Surface-Water Quality-Assurance Plan for the Arizona District of the U.S. Geological Survey

U.S. GEOLOGICAL SURVEY
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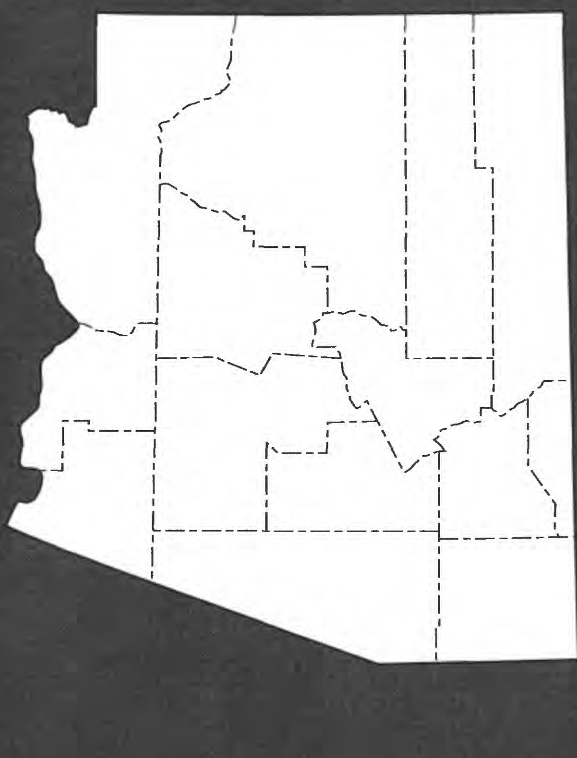

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For additional information write to:

District Chief
U.S. Geological Survey
Water Resources Division
375 South Euclid Avenue
Tucson, AZ 85719-6644

Copies of this report can be purchased from:

U.S. Geological Survey
U.S. Branch of Information Services
Box 25286
Denver, Colorado 80225-0286

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FIGURES

1. Chart showing the organization of the Water Resources Division of the U.S. Geological Survey, 1991 2
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CONVERSION FACTORS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
square foot (ft^2)	0.0929	square meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
acre	0.4047	hectare
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06308	liter per second

In this report, temperature is reported in degrees Fahrenheit (°F), which can be converted to degrees Celsius (°C) by using the following equation:

$$°C = (°F-32)/1.8$$

VERTICAL DATUM

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum 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.

Surface-Water Quality-Assurance Plan for the Arizona District of the U.S. Geological Survey

By G.L. Pope

Abstract

Surface-water activities in the Arizona District are part of the Water Resources Division's overall mission of appraising the quantity and quality of the Nation's water resources. The surface-water data collected and the analyses made are used to describe flood frequency, flood-plain boundary, base runoff, time-of-travel, and other characteristics of Arizona streams. Streamflow data are part of the water-resources inventory that is used for hydroelectric-power generation, waste loading, flood-plain management, water supply, and a host of other water-management and planning activities.

This District Surface-Water Quality-Assurance Plan documents the standards, policies, and procedures used by the Arizona District for activities related to the collection, processing, storage, analysis, and publication of surface-water data. The plan is a guide for all personnel involved in District surface-water activities. Responsibility for implementation of quality assurance is described so that employees are clearly aware of their role. The plan also describes the system of checks and balances used by the Water Resources Division (WRD) and highlights the importance of quality products for the users of our data.

INTRODUCTION

The U.S. Geological Survey (USGS) was established by an Act of Congress on March 3, 1879, to provide a permanent Federal agency to conduct the systematic and scientific "classification of the public lands, and examination of the geologic structure, mineral resources, and products of the national domain." Surface-water activities in the Arizona District are part of the Water Resources Division's (WRD; fig. 1) overall mission of appraising the Nation's water resources. Surface-water information, including streamflow, stage, and sediment data, are used at the Federal, State, and local levels for resource planning and management.

The purpose of this District Surface-Water Quality-Assurance Plan (QA Plan) is to document the standards, policies, and procedures used by the Arizona District for activities related to the collection, processing, storage, analysis, and publication of surface-water data. This plan identifies responsibilities for ensuring that stated policies and procedures are carried out. The plan also serves as a guide for all District employees involved in surface-water activities and as a resource for memorandums, publications, and other literature that describe associated techniques and requirements in more detail. This QA Plan is reviewed and revised at least once every 3 years so that responsibilities and methodologies are kept current and ongoing procedural improvements are documented.

The scope of this plan includes discussions of the policies and procedures followed by this District for the collection, processing, analysis, storage, and publication of surface-water data. Specific types of surface-water data include stage, streamflow, sediment, and basin characteristics. In addition, issues related to the management of the

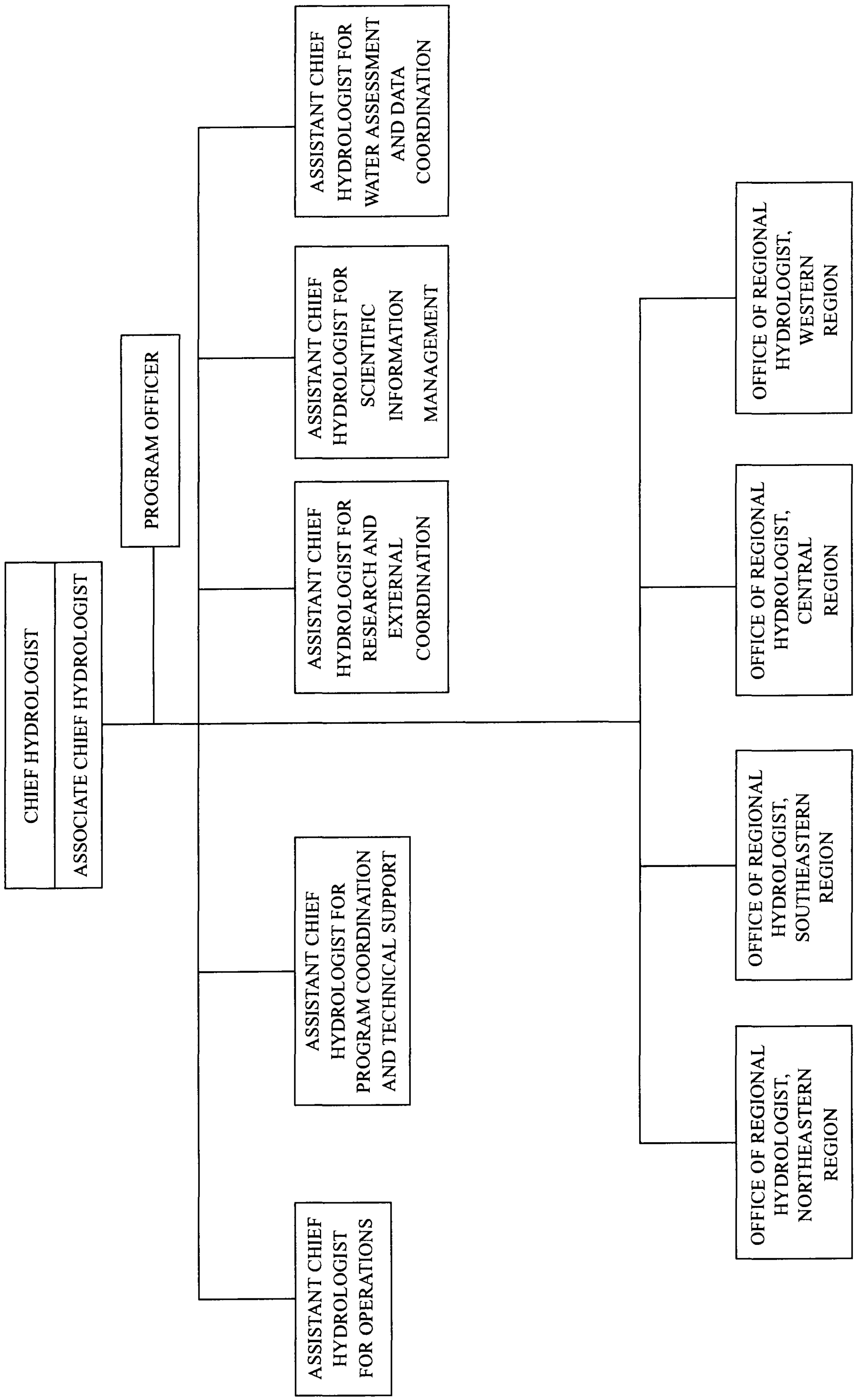

Figure 1. Organization of the Water Resources Division of the U.S. Geological Survey, 1991

computer data base and employee safety and training are discussed. Although procedures and products of interpretive projects are subject to the criteria presented in this report, individual interpretive projects are required to have a separate and complete quality-assurance plan.

RESPONSIBILITIES

Quality assurance (QA) is an active process, and achieving and maintaining high-quality standards for surface-water data are accomplished by specific actions carried out by specific individuals. Errors and deficiencies can occur when individuals fail to carry out their responsibilities. Clear and specific statements of responsibilities promote an understanding of each person's duties in the overall process of assuring the quality of the surface-water data.

Responsibilities are assigned to employees by position title and not by employee name. The District Chief is responsible for the preparation and implementation of and adherence to the QA policies described in the QA Plan (Schroder and Shampine, 1992, p. 7). The District Chief has delegated that responsibility to the Data Chief, who is responsible for future updates and revisions of the QA Plan. Project Chiefs involved in the collection of surface-water data are required to prepare a QA plan as part of their proposal and work plan that conforms to the policies and procedures outlined in this plan (Shampine and others, 1992, p. 2).

The following is a list of responsibilities of District employees involved in the collection, processing, storage, analysis, or publication of surface-water data. The District Chief and (or) Field Office Chief is responsible for:

1. Managing and directing the District and (or) Field Office program, which includes all surface-water activities,
2. Ensuring that surface-water activities in the District meet the needs of the Federal Government, the Arizona District, State and local agencies, other cooperating agencies, and the general public,
3. Ensuring that all aspects of this QA Plan are understood and followed by District employees by the District Chief's direct involvement or through clearly stated delegation of this responsibility to other employees in the District,
4. Providing final resolution of any conflicts or disputes related to surface-water activities within the District,
5. Keeping subordinates informed about procedural and technical communications from Region and (or) national headquarters, and
6. Ensuring that all publications and other technical communications released by the District are accurate and are in accordance with policies of the USGS.

The Surface-Water Specialist is responsible for:

1. Ensuring that correct technical procedures are used in the collection and use of surface-water data,
2. Providing technical assistance to personnel involved with data-collection activities,
3. Providing technical assistance to personnel in data analysis and provide interpretation for surface-water hydrologic investigations,
4. Reviewing hydrologic-conditions text and surface-water records for the annual data reports,
5. Ensuring that correct procedures are followed and that all indirect measurements are checked, and
6. Reviewing flood activities of the District and the District Flood Plan.

The Data Chief is responsible for the overall operation of the Data Section, which includes:

1. Preparing budget estimates for the Data Section, which includes the Field Offices,
2. Ensuring that all surface-water data are collected in accordance with USGS standards and procedures,
3. Ensuring that gage construction and selection of stage-recording equipment is correct and sound,
4. Reviewing computed surface-water records for compliance with policies and procedures in coordination with the Field Office Chief,

5. Overseeing the maintenance of the official drainage-map files, and
6. Addressing the training needs of all Data Section personnel.

The Field Office Chief is responsible for the day-to-day operation of the Data Section, which includes:

1. Ensuring the proper service and maintenance of gage instrumentation and structures,
2. Ensuring that correct procedures are followed for discharge measurements and levels,
3. Maintaining the District Flood Plan,
4. Assisting the Data Chief in the review of computed surface-water records, and
5. Preparing the annual operation and maintenance budgets for their respective field offices for the Data Chief.

COLLECTION OF STAGE AND STREAMFLOW DATA

Many of society's daily activities, including industry, agriculture, energy production, waste disposal, and recreation, are closely linked to streamflow and water availability; therefore, reliable surface-water data are necessary for planning and resource management. The collection of stage and streamflow data is a primary component in the ongoing operation of streamflow-gaging stations (referred to in the remainder of this report as gaging stations) and other water-resource studies by the USGS and the Arizona District.

The objective of operating a gaging station is to obtain a continuous record of stage and discharge at the site (Carter and Davidian, 1968, p. 1). A continuous record of stage is obtained by installing instruments that sense and record water-surface elevation in the stream. Discharge measurements are made at periodic intervals to define or verify the stage-discharge relation and to define the time and magnitude of variations in that relation. The policy of this District is that all employees involved in the collection of stage and discharge data will be informed of and follow the surface- water data-collection policies and procedures established by WRD.

Installation and Maintenance of Gaging Stations

Proper installation and maintenance of gaging stations are critical activities for ensuring quality in streamflow-data collection and analysis. Effective site selection, correct design and construction, and regular maintenance of a gaging station can make the difference between efficient and accurate determination of drainage-basin discharge or time-consuming and poor estimations of flow.

Sites for installation of gaging stations are selected to meet the purpose of each specific gaging station. Additionally, sites are selected with the intent of achieving, to the greatest extent possible, ideal conditions. Criteria that describe the ideal gaging-station site are listed in Rantz and others (1982, p. 5). These criteria include unchanging natural controls that promote a stable stage-discharge relation, a satisfactory reach for measuring discharge throughout the range of stage, and efficient access to the gaging station and measuring location. Other aspects of controls considered by District employees when planning gaging-station installations include those discussed in Kennedy (1984, p. 2).

The Field Office Chief is responsible for the selection of sites for new gaging stations after consulting with the District Surface-Water Specialist about hydraulic conditions when necessary. The process of site selection includes discussion with cooperators on the purpose of the gaging station, analysis of terrain with the use of topographic maps, field reconnaissance, file search to determine if discontinued stations or partial-record stations existed in the area, and acquisition of permission to install necessary equipment. The Field Office Chief is responsible for ensuring proper documentation of agreements with property owners. The Field Office Chief also is responsible for the approval of site design, construction of the gaging station, and inspection and approval of the completed station.

A program of careful inspection and maintenance of gaging-station sites promotes the collection of reliable and accurate data. Allowing the equipment and structures to fall into disrepair can result in unreliable data and safety problems. District policy states that a visual inspection is performed at sites by field personnel during each site visit. To prevent the buildup of mud, stilling wells are cleaned on each field visit following an event. Other maintenance activities performed on a regular basis include checking float tapes for obstructions and replacing batteries unless auxiliary power is available.

The Field Office Chief has the responsibility to ensure that gaging stations are kept in good repair. To ensure these responsibilities are carried out, the Field Office Chief receives reports from field personnel, inspects sites if necessary, and reports corrective action, and requests associated funding if needed from the Data Chief.

Measurement of Stage

Many types of instruments are available for measuring the water level or stage at gaging stations. Depending on the needs of the project, either a nonrecording gage (Rantz and others, 1982, p. 24) or a recording gage (Rantz and others, 1982, p. 32) may be used. Because the uses for stage data cannot be predicted, Office of Surface Water (OSW) policy states that surface-water stage records at stream sites be collected using instruments and procedures that provide sufficient accuracy to support computation of discharge from a stage-discharge relation unless greater accuracy is required (OSW Memorandum 93.07).

In general, operation of gaging stations for the purpose of determining daily discharge includes the goal of collecting stage data at the accuracy of 0.01 ft (OSW Memorandum 89.08). WRD policy on stage-measurement accuracy as it relates to instrumentation is provided in OSW Memorandum 93.07.

The types of instrumentation installed at any gaging station operated by the Arizona District depends on cooperator needs, availability of utility lines, terrain, expected range of stage, and type of data to be collected. Types of water-level recorders operated by employees in this District range from a simple crest-stage station to complicated multiparameter electronic recorders that transmit information on a real-time basis by communication satellites. The Field Office Chief determines the type of water-level recorder that is operated in each gaging station and ensures that the new equipment has been installed correctly. Field technicians who service the gaging station are responsible for the proper maintenance of gaging-station instruments and (or) replacement of equipment.

Accurate stage measurement requires not only accurate instrumentation but also proper installation and continual monitoring of all system components to ensure that the accuracy of the data does not deteriorate with time (OSW Memorandum 93.07). In order to ensure that instruments in the gaging-station shelter record accurate water levels, inside and outside water-level readings are obtained by independent means. For example at stilling-well gaging stations, all recording equipment is calibrated to an inside gage, and outside readings are made with a wire-weight gage or staff gage mounted near the gaging station. The recorder readings inside the gaging station do not necessarily always equal the outside readings, especially if the outside gage and the recorder are not recording the same flow of water at all ranges of stage. At stations equipped with a stilling well, the base or reference gage usually is an instrument installed inside the gage house, and other gages are installed outside the gage house to indicate if the intakes are operating properly (Rantz and others, 1982, p. 53 and p. 64).

Employees who service the gaging station are responsible for comparing inside and outside readings during each site visit to determine if the outside water level is being represented correctly by the recording equipment. If a deficiency is identified, the employee who services the gaging station is responsible for thoroughly documenting the problem in the field notes and either correcting the problem immediately or contacting the Field Office Chief so that corrective actions can be taken at the earliest opportunity.

The Field Office Chief is responsible for ensuring that instrumentation installed at gaging stations is properly serviced and calibrated by carefully reviewing all field data, viewing plots of the raw data, comparing hydrographs, and using available information on the site conditions. When deficiencies are identified, the field technician takes corrective action by recalibrating or replacing the faulty equipment. Employees who have questions about the calibration and maintenance of water-level recorders should contact the Field Office Chief for additional help. As immediate needs are identified, training classes are established at the appropriate level of difficulty.

Gaging-Station Documents

District policy states that certain documents are placed in each gaging station for the purpose of keeping an on-site record of observations, equipment maintenance, structural maintenance, and other information that is needed by the field personnel. Documents maintained at each gaging station include: (1) the most recent digital stage-discharge relation (rating); (2) the most recent station description listing all gages and reference marks at the site and associated elevations, locations of measurement cross sections, information related to extreme events including the potential for channel storage between the gage and measuring section during flood conditions; (3) a log updated by field technicians at the time of each site visit that describes control conditions and lists gage readings, measurement values, gaging-station and equipment maintenance; and (4) a calendar.

The field technician who is assigned to the station is responsible for updating documents in the gaging station. When field personnel visit a gaging station and identify a need to update one or more of the documents, the information will be replaced on the next visit to the gaging station. Employees who have questions about what documents should be kept in a gaging station, when the documents should be replaced with newer documents, or appropriate methods of appending logs or plotting measurements should contact the Field Office Chief.

Levels

The various gages at a gaging station are set to register the elevation of a water surface above a selected level reference surface called the gage datum. The supporting structures of the gaging station—stilling wells, backings, shelters, bridges, and other structures—tend to settle or rise as a result of earth movement, static or dynamic loads, vibration, or battering by floodwaters and flood-borne ice or debris. Vertical movement of a structure makes the attached gages read too high or too low and, if the errors go undetected, may lead to increased uncertainties in streamflow records. Leveling, a procedure by which surveying instruments are used to determine the differences in elevation between points, is used to set the gages and to check them from time to time for vertical movement (Kennedy, 1990, p. 1). Levels are run periodically to all bench marks, reference marks, reference points, and gages at each station for the purpose of determining if any datum changes have occurred (Rantz and others, 1982, p. 545).

District policy states that levels are run at newly installed gaging stations at the completion of construction and then annually for the first 3 years. Levels are run to established gaging stations every 3 years unless the gage has proven to be unstable, in which case, levels are run annually. Staff gages are reset to agree with levels when the levels indicate a 0.02-foot vertical change. When gages are reset, field personnel document the reset by recording the changes on the level notes. Levels will be run to all gages and both the inside and outside water surface will be determined by direct levels or by taping down from a current reference point if direct levels are not practical.

Leveling procedures followed by District employees pertaining to circuit closure, instrument reset, and repeated use of turning points are described in Kennedy (1990) and in OSW Memorandum 93.12. The level instruments are kept in proper adjustment and checked by use of a peg test before each major level run or if it has been more than 6 months since the last test. Electronic-measuring devices (EDM) are cleaned and serviced annually. The Field Office Chief must ensure that levels are run correctly at proper intervals and that all field level notes are checked and completed. The level information is entered in the level summary form by the appropriate field person after the levels are checked.

Site Documentation

Thorough documentation of qualitative and quantitative information describing each gaging station is required. A station description and photographs provide a permanent record of site characteristics, structures, equipment, instrumentation, elevations, location, and changes in conditions at each site. Information about how and where this documentation is maintained is discussed in the section of this report entitled "Office Setting."

Station Descriptions

A station description is prepared for each gaging station and becomes part of the permanent record for each station (fig. 2). District policy states that the advanced station description is written when the site is selected and the final description prepared by the time the first year of record is computed. Station descriptions are reviewed annually when records are computed. The Field Office Chief is responsible for ensuring that station descriptions are prepared correctly, in a timely manner, and are updated annually. Station descriptions are written to include specific types of information in a consistent format (Kennedy, 1983, p. 2).

Photographs

Field personnel photograph gaging stations, station controls, channel changes with respect to geometry as well as vegetation, changes in reference marks, and damaged structures as a result of accidents or unusual events in order to document gaging-station construction, changes in control conditions, or to supplement various forms of written descriptions. Each photograph that becomes part of the station record is identified by writing specific information, such as date, gage height, discharge, and the direction of photographs on the back of the photograph with a permanent-ink marker. Photographs are placed in the current technical folder for that station.

Direct Measurements

Direct measurements of discharge are made using any one of a number of methods approved by WRD. The most common method is the current-meter method, which is the summation of the products of the subsection areas of the stream cross section and their respective average velocities (Carter and Davidian, 1968, p. 7; Buchanan and Somers, 1969, p. 1; Rantz and others, 1982, p. 80 and 139). When employees make measurements of stream discharge, attempts are made to minimize errors (Sauer and Meyer, 1992). Errors include depth errors associated with soft, uneven, or mobile streambeds; uncertainties in mean velocity associated with vertical-velocity distribution errors, pulsation errors, systematic errors, or bias associated with improperly calibrated equipment; or the improper use of such equipment. Field trips are rotated to different personnel every year or so to help minimize some of these errors. District policies related to the measurement of discharge by use of the current-meter method, in accordance with WRD policies, include the following procedures. Employees who have questions concerning the appropriate procedures for making stage and discharge measurements should address their questions to the Field Office Chief.

Depth Criteria For Meter Selection

District employees select the type of current meter to be used for each discharge measurement on the basis of criteria in OSW Memorandum 85.07. Meters are used with caution when a measurement must be made in conditions outside ranges presented in OSW Memorandum 85.07. Any deviation from those criteria are noted and the measurement accuracy is downgraded accordingly. A change of meter is not recommended during a measurement when one or two subsections in a single measurement cross section exceed the stated ranges of depth and velocity. On the basis of these observations, and after realizing that under those conditions the current meter will not register velocity accurately, the technician must make a judgement decision on the proper meter to be used. If the total affected area represents less than 10 percent of the total discharge, then the error associated

09482500 SANTA CRUZ RIVER AT TUCSON, AZ

Location.--Lat. 32°13'19", long. 110°58'52", in SE$\frac{1}{4}$, SE$\frac{1}{4}$, sec. 11, T. 14 S., R. 13 E., Pima County, Hydrologic Unit 15050301, 200 ft downstream from Congress Street bridge in Tucson. Station can be located on the Tucson 7-1/2' and 15' quadrangle maps.

Drainage area.--2,222 mi^2, of which 395 mi^2 is in Mexico, adjusted for 15.2 mi^2 of Tucson Arroyo drainage area contributing to this station effective July 1956.

Establishment.--October 15, 1905, by G.E.P. Smith of the University of Arizona. Station maintained by the University until 1912. From 1912 to 1925, the station was operated by the U.S. Geological Survey (USGS) in cooperation with the University. Since January 1, 1926, the station has been operated by the USGS.

Gage.--A Campbell Scientific CR21X data logger interfacing a Druck pressure transducer inputting data to a Campbell SM192 storage module housed in a 5- by 5-foot metal shelter on the right bank. The orifice, outside staff gage, and crest-stage gages are located about 1 ft downstream from the gage; gage height of orifice is 2.16 ft. The outside staff gage extends from 3.50 ft to 5.14 ft.

History.--First gage established Oct. 15, 1905, by the University of Arizona. Staff or chain gages were used until November 1929 when a recording station was built. The station was removed Oct. 27, 1970, when a new bridge was constructed and was replaced Oct. 1, 1971. The flood of Oct. 9, 1977, washed the stilling well and shelter away, and the recorder was not recovered. On Feb. 14, 1978, a manometer installation was put into use. Station discontinued Sept. 30, 1981. Station reactivated on June 19, 1986, and a Druck pressure transducer replaced the manometer.

Reference marks.--BM No. 1 (elev. 25.75 ft gage datum), which is 2,346.43 ft above sea level, is Arizona Highway Department brass tablet in center of Congress Street west of bridge.
BM No. 2, USGS tablet on left bank 10 ft upstream from crest-stage gage (elev. 12.67 ft gage datum), 6/11/86.
BM No. 3, USGS tablet on southwest corner of gage-house pad (elev. 21.64 ft gage datum), 6/27/89.
Zero gage datum is 2,320.68 ft above sea level.
RM No. 1, 1/2" bolt, top of right bank 20 ft upstream from gage (elev. 18.15 ft gage datum), 6/11/86.
Crest-stage gage (CSG) pin elevations:
#1 CSG left bank; 9.64 ft,
#2 CSG lower right bank; 3.70 ft, and
#3 CSG upper right bank; 10.94 ft.

Channel and control.--The channel is confined to a width of about 180 ft by banks about 12 ft high. The banks are not subject to overflow except in extreme floods. The streambed is composed of silt, sand, and gravel on top of hard pan. The low-water channel shifts considerably.

The control is poorly defined at all stages. At low water, it consists of sand and silt bars near the gage. At high stages, it is the channel downstream from the gage. The control shifts almost continually so frequent visits to the station are necessary.

Discharge measurements.--Wading measurements can be made near the gage in flow of as much as 700 ft^3/s. High-water measurements are made from the downstream side of the Congress Street bridge.

Indirect measurement site.--The last slope-area measurement (1/19/93) was made starting at the Congress Street bridge to about 1,500 ft downstream.

Floods.--Maximum discharge 52,700 ft^3/s on Oct. 2, 1983 (gage height, 22.2 ft from floodmark, gage datum). Jan. 19, 1993, 37,400 ft^3/s (gage height, 11.67 ft).

Point of zero flow.--It varies continually.

Winter flow.--About like summer flow. No ice or snow to change the flow.

Regulation.--None.

Diversion.--Diversion for irrigation both from streamflow and the ground-water table in the basin.

Accuracy.--Records poor.

Land ownership.--City of Tucson.

Cooperation.--Pima County.

Classification.--BPI-long term, principal, unregulated and Federally financed station.

Justification.--City and State bridge program, City flood warning, sewer-drainage program.

Sketch and photographs.--See separate sheet attached.

Road log.--From the Federal Building, proceed west on Congress Street for approximately 0.4 mi to the bridge on Congress Street. The shelter is 300 ft downstream on right bank.

Written by: G.L. Pope.

Revised by: N.K. Nellson 2/3/95.

Figure 2. Description of a streamflow-gaging station.

with those subsections will not affect the error of the measurement significantly.

Number of Measurement Subsections

The spacing of observation verticals in the measurement section can affect the accuracy of the measurement (Rantz and others, 1982, p. 179). Observations of depth and velocity are to be made at a minimum of 25 to 30 verticals. This spacing is necessary so that no more than 5 percent of the total flow is measured in any one vertical. Even under the worst conditions, the discharge computed for each vertical should not exceed 10 percent of the total discharge and ideally not exceed more than 5 percent (Rantz and others, 1982, p. 140). Exceptions to this rule are allowed in circumstances where accuracy would be sacrificed if this number of verticals were maintained, such as measurements made during rapidly changing stage (Rantz and others, 1982, p. 174). Fewer verticals than are ideal sometimes are used for very narrow streams (about 12 ft wide when an Price AA meter is used and about 5 ft wide when a Price pygmy meter is used). Measurement of discharge is essentially a sampling process, and the accuracy of sampling results typically decreases markedly when the number of samples is less than 25 or so.

Other Direct Methods of Measuring Discharge

WRD and OSW techniques and guidelines are to be followed when discharge measurements are made using any selected method of measurement. These methods include float or volumetric techniques and methods involving portable weirs and flumes.

Computation of Mean Gage Height

Mean gage height is one of the coordinates used in describing the stage-discharge relation at a streamflow-gaging site. Procedures for the computation of mean gage height during a discharge measurement are to be used as presented in Rantz and others (1982, p. 170).

Check Measurements

A second discharge measurement is made for the purpose of checking a first discharge measurement when the measurement differs from the rating or the recent trend by more than 10 percent unless a change in the control is documented. When a check measurement is made, a different meter, stop watch, and stationing should be used.

Corrections for Storage

During periods of a changing stage, discharge measurements made at a considerable distance from the station will not be equal because of the effect of channel storage that occurs between the measuring section and the gaging station. Corrections for storage applied to measured discharges for the purpose of defining stage-discharge relations are discussed in Rantz and others, 1982, p. 177 and in OSW Memorandum 92.09.

Field Notes

Thorough documentation of field observations and data-collection activities performed by field personnel is a necessary component of surface-water data collection and analysis. To ensure that clear, thorough, and systematic notations are made during field observations, discharge measurements are recorded by the hydrographer on the discharge-measurement note sheet (Form 9-275). After observations are written on the note sheet, they are not erased. Original data are corrected by crossing the value out and writing in the correct value. Some examples of original data on a discharge-measurement note sheet include gage readings, depth, station, meter revolutions, and time. Examples of information on a discharge-measurement note sheet that is derived from original data, but is not considered original data, include the total discharge on the front sheet, mean gage height, width, mean velocity, and the gage height of zero flow (GZF). All discharge measurements are calculated in their entirety before the hydrographer leaves the field site unless emergency evacuation is required for reasons of safety. Information required to be included by the hydrographer on the measurement note sheet includes, at minimum, the initials and last name of all field-party members, date, times associated with gage readings, and other observations such as control and weather conditions.

Notations associated with miscellaneous surface-water data-collection activities are to be documented by use of a standard miscellaneous note sheet. All miscellaneous notes are required to include at least initials and last name of field-party members, date, time associated with observations, purpose of the site visit, and a detailed description of the observations.

A review of field note sheets is required after each trip by the Field Office Chief or by a Senior Technician. Deficiencies found in the content, accuracy, clarity, or thoroughness of field notes are identified and communicated orally to the field personnel. The deficiencies are remedied by the Field Office Chief who provides specific instructions to individuals who fail to record notations that meet USGS and District standards.

Acceptable Equipment

Equipment used by the Arizona District for the measurement of surface-water discharge has been found acceptable by the WRD through use and testing. Acceptable equipment for measuring discharge includes current meters, timers, wading rods, bridge cranes, tag lines, and other types of measurement equipment (Smoot and Novak, 1968; Rantz and others, 1982, p. 82). Although an official list of acceptable or standard equipment is not available, this equipment generally is in long-term use, is described in WRD literature for measuring discharge, and is available from the Hydrologic Instrumentation Facility (HIF). Information pertaining to some acceptable equipment available on the open market can be obtained from the HIF or OSW.

The meters most commonly used by District employees for measuring surface-water discharge are the Price AA current meter and the Price pygmy current meter. The Price AA and Price pygmy current meters are delicate instruments and should be treated with care. Meters are to be stored in appropriate boxes when the meters are not being used for measuring. Special care should be given to protect meters that are transported over rough roads when carried in the back of the field vehicles. Routine care should be taken to maintain the pivots and to keep meters clean and oiled. The technician or hydrologist using the current meter is responsible for its condition and maintenance. Methods followed by District employees for inspecting, repairing, and cleaning these meters are described in Smoot and Novak (1968, p. 9), Buchanan and Somers (1969, p. 7), Rantz and others (1982, p. 93), and OSW Memorandum 89.07.

Spin Tests

Spin tests that meet minimum requirements (45 seconds for a Price pygmy meter and 2 minutes for a Price AA meter; OSW Memorandum 89.07) are required before each field trip, and the results are documented in a log that is maintained for each instrument. Each hydrographer is to maintain the log for the meter for which he or she is responsible. This log is part of the archived data of WRD (OSW Memorandum 89.07). Repairs are made to meters when deficiencies are identified through the spin test or inspection. The Field Office Chief will review current-meter logs annually. If deficiencies are observed during this review of the logs, the field personnel will be informed orally, and the problem will be corrected immediately.

In addition to the timed spin tests performed before field trips, the hydrographer is required to inspect the meter before and after each measurement to see that the meter is in good condition, that the cups spin freely, and that the cups do not come to an abrupt stop. A timed spin test made a few minutes before a measurement does not ensure that the meter will not become damaged or fouled during the measurement. The hydrographer must assess apparent changes in velocity or visually inspect the meter periodically during the measurement to ensure that the meter continues to remain in proper operating condition. Descriptive notations are made at the appropriate location on the field note sheet concerning the meter condition, such as "OK" or "free" or other such comments. The Field Office Chief will make a semiannual inspection of the meter equipment to ensure that field personnel are maintaining the equipment they use. After the inspection, the Field Office Chief will discuss any deficiencies with the field personnel, and repair or replacement will be made immediately.

Alternative Equipment

New conditions and the development of new technology sometimes involve the collection of surface-water data with alternative equipment that has not been fully accepted by WRD. To demonstrate the quality of surface-water data collected with alternative equipment, thorough documentation of procedures and observations must be maintained. The Data Chief is responsible for ensuring that alternative equipment is utilized correctly, that documentation is complete, and that the data are stored correctly.

Indirect Measurements

In many situations, especially during floods, it is impossible or impractical to measure peak discharges by means of a current meter. Advance warning may not be sufficient to allow travel to the site for a direct measurement, or physical access to the site during the event may be too hazardous. A peak discharge determined by indirect methods is in many situations the best available means of defining the upper portions of the stage-discharge relation at a site. Because extrapolation of a stage-discharge relation, or rating, beyond twice the measured discharge at a gaging station is undesirable and may be unreliable, discharge measurements made by indirect methods during periods of high flows are important methods of data collection (Rantz and others, 1982, p. 334).

Data-collection and computation procedures presented in Benson and Dalrymple (1967) are to be followed. That report includes policies and procedures related to site selection, field survey, identification of high-water marks, the selection of roughness coefficients, computations, and the written summary. Procedures for measurement of peak discharge by indirect methods also are presented in Rantz and others (1982, p. 273) and are to be followed.

In addition to the general procedures presented in Benson and Dalrymple (1967), field personnel are to follow guidelines presented in other reports that describe specific types of indirect measurements suited to specific types of flow conditions. The slope-area method is described in Barnes (1967) and Dalrymple and Benson (1967). The USGS uses the Manning equation in application of the slope-area method. Procedures used for selecting the roughness coefficient are described in Arcement and Schneider (1989), Thomsen and Hjalmarson (1991), and Coons (1995). The computer-based tool, program C374, is available to assist in computations of peak discharge using the slope-area method and is discussed in OSW Memorandum 83.07, as are computer programs SLOPE and SAC. Procedures for the determination of peak discharge through culverts, based on a classification system that delineates six types of flow, are described in Bodhaine (1982). The computer-based tool, program A526, available to assist in computations of peak discharge at culverts, is discussed in OSW Memorandum 83.07. At sites where open-channel width contractions occur, such as flow through a bridge structure, peak discharge can be measured using methods described in Matthai (1967) and using the Water-Surface Profile Computation model (WSPRO; Shearman, 1990). Debris-flow conditions, which are most common in small mountainous basins, are discussed in OSW Memorandum 92.11.

Determinations of water-surface profiles along a stream channel in association with selected discharges are made when studies are conducted that involve delineations of flood plains or when extensions are made to stage-discharge relations at streamflow sites. District employees are required to follow the procedures associated with step-backwater methods described in Davidian (1984). The computer-based tool used for assisting in the computations of water-surface profiles using step-backwater methods, WSPRO, is discussed in OSW Memorandum 87.05 and Shearman and others (1986). General guidelines that are followed by the District when making indirect measurements include those discussed in OSW Memorandum 92.10 and in Shearman (1990). Violation of any one of the general guidelines does not necessarily invalidate an indirect measurement (OSW Memorandum 92.10).

The Surface-Water Specialist is responsible for ensuring that indirect measurements are performed correctly. The Surface-Water Specialist also will review procedures and documentation for all indirect measurements made for rating extension or flood-peak determination. When deficiencies are found during the review, the Surface-Water Specialist will inform the Field Office Chief and schedule USGS training and (or) hold one-on-one training as needed. Measurements that are questionable and difficult to assess are reviewed by specialists outside the District, and the Surface-Water Specialist is responsible for ensuring that deficiencies identified by the outside parties are corrected.

The Surface-Water Specialist, Field Office Chief, or Data Chief will determine when and where indirect measurements are made. In the Arizona District, it is a general rule that indirect measurements are made at sites where it is impossible to obtain discharge measurements of flow or when peak flow at a site is estimated to be at least twice the discharge of the greatest measured flow, and sufficient head loss exists for the indicated type of indirect measurement.

The survey party crew chief is responsible for the proper identification and flagging of high-water marks. Because the quality and clarity of high-water marks are best soon after the flood event occurs, employees traveling in the field are required to have available in their field vehicles a hammer, nails, spray paint, survey flagging, and stakes. Selection of a suitable reach of channel is an extremely important element in making an indirect measurement. At some streamflow-gaging stations, the stream reach for indirect measurements at specified ranges of stage, therefore, has been preselected and that information has been included in the station description.

After each indirect measurement is computed, the graphs, field notes and data, plotted profiles, maps, calculations or computer output, and written analysis associated with the measurement are checked by the Surface-Water Specialist. The information is organized by grouping all information for a single measurement in a labeled folder that is filed in the appropriate station file.

The responsibility of maintaining the accuracy of the peak-flow data files, including computer data-base files, lies within the District (OSW Memorandum 92.10). The Data Chief is to ensure that appropriate indirect-measurement results are entered into the peak-flow files and must ensure that peak-flow files are correct. For further discussion on the update and review of the peak-flow files, refer to the section entitled "Data-Base Management."

Crest-Stage Gages

Crest-stage gages are used as tools throughout the WRD to determine peak stages at otherwise ungaged sites, confirm peak stages at selected sites where recording gages are located, confirm peak stages where manometers or pressure transducers are used, and determine peak stages along selected stream reaches or other locations such as upstream and downstream from bridges and culverts. The OSW requires quality-assurance procedures comparable to those used at continuous-record stations for the operation of crest-stage gages and for the computation of annual peaks at crest-stage gages (OSW Memorandum 88.07).

The operation of crest-stage gages is part of this District's surface-water program. Procedures followed by this District in the operation of crest-stage gages are presented in Rantz and others (1982, p. 9, 77, and 78). One or more gages are maintained at each selected site where peak elevations are required on a stream. Upstream and downstream gages are maintained at culverts or other structures where water-surface elevations are required to compute flow through the structure and to establish the type of flow that occurred.

Except at sites where crest-stage gages are used only to confirm or determine peak stages, stage-discharge relations are developed in association with the gage on the basis of direct or indirect high-water measurements. Direct or indirect measurements are obtained annually to verify or adjust the rating. Levels are run to the gage every 3 years or as soon as possible after significant changes in the gage occurred because of damage to the gage, reconstruction, or other situations. When extremely high peaks occur, an outside high-water mark is found when possible to confirm the gage reading and is described on the note sheet and flagged by a durable indicator, such as survey flagging tape, so that the elevation of the high-water mark can be determined the next time levels are run.

Field observations are written on crest-stage inspection sheets. All field notes are required to include, at minimum, initials and last name of field personnel, date, time of observation, and distance from the measuring point to the flood mark. The Field Office Chief will ensure that correct data-collection procedures are used by the field personnel and examine all note sheets. When a deficiency in data-collection activities is identified, the Field Office Chief will give the field person individual training. Policies and procedures for computation of peak discharges at crest-stage gages and associated documentation are presented in the section entitled "Processing and Analysis of Stage and Streamflow Data."

Artificial Controls

Artificial controls, including broad-crested weirs, thin-plate weirs, and flumes, are built in stream channels for the purpose of simplifying the procedure of obtaining accurate records of discharge (Rantz and others, 1982, p. 12). Such structures serve to stabilize and constrict the channel at a section, and reduce the variability of the stage-discharge relation.

Where artificial controls are installed as permanent structures, stage-discharge relations are determined by making current-meter measurements throughout the range of stage, or relying on the design rating when measurements cannot be made. Portable weir plates and flumes may be used by District employees in situations that include flows too low to be measured with a current meter. For low flows, volumetric measurements are made using calibrated containers according to methods described in Buchanan and Somers (1969, p. 57) and Rantz and others (1982, p. 263).

The Field Office Chief is responsible for the correct design and installation of artificial controls. When installing an artificial control, District personnel take into account the criteria for selecting the various types of controls, principles governing their design, and the attributes considered to be desirable in such structures (Carter and Davidian, 1968, p. 3; Rantz and others, 1982, p. 15 and 348; and Kilpatrick and Schneider, 1983, p. 2 and 44).

When field inspections of artificial controls are performed, specific information pertaining to control conditions are written in the field notes for the purpose of assisting in analysis of the surface-water data. These notes include comments on scour or fill of the streambed immediately upstream from the control, debris on the control, and any damage to the structure. Regular maintenance at artificial controls include cleaning the controls and approach sections during each visit or as needed. Any changes such as cleaning should be noted in the field notes. When problems with the artificial control are encountered, field personnel should contact the Field Office Chief before leaving the site, if possible.

Flood Conditions

Flood conditions present problems that can include difficulties in gaining access to a streamflow-gaging station or measuring site because roads and bridges are flooded, closed, or destroyed. Debris in the streamflow can damage equipment and present dangers to those collecting the data. Rapidly changing stage or the presence of conditions requiring measurements to be made at locations some distance away from the gage can create problems in associating a gage height to a measured discharge.

The District maintains a flood plan so that high-priority surface-water data associated with flood conditions are collected correctly and in a timely manner. The flood plan describes responsibilities before, during, and after a flood, informational-reporting procedures, and field-activity priorities. The flood plan serves as a central reference for emergency communications, telephone numbers for key District employees, and codes for accessing streamflow-gaging stations equipped with telemetry.

The Field Office Chief is responsible for ensuring that the flood plan includes all appropriate information including updated information. The flood plan is reviewed every 3 years or after each major flood by the Surface-Water Specialist. A copy of the flood plan is provided to all Data Section employees and is to be kept with the field files. The Field Office Chief is to ensure that individuals who receive a copy of the plan are proficient with the procedures in the flood plan.

During periods when potential flooding is likely to occur, including evenings and weekends, surveillance of the Arizona streamflow-gaging station network is accomplished using terminals and laptop personal computers to access the data-collection platforms through the Prime data base, and the local readout ground stations. During a flood, the Field Office Chief serves as Flood Coordinator and coordinates flood activities unless the flooding is Statewide. In that case, the Data Chief serves as the Flood Coordinator and coordinates flood activities with the Field Office Chiefs. During flood conditions, personnel who are not already in the field are to call the Flood Coordinator before coming to the office. Employees who are already in the field are to call the Flood Coordinator at the first opportunity. Employees who arrive at a gaging station to find that a flood has occurred are to call the Flood Coordinator if cellular phone coverage is available, make a discharge measurement, then proceed to find and document high-water marks. If cellular phone coverage is not available, the Flood Coordinator should be contacted after making the measurement. Personnel are to use methods discussed in Rantz and others (1982, p. 60) for determining peak stage at gaging stations.

District personnel are to follow policies and procedures stated in publications and memorandums when collecting surface-water data during floods. Techniques for current-meter measurements of floodflow are presented in Rantz and others (1982, p. 159–170). Procedures for identifying high-water marks for indirect discharge measurements are presented in Benson and Dalrymple (1967, p. 11). Adjustments applied to make measured flow hydraulically comparable with recorded gage height when discharge measurements are made a distance from the gaging station are presented in OSW Memorandum 92.09 and in Buchanan and Somers (1969, p. 54). All employees who have questions about particular policies or procedures related to flood activities or who recognize a need for further training in any aspect of flood-data collection are to contact the Field Office Chief.

The District Surface-Water Specialist will review District activities related to floods. This review includes seeing that guidelines and priorities spelled out in the flood plan are followed and that the guidelines appropriately address District requirements for obtaining flood information in a safe and thorough manner. When deficiencies are identified by the Surface-Water Specialist, the problem and possible solution is discussed in writing with the Field Office Chief, who is expected to correct the problem.

Low-Flow Conditions

Streamflow conditions during periods of low flow are different from streamflow conditions during periods of medium and high flow and include braided sand channels and aquatic mass buildup creating poor discharge-measurement conditions. Low-flow discharge measurements are made to define or confirm the lower portions of stage-discharge relations for gaging stations, as part of seepage runs to identify channel gains or losses, and in the interpretation of other associated data. Additionally, low-flow measurements are made to define the relation between low-flow characteristics in one basin and those of a nearby basin for which more data are available (OSW Memorandum 85.17).

In many situations, low flows are associated with factors that reduce the accuracy of discharge measurements. Factors include algae growth that impedes the free movement of current-meter buckets and larger percentages of the flow moving in the narrow spaces between cobbles. When natural conditions are in the range considered by the field employees to be undependable, the cross section is physically improved for measurement by removal of debris or large cobbles, and construction of dikes to reduce the amount of nonflowing water (Buchanan and Somers, 1969, p. 39). After modification of the cross section, the flow is allowed to stabilize before the discharge measurement is initiated. If the modification affects the stage at the gage, notes are to be made on both the measurement and recorder note sheet. Field personnel are to make point-of-zero flow measurements for all wading measurements when a section control is evident. The Field Office Chief will ensure that District personnel use appropriate equipment and procedures during periods of low flow and will review all drought-related data.

PROCESSING AND ANALYSIS OF STREAMFLOW DATA

The computation of streamflow records involves the analysis of field observations and field measurements, the determination of stage-discharge relations, adjustment and application of those relations, and systematic documentation of the methods and decisions that were applied. Streamflow records are computed and published for each gaging station annually (Rantz and others, 1982, p. 544). Data for short-term project gaging stations also are published if the data are considered to represent the natural conditions of the study area. This section of the QA Plan describes procedures and policies that are to be followed in the processing and analysis of data associated with the computation of streamflow records (Rantz and others, 1982; Kennedy, 1983.

Measurements and Field Notes

The gage-height information, discharge information, control conditions, and other field observations on the measurement note sheets and other field note sheets form the basis for records computed for each gaging station. Measurements and field notes that contain original data are required to be stored indefinitely (Hubbard, 1992). Measurements and other field notes for the water year that are currently being computed are filed in the current-year technical file. Measurements and notes for previous water years are filed with final records for the corresponding water year.

All measurements are to be completely checked by reviewing the mathematics and techniques used in compiling the data (Kennedy, 1983, p. 7). The data are entered into the computer data base using the current USGS program, and when the final record computation is completed, a measurement summary (Form 9-207) is retrieved from the data base and filed in the current folder.

Continuous Record

Surface-water gage-height data are collected as continuous record (hourly, 15-minute, or 5-minute values, for example) in the form of punches on paper tape, pen traces on graph paper, electronic transmissions by satellite, and electronic media. Streamflow records are computed by converting gage-height record to discharge record through application of stage-discharge relations. Ensuring the accuracy of the gage-height record, therefore, is a necessary component of ensuring the accuracy of computed discharges.

The gage-height record is assembled for the period of analysis in as complete a manner as possible. Periods of inaccurate gage-height data are identified, then corrected (see the section "Datum Corrections, Gage-Height Corrections, and Shifts"), or deleted as appropriate. Assembly of the gage-height record and procedures for processing the data are discussed in Kennedy (1983, p. 6), and Rantz and others (1982, p. 560 and 587). A gage-height record that is questionable should be deleted from the primary record but can be retained in a work record. If independent backup record is available and is deemed correct, it should be entered into the primary gage-height record.

Records and Computation

The computation of records on a continuous basis is encouraged in order to minimize the work effort after the end of the water year and to improve provisional records that may be released during the year. The hydrographer responsible for the station is responsible for completely working the record. The record is then checked to determine if the record was worked as described in the analysis and to detect any possible errors in data entry or analysis. The Data Chief and Field Office Chiefs will review the checked records to ensure compliance with USGS policies and procedures.

Procedures for Working and Checking Records

Procedures for ensuring the thoroughness, consistency, and accuracy of streamflow records are described in this section of the QA Plan. The goals, procedures, and policies presented in this section are grouped in association with the separate components that are included in the records-computation process.

Gage height.—The accuracy of surface-water discharge records depends on the accuracy of discharge measurement, the accuracy of rating definition, and the completeness and accuracy of the gage-height record (OSW Memorandum 93.07). Computation of streamflow records includes ensuring the accuracy of the gage-height record by comparisons of gage-height readings made by use of independent reference gages, comparison of inside and outside gages, examination of high-water marks, comparisons of the redundant recordings of peaks and troughs by use of maximum and minimum indicators, examination of data obtained at crest-stage gages, and confirmation or updating of gage datums by levels.

Record computation includes examination of the gage-height record to determine if the record accurately represents the water level of the body of water being monitored. Additionally, it includes identifying periods of time during which inaccuracies have occurred and determining the cause for those inaccuracies. When possible and appropriate, an inaccurate gage-height record is corrected. When corrections are not possible, the erroneous gage-height data are removed from the set of data used for streamflow-record computation. If backup gage-height record is available, it should be copied to the primary data descriptor and noted on the primary computation sheet and in the station analysis. Whenever a correction is made, notes describing what the correction is based on and how the correction was applied should be made on the primary computation sheet and in the station analysis. A unit-value plot of the gage-height record should be made to check for periods of questionable record. The hydrographer working the record is responsible for ensuring that the final record contains all the corrections needed, and record checkers and reviewers verify that the correct procedure was followed.

Levels.—Errors in gage-height data caused by vertical changes in the gage or gage-supporting structure can be measured by running levels. Gages can be reset or their readings can be adjusted by applying corrections on the basis of level data (Kennedy, 1983, p. 6).

Procedures for computing records for each station include ensuring that the front sheet has been completed for each set of levels, checking the levels for errors, ensuring that the level information was listed in the historical level summary, and ensuring that information was applied appropriately as datum corrections. The individual computing the record is required to check field notes for indications that the gages were reset correctly by field personnel. The Field Office Chief is to be notified when the gage was reset incorrectly so that appropriate action can be taken. The individual computing the records makes appropriate adjustments to the gage-height record by applying datum corrections. All changes or nonchanges should be noted in the station analysis and on the primary computation sheet.

Rating.—The development of the stage-discharge relation, also called the rating, is one of the principal tasks in computing discharge record. The rating is usually the relation between gage height and discharge (simple rating). Ratings for some special sites involve additional factors such as rate of change in stage or fall in slope reach (complex ratings; Kennedy, 1983, p. 14). District personnel are to follow procedures for the development, modification, and application of ratings that are described in Kennedy (1984) and guidelines on rating and records computation in Kennedy (1983, p. 14) and Rantz and others (1982, chap. 10–14 and p. 549).

For each gaging station, a copy of the most recent digital-rating table should be kept in the gage house, and current field and office folders. A graphical plot of the most recent rating will be kept in the office rating file. A digital copy and the graphical copy of an old rating will be kept in the old rating folder in the office. All high-stage (generally above bankfull) measurements should be plotted and numbered on the graphical rating. All new ratings must be approved by the Field Office Chief or Senior Technician before the new ratings are put into use. The hydrographer enters the rating into the computer, and the checker verifies that the rating was entered correctly.

Datum corrections, gage-height corrections, and shifts.—A correction applied to gage-height readings to compensate for the effect of settlement or uplift of the gage usually is measured by levels and is called a "datum correction" (Kennedy, 1983, p. 9). Datum corrections are applied to the gage-height record in terms of magnitude (feet) and in terms of when the datum change occurred. In the absence of any evidence indicating exactly when the change occurred, the change is assumed to have occurred gradually from the time the previous levels were run, and the correction is prorated with time (Rantz and others, 1982, p. 545). Datum corrections are applied when the magnitude of the vertical change is equal to or greater than 0.015 ft.

A correction applied to gage-height readings to compensate for differences between the recording gage and the base gage is called a "gage-height correction" (Rantz and others, 1982, p. 563). These corrections are applied in the same manner as datum corrections by use of the same computer software. Gage-height corrections are applied so that the recorded data agree with the base-gage data. These corrections are applied when the difference between the recording gage and the base gage is greater than 0.01 ft, or for as little as 0.01 ft where the low-water control is a permanent weir and zero flow occurs, or the percent difference is excessive because of the range of the rating that warrants the correction.

A correction applied to the stage-discharge relation, or rating, to compensate for variations in the rating is called a shift. Shifts reflect the fact that stage-discharge relations are not permanent and vary from time to time, either gradually or abruptly, because of changes in the physical features that form the control at the gaging station (Rantz and others, 1982, p. 344). Shifts can be applied to vary in magnitude with time and with stage (Kennedy, 1983, p. 35). Shift curves are developed on the existing rating-curve plots in log space and transferred to arithmetic space in the form of variable shift diagrams to be used in the shift-application process. The use of the stage-shift program for time-only shifts is encouraged. All shifts should be documented in the station analysis and entered into the measurement file. Care should be taken to explain why a shift occurred as well as how the shift was applied. Average shifts may be used even though they may be larger than computed shifts provided they are within the limits of the measurement and represent an average over a period of time.

Hydrographs.—A discharge hydrograph is a plot of daily mean discharges and time. The date is aligned with the horizontal axis, and the discharge is aligned with the logarithmic vertical axis. In the process of computing station records, this hydrograph is a useful tool in identifying periods of erroneous information such as incorrect shifts or datum corrections. Additionally, hydrographs are helpful when estimating discharges for periods of undefined stage-discharge relation, such as backwater or ice conditions, and in estimating discharges for periods of missing record.

Information placed on the hydrograph for each station includes station name, station number, water year, and measurements. Hydrographs are an important analysis tool and should be used to check computed record by comparison with nearby or similar stations. A final hydrograph should be filed in the current water-year folder.

Station analysis.—A complete analysis of data collected, procedures used in processing the data, and the logic on which the computations were based is documented for each year of record for each station to provide a basis for review and to serve as a reference in the event that questions arise about the records at some future date (Rantz and others, 1982, p. 580). Topics discussed in detail in the station analysis include equipment, hydrologic conditions, gage-height record, datum corrections, recorder corrections, rating, discharge, special computation, cause of shifts, and how shifts were applied. The station analysis is written by the individual who prepares the record for the water year. The analysis is checked and reviewed along with the record. The analysis will be prepared on the computer using a current word-processing package. A paper copy should be filed with the current record as it is being worked and checked. The final analysis should be filed in the current water-year folder, and stored in an electronic file on the current computer system under AN.DATA.

Furnished records.—Surface-water data collected under the supervision of other agencies, organizations, or institutions are received by this office and are used for publication of the annual data report. Furnished records of streamflow data, including surface-water interpretive studies are reviewed before publication by the same process that is applied to USGS data (WRD Memorandum 85.129). The review of these records should, if practical, include discharge measurements to verify the ratings, as well as seepage runs to address channel gains and losses in those types of studies. In cases where only final daily value data are received, hydrographic comparison with nearby sites will be made as a minimal check. If errors in the data are suspected, the furnishing agency is contacted to determine if an error has been made. Letters of correspondence and the computer disk or printed copy of the data received from the agency are stored in the technical data files.

Daily values table.—A discharge value is determined and stored for each day for each gaging station operated by the WRD with few exceptions. The daily values table that is generated by use of the record-computation software represents what discharge values are stored for each day of the water year. The checking and reviewing process is directly related to ensuring that the daily values computed are the daily values published. All tables published or mailed for request, therefore, should be checked to determine if the values match the computer data base.

Manuscript and annual report.—When records for the water year have been completed and the data collected and analyzed by District employees have been determined to be correct and finalized, the surface-water data for that water year are published along with other data in the annual data report. The annual data report is part of the series titled "U.S. Geological Survey Water-Data Reports." Information presented in the annual data report includes daily discharge values during the year, extremes for the year and period of record, and various statistics as well as the manuscript station descriptions. Information contained in the manuscript includes physical descriptions of the gaging station and (or) gage and basin, history of the gaging station and data, and statements of cooperation. In preparing the annual data report for publication, the District follows the guidelines presented in Novak (1985).

District Checkoff List

Each station will have a checkoff list that is kept in the current folder. The sheet will have all of the major headings discussed in the previous section entitled "Procedures of Working and Checking Records." Space will be provided for the initials of the record worker and checker. Except for the approval of ratings, stations will be completed before a checker initials any item on the check list.

Review of Records

After streamflow records for each station are computed and checked, records of the District's gaging stations are reviewed by a team consisting of the Field Office Chiefs and senior technical personnel. The goal of the review is to ensure that proper methods were used throughout the process of obtaining the surface-water data and computing the record.

CREST-STAGE GAGES

Records for crest-stage gages are computed with goals and procedures similar to goals and procedures for other gaging stations. The field notes are examined for correctness and accuracy. Peak stages recorded by crest-stage gages are cross referenced with other available information; the dates of the peaks are determined by analyzing available precipitation data and peak data from recording gages within the same basin or from nearby basins.

A discussion on the policies and procedures used for field aspects of collecting data at crest-stage gages is included in this report in the section "Collection of Stage and Streamflow Data." The discussion in this section describes the analysis and office documentation of crest-stage data. This section does not pertain to data collected at crest-stage gages installed solely for the purpose of confirming peak stages at sites where manometer or pressure-transducer gages are used.

At sites where crest-stage gages are used to compute peak discharges, an initial stage-discharge relation, or rating, is developed for the site by direct or indirect high-water measurements. The rating is verified or adjusted on the basis of subsequent direct or indirect high-water measurements.

For each station, a list of all measurements are maintained, and each measurement is assigned a chronological number. Ratings, both graphic and digital, are maintained and updated with the same accuracy as a daily discharge station. For each station, a list of peak gage heights are maintained and are verified by checking against the field notes when the record is worked. Current station descriptions and a summary of levels are maintained in the office station folder as well as in electronic format in AN.DATA. A brief station analysis is written each year describing how the annual peak was computed, identifying which rating was used, the type of flow condition, how the dates of the peaks were determined, and explaining any shift that may be applied. Computing peak discharges and updating the manuscript for each crest-stage gaging station is the responsibility of the hydrographer assigned to the station. Computations are checked by the Senior Technician and reviewed by the District Review Team.

The Field Office Chief is to ensure the correct computation of annual peaks at crest-stage gages. When incorrect actions or procedures are identified during the review, the problems are remedied by providing one-on-one training by the Field Office Chief or Senior Technician. The Data Chief is responsible for updating the peak-flow file promptly after peak data have been finalized. A current listing of annual peaks is maintained in the station folder for review purposes (OSW Memorandum 88.07).

OFFICE SETTING

Maintaining surface-water data and related information in a systematic and organized manner increases the efficiency and effectiveness of data-analysis and data-dissemination efforts. Good organization of files reduces the occurrence of misplaced information; misplaced data and field notes can lead to analyses based on inadequate information, and a possible decrease in the quality of analytical results. This section of the QA Plan includes descriptions of how station folders, reference maps, level documentation, and other information related to surface-water data are organized and maintained. Additionally, this section provides an overview of how work activities are designed to be carried out within the office setting.

Work Plan

Each employee has a work plan, which is reviewed and updated annually or more often if sudden changes in the work load occur. The work plan outlines general areas of work for which the employee is responsible. Specific work loads are determined and field trips assigned by the Field Office Chief or the Senior Technician under the general guidance of the Field Office Chief. The work plan outlines tasks and the time frame for completion of the tasks, which allows the employee to be reviewed and rated on the basis of work accomplished.

File Folders for Surface-Water Stations

This section of the QA Plan describes the location and makeup of hard-copy files associated with surface-water data. Information pertaining to files maintained in computer storage can be found in the section entitled "Data-Base Management."

For each gaging station, a separate set of file folders is maintained that includes folders for current work, measurement (Form 9-207), station analysis, station description, ratings, and water year. The files may be arranged alphabetically or by downstream order number depending on the office preference. Extraneous items are removed from the current files each year when the record is reviewed. Discontinued stations are placed in a separate file and generally are combined into one folder.

The set of current work files for each station are grouped as follows.

1. Current work—The current folders contain a checkoff sheet for tracking work progress and ensuring that all steps are completed, a current digital rating, station description, list of peaks, runoff computation sheet, level summary sheet, and any other information needed on a continuing basis for working records.
2. Measurement—The measurement folder contains a Form 9-207 for each water year in the period of record.

3. Station Analysis—The station-analysis folder contains a complete set of station analyses that should describe how each water year of record was worked. For stations with long periods of record, compilation report summaries may be needed in this folder to obtain a complete history.
4. Station Description—The station-description folder contains a complete set of superseded descriptions plus the current station description.
5. Rating—The rating folder contains the original Form 9-210 and (or) digital printout and the original graphical ratings of all superseded ratings.
6. Water Year—The water-year folder contains the primary computation sheets, shift-analysis sheets, any stage-shift diagrams, stage and discharge hydrographs, and any other information used to work the final record for the water year.

Field-Trip Folders

Each hydrographer has a set of field folders for the areas for which he or she is responsible. Each folder contains a list of measurements that gives the gage height, discharge, and where the measurement was made, a current-station description, and rating table. Additional information such as a copy of the level summary, observers names and addresses, and other information, also is encouraged. Each person is responsible for maintaining the folder as long as the station is assigned to him or her. Each group of stations for a field trip should be kept in a field file along with a current flood plan and a good road map of the area.

Levels

Level notes are filed in the level file immediately after checking and final review of the record. A summary of levels for each station is kept in the current station and field folders. All levels—current and backfile—are kept in the same location and are not removed from the office. All levels should have a front cover sheet that summarizes the results of the levels and the action taken.

Discontinued Stations

A discontinued station file is maintained for discontinued stations. The current work, measurement, station description, and rating folders for a station that is being discontinued are combined into one folder and moved from the data-records file to the discontinued-station file. The water-year folders are transferred to the Federal Records Center at this time if local filing space is not available.

Map Files

The District Office maintains the official drainage-area map file. This file consists of a set of quadrangle maps on which the drainage areas for all gaging stations have been delineated and the station number for the site identified. The Data Chief is responsible for the maintenance of the files.

Archiving

All WRD employees are directed to safeguard all original field records containing geologic and hydrogeologic measurements and observations. Selected materials that are not maintained in field offices are placed in archival storage. Detailed information on what records have been removed to archival centers should be retained in the District or project office (WRD Memorandum 77.83). The types of original data that should be archived include, but are not limited to, recorder charts and tapes, original data and edited data, observer's notes and readings, station descriptions, analyses, and other supporting information (WRD Memorandum 92.59; Hubbard, 1992, p. 12). At this time, there is an agreement between WRD and the Federal Records Centers (FRC) of the National Archives and Records Administration to hold original data records (Branch of Operation Support Memorandum, May 7, 1993).

Surface-water information is sent to the FRC from each office in the District as needed but generally about every 7 years. The Data Chief is responsible for deciding what information is sent to the FRC, for ensuring that the information is properly packed and logged, and for ascertaining that the information is received by the FRC. Records of exactly what has been archived are maintained in the office responsible for the records and generally is the responsibility of the secretary of the office but can be assigned to other individuals. Employees who have questions concerning archiving procedures should address their questions to the Data Chief. Employees who receive requests for information that require accessing archived records should obtain the requested records from archives with assistance from the person designated with the retrieval responsibility. Project chiefs are responsible for ensuring that appropriate project data are archived under the direction of the Chief, Hydrologic Investigations and Research.

Communication of New Methods and Current Procedures

The Field Office Chief will hold in-house training sessions as needed to communicate any new methods or procedures in data-collection activities. Formal training (National Training Center, local colleges and universities, and district seminars) is provided to all employees whenever the need arises because of changes in personnel, job title or position changes, or reassignment of responsibilities.

COLLECTION OF SEDIMENT DATA

Surface-water activities in the District include the collection, analysis, and publication of sediment data, but only on a limited basis. Data processing of periodic measurements consists of four steps: tabulation, evaluation, editing, and verification (Porterfield, 1972; Guy, 1969; OSW Memorandum 91.15). Sediment samples are sent to selected laboratories for analysis because the District does not maintain a sediment laboratory.

Sediment-Station Analysis

A sediment-station analysis is written for each sediment station operated by the District in each water year. The sediment-station analysis is a summary of the sediment activities at the station for a given year. The analysis describes the coverage of sampling, the types of samples and sampling, changes that might affect sediment transport or the data record, and the methods and reasoning used to compute the record. Information included in the sediment-station analysis is presented in such a manner that the checker and the reviewer can determine the adequacy of the activities in defining the sediment record (OSW Memorandum 91.15).

DATA-BASE MANAGEMENT

Surface-water data are collected by employees of the WRD and stored in computer data bases. Proper storage and maintenance of surface-water data are critical components in the effective utilization of that data. Because computer hardware and software used in the processing and storage of surface-water data are continually changing, many Districts hesitate in describing policies and procedures associated with these functions. But having to deal with recurring periods of transition, in effect, emphasizes the importance of having clearly assigned authority and clearly stated procedures for correctly populating, updating, reviewing, and maintaining a data base.

The data-base management system in Arizona is comprised of data-base managers for each of the disciplines. The Data Chief has the final responsibility for ensuring that the surface-water data base is current and correct. The Data Chief is responsible for ensuring that the latest updates to the NWIS computer programs are loaded and operational on a timely basis and that training in new programs is provided to personnel of the Data Section. The Data Chief is responsible for updating the national data base on a timely basis and flagging all daily values as final after the data have been reviewed and approved for publication.

PUBLICATION OF SURFACE-WATER DATA

The Act of Congress (Organic Act) that created the U.S. Geological Survey in 1879 established the Survey's obligation to make public the results of its investigations and research and to conduct, on a continuing, systematic, and scientific basis, the investigation of the geologic structure, mineral resources, and products of the National domain (Alt and Iseri, 1986, p. 4). Fulfilling this obligation includes the publication of surface-water data and the interpretive information derived from the analyses of surface-water data.

Publication Policy

The USGS and WRD have created specific policies pertaining to publication of data and interpretation of those data. All WRD employees are required to abide by those policies. A brief summary of goals, procedures, and policies are presented in Alt and Iseri (1986, p. 4–37).

All information obtained through investigations and observations by the staff of the USGS or by its contractors must be held confidential and not be disclosed to others until the information is made available to all, impartially and simultaneously, through Director-approved formal publication or other means of public release, except to the extent that such release is mandated by law (Alt and Iseri, 1986, p. 14). With the approval of the Director, hydrologic measurements resulting from observations and laboratory analyses, after they have been reviewed for accuracy by designated WRD employees, have been excluded from the requirements to hold unpublished information confidential (Alt and Iseri, 1986, p. 15).

All interpretive writings in which the USGS has a proprietary interest, including abstracts, letters to the editor, and all writings that show the author's title and USGS affiliation, must be approved by the Director before release for publication. The objectives of the Director's review are to check the technical quality of the writing and to make certain that it meets USGS publication standards and is consistent with policies of the USGS and the U.S. Department of the Interior. Director's approval ensures that (1) each publication or writing is impartial and objective, (2) has conclusions that do not compromise the USGS's official position, (3) does not take an unwarranted advocacy position, and (4) does not criticize or compete with other governmental agencies or the private sector (Hanson, 1991, p. 10).

Types of Publications

There are various types of book publications released by the USGS in which surface-water data and data analyses are presented. Publications of the formal series include Water-Supply Papers, Professional Papers, Bulletins, Circulars, Techniques of Water-Resources Investigations, Special Reports, and Selected Papers in the Hydrologic Sciences (Alt and Iseri, 1986, p. 42). Publications in the informal series include Water-Resources Investigations Reports, Open-File Reports, and Administrative Reports (Alt and Iseri, 1986, p. 52). Factors considered by the District when deciding which form of publication should be used in presenting various types of information are presented in Green (1991, p. 14). Data reports are in the open-file report series, which includes basic-data reports. Surface-water data collected by this District are published each year in a basic-data report that is in an annual series entitled "U.S. Geological Survey Water-Data Reports" (Alt and Iseri, 1986). The District Chief or the designated representative, in this case the Data Chief, has been given the authority to approve the annual data report for publication (Alt and Iseri, 1986, p. 129).

Review Process

Procedures for publication and requirements for manuscript review by WRD are summarized in Hanson (1991, p. 36–41) and Alt and Iseri (1986). This District fulfills those requirements for review and approval of reports before printing and distribution. All reports written by USGS scientists in connection with their official duties must be approved by the originating Division and the Director or the designated representative. At least two technical reviews of each report are required by WRD (Hanson, 1991, p. 36). Competent and thorough editorial and technical review is the most certain way to improve and assure the high quality of the final report (Moore and others, 1990, p. 24–29). Although the annual data reports are considered open-file reports, they are not required to receive editorial review. The report is reviewed for policy and reproducibility (Hanson, 1991, p. 36). In addition to the standard checking and reviewing of the data included in the annual data report, the Data Chief and Field Office Chiefs are responsible for reviewing the final copy before it is sent to the printer and the proof copy before the final run is made.

SAFETY

Surface-water activities in this District include making streamflow-discharge measurements during adverse weather conditions. Cold temperatures, wind, snow, ice, extreme heat, and blowing sand can create difficulties in collecting data and can create danger to field employees. Additional attention must be given to safety when working on cableways and bridges. Vehicles must be maintained in the safest condition possible to ensure employee safety. The highest priority in collecting streamflow data is employee safety.

Conducting work activities in a manner that ensures the safety of employees and others is of the highest priority for the USGS and the Arizona District. Beyond the obvious negative effect unsafe conditions can have on employees, such as accidents and personal injuries, they also can have a direct effect on the quality of surface-water data and data analysis. For example, errors may be made when an individual's attention to detail is compromised when dangerous conditions create distractions. So that employees follow established procedures and policies that promote all aspects of safety, the District communicates information and directives related to safety to all employees by in-house training classes, memorandums, videotapes, and safety posters. Specific policies and procedures related to safety can be found in the USGS Occupational Hazard and Safety Handbook. Each employee must attend scheduled safety training, read safety memorandums, and follow all safety procedures.

A Safety Officer has been designated by the District, and his or her duties include being knowledgeable on the latest safety information, making each office aware of the information, providing a list of training courses, making suggestions for individuals who need training and, in some cases, conducting training classes. Each Field Office is responsible for the annual District safety inspections of existing cableways, gaging stations, and field vehicles. A copy of these inspections are forwarded to the District Safety Officer for their files. Employees who have questions or concerns or who have suggestions for improving some aspects of safety should direct those questions, concerns, and suggestions to the Safety Officer.

TRAINING

The quality of surface-water data and analysis depends on employees being aware of correct methods and procedures. The District increases the quality of work and eliminates the source of many potential errors by providing appropriate training to the employees. The Arizona District has a training committee and a designated Training Officer who ensures that all employees are aware of the training opportunities available to them and who establishes priority training needs. In addition, it is the responsibility of each supervisor to ensure that all new employees complete the required training in the first 3 years of employment. The USGS provides a variety of training opportunities including on-the-job, USGS-sponsored training, local community colleges and universities, Federal Training Center courses, and training provided by other agencies. Training materials available for employee reference include the Techniques of Water-Resources Investigations (TWRI) series, Water-Supply Paper series, and memorandums from the Office of Surface Water.

SUMMARY

Surface-water activities in the Arizona District are part of the Water Resources Division's overall mission of appraising the quantity and quality of the Nation's water resources. The surface-water data collected and the analyses made are used to describe flood frequency, flood-plain boundary, base runoff, time-of-travel, and other characteristics of Arizona streams. Streamflow data are part of the water-resources inventory that is used for hydroelectric-power generation, waste loading, flood-plain management, water supply, and a host of other water-management and planning activities.

This District Surface-Water Quality-Assurance Plan documents the standards, policies, and procedures used by the Arizona District for activities related to the collection, processing, storage, analysis, and publication of surface-water data. The plan is a guide for all personnel involved in District surface-water activities. Responsibility for implementation of quality assurance is described so that each employee is clearly aware of his or her role. The plan also describes the system of checks and balances used by the Water Resources Division (WRD) and highlights the importance of quality products for the users of USGS data.

REFERENCES CITED

Alt, D.W., and Iseri, K.T., 1986, Water Resources Division publications guide—Volume I, Publications policy and text preparation: U.S. Geological Survey report, 429 p.

Arcement, G.J., and Schneider, V.R., 1989, Guide for selecting Manning's roughness coefficients for natural channels and flood plains: U.S. Geological Survey Water-Supply Paper 2339, 38 p.

Barnes, H.B, 1967, Roughness characteristics of natural channels: U.S. Geological Survey Water-Supply Paper 1849, 213 p.

Benson, M.A., and Dalrymple, Tate, 1967, General field and office procedures for indirect discharge measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A1, 30 p.

Bodhaine, G.L., 1982, Measurement of peak discharge at culverts by indirect methods: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A3, 60 p.

Buchanan, T.J., and Somers, W.P., 1969, Discharge measurements at gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A8, 65 p.

Carter, R.W., and Davidian, Jacob, 1968, General procedures for gaging streams: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A6, 13 p.

Coons, W.F., 1995, Estimates of roughness coefficients for selected natural stream channels with vegetated banks in New York: U.S. Geological Survey Open-File Report 93–161, 133 p.

Dalrymple, Tate, and Benson, M.A., 1967, Measurement of peak discharge by the slope-area method: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A2, 12 p.

Davidian, Jacob, 1984, Computation of water-surface profiles in open channels: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A15, 48 p.

Green, J.H., 1991, WRD project and report management guide: U.S. Geological Survey Open-File Report 91–224, 152 p.

Guy, H.P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of Water Resources Investigations, book 5, chap. C1, 58 p.

Hansen, W.R., 1991, Suggestions to authors of the reports of the United States Geological Survey, 7th ed: U.S. Geological Survey report, 289 p.

Hubbard, E.F., 1992, Policy recommendations for management and retention of hydrologic data of the U.S. Geological Survey: U.S. Geological Survey Open-File Report 92–56, 32 p.

Kennedy, E.J., 1983, Computation of continuous records of streamflow: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A13, 53 p.

____ 1984, Discharge ratings at gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A10, 59 p.

____ 1990, Levels at streamflow gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A19, 31 p.

Kilpatrick, F.A., and Schneider, V.R., 1983, Use of flumes in measuring discharge: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A14, 46 p.

Matthai, H.F., 1967, Measurement of peak discharge at width contractions by indirect methods: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A4, 44 p.

Moore, J.E, Aronson, D.A., Green, J.H., Puente, Celso, 1990, Report planning, preparation, and review guide: U.S. Geological Survey Open-File Report 89–275, 81 p.

Novak, C.E., 1985, WRD data reports preparation guide, 1985 ed.: U.S. Geological Survey report, 199 p.

Porterfield, George, 1972, Computation of fluvial-sediment discharge: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. C3, 66 p.

Rantz, S.E., and others, 1982, Measurements and computation of streamflow, volumes 1 and 2: U.S. Geological Survey Water-Supply Paper 2175, 631 p.

Sauer, V.B., and Meyer, R.W., 1992, Determination of errors in individual discharge measurements: U.S. Geological Survey Open-File Report 92–144, 21 p.

Schroder, L.J., and Shampine, W.J., 1992, Guidelines for preparing a quality assurance plan for the district offices of the U.S. Geological Survey: U.S. Geological Survey Open-File Report 92–136, 14 p.

Shampine, W.J., Pope, L.M., and Koterba, M.T., 1992, Integrating quality assurance in project work plans of the U.S. Geological Survey: U.S. Geological Survey Open-File Report 92–162, 12 p.

Shearman, J.O., 1990, User's manual for WSPRO—A computer model for water surface profile computations: U.S. Federal Highway Administration Report FHWA–IP–89–027, 187 p.

Shearman, J.O., Kirby, W.H., Schneider, V.R., and Flippo, H.N., 1986, Bridge waterways analysis—Research report: U.S. Federal Highway Administration Report FHWA/RO–86/108, 112 p.

Smoot, G.F., and Novak, C.E., 1968, Calibration and maintenance of vertical-axis type current meters: U.S. Geological Survey Techniques of Water-Resources Investigations, book 8, chap. B2, 15 p.

Thomsen, B.W., and Hjalmarson, H.W., 1991, Estimated Manning's roughness coefficients for stream channels and flood plains in Maricopa County, Arizona: Phoenix, Arizona, Flood Control District of Maricopa County report, 126 p.

Water Resources Division Memorandums

Memorandum number	Date	Title
		Office of Surface Water
93.12	02–04–93	Clarification of leveling procedure (See Kennedy, 1990).
93.07	12–04–92	Policy statement on stage accuracy.
92.11	17–12–92	Flow process recognition for floods in mountain streams.
92.10	07–02–92	Guidelines for identifying and evaluating peak-discharge errors.
92.09	06–17–92	Adjustment of discharge measurements made at a distance from the gaging station during periods of changing stage and discharge.
91.15	09–30–91	PROGRAMS AND PLANS—Guidelines for the analyses of sediment data.
89.08	06–02–89	Policy statement on stage accuracy.
89.07	06–02–89	Policy to ensure the accurate performance of current meters.
88.07	04–14–88	Guidelines for the operation of a crest-stage program.
87.05	03–06–87	PUBLICATIONS—Bridge waterways analysis: Research report (See Shearman and others, 1986).
85.17	09–20–85	PROGRAMS AND PLANS—Policy providing low-flow information.
85.07	05–13–85	EQUIPMENT AND SUPPLIES—Current meters.
83.07	09–09–83	COMPUTATION—Availability of hydraulics programs for Prime computers.
		Water Resources Division
92.59	10–28–92	Policy for management and retention of hydrologic data of the U.S. Geological Survey.
85.129	07–31–85	Publication of furnished streamflow data.
77.83	03–30–77	Retention of original water records.
		Branch of Operation Support
Unnumbered	05–07–93	Disposition of original hydrologic records.