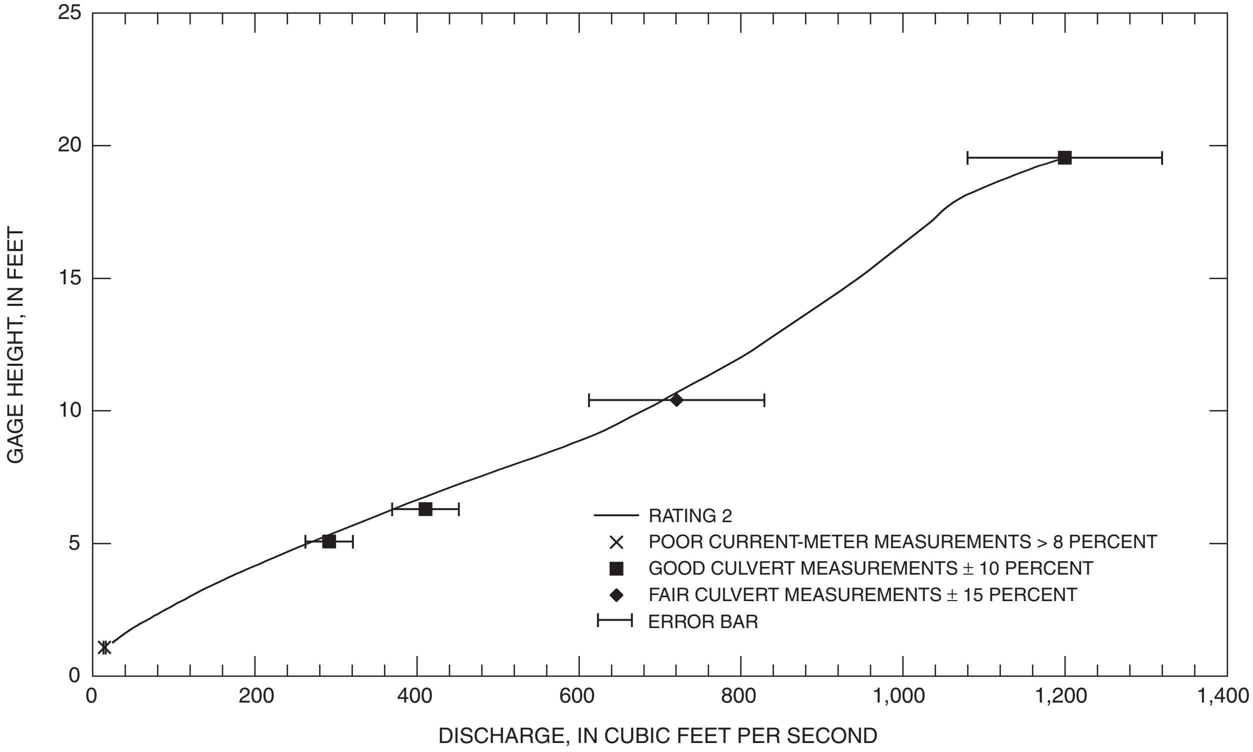

Figure 20. Stage-discharge relation, Agua Fria River Tributary No. 2 near Rock Springs, Arizona.

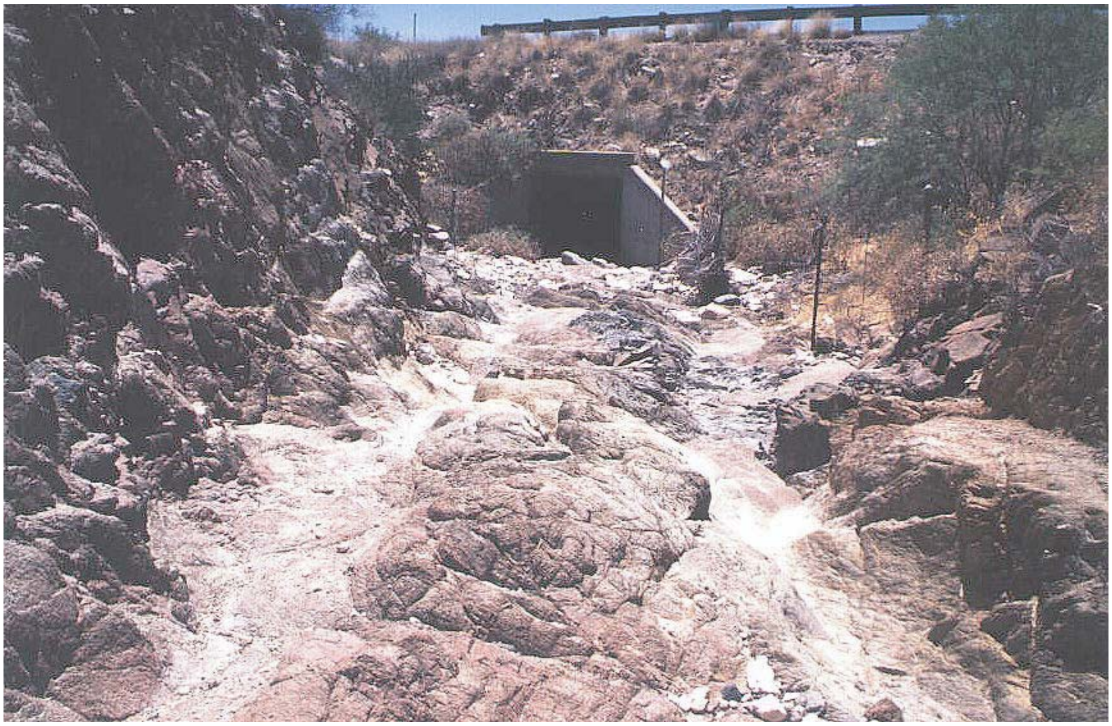

Figure 21. View looking downstream at gaging station, Agua Fria River Tributary No. 2 near Rock Springs, Arizona.

09514200 Waterman Wash near Buckeye, Arizona

Description of channel conditions.—The channel is composed primarily of sand-sized material and is about 120 ft wide. The channel is straight for several hundred feet both upstream and downstream from the crest-stage gaging station. A bar composed of sand and gravel is midchannel just upstream from the station. Vegetation often is found growing on this mound, in other small areas throughout the channel, and on the channel banks. The stage-discharge relation is controlled by the channel for all but low stages. The channel is susceptible to scour and fill during flows, which directly affect the stage-discharge relation.

Table 14. Data from discharge measurements, Waterman Wash near Buckeye, Arizona

Date	Gage height, in feet	Discharge, in cubic feet per second	Method	Measurement rating	Potential error, in percent
Measurements used to define rating 5					
08–08–97	7.8	9,400	Slope conveyance	Poor	25
08–17–97	3.98	408	Slope conveyance	Poor	25
09–06–97	5.10	1,636	Slope conveyance	Poor	25
Measurements made since rating 5 was developed					
02–09–98	3.04	65.5	Current meter	Fair	8

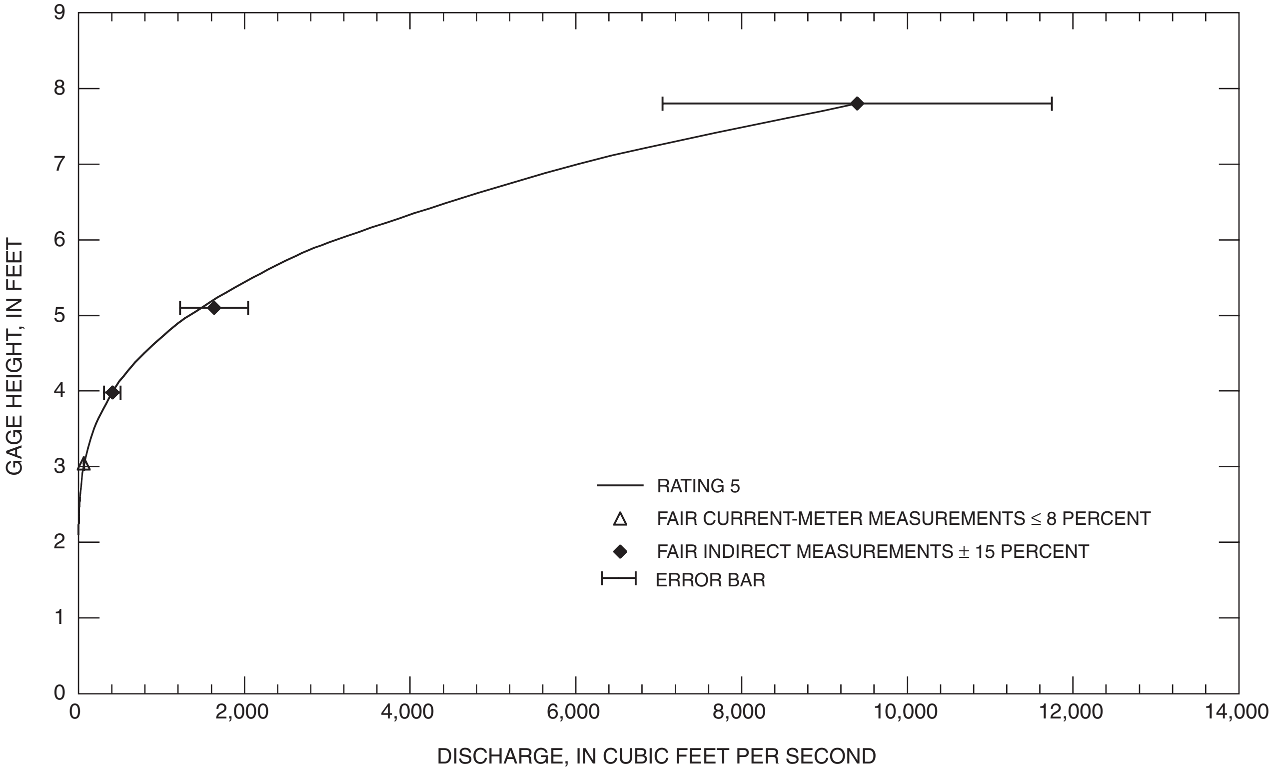

Figure 22. Stage-discharge relation, Waterman Wash, near Buckeye, Arizona.

Figure 23. View looking upstream, Waterman Wash near Buckeye, Arizona.

09516600 Ox Wash near Morristown, Arizona

Description of channel conditions.—The low-flow control is the alluvial channel between the gaging station and the box culvert. The high-flow control is a 3-barrel box culvert, which is just downstream from the gaging station. Sediment can fill the culvert bottom decreasing its effective area during flow. Additionally, vegetation growing in the channel and along the channel margins may affect the theoretical culvert hydraulic measurements and thus, the accuracy of the rating curve. Vegetation dislodged from upstream sources also may catch on the vertical walls of the culvert and further decrease the effective area.

Table 15. Data from discharge measurements, Ox Wash near Morristown, Arizona

Date	Gage height, in feet	Discharge, in cubic feet per second	Method	Measurement rating	Potential error, in percent
Measurements used to define rating 1					
08–64	10.2	2,900	Culvert	Poor	25
12–10–65	4.23	820	Culvert	Fair	15
09–13–66	6.02	1,300	Culvert	Good	10
Measurements made since rating 1 was developed					
08–01–70	1.72	120	Slope conveyance	Poor	25
01–13–97	1.69	38.8	Current meter	Fair	8

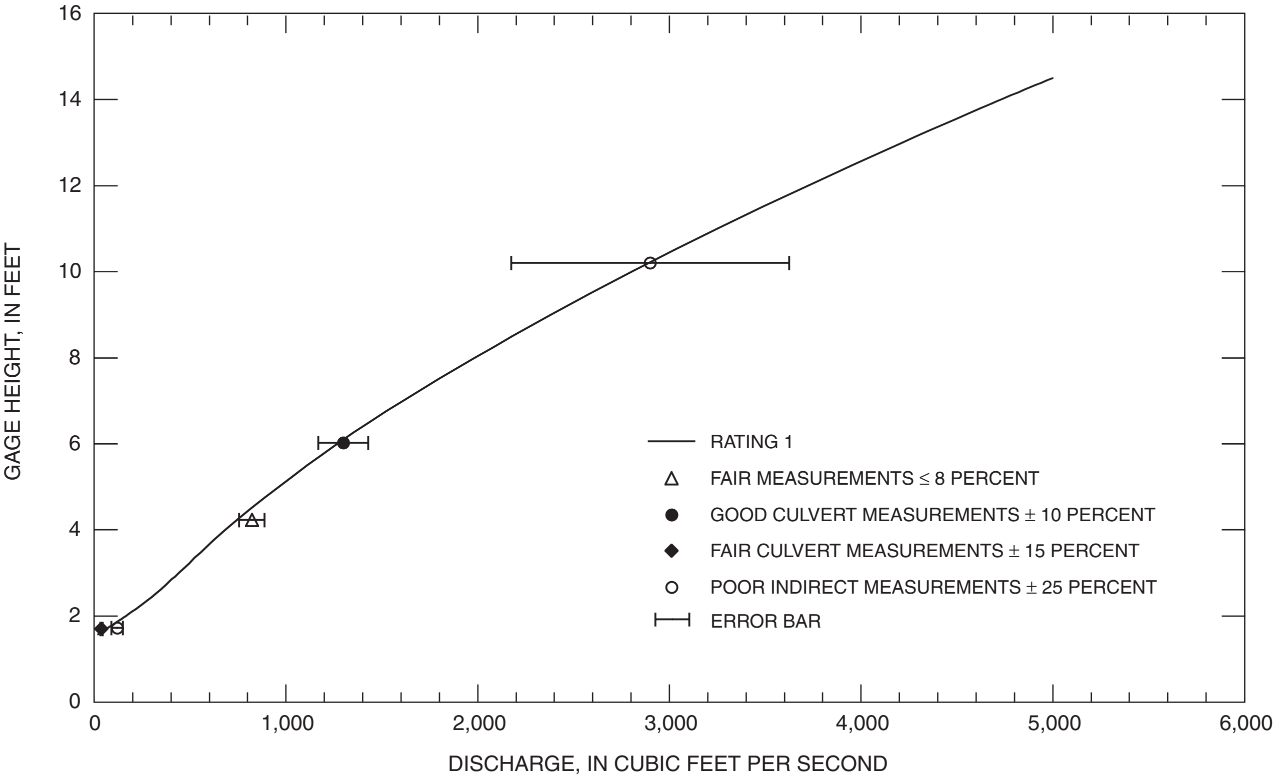

Figure 24. Graph showing stage-discharge relation, Ox Wash near Morristown, Arizona.

Figure 25. View looking downstream at culvert from gaging station, Ox Wash near Morristown, Arizona.

09501300 Tortilla Creek at Tortilla Flat, Arizona

Description of channel conditions.—The control is an 80-foot-long concrete weir, about 1 ft above the ground surface that extends across the channel 90 ft downstream from the gaging station. A stand of thick vegetation (cattails) grows between the gaging station and the weir. The channel bends left just upstream from the gaging station and is straight for several hundred feet downstream. A small notch that controls low flows is near the left end of the weir. The left side of the weir is bedrock that is inundated at higher stages. The right bank is steep and is mostly gravel. The banks are covered with vegetation that may alter the stage-discharge relation. The approach section is composed of unconsolidated material and may shift during flows that also may affect the stage-discharge relation.

Table 16. Data from discharge measurements, Tortilla Creek at Tortilla Flat, Arizona

Date	Gage height, in feet	Discharge, in cubic feet per second	Method	Measurement rating	Potential error, in percent
Measurements used to define rating 3					
12–22–65	8.4	2,440	Weir computation	Fair	15
09–13–66	12.3	6,660	Weir computation	Poor	25
08–18–67	6.8	975	Weir computation	Poor	25
12–01–82	4.12	42.8	Current meter	Poor	15
12–20–91	4.14	40.8	Current meter	Fair	8
03–26–92	3.42	2.36	Current meter	Poor	15
Measurements made since rating 3 was developed					
02–19–93	4.05	34.4	Current meter	Good	5
01–14–97	4.46	96.1	Current meter	Good	5
02–17–98	4.07	25.4	Current meter	Good	5
02–26–98	4.25	49.0	Current meter	Good	5

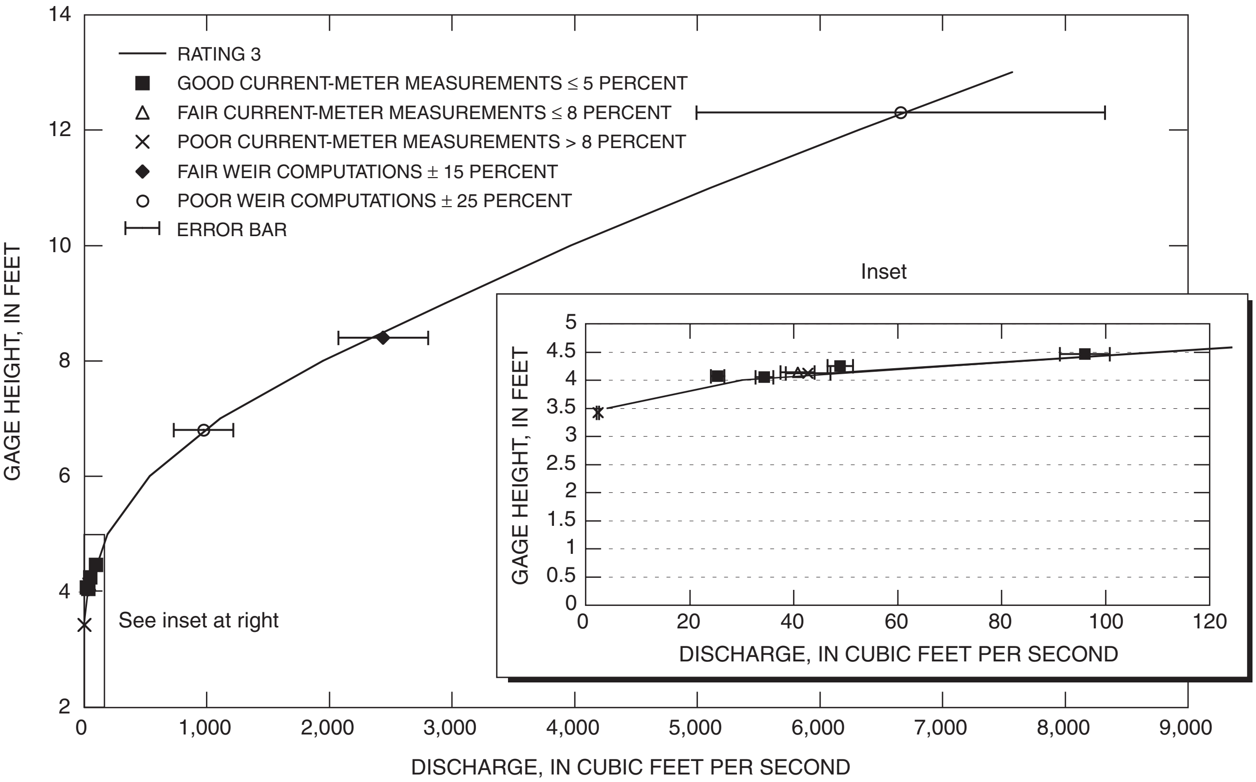

Figure 26. Stage-discharge relation, Tortilla Creek at Tortilla Flat, Arizona.

Figure 27. View looking upstream at gaging station from left bank, Tortilla Creek at Tortilla Flat, Arizona.

09516800 Jack Rabbit Wash near Tonopah, Arizona

Description of channel conditions.—The control is a wide sandy channel that has some gravel and small cobbles. The rectangular channel is unstable and contains vegetation along both banks. Shifting of the control is possible at all stages but is particularly significant at low stages because the control is affected by a man-made berm that is about 160 ft below the gaging station. The berm tends to wash out at high stages.

Table 17. Data from discharge measurements, Jack Rabbit Wash near Tonopah, Arizona

Date	Gage height, in feet	Discharge, in cubic feet per second	Method	Measurement rating	Potential error, in percent
		Measurements used to define rating 5			
09–26–97	9.97	2,306	Current meter	Poor	15
09–26–97	9.63	1,035	Current meter	Poor	15
09–26–97	9.3	675	Current meter	Poor	15
10–23–97	11.31	8,200	Slope conveyance	Poor	25

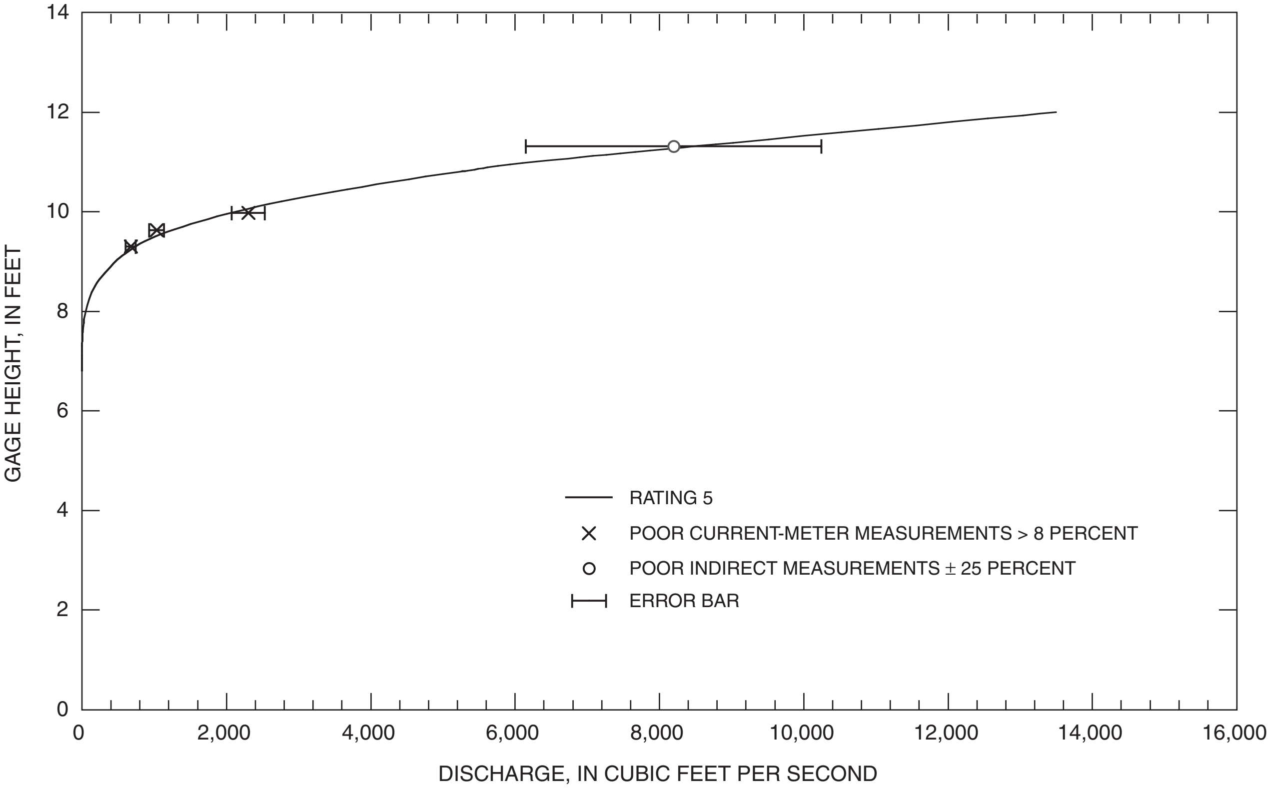

Figure 28. Stage-discharge relation, Jack Rabbit Wash near Tonopah, Arizona.

Figure 29. View looking upstream at gaging station from right bank, Jack Rabbit Wash near Tonopah, Arizona.

09517280 Tiger Wash near Aguila, Arizona

Description of channel conditions.—The control is a sand-and-gravel channel that is straight for several hundred feet upstream and several hundred feet downstream from the gage. An overflow channel is on the right bank and has a dense growth of vegetation that may affect the stage-discharge relation at high flows.

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Table 18. Data from discharge measurements, Tiger Wash near Aguila, Arizona

Date	Gage height, in feet	Discharge, in cubic feet per second	Method	Measure-ment rating	Potential error, in percent
Measurements used to define rating 3					
09–26–97	10.17	8,100	Slope area	Fair	15

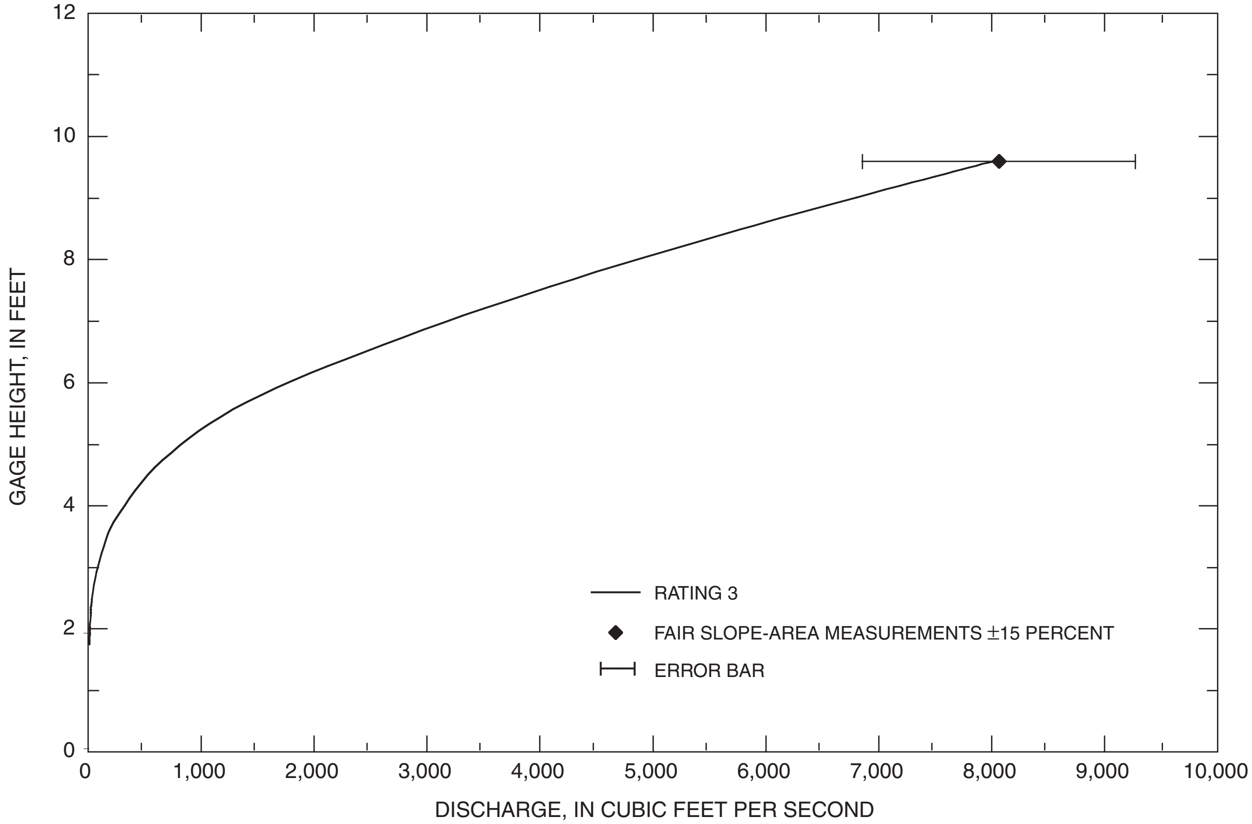

Figure 30. Stage-discharge relation, Tiger Wash near Aguila, Arizona.

Figure 31. View looking upstream at gaging station, Tiger Wash near Aguila, Arizona.

09519750 Bender Wash near Gila Bend, Arizona

Description of channel conditions.—The sand-bed channel at the gaging station is straight and constricted by a steep bedrock outcrop on left bank and the freeway embankment on right bank. The control is a rock outcrop crossing the channel diagonally from the left bank downstream to the right bank. The control is considered stable except for low flows when shifts may result because of movement of sediment.

On May 16, 1996, a three-section step-backwater survey was made to determine if rating number 3 was still valid. According to the step-backwater results, no apparent change in the medium- to high-flow control has occurred since rating number 3 was developed.

Table 19. Data from discharge measurements, Bender Wash near Gila Bend, Arizona

Date	Gage height, in feet	Discharge, in cubic feet per second	Method	Measure-ment rating	Potential error, in percent
Measurements used to define rating 3					
08–71	7.35	2,670	Slope area	Fair	15
08–11–75	6.92	2,290	Slope area	Poor	25
Measurements made since rating 3 was developed					
09–10–95	4.95	408	Slope conveyance	Poor	25
07–15–96	3.69	24	Slope conveyance	Poor	25

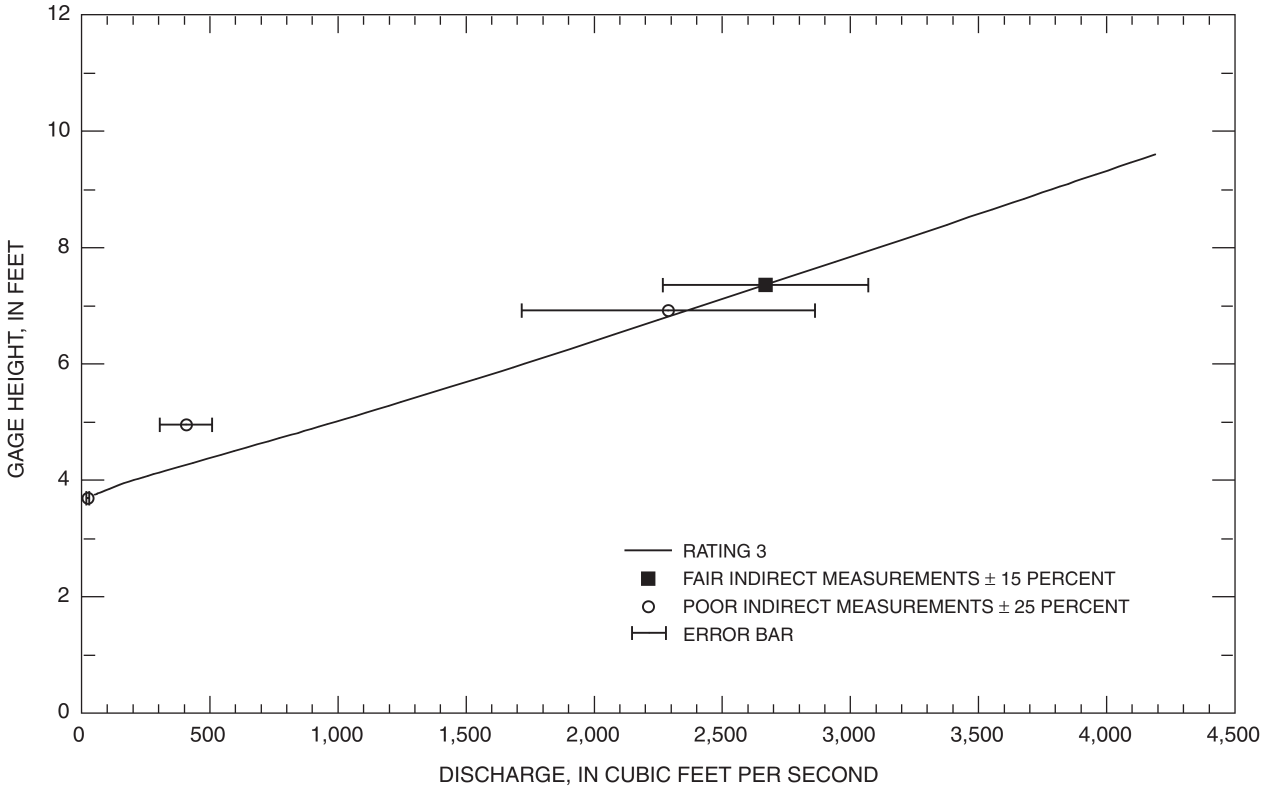

Figure 32. Stage-discharge relation, Bender Wash near Gila Bend, Arizona.

Figure 33. View looking upstream at gaging station, Bender Wash near Gila Bend, Arizona.

09519760 Sauceda Wash near Gila Bend, Arizona

Description of channel conditions.—The channel is straight for about 220 ft upstream from the gaging station and for about 300 ft downstream from the gaging station. The main channel bed has coarse sand and gravel and is subject to scour and fill during moderate to high flows. The banks are 10 ft high and are mostly covered with rock, brush, and scattered mesquite trees. Near the station, the channel is confined by the culvert wing walls to a width of about 100 ft and usually is clear of vegetation. The stage-discharge relation is controlled by the seven culvert boxes downstream from the crest-stage gaging station. The culverts are skewed at a 28× angle to the channel. The culverts are subject to filling with sediment and plugging with vegetation during moderate to large flows that may significantly affect the stage-discharge relation

Table 20. Data from discharge measurements, Sauceda Wash near Gila Bend, Arizona

Date	Gage height, in feet	Discharge, in cubic feet per second	Method	Measurement rating	Potential error, in percent
Measurements used to define rating 4					
08–14–70	5.80	2,850	([1])	Poor	25
09–25–76	6.30	3,160	Culvert	Poor	25
09–11–77	3.69	1,120	Slope conveyance	Poor	25
07–11–90	1.49	41.9	Current meter	Fair	8

[1] Method unknown.

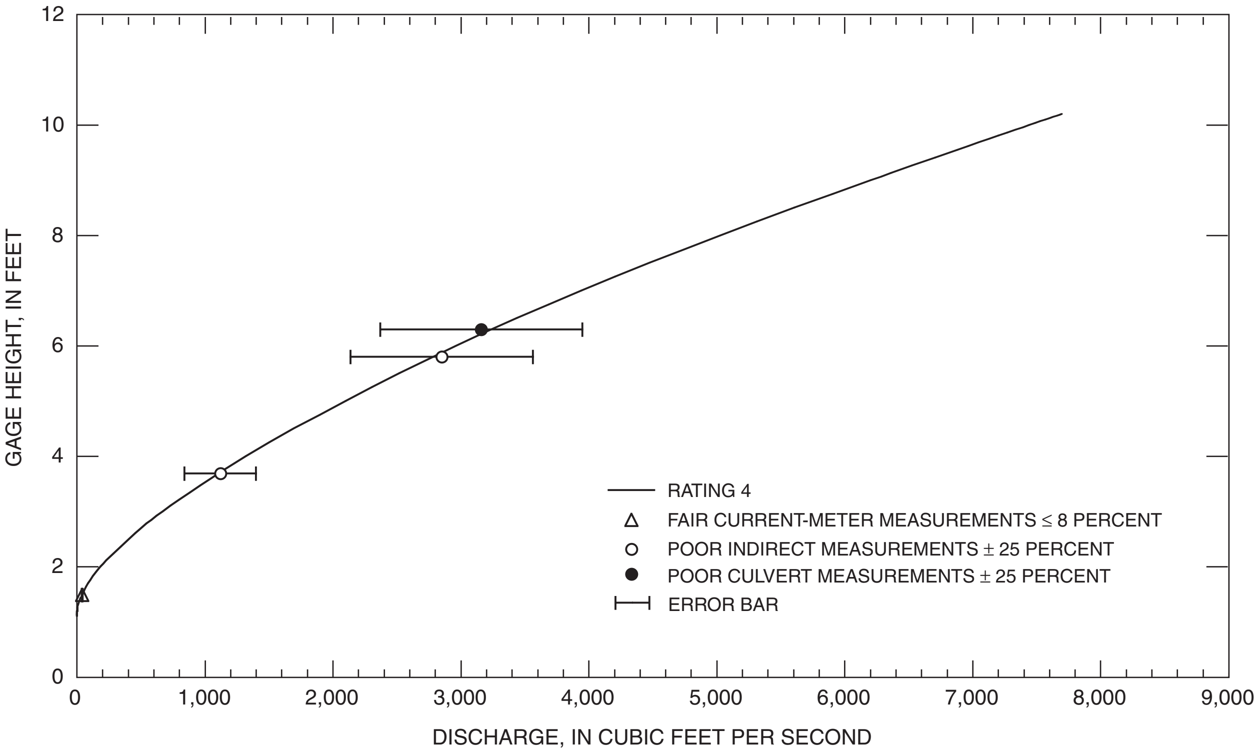

Figure 34. Stage-discharge relation, Sauceda Wash near Gila Bend, Arizona.

Figure 35. View looking downstream at gaging station, Sauceda Wash near Gila Bend, Arizona.