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Standards for the Analysis and Processing of Surface-Water Data and Information Using Electronic Methods

Water-Resources Investigations Report 01–4044

U.S. Department of the Interior
U.S. Geological Survey

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By V.B. Sauer

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Conversion Factors and Datum

Multiply	By	To obtain
	Length	
inch (in.)	25.4×10^{1}	millimeter (mm)
inch (in.)	25.4×10^{-2}	meter (m)
foot (ft)	3.048×10^{-1}	meter (m)
mile (mi)	1.609×10^{0}	kilometer (km)
	Area	
acre	4.047×10^{3}	square meter (m^2)
acre	4.047×10^{-1}	square hectometer (hm^2)
acre	4.047×10^{-3}	square kilometer (km^2)
square foot (ft^2)	9.290×10^{-2}	square meter (m^2)
square mile (mi^2)	2.590×10^{0}	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	2.832×10^{1}	cubic decimeter (dm^3)
cubic foot (ft^3)	2.832×10^{-2}	cubic meter (m^3)
cubic foot per second day [(ft^3/s)d]	2.447×10^{3}	cubic meter (m^3)
cubic foot per second day [(ft^3/s)d]	2.447×10^{-3}	cubic hectometer (hm^3)
acre-foot (acre-ft)	1.233×10^{3}	cubic meter (m^3)
acre-foot (acre-ft)	1.233×10^{-3}	cubic hectometer (hm^3)
acre-foot (acre-ft)	1.233×10^{-6}	cubic kilometer (km^3)
	Flow rate	
cubic foot per second (ft^3/s)	2.832×10^{1}	liter per second (l/s)
cubic foot per second (ft^3/s)	2.832×10^{1}	cubic decimeter per second (dm^3/s)
cubic foot per second (ft^3/s)	2.832×10^{-2}	cubic meter per second (m^3/s)
	Velocity	
foot per second (ft/s)	3.048×10^{-1}	meter per second (m/s)
foot per hour (ft/hr)	3.048×10^{-1}	meter per hour (m/hr)
foot per hour (ft/hr)	2.54×10^{1}	millimeter per hour (mm/hr)

Sea level: In this report, “sea level” refers to the National Geodetic Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment for the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Standards for the Analysis and Processing of Surface-Water Data and Information Using Electronic Methods

by V.B. Sauer

Abstract

Surface-water computation methods and procedures are described in this report to provide standards from which a completely automated electronic processing system can be developed. To the greatest extent possible, the traditional U. S. Geological Survey (USGS) methodology and standards for streamflow data collection and analysis have been incorporated into these standards. Although USGS methodology and standards are the basis for this report, the report is applicable to other organizations doing similar work. The proposed electronic processing system allows field measurement data, including data stored on automatic field recording devices and data recorded by the field hydrographer (a person who collects streamflow and other surface-water data) in electronic field notebooks, to be input easily and automatically. A user of the electronic processing system easily can monitor the incoming data and verify and edit the data, if necessary. Input of the computational procedures, rating curves, shift requirements, and other special methods are interactive processes between the user and the electronic processing system, with much of this processing being automatic. Special computation procedures are provided for complex stations such as velocity-index, slope, control structures, and unsteady-flow models, such as the Branch-Network Dynamic Flow Model (BRANCH). Navigation paths are designed to lead the user through the computational steps for each type of gaging station (stage-only, stage-discharge, velocity-index, slope, rate-of-change in stage, reservoir, tide, structure, and hydraulic model stations). The proposed electronic processing system emphasizes the use of interactive graphics to provide good visual tools for unit values editing, rating curve and shift analysis, hydrograph comparisons, data-estimation procedures, data review, and other needs. Documentation, review, finalization, and publication of records are provided for with the electronic processing system, as well as archiving, quality assurance, and quality control.

1. Introduction

The U.S. Geological Survey (USGS), Water Resources Division (WRD), has been using automated data-processing methods to compute, analyze, and publish surface-water records since about 1963. Surface-water records, by definition, generally include stage and streamflow of rivers, creeks, and other streams; reservoir stage and contents; and tide stages in and near the mouths of coastal streams. Prior to 1963, almost all streamflow data were processed by hand and desktop calculators. After 1963, some of the processing steps, such as drawing rating curves, were accomplished by hand methods and transferred to the computer by keying in the necessary values. The first nationally used computer program for processing streamflow data was installed in 1972 and was part of the National Water Data Storage and Retrieval System, referred to as WATSTORE (Hutchinson, 1977). In about 1983, a second program referred to as the New Jersey District Automatic Data Recorder (ADR) Processing System, or WRD Interim System, was used nationally and essentially replaced the WATSTORE system. The New Jersey System was installed for use on the Prime Computers and was intended only for interim use until a new program, the Automated Data Processing System, ADAPS (Dempster, 1990), could be completed and installed. ADAPS was installed nationally in 1985 and is part of the National Water Information System (NWIS). In 1996–97, ADAPS was converted to run on the Data General computer superseding the Prime computer, and has since been further converted to run on the Sun computer that superseded the Data General computer.

Instrumentation for the collection and field recording of time-series data has attempted to keep pace with computer capabilities for processing the data; however, a noticeable lag has resulted. The evolution of data-collection methods shows a progression from analog, or graphic, recorders to digital recorders, and finally to electronic data loggers and data-collection platforms. Even so, many digital recorders still are in use as primary instruments, and many graphic recorders are in use as backup instruments. Part of the reason for this is a lag in the development and acceptance of electronic data loggers, and part of the reason is lack of funds to support a full conversion. With a mixture of instrumentation still in use, it becomes important that data-processing software be able to accommodate the various formats of input for time-series data.

Field measurements, such as discrete discharge determinations, traditionally have been recorded on paper forms. This form is still the accepted mode for these types of measurements. However, electronic field notebooks have been developed that may eventually become the standard for recording field notes and measurements. Processing software must be able to accept both types of input: keyboard entry from field notes recorded on paper forms, and direct entry from electronic field notebooks.

In addition to changing instrumentation, increased capabilities have developed for the analysis of streamflow information. Traditionally, streamflow information is produced primarily through the use of stage-discharge relations, with adjustments to these relations for shifting controls. For some stations, more complex computation procedures are used to account for variable backwater and rate-of-change in stage. Structures, such as dams, spillways, and turbines, are used at some stations to measure streamflow. The use of electromagnetic velocity meters and acoustic velocity meters has increased our abilities to continuously monitor stream velocity, and, thereby, provide an index of variable backwater. Unsteady-flow models, such as the Branch-Network Dynamic Flow Model (BRANCH), by Schaffrannek and others (1981), also have been accepted as viable methods to compute streamflow records. An unsteady-flow model uses detailed hydraulic characteristics of a stream reach, and has the capability to provide streamflow information at virtually every location in the stream reach, which may extend for many miles. This capability is a distinct advantage over the traditional gaging station that provides information at only one location.

Another aspect of streamgaging and the production of streamflow records is the increased need for streamflow information on a real-time, or near-real-time, basis. This aspect has led to remote sensing and transmitting systems where data are received in the office within minutes, or at the most hours, of the time of occurrence. These data usually are processed immediately upon reception in the office using automated computer systems. In many instances, these same data are received by agencies other than the USGS. Data and information of this type should be classified as operational, having more uncertainty than data and information that are subjected to verification, interpretation, and review. Operational data and information should not be considered the final answer for publication and archiving.

The changing technologies of data collection and data processing require changes in computer software. There is no doubt that this will be a continuing process as new and better computer technologies become available. In order to produce an accurate and consistent data base, it is important that certain procedures be standardized. The traditional hand methods, and some of the more recent computer methods, have been described in various USGS manuals, publications, and policy memorandum. Probably the oldest and most well known of the publications is Water Supply Paper 888 (Corbett and others, 1943). A recent update of that report is Water Supply Paper 2175 (Rantz and others, 1982). Two reports, "Computation of Continuous Records of Streamflow" (Kennedy, 1983), and "Discharge Ratings at Gaging Stations" (Kennedy, 1984) are the most recent documentation of surface-water analysis procedures. It is not the intent of this report to discount the applicability or soundness of the above mentioned reports. In fact, many of the field and office procedures, as well as the equipment, described in those reports are still valid today. In particular, the concepts and theory of surface-water analysis are correct and accepted. However, much of the information in those reports apply to processing techniques where hand methods are used either totally or partially. This report is intended to document and establish a standard set of techniques for surface-water data analysis and processing using electronic methods.

2. Purpose and Scope

The purpose of this report is to describe the standards to be used in the automated processing of surface- water records by computer. Although these standards are intended for use primarily by the USGS, they may be used by other organizations doing similiar work. By definition, surface-water records include reservoir, stage-only, tide, and streamflow records. All streamflow computation methods, including stage-discharge relations, slope station method, index-velocity method, rate-of-change in stage method, control structure methods, and unsteady-flow model methods are described in this report. The emphasis of the report concerns automated, electronic processing and analysis, but by necessity, user interaction is required to provide the necessary interpretation and quality control.

3. Surface-Water Data and Information

Surface-water data and information are composed of a number of measured and computed variables. This section of the report will describe some of these, and will define some of the terminology used throughout the report. These definitions should become part of the standards, just as the methodology is part of the standards.

3.1 Definitions

The words *data* and *information*, as used in this report, are intended to have special meanings. The term data is used for the results obtained from the measurement of a basic variable, which cannot be repeated. Data can be accepted, qualified, or rejected, but they cannot be modified without compromising their identity as data. Any change or modification of a data value converts that value into *information*. For example, if an original measurement of gage height is corrected for sensor error (such as drift related to time, gage height, temperature, or other factors), the new value of gage height is *information*.

Another example would be the use of a gage-height value and a relation of gage height to discharge, to compute a value of discharge. The computed discharge value is *information*. Unlike data, information can be modified, as would be the case if a stage-discharge relation were revised. Data generally are treated as a primary record, whereas information usually is treated as a secondary record.

The term *unit value* is used to denote a measured or computed value that is associated with a specified instantaneous time and date. In addition, unit values generally are part of a time-series data set. For surface-water records, unit values for all parameters always should be instantaneous values. Some parameters, such as velocity, tend to fluctuate rapidly and a true instantaneous value would be difficult to use in the analysis and processing of the records. Some instruments are designed to take frequent (for example, every second) readings, temporarily store these readings, and then compute and store a mean value for a short time period. For these situations, the field instruments should be programmed to record mean unit values for very short time intervals (1 to 2 minutes) so they can be considered for practical purposes to be instantaneous unit values.

Daily values are measured or computed values of a parameter for a specific date only. The time of the daily value is not required, although for certain daily values, time sometimes is stated. Examples of daily values are daily mean value, maximum instantaneous value for a day, and minimum instantaneous value for a day. In the case of maximum and minimum instantaneous values for a day, the time of the value usually is stated.

A *hydrographer* is defined for purposes of this report to be a person who collects streamflow and other surface-water data in the field. A *user* is a person who uses the electronic processing system to input data, analyze data, and process streamflow and other surface-water data and information. In many cases, the hydrographer and user may be the same person, but sometimes may be different persons.

3.2 Gage-Height Data

The height of the surface of a water feature, such as a stream, reservoir, lake, or canal, usually is referred to as gage height, stage, or elevation. For a streamgaging station, gage height is the more appropriate terminology, but the more general term “stage” is sometimes used interchangeably (Langbein and Iseri, 1960). For lakes, reservoirs and tidal streams, the height of the water surface usually is referred to as elevation. Gage height (also stage) is measured above an arbitrary gage datum, whereas elevation is measured above National Geodetic Vertical Datum (NGVD). Gage heights and elevations are principal data elements in the collection, processing, and analysis of surface-water data and information. Gage heights and elevations are measured in various ways, such as by direct observation of a gaging device, or by automatic sensing through the use of floats, transducers, gas-bubbler manometers, and acoustic methods. Gage heights and elevations should be measured and stored as instantaneous unit values. Subsequent data processing and analysis will provide the means for any required analysis, such as averaging.

3.3 Velocity Data

Another data element in a streamgaging system is stream velocity. Unit values of stream velocity are measured at some sites for the purpose of computing stream discharge where variable backwater conditions are present. The three principal instruments for measuring stream velocity are the deflection vane gage, the electromagnetic velocity meter, and the acoustic velocity meter. The methods for using each of these to compute stream discharge will be described in section 9.1.3. For purposes of definition, the deflection vane gage readings are simply an index of stream velocity, whereas the electromagnetic and acoustic meters provide actual velocity readings. Deflection vane gage readings are instantaneous values. Electromagnetic and acoustic velocity readings usually are recorded as an average of a number of instantaneous readings. The averaging period should be short, on the order of 1 or 2 minutes. The recording interval is determined by the site characteristics and the flashiness of the stream. For example, a typical electromagnetic or acoustic gage setup may compute 1 minute averages of stream velocity every 15 minutes and record these as instantaneous readings. The instrument would be active for 1 minute, and idle for 14 minutes.

3.4 Control Structure Data

Control structures, for the purpose of this report, are defined as manmade structures that are used to control the flow of water in a river or stream. These structures are located mostly at dams. A number of devices, such as free-flow spillways, gated spillways, sluice gates, turbines, pumps, siphons, and navigation locks convey flow through, over, and/or under a structure. In many cases, these can be instrumented and calibrated so that the stream discharge can be accurately determined. At a control-structure streamgage site, instrumentation may be required to record unit values of headwater gage height, tailwater gage height, gate openings, turbine pressures, lockages, and other variables that relate to the flow through the structure. A control structure is frequently a very complex system requiring numerous instruments and sensors to accurately measure the flow. A special computer program is part of the control-structure system and is used to process the structure data and compute discharge.

3.5 Discharge Information

A very important element, and frequently the ultimate goal in streamgaging, is the determination of stream discharge. Discharge cannot be measured directly, but must be computed from other measured variables such as gage height, stream depth, stream width, and stream velocity. Therefore, discharge is considered to be information rather than data. It is common practice to compute instantaneous unit values and daily mean values of discharge for gage sites. Instantaneous unit values of discharge are computed from various types of relations, such as a stage-discharge relation, a stage-area-velocity-discharge relation, or a stage-fall-discharge relation. Other relations might involve rate-of-change in stage, unsteady-flow models, and various structures such as gates, turbines, navigation locks, pumps, and siphons. Each of these computational procedures will be discussed in subsequent parts of this report.

Daily mean values of discharge are computed from instantaneous unit values of discharge. This method differs from some of the methods used in the past where daily mean values of discharge were computed from daily mean values of gage height. It also differs from procedures where mean values of gage height for subdivided parts of a day were used to compute discharge. The procedure for computing daily mean values of discharge from instantaneous unit values is described in section 9.2.

3.6 Field Measurements

Various kinds of data and information that are needed for the calibration and maintenance of a streamgaging station are obtained from field measurements. Most notable of these field measurements is the current meter measurement that is obtained periodically to define and check the discharge rating curve. Other types of field measurements include gage-datum leveling, indirect discharge measurements, and crest-stage gage measurements. Various measurements, other than discharge, and gage inspection notes sometimes are made and reported on field note sheets. For some stations with special methods for determining discharge, field measurements will be made of stream cross sections, estimates of stream roughness coefficients, and details of structures such as spillways, gates, and others. It is beyond the scope of this report to describe the details of most field measurements, but the surface-water analysis and processing system must provide an efficient method for entry and use of the field data and information.

3.7 Accuracy, Precision, and Significant Figures

Accuracy, precision, and *significant figures* are terms that are often confused and misinterpreted. This section of the report will describe the meanings of these terms, and provide a standard for use with surface-water data and information.

Accuracy is defined as the closeness or agreement of a measurement to the absolute or true value. *Precision,* refers to the closeness or agreement of repeated measurements to each other. Thus, precision also refers to the degree of refinement with which a measurement is made and repeated. An accurate measurement also is a precise measurement, but a precise measurement is not necessarily an accurate measurement. For example, a person making a measurement of gage height by using a wire-weight gage carefully can perform all techniques for setting the weight at the exact water surface, carefully can read the gage dials, and can repeat the measurement a number of times. The average reading obtained is a very precise measurement of gage height. The reading may not be accurate, however, because error may be present in the wire-weight gage mechanism, or expansion/contraction error in the cable, or error in the datum setting of the gage, or a combination of these errors.

Accuracy and/or precision also may vary according to the magnitude of the measurement being made. Again, using the measurement of gage height as an example, a gage reading at low values may be more precise than a gage reading at high values because the water surface may have more surging and wave action at high values. Accuracy also may be different between high and low values because gage-datum setting, or other gage errors, may be different at high and low values.

Another way of expressing accuracy and precision is from a statistical point of view. If an observer makes a number of readings of a gage over a very short time period (minutes), and during a time when the stream stage is not changing, then theoretically the same gage height is measured each time the gage is read, assuming the equipment is in perfect working order, including the observer's ability to read the gage. Because equipment and people are not perfect, the gage readings will not always be the same. A statistical measure of the dispersion or scatter of the gage readings is defined as precision. Generally, the statistical measure used is the standard deviation, or the spread of about two-thirds of the readings. Precision, or lack of precision, is a random error having both plus and minus deviations. Averages of individual readings usually have less scatter than individual readings. Thus, the precision can be increased by averaging readings. However, averaging does not totally eliminate scatter and, thus, even the average has limited precision.

The preciseness of a gage reading, as described above, is not the sole measure of the accuracy of the reading. For example, if the cable of a wire-weight gage is longer or shorter because of an uncorrected temperature difference, then this error affects all gage readings during the short time period in question. Averaging does not remove this error, because all of the gage readings are affected by it with exactly the same magnitude and sign. Such errors, which do not change during a series of repeated gage readings, and that are not reduced by averaging, are called systematic errors or biases.

Accuracy is expressed in terms of the difference between a measurement result (whether a single measurement or the mean of various measurements) and the true gage height. The measurement result can differ from the true value because of random errors (precision) or systematic errors (bias), or both. Accuracy, or more properly, its obverse, uncertainty, normally is expressed as the square root of the sum of squares of standard deviation of random errors plus the sum of squares of estimated systematic errors. A discussion of accuracy is given also by Rantz and others (1982).

The precision of various types of measurements necessary for processing surface-water records is given in table 1. The value given for each parameter is not based on a statistical analysis, but has been based on experience and commonly accepted precision used for surface-water analysis. For instance, it commonly is accepted that gage heights can be measured to a precision of 0.01 ft. Gage heights may not be that accurate, although if gages are maintained properly, and gage datum is checked and maintained carefully, it generally is accepted that gage-height accuracy can be within 0.01 ft at most sites. Some sites where conditions are not conducive to precise measurement of gage height may require that gage-height precision be as low as 0.1 ft.

Table 1. Normal precision of measurements of surface water and related parameters

[ft, feet; ft/s, feet per second]

Parameter	Precision of Measurements	
	English Units	Metric Units
Gage height or elevation of water surface	0.01 ft	0.001 meter
Gage height of zero flow, natural channel	.1 ft	.01 meter
Gage height of zero flow, manmade control structure	.01 ft	.001 meter
Gage height of gage features	.01 ft	.001 meter
Velocity (Electromagnetic meter (EM), ultrasonic velocity meter (UVM), Price current meter)	.01 ft/s	.001 meters per second
Depth (uneven streambed, deep streams)	.1 ft	.01 meter
Depth (smooth streambed, shallow streams)	.01 ft	.001 meter
Width (wading measurements, narrow cross sections)	.1 ft	.01 meter
Width (bridge, cable, boat, wide cross sections)	1 ft	.1 meter
Ground elevation (cross section)	.1 ft	.01 meter
Reference and benchmarks	.001 ft	.001 meter

A third term to be defined is *significant figures*. As the name implies, a significant figure is a figure that expresses meaning, and can aid in evaluating the accuracy of a value. Every digit in a number is considered significant except zeros that are added for the purpose of locating the decimal. Zeros usually are not considered significant when they are to the extreme right of a number but to the left of the decimal, and when they are at the extreme left of a number. Zeros to the extreme right of a number and to the right of the decimal are considered significant because they are *not* needed to locate the decimal. All zeros that are between other digits are considered significant.

For surface-water records, the standards for significant figures have been established and accepted for most of the data and information values used (table 2). Exceptions to the standard significant figures can be made when conditions warrant. For instance, a daily mean discharge greater than or equal to 100 ft^3/s usually is shown to three significant figures, but an estimated daily mean discharge might not be considered accurate to more than two significant figures, or in some cases even one significant figure. Such a reduction in the number of significant figures implies a reduction in the accuracy of the value.

Table 2. Standard significant figures for surface-water data and information (English units)

[x = significant figure, 0 = nonsignificant figure]

Data or Information Value	Significant Figures
Water-surface gage height and elevation	.0x, .xx, x.xx, xx.xx, xxx.xx, xxxx.xx
Stream depth	.0x, .xx, x.x, xx.x xxx.
Stream width	.xx, x.x, xx., xxx., xxxx., xxxx0.
Cross-section area	.xx, x.x, xx.x, xxx., xxx0., xxx00., xxx000.
Cross-section conveyance	x., xx., xxx., xxx0., xxx00., xxx000., xxx0000.
Stream velocity (mean or instantaneous)	.0x, .xx, x.xx, xx.xx
Velocity adjustment factor (index-velocity)	.0x, .xx, x.xx
Boyer factor ($1/US_c$)	.0x, .xx, x.xx
Reservoir contents	xxxx., xxxx0., xxxx00., xxxx000., and so forth
Stream discharge (daily mean)	.0x, .xx, x.x, xx., xxx., xxx0., xxx00., xxx000., xxx0000.
Stream discharge (measurement)	.0xx, .xx, x.xx, xx.x, xxx., xxx0., xxx00., xxx000., xxx0000.
Water-surface fall (slope stations)	.0x, .xx, x.xx, xx.xx
Fall ratio (slope stations)	.0x, .xx, x.xx
Discharge ratio (slope stations)	.0x, .xx, x.xx
Gage height of zero flow	.0x, x.xx, xx.xx
Gage height of high water marks	.xx, x.xx, xx.xx, xxx.xx
Gage height of gage features	.xx, .xx, x.xx, xx.xx, xxx.xx
Reference and benchmark elevations	.00x, .0xx, .xxx, x.xxx, xx.xxx, xxx.xxx, xxxx.xxx
Control structure elevations and gage heights	.0x, .xx, x.xx, xx.xx, xxx.xx
Natural ground elevations and gage heights	.x, x.x, xx.x, xxx.x

4. Entry of Data to the Electronic Processing System

The first step required for the processing of surface-water data is the entry of field data and information to the electronic processing system. This processing will include unit value data and field measurement data and information. Field measurement data can include discharge measurement data and information, gage-datum leveling data, crest-stage gage data, channel and control cross-section data, and other miscellaneous data, information, and notes.

4.1 Unit Value Data

The recording of unit value data has evolved from simple hand written notes, to analog recorders, to digital recorders, to sophisticated programmable data loggers, and to direct data transmission to the computer by radio, telephone, or satellite. Although the trend today is toward the use of programmable data loggers and direct data transmission, digital recorders still are widely used, and some use of analog recorders and hand written observer records. Therefore, the electronic processing system must accommodate each of these types of data formats.

Preparation of unit value data for electronic processing should follow a basic sequence. However, because different methods are available for collecting and recording field data, there may be instances where the preferred sequence cannot be followed. The following sequence is advised:

1. A copy of the original, unedited unit values should be stored (archived) before any editing, conversions, or computations are made. All editing, conversions, and computations should be performed using an electronic copy of the original data.
2. The unit values should be translated into a standard format (see section 4.1.4).
3. The unit value times should be corrected for clock errors, if applicable (see section 5.2).
4. Conversions to UTC time should be made (see section 5.2) so that all unit value data can be related to standard time or daylight savings time, as required.
5. The unit values prepared in this manner then can be used for all further computations, analysis, and archiving, as described in this report.

Various types of unit value data can be entered into the electronic processing system. These data include unit values of gage height (stage or elevation), velocity or velocity index, spillway gate opening or index, turbine pressures, navigation lockages, and other readings associated with structures. For some gage sites, multiple data sets of unit values may be available for a given parameter. For instance, a stream affected by backwater may have two gages at different locations for the purpose of measuring gage height. Unit values of gage height (stage or elevation) is a mandatory entry for each gage site.

4.1.1 Sources of Unit Value Data

A brief description of the six methods of obtaining, recording, and entering unit value data to the electronic processing system is given in the following paragraphs. Each set of unit values must be identified as to the source and method of aquisition.

Observer data—At some gage sites, gage readings are made by an observer. These readings are recorded, along with date and time of the reading, on a preprinted form. Such readings may be used as the primary set of unit values for the station, or they may be used only for backup and verification of another measuring and recording method. The hand written unit values made by an observer must be entered into the electronic processing system by direct keyboard entry. The date and time must be entered for each unit value, and the time zone designation must be entered for each set of unit values.

Analog recorders—Analog, or graphical, recorders are frequently used to record the gage height, or other parameters, as sensed by a float, pressure system, or other measuring device connected to the recorder. Analog recorders provide a continuous trace of the measurements on a graphical chart that is driven by a clock to provide a time scale. Unit value data from these charts are entered to the electronic processing system through the use of an automatic, or hand operated, digitizer. The digitizer enters unit values from the chart at time intervals specified by the user. Beginning and ending dates and times, and the time zone designation, must be entered for each segment of chart that is digitized. Analog records may be used as the primary unit values for a station, but are more frequently used for backup and verification of unit values collected with a different method.

Automated digital recorders—The automated digital recorder (ADR) is a device that records data on a narrow paper strip by punching a series of holes that digitally are coded to represent the unit value reading. The paper strip advances after each punch and data are recorded at a specified time interval, commonly 5, 15 or 60 minutes. Other time intervals may be used in some instances, but the time interval is uniform for each gage. Unit value data are entered to the electronic processing system by passing the paper strip through a digital tape reader. Starting and ending dates and times, and the time zone designation, must be entered for each processing period. ADR's frequently are used as the primary recording instrument for a gage site, but also are used as backup and verification for other types of instruments.

Electronic data loggers—Various types of electronic data loggers are in use for recording unit value data. These devices receive data from a sensing instrument and record the unit value in electronic memory. Data are extracted from the data logger either by removing the memory chip or by reading data from the memory into an external storage module or field computer. Because of the many configurations and types of data loggers currently in use, and because changes occur frequently, it is not practical to attempt a description in this report. The process of entering data from these types of recorders primarily is electronic. Electronic data loggers have the advantage over analog recorders and ADR’s because they can be programmed to sense and record according to pre-defined rules, as discussed in section 4.1.2. A recording system of this type results in a variable time interval between unit values, and necessitates the recording of the time and date associated with each unit value. If the recording time interval is constant, then most electronic data loggers do not record the time and date associated with each unit value. For either method, variable or constant recording interval, the starting and ending date and time must be entered for the period of record being processed. Electronic data loggers frequently are used for the primary recording instrument, but in some cases they may be used only for backup and verification.

Data-collection platforms—Data-collection platforms (DCP's) are field systems whereby data are stored electronically for a relatively short time (from 2 to 4 hours) and then transmitted by radio, telephone, or satellite to an office computer. For some types of DCP's, storage may be comparable to an electronic data logger and the data can be retrieved in similar fashion. DCP's are frequently operated in conjunction with an electronic data logger, ADR, or analog recorder. A variety of gage and recorder configurations is possible. Where two or more recorders are used, one should be designated the primary instrument, and the DCP frequently is given that distinction. In some instances, the DCP is the only instrument used and the primary record is received directly in the office. Unit value data transmitted and received by satellite automatically are tagged with date and time, which is determined from Universal Coordinated Time (UTC).

Other—Unit value data that are stored on other computer systems can be transferred to the electronic processing system by use of card images or other standard data formats.

One of the recorder types described above usually is designated as the primary recorder for computing the primary records of gage height, discharge, reservoir contents, or other parameters. Frequently, a second recorder is operated in conjunction with the primary recorder, and is designated the backup recorder. In the event of the malfunction of the primary recorder, the electronic processing system should allow the entry of unit values from the backup recorder as a substitute for the primary recorder values. These substitute unit values should be identified with a flag as to the source of the backup records. These records also should be subject to all further analysis, such as time corrections, parameter value corrections, and others, as described in section 5.

4.1.2 Unit Value Recording Time Interval

The time interval between recorded unit values may be a constant value, or the time interval may be variable. The programmable data logger allows the recording interval to be varied according to user- specified rules. The variable time interval can be based on the value of the parameter being recorded, the time length since the last recording, the rate of change of the parameter value being recorded, the value or rate of change of some other parameter, or some combination of these. The electronic processing system can accommodate either method of data recording, constant or variable time interval.

4.1.3 Time System Requirements

The time system used in most field data-collection systems is based on the local time in use at each gaging location. For most parts of the United States, the local time is a changing time system where the clock is advanced 1 hour in the spring, and set back 1 hour in the fall. The time during the summer period commonly is referred to as daylight savings time, and the remainder of the year as standard time. The advent of the satellite data collection platforms (DCP) has required the use of Universal Coordinated Time (UTC) for DCP field instruments. Additionally, some gage sites are operated year around on local standard time without making the change for daylight savings time. Consequently, there is a mixture of time systems being used for collection and recording of surface-water data. The surface-water electronic processing system must accommodate the entry of data in any of the time systems. Therefore, all data entry must include a designation of the time system at which the data were recorded. Time system designations will be an acronym based on the time zone, or time system, to which the gage is operated. Standard and daylight savings time zones, and the UTC offset, for the United States and possessions are shown in table 3.

Table 3. Standard and daylight savings time zones of the United States and possessions

Designation	Time Zone Name[1]	UTC Offset[2] (hours)
UTC	Universal Coordinated Time	0
AST	Atlantic Standard Time	+ 4
ADST	Atlantic Daylight Savings Time	+ 3
EST	Eastern Standard Time	+ 5
EDST	Eastern Daylight Savings Time	+ 4
CST	Central Standard Time	+ 6
CDST	Central Daylight Savings Time	+ 5
MST	Mountain Standard Time	+ 7
MDST	Mountain Daylight Savings Time	+ 6
PST	Pacific Standard Time	+ 8
PDST	Pacific Daylight Savings Time	+ 7
YST	Yukon Standard Time	+ 9
YDST	Yukon Daylight Savings Time	+ 8
AHST	Alaska-Hawaii Standard Time	+10
BST	Bering Standard Time	+11
BDST	Bering Daylight Savings Time	+10

[1]Time zone names and designations not defined for the United States Trust Territory west of the international date line, where UTC offsets vary from -10 to -12 hours.

[2]UTC offsets are added to the standard and daylight savings local times to obtain Universal Coordinated Time (UTC)

All times, both for time series data and for measurement data, automatically will be converted to UTC time for storage within the electronic processing system. Therefore, time adjustments for the 1-hour daylight savings time offset automatically will be accounted for when times are converted to UTC. The user will be able to perform computations, such as for daily mean values of streamflow, using any specified time system. The electronic processing system automatically will make the necessary time conversions, including changes between standard and daylight savings times, prior to making the computations. Likewise, unit values of gage height, discharge, or other parameters, would be retrieved using a time system of the user's choice.

4.1.4 Standard Format

All unit value data stored in the electronic processing system should conform to a standard unit value format. This format essentially means that the electronic processing system should convert all unit values to engineering units, including a decimal, and assign times and dates based on the time system used for field recording of data. Time adjustments for the purpose of converting the unit value times to standard UTC time are made automatically. Time corrections made for clock errors should be made after the data are converted to a standard format. Parameter value corrections are made on the basis of user instructions after data are entered to the electronic processing system. Additional details regarding time and parameter corrections are described in section 5.

4.2 Field Measurement Data

Various types of field measurements are made at surface-water gaging stations, each providing various kinds of data and information. These include measurements of stream discharge, leveling for gage datum checking, crest-stage gage measurements, channel and control cross-section measurements, and other miscellaneous data and information. Usually, each type of field measurement is recorded on a form designed especially for that type of measurement. The electronic processing system should be able to receive, process, and store the field measurement data and information so the data can be used in other parts of the electronic processing system.

Most field data are recorded on paper forms and must be transferred to the electronic processing system by keyboard entry. Field data and information that are recorded electronically in a field computer will require an interface between the field computer and the office computer to transfer the data automatically.

4.2.1 Discharge Measurements

The electronic processing system should have the capability to receive and store essentially all of the data and information recorded on discharge measurement note sheets. This capability would include the information shown on the front sheet of the notes and the detailed measurement data shown in the body of the notes. In the case where discharge measurements and associated information are recorded in electronic field computers, the electronic processing system would receive the data and information automatically through an interface.

Although the electronic processing system should be able to receive all data (front sheet and inside body) from a discharge measurement recorded on paper forms, it is not mandatory that the inside body data and information be entered. This part of the measurement is not normally used in the processing of daily discharge records. The main purpose for entering the data and information from the inside body would be for computational checking (see section 6.1), and for special studies.

The original measurement is either the data and information recorded on paper notes, or the data and information recorded in an electronic field notebook. If the measurement was recorded on paper, those original paper notes are saved for archival. If the measurement was recorded electronically, the first electronic copy entered to the electronic processing system becomes the archival copy. For this reason, it is mandatory that the entire measurement recorded in an electronic field notebook, including all of the individual data elements, be entered in the electronic processing system. Additional information about archiving requirements can be found in section 17.

4.2.1.1 Discharge Measurement Entry Requirements

Discharge measurement data will be acquired from 1 of 10 different methods of measurement. These methods include

1. standard current meter measurements (wading, bridgeboard, handline, bridge crane, cableway, and stationary boat),
2. ice measurements,
3. moving boat measurements (manual and automated),
4. acoustic Doppler profiler measurements (ADCP),
5. tracer-dilution measurements,
6. portable weir and flume measurements,
7. indirect measurements (slope area, contracted opening, culvert, stepbackwater, and critical depth),
8. surface velocity measurements (timing of floats or drift, optical, and others),
9. volumetric measurements, and
10. simple estimates of discharge.

The input forms presented to the user with the electronic processing system should be designed to conform with the measurement method. That is, the input form for measurement summary information for a specific method of measurement (for example, portable flume) would have input items specific to that method of measurement, and would omit input items that are not applicable to that method of measurement. Data-entry requirements for entry of summary information for discharge measurements, according to the method of measurement are listed in table 4.

The specific measurement data on the inside of the discharge measurement, although not mandatory, would be entered on separate input forms. The data and information required for these forms are listed in table 5. For some measurement methods the inside data may require multiple entries of some items.

Table 4. Items to be entered to the electronic processing system from a discharge measurement front sheet

Item Number	Measurement Item	Discharge Measurement Method									
		Standard Current Meter	Ice	Moving Boat (Manual and Automated)	Acoustic Doppler Current Profiler	Dye Dilution	Portable Weir or Flume	Indirect	Surface Velocity	Volumetric	Estimate
[1]1	Station identification number	X	X	X	X	X	X	X	X	X	X
[1]2	Station name (Obtain from site file, if available)	X	X	X	X	X	X	X	X	X	X
[1]3	Measurement type[1]	X	X	X	X	X	X	X	X	X	X
[1]4	Measurement sequence number	X	X	X	X	X	X	X	X	X	
[1]5	Party	X	X	X	X	X	X	X	X	X	X
[1]6	Start date (date of flood for indirects)	X	X	X	X	X	X	X	X	X	X
7	End date	X	X	X	X	X	X		X	X	X
8	Start time	X	X	X	X	X	X		X	X	X
9	End time	X	X	X	X	X	X		X	X	X
10	Time zone	X	X	X	X	X	X	X	X	X	X
11	Gage readings (table)	X	X	X	X	X	X		X	X	X
[1]12	Mean gage height, Inside Gage	X	X	X	X	X	X	X	X	X	X
13	Mean gage height, Outside Gage	X	X	X	X	X	X	X	X	X	X
14	Gage-height change	X	X	X	X	X	X		X	X	X
15	Gage-height change time	X	X	X	X	X	X		X	X	X
16	Mean index velocity	X	X	X	X	X	X	X	X	X	X
17	Mean auxiliary gage height	X	X	X	X	X	X	X	X	X	X
18	Stream width	X	X	X	X				X		
19	Stream area	X	X	X	X				X		
20	Mean velocity	X	X	X	X				X		
21	Number of sections	X	X	X	X				X		
[1]22	Measured discharge	X	X	X	X	X	X	X	X	X	X
23	Channels measured	X	X	X	X	X	X	X	X	X	X
24	Adjusted discharge	X	X	X	X	X			X		

Table 4. Items to be entered to the electronic processing system from a discharge measurement front sheet—Continued

Item Number	Measurement Item	Discharge Measurement Method									
		Standard Current Meter	Ice	Moving Boat (Manual and Automated)	Acoustic Doppler Current Profiler	Dye Dilution	Portable Weir or Flume	Indirect	Surface Velocity	Volumetric	Estimate
25	Adjustment method [2]	X	X	X	X	X			X		
26	Measurement location [2]	X	X	X	X	X	X	X	X	X	X
27	Current meter type [2]	X	X	X					X		
28	Current meter number	X	X	X					X		
29	Initial current meter inspection	X	X	X					X		
30	Final current meter inspection	X	X	X					X		
31	Suspension method [2]	X	X						X		
32	Observation method [2]	X	X						X		
33	Description of measuring section	X	X	X	X	X			X		X
34	Flow conditions [2]	X	X	X	X	X	X		X		
35	Horizontal angle coefficient	X	X						X		
36	Method coefficient [2]	X	X	X					X		
37	Suspension coefficient [2]	X	X								
38	Average time for point velocities	X	X						X		
39	Accuracy rating [2]	X	X	X	X	X	X	X	X	X	X
40	Computed accuracy	X									
41	Control description [2]	X	X	X	X	X	X	X	X	X	X
42	Control conditions [2]	X	X	X	X	X	X	X	X	X	X
43	Control cleaned	X	X			X	X			X	X
44	Time of control cleaning	X	X			X	X			X	X
45	Gage-height change from cleaning	X	X			X	X			X	X
46	Maximum stage indicator	X	X	X	X	X	X		X	X	X
47	Minimum stage indicator	X	X	X	X	X	X		X	X	X
48	Highwater marks [2]	X	X	X	X	X	X	X	X	X	X
49	Air temperature	X	X	X	X	X	X		X	X	X

Table 4. Items to be entered to the electronic processing system from a discharge measurement front sheet—Continued

Item Number	Measurement Item	Discharge Measurement Method									
		Standard Current Meter	Ice	Moving Boat (Manual and Automated)	Acoustic Doppler Current Profiler	Dye Dilution	Portable Weir or Flume	Indirect	Surface Velocity	Volumetric	Estimate
50	Water temperature	X	X	X	X	X	X		X	X	X
51	Base flow [2]	X				X	X			X	X
52	Gage height of zero flow	X	X			X	X			X	X
53	Gage height of zero flow accuracy	X	X			X	X			X	X
54	Remarks, written comments	X	X	X	X	X	X	X	X	X	X

[1]Mandatory.

[2]Requires supplementary table or menu selections.

Table 5. Items to be entered to the electronic processing system from the inside body of a discharge measurement

Item Number	Measurement Item	Discharge Measurement Method									
		Standard Current Meter	Ice	Moving Boat (Manual Only)[1]	Acoustic Doppler current profiler[1]	Dye Dilution[2]	Portable Weir orFflume	Indirect[2]	Surface Velocity	Volumetric	Estimate[2]
[3]1	Station identification number	X	X	X			X		X	X	
[3]2	Station Name	X	X	X			X		X	X	
[3]3	Measurement sequence number	X	X	X			X		X	X	
4	Channel number or name	X	X	X			X		X	X	
5	Distance from initial point	X	X	X					X		
6	Subsection width	X	X						X		
7	Horizontal angle coefficient	X	X						X		
8	Depth, water surface to streambed	X	X	X					X		

Table 5. Items to be entered to the electronic processing system from the inside body of a discharge measurement—Continued

Item Number	Measurement Item	Discharge Measurement Method									
		Standard Current Meter	Ice	Moving Boat (Manual Only)[1]	Acoustic Doppler current profiler[1]	Dye Dilution[2]	Portable Weir orFflume	Indirect[2]	Surface Velocity	Volumetric	Estimate[2]
9	Velocity observation depth(for example, .2, .6, .8, Surface)	X	X						X		
10	Current meter revolutions	X	X						X		
11	Time of current meter revolutions	X	X						X		
12	Velocity at point	X	X						X		
13	Mean velocity in vertical	X	X	X					X		
14	Subsection area	X	X						X		
15	Depth, water surface to bottom of ice		X								
16	Effective depth	X	X								
17	Air line distance (for vertical angle corrections)	X									
18	Vertical angle	X									
19	Horizontal angle, manual moving boat			X							
20	Pulses per second			X							
21	Boat travel distance			X							
22	Vector velocity			X							
23	Sine of horizontal angle			X							
24	Subsection discharge	X	X	X							
25	Surface velocity measuring distance								X		
26	Surface velocity travel time								X		
27	Surface velocity								X		
28	Total container volume									X	
29	Starting volume									X	
30	Ending volume									X	
31	Flow volume (difference of start and end volumes									X	
32	Fill time									X	

Table 5. Items to be entered to the electronic processing system from the inside body of a discharge measurement—Continued

Item Number	Measurement Item	Discharge Measurement Method									
		Standard Current Meter	Ice	Moving Boat (Manual Only)[1]	Acoustic Doppler current profiler[1]	Dye Dilution[2]	Portable Weir orFflume	Indirect[2]	Surface Velocity	Volumetric	Estimate[2]
33	Total volume (sum of flow volumes)									X	
34	Total time (sum of fill times)									X	
35	Subsection number (items 35-39 for volumetric-incremental method)									X	
36	Subsection width									X	
37	Sample width									X	
38	Subsection/sample width ratio									X	
39	Subsection discharge									X	
40	Head						X				
41	Average head						X				
42	Total width	X	X	X					X		
43	Total area	X	X	X					X		
44	Total discharge	X	X	X			X		X	X	

[1]Inside notes are entered electronically for automated moving boat and accoustic Doppler current profiler (ADCP).

[2]Inside notes not required.

[3]These items may not require direct entry. They should correspond to the front sheet entries for the given measurement, and may be provided directly with the electronic processing system.

4.2.1.2 Numbering Discharge Measurements

Although separate input formats are used for the various types of measurements, all measurements are numbered consecutively and are maintained in only one file of discharge measurements. The numbering sequence should begin with 1 for the first discharge measurement of record, and continue consecutively throughout the period of record, with all discharge measurements numbered in chronological order. Discharge measurement numbers may contain alphabetic characters (for example, 127A, 127B, and others) to allow insertion of a measurement in an established sequence. Renumbering of discharge measurements should be discouraged.

4.2.2 Gage Datum Leveling

Leveling for the purpose of establishing or checking the datum of reference marks, benchmarks, staff gages, wire-weight gages, and other gage features is performed occasionally at most gaging stations. Guidelines for leveling procedures are described by Kennedy (1990). The electronic processing system should provide capability to accept leveling data and should be able to produce an analysis and summary of the leveling information. Items that may be entered from the leveling field notes are listed in table 6.

Table 6. Items that may be entered to an electronic processing system from level notes

[Note—Items 4–9, 11–21, and 23–24 may require more than one entry. For example, more than one reference mark, such as RM2, RM 3, RM 4, and others may be present.]

[1]1.	Station identification number
[1]2.	Date of leveling
[1]3.	Party—initials and last name of each person
4.	Benchmark number (Benchmark, or Reference mark, that is used for the base should be separately identified)
5.	Benchmark elevation, as found by levels
6.	Reference mark number
7.	Reference mark elevation, as found by levels
8.	Reference point number
9.	Reference point elevation, as found by levels
10.	Electric tape reference point elevation, as found by levels
11.	Inside gage reference point elevation, as found by levels
12.	Inside gage reference point elevation, as read on gage
13.	Outside gage reference point elevations, as found by levels
14.	Outside gage reference point elevation, as read on gage
15.	Wire-weight elevation (bottom of weight), as found by levels
16.	Wire-weight elevation, as read on dial and corresponding to above item
17.	Wire-weight check bar elevation, as found by levels
18.	Wire-weight check bar elevation, as read on dial
19.	Outside water surface elevation, as read on outside reference gage
20.	Inside water surface elevation, as read on inside reference gage
21.	Time of reading outside and inside gages, for two above items
22.	Base (primary reference gage) correction, as found by levels
23.	Highwater mark elevation
24.	Crest-stage gage reference point elevation, (top of rod/stick, bottom pin, etc), as found by levels
25.	Orifice elevation, by levels
26.	Point of zero flow elevation, as found by levels
27.	Remarks—written comments from level notes

[1]Mandatory.

4.2.3 Crest-Stage Gage Data

Crest-stage gages are special gages capable of recording the highest level that a flood peak reaches. These gages may be operated independently as a partial record site, or they may be operated at a continuous record site for the purpose of verifying the peak gage height. A special note sheet is used to record data and information for crest-stage gages. The electronic processing system should be able to accept these data. Items that can be entered from crest-stage gage note sheets are listed in table 7.

Table 7. Items that may be entered to an electronic processing system from crest-stage gage notes

[Items 4–9 may require multiple entries to accomodate more than one crest-stage gage or highwater mark.]

[1]1.	Station identification number
[1]2.	Date of crest-stage gage inspection
[1]3.	Party—Initials and last name of each person
4.	Crest-stage gage identification (for example, upstream gage, downstream gage, and others)
5.	Elevation of crest-stage gage reference point (top of rod/stick or bottom pin), as given in station description
6.	Distance measured from crest-stage gage reference point to high water mark on rod/stick
7.	Highwater mark elevation, as calculated from two above items
8.	Highwater mark elevation, as determined from marks outside the crest-stage gage
9.	Estimated date of highwater mark
10.	Gage height of current water surface
11.	Gage read to obtain corresponding item 10 above (staff gage, wire weight, tape down, or other)
12.	Time of gage reading
13.	Time zone
14.	Remarks—written comments from notes

[1]Mandatory.

4.2.4 Channel and Control Cross Sections

Data defining cross sections of the stream channel and/or control are useful in rating curve analysis. Also, unsteady-flow model methods of computing stream discharge must have cross-section data at intervals along the stream reach for which the model is defined. The electronic processing system should allow input of items necessary for defining the cross-section location and the descriptors for each cross section. In addition, Manning roughness coefficients may be required and should be variable, both horizontally and vertically. For some cross sections that are considered section controls, a weir coefficient (C) should be an optional entry, which also may be variable with stage. Transverse stationing for cross sections should begin on the left bank of the stream and increase from left to right. If survey data are entered with transverse stationing that increases from right to left, the electronic processing system should provide an automatic conversion of the data to the left-to-right format. The electronic processing system also should accomodate input of cross-section data that were collected and recorded electronically. A listing of data that should be allowable entries for cross sections is listed in table 8.

Table 8. Items that may be entered to an electronic processing system from cross-section notes

[Multiple cross sections may be entered. For items 7–14 multiple entries may be entered]

[1]1.	Station identification number
[1]2.	Date of survey
[1]3.	Party—initials and last name of each person
[1]4.	Cross-section ID number—an alpha-numeric ID unique for each cross section.
[1]5.	A descriptive identification of the cross section, such as "section control" or "typical channel control section".
[1]6.	Longitudinal stationing, in ft, that locates the section relative to the gage. Positive stationing increases in the downstream direction and negative stationing increases in the upstream direction. The gage is station 0.
7.	Transverse stationing along the cross section, with the initial point beginning on the left bank.
8.	Ground elevation for each transverse station.
9.	Sub-area breakpoint station (rightmost transverse station of a sub-area).
10.	Sub-area low elevation breakpoint for roughness coefficients.
11.	Sub-area high elevation breakpoint for roughness coefficients.
12.	Sub-area low elevation roughness coefficient, Manning’s n.
13.	Sub-area high elevation roughness coefficient, Manning’s n.
14.	Cross-section weir coefficient, C, if applicable (can be variable with stage).
15.	Remarks

[1]Mandatory.

4.2.5 Miscellaneous Field Notes

Miscellaneous field notes occasionally are made at most gage sites. These may be just a gage reading, a measurement of some feature or variable, or simply some written comments. The electronic processing system should allow entry of these notes. Items that might be entered from miscellaneous field notes are listed in table 9.

Table 9. Items that may be entered to an electronic processing system from miscellaneous field notes

[Items 4–6 and 8 may have multiple entries.]

[1]1.	Station identification number
[1]2.	Date of field notes
[1]3.	Party—initials and last name of each person
4.	Gage reading of water surface
5.	Gage read to obtain corresponding item 4 above (IG, OG, Tape, WW, recorder dial, other)
6.	Time of gage reading
7.	Time zone
8.	Highwater mark elevation
9.	Gage height of zero flow as determined from field measurement
10.	Remarks—written comments from notes

[1]Mandatory.

5. Verification and Editing of Unit Values

Unit values for the various parameters, such as gage height and velocity, must be carefully checked and verified before used in further analysis. Erroneous or suspicious data may require editing and appending special identification codes (flags) to individual values. Before any editing is performed, the original unit values should be set aside for archiving. Details of archiving requirements are described in another part of this report. This section of the report describes techniques for verification and editing, which includes time corrections, unit value corrections, datum adjustments, various comparisons and cross-checking, and flagging requirements. All verification, editing, and time corrections must be performed on a copy of the original data, and not on the original. This copy will become the work file, and also will be archived following completion and finalization of the records.

5.1 Times and Dates

Unit values of gage height and other streamflow parameters generally are recorded in field instruments at a fixed time interval, such as every 15 minutes, 1 hour, and so forth. The time and date associated with each unit value are not always recorded, but are determined on the basis of the initial time and date, and the recording time interval. Times and dates are recorded for each unit value when field recorders are programmed for variable time-interval data. Field instrument clocks are fairly reliable, but occasionally clock errors will result. True times and dates are those noted by the hydrographer using his watch and calendar at the time the field instrument is serviced. Servicing would be at the beginning and end of a record period, and occasionally at intermediate points of a record period. Also, the hydrographer should note the time-system designation, such as CST, CDST, PST, and others, whenever the time and date are noted. Times, dates, and time system designations noted by hydrographers will be used as the basis for making time corrections, standard and daylight savings time adjustments, and conversion to UTC of the unit value data.

Data acquired by satellite DCP installations will have UTC times and dates assigned automatically. These times and dates are considered accurate and do not need adjustment or correction.

5.2 Time Corrections and Adjustments

Time corrections to account for clock errors may be necessary for unit value data recorded in the field. In addition, all unit value times must be adjusted to UTC time for purposes of archiving. These time corrections and adjustments do not apply to data collected by way of a satellite DCP because those data are considered correct as collected.

5.2.1 Clock Error Corrections

The simplest case of clock error is where the beginning time and date are correct and the ending time and date are incorrect by a known amount. Lacking any evidence of intermediate clock or recorder problems, it usually is assumed that the clock error is a gradual and uniform error. The correction for this type of error should be prorated uniformly throughout the record period.

A somewhat more complex case involves a clock or recorder malfunction somewhere in the middle of the record period, or where the clock was set wrong at the beginning of a record period. One or more instances of intermediate clock problems may result in some cases. The time-correction procedure should allow the user to assign time and date values at more than one place within a record period, and the electronic processing system should adjust all intermediate or intervening unit value times accordingly. Occasionally, it may not be possible to determine why the time for a record is incorrect, or at what point in a record that timing problems occurred. A user may need to make arbitrary time assignments, based on their best judgement.

In some cases, intermediate time and date readings may be available from discharge measurement notes or miscellaneous field notes when the gage was visited but the record was not removed. The electronic processing system should automatically retrieve dates and times from the field note entries for checking clock performance. This requires that the unit value file has been marked or tagged in some way so the user can identify the place in the record where the correct times and dates apply. Such readings would be treated the same as described above, and corrections would be made by linear proration between adjacent readings.

Past methods for making time corrections, such as used in ADAPS, provide a method referred to as the "historical" method, whereby occasional unit values are dropped, or added, in order to account for a time error. This method is not considered as good as the linear proration method and should not be used.

The standard time-correction method, or linear proration method, described herein will result in unit values of gage height (or velocity, or other parameter) that will not be on the even hour, or 15 minutes, or other even time. This is not considered detrimental to the record. If unit values of gage height (or other parameter) are needed on the even hour or other even time interval, they can be obtained by interpolation between the time-adjusted values.

Time differences caused by a change into or out of daylight savings time should not be treated the same as a clock error. If a clock error exists during a period of record where the time changed because of daylight savings time, the clock error should first be prorated by assuming a uniform time designation for all of the period of record being processed. The electronic processing system should adjust times and dates input from field notes to the same time designation. The clock error is then corrected according to the user's instructions. After clock error corrections are made, the record is automatically converted with the electronic processing system to UTC time for storage and archiving. No unit values would be dropped or artificially added because of the daylight savings time change.

5.2.2 Universal Coordinated Time (UTC) Adjustments

All data and information should be stored and archived with Universal Coordinated Time (UTC). Therefore, following the standard time-correction method for making clock error adjustments, the electronic processing system should automatically adjust all local times to UTC. This is a simple process of adding the time offset shown in table 3 to the recorded local times. The recorded local times must have a time-zone designation as part of the input to define the time-zone system used for recording.

Unit values used in other analyses, such as computation of daily values, will adjust the UTC times to whatever time system is designated by the user. In this way, the electronic processing system can produce records on the basis of any designated time system. The time adjustments resulting for a period where time changes from standard time to daylight savings time, and for a period where time changes from daylight savings time to standard time is illustrated in figure 1. Also shown are unit values that would be used for computing daily values for days that change between standard time and daylight savings time. Note that all unit values are used in the computations, and none are dropped or artifically added. The day when time changes into daylight savings time will contain 23 hours, and the day when time changes out of daylight savings time will contain 25 hours.

5.3 Parameter Value Verifications

Unit values of gage height and other parameters that have been automatically measured and recorded by field instruments always should be carefully inspected and verified before accepting them for further analysis and computations. Various methods are available in electronic data processing to make this task relatively easy. The most frequently used methods are threshold comparisons, rating comparisons, direct reading comparisons, and graphical methods. Of these, graphical methods are the most versatile and can be easily adapted to any of the other methods.

5.3.1 Threshold Comparisons

A threshold is a minimum or maximum value that can help detect unit values that might be erroneous. Thresholds can be compared directly to unit values, or to differences between adjacent unit values. Testing a period of record against a set of thresholds is performed automatically with the electronic processing system. The user is alerted whenever a unit value exceeds the threshold value. Thresholds can be established by the user, or they can be automatically computed based on a period of record.

The set of thresholds should consist of (1) a high-value threshold, (2) a low-value threshold, (3) a maximum difference threshold, and (4) a flat-spot threshold (maximum time for constant values). Thresholds should be used to detect values that are unusual and outside the normal expected range of the data. For instance, an ADR punch recorder malfunctions and punches additional holes in the paper tape, which translates to unit values outside of the expected range of values. The threshold check should alert the user to this condition. Maximum and minimum threshold values should be set at or near the maximum and minimum values actually experienced during the past

Example A—Time changes from standard time to daylight savings time.

Unit Value	Local Date	Local Time	UTC Time	Time Zone
xxxx	04/03	2300	0400	EST
xxxx	04/03	2400	0500	
xxxx	04/04	0100	0600	
xxxx		**0200**	0700	EST
xxxx		**0400**	0800	EDST
xxxx		0500	0900	
xxxx		0600	1000	
xxxx		0700	1100	
xxxx		0800	1200	
xxxx		0900	1300	
xxxx		1000	1400	
xxxx		1100	1500	
xxxx		1200	1600	
xxxx		1300	1700	
xxxx		1400	1800	
xxxx		1500	1900	
xxxx		1600	2000	
xxxx		1700	2100	
xxxx		1800	2200	
xxxx		1900	2300	
xxxx		2000	2400	
xxxx		2100	0100	
xxxx		2200	0200	
xxxx		2300	0300	
xxxx	04/04	2400	0400	
xxxx	04/05	0100	0500	
xxxx		0200	0600	
xxxx		0300	0700	
xxxx	04/05	0400	0800	EDST

24 unit values used to compute daily value for April 4

Example B—Time changes from daylight savings time to standard time.

Unit Value	Local Date	Local Time	UTC Time	Time Zone
xxxx	10/24	2300	0300	EDST
xxxx	10/24	2400	0400	
xxxx	10/25	0100	0500	EDST
xxxx		0100	0600	EST
xxxx		0200	0700	
xxxx		0300	0800	
xxxx		0400	0900	
xxxx		0500	1000	
xxxx		0600	1100	
xxxx		0700	1200	
xxxx		0800	1300	
xxxx		0900	1400	
xxxx		1000	1500	
xxxx		1100	1600	
xxxx		1200	1700	
xxxx		1300	1800	
xxxx		1400	1900	
xxxx		1500	2000	
xxxx		1600	2100	
xxxx		1700	2200	
xxxx		1800	2300	
xxxx		1900	2400	
xxxx		2000	0100	
xxxx		2100	0200	
xxxx		2200	0300	
xxxx		2300	0400	
xxxx	10/25	2400	0500	
xxxx	10/26	0100	0600	
xxxx	10/26	0200	0700	EST

26 unit values used to compute daily value for October 25

Figure 1. Comparison of time system examples where daylight savings time is used. [UTC, Coordinated Universal Time; EST, Eastern Standard Time; EDST, Eastern Standard Daylight Savings Time.]

3 to 5 years of record. The difference threshold also should be set at or near the largest valid difference during the past 3 to 5 years.

Selection of threshold values should be based, if possible, on an analysis of the observed record for the past 3 to 5 years. This analysis should be performed with the electronic processing system and should furnish listings of the 20 highest peak unit values, and the 20 lowest trough unit values during the period. The electronic processing system also should provide the 20 greatest differences between consecutive unit values, and the 20 longest time periods during which there was no change in unit values (flat spots). This type of analysis would provide data for the user to use in selecting appropriate thresholds and would be performed every three years, or whenever it is desired to change thresholds.

Threshold checking, if used primarily for the purpose of identifying unit values that are outside the range of most experience, is a very valuable tool for identifying erroneous unit values. However, caution should be exercised if high-value thresholds are set too low, or low-value thresholds set too high, so that many unit values within the range of experience are identified by the threshold test. In this case, the user always should apply other methods to verify, or disqualify, unit values that have failed the threshold test.

5.3.2 Rating Comparisons

A simple comparison, similar to threshold comparisons, is the rating comparison. This comparison identifies all unit values that exceed the high end or fall below the low end of the rating currently in use. This comparison can be performed automatically with the electronic processing system, because ratings are stored in the electronic processing system. This test would alert the user to possible erroneous unit values as well as to the possible need to extend the rating currently in use.

5.3.3 Direct Reading Comparisons

Various types of direct readings may be available for comparison and verification of recorded unit values. These include actual gage readings made by an observer or hydrographer, readings obtained from maximum and minimum indicators, highwater mark readings, and crest gage readings. All of these various direct readings should be input to the electronic processing system and automatically displayed to the user in conjunction with the unit values being verified.

At some gaging stations auxiliary and/or backup gages are operated in conjunction with the primary gage. In many cases, the records from these gages can be used as an independent check, or comparison, to the primary record.

5.3.4 Graphical Comparisons

Graphics can be the most important and easily used method to verify a period of unit values. All of the methods described in sections 5.3.1 through 5.3.3 should be incorporated into a graphic system to automatically scan and review a period of record for the purpose of verification. The primary record of unit values should be plotted as a time series, with a unit-values scale that allows the user to see each value clearly and that does not distort the general shape of the record. The time scale should automatically default to the time zone normally used for the station, but there should be provision for the user to change to any other time zone. A basic plot of unit values can be used to identify erroneous data by an experienced user. With the addition to the plot of thresholds, rating limits, observer and hydrographer gage readings, high water marks, maximum and minimum indicator readings, and auxiliary gage records, much more can be done to verify the primary record.

The primary record of recorded unit values should be plotted and considered the base plot. The processing system should plot all direct gage readings by observers and streamgagers at the correct time on the base plot. High and low thresholds, high and low rating limits, highwater mark readings, maximum and minimum indicator readings, and crest-stage gage readings should be plotted at their respective elevations as a horizontal line that extends throughout the period of record being verified. This process will allow the user to compare these readings to peaks and troughs in the primary record. Auxiliary and backup records should be plotted as a time series for comparison to the primary record. The plotting system should use different colors and symbols to easily distinguish the various components. Unit values that trigger the difference threshold and the flat spot threshold also should be easily identified by color or symbol.

5.4 Parameter Value Corrections

The verification process described in section 5.3 will sometimes identify unit values of gage height or other parameters that are either erroneous or suspected of being erroneous. By definition, an erroneous gage reading results when the recording instrument does not record the true parameter value (for example, stage, velocity, and other) occurring in the stream, lake, or other water body. A base, or reference gage, usually is used for determining the true parameter value.

An erroneous gage reading can result from either *instrument errors* or *datum errors*, or both. Instrument errors are those errors resulting from a malfunction, an incorrect setting, an incorrect calibration, or other problem with the recording instrument. An instrument error usually can be detected by comparing a recorded parameter value with a corresponding reference gage reading. Datum errors, on the other hand, are those errors resulting from a change in the reference gage, and apply only to gage heights or elevations. A datum error usually can be detected only by running levels to the reference gage, using a stable benchmark of known elevation as a reference.

Another distinction between datum errors and instrument errors, is that datum errors generally occur over a long period of time (many months or years), whereas instrument errors usually are short term (a few days or weeks). Consequently, corrections for datum errors and instrument errors usually are made separately. However, correction for datum errors should use the same methods as those used for instrument errors, as described in section 5.4.2 below for instrument error corrections.

When a parameter value, or series of values, has been determined to be erroneous, it may be corrected, or edited, if the user has a sufficient basis for doing so. Editing of individual unit values should be allowed with the electronic processing system at any of the verification steps, including the graphical display. In the graphical display, the user should be allowed to edit unit values directly on the graph, or in a supplemental table of unit values. In addition to correcting and editing unit values, the electronic processing system also should allow the user to flag unit values in such a way that they will not be used in further analysis.

5.4.1 Datum Adjustments and Conversions

The gage datum of a gage site usually is an arbitrary datum, unique and specifically selected as a convenient working reference for each gage site. The datum frequently is located at a level just below the lowest expected gage height, or just below the gage height of zero flow. For some stations, such as at reservoirs and coastal streams, the gage datum may not be arbitrary, but is established to be the same as sea level, or other known and common datum. In any case, there are times when datum adjustments must be made to correct a datum error. Also, there are some stations for which it is necessary to convert an arbitrary datum to a known datum, such as sea level. These are described in sections 5.4.1.1 and 5.4.1.2.

5.4.1.1 Adjustments For Gage Datum Error

Gage datum adjustments generally are considered to be corrections applied to recorded gage heights and water-surface elevations to make them consistent with the gage datum. Physical movement of a gage or gage structure can sometimes occur, thereby causing an error of gage readings in relation to the gage datum. Such a change may be gradual over a long period of time, such as from settling or subsidence, or the change may be sudden, such as from an earthquake, flood damage, or accident. Whether the change is gradual or sudden, the result is the same, in that the gage no longer records gage heights and elevations that are correct in relation to the original gage datum. Gage movement, relative to gage datum, is quantitatively measured by leveling from stable reference marks or benchmarks of known elevation. Leveling procedures for surface-water gaging stations are well established and are described by Kennedy (1990).

Datum errors should be carefully analyzed to determine the best method to make corrections. Frequently, it cannot be determined when a datum error occurred, and the best method of correction is to prorate it uniformly throughout the period in question. If a specific time of occurrence can be defined, then the correction can be made starting at that time and carrying the correction forward until the datum is restored. As a general rule, corrections for gage-datum errors of 0.02 ft or less are not applied, except in cases where smaller gage-datum errors are critical in correctly defining another parameter, such as for reservoir contents computations. Small errors of this kind usually are absorbed by ratings and rating shifts.

5.4.1.2 Conversion to NGVD or Other Datum

In addition to making datum adjustments for the purpose of correcting gage-height values that are incorrect because of a change of the base (reference) gage, it is sometimes necessary to convert recorded gage heights to a different datum. The most common conversion is where the recorded values must be converted to National Geodetic Vertical Datum (NGVD), sometimes referred to as mean sea level. This type of conversion requires that a constant value be added to, or subtracted from, the recorded gage heights throughout the record period. A gage datum adjustment for gage movement, as described in section 5.4.1.1, also may be needed at times. In such cases, two simultaneous adjustments would be needed.

5.4.2 Instrument Error Corrections

Recording instruments and parameter sensors may, at times, produce erroneous gage readings for a number of reasons. For example, float tapes may slip, recorders may punch incorrectly, gage drawdown because of high velocity may occur at some stages, stage or velocity sensors may drift because of temperature or other reason, and the recorder even may be set wrong by the user. These, and numerous other causes, will result in erroneous unit values of gage height, velocity, or other parameters.

The electronic processing system must provide easy and quick ways to make corrections when instrument errors are identified. Corrections should be possible through a graphical interface, such as the one described above for review and verification, and also with a tabular format. The user should be able to make corrections to individual unit values, or to sequences of unit values. Three types of corrections should be available for use; (1) constant value corrections, (2) parameter (usually stage) variable corrections, and (3) time variable corrections. To make entry and application of the corrections as easy as possible, each of these types of corrections should be definable on the same entry form or graphical interface. In addition, the same methods and entry form should be applicable to datum error corrections.

5.4.2.1 Constant Value Corrections

Constant value corrections are simply the addition or subtraction of a constant value from a sequence of unit values. The user should be able to specify the constant value correction to be used, and the dates and times for which the correction is to be applied. The electronic processing system then should apply the correction automatically.

5.4.2.2 Parameter Variable Corrections

Certain types of parameter errors may vary according to the value of the parameter. For instance, for some gaging stations the stage measurements may not reflect actual river stage because of drawdown caused by high flow velocity near the gage intake or orifice. The resulting stage error is directly related to the velocity, which in turn is often related to the stage. A relation between stage and stage-correction can sometimes be defined that is reasonably consistent for long time periods and can be used to determine the gage-height correction on the basis of the recorded stage.

Parameter variable corrections require a relation between the parameter and the correction. The user should be able to input this relation to the electronic processing system, along with a starting date and time, and if needed an ending date and time. The electronic processing system should calculate and apply the corrections automatically. When a correction relation of this type is entered, and no ending date and time are specified, then it should be continued in use until such time that an ending date and time are specified.

A parameter variable correction relation should be defined by entering point pairs of parameter and corresponding corrections for as many points as necessary through the intended range of correction. The processing system should automatically interpolate corrections that are needed between the input points. If parameter values occur below the lowest point of the correction relation, then the correction value for the lowest point of the relation should be used for all corrections below this point. Likewise, the correction values above the highest point of the correction relation should be the same as the highest correction value of the relation. Alternatively, the correction relation can be entered as an equation. Upper and lower limits of the input parameter should be specified for the equation. The correction values corresponding to these limits should be held constant when parameter values are less than the lower limit or greater than the upper limit.

5.4.2.3 Time Variable Corrections

Time variable corrections are corrections that are distributed between specified dates and times. This type of correction usually is referred to as time proration. Time proration should apply to singular correction values and to parameter variable correction relations. Likewise, time variable corrections should apply to datum corrections as well as instrument error corrections.

Corrections that do not vary with parameter value are considered a singular correction for a given point in time. However, such a correction may vary with time. For example, at the beginning of a time series of unit values, a correction of +0.15 ft is defined, which does not vary with stage. At a subsequent date and time, a correction of +0.10 ft is defined, which likewise does not vary with stage. The electronic processing system should allow the user to make a linear, time proration between these two correction values and defined times.

Corrections that vary with parameter value (as defined by a parameter variable correction relation) sometimes gradually may change shape or position with time. The electronic processing system should allow time proration between two consecutive parameter variable correction relations. Time proration between two correction relations should be made on the basis of equal parameter values. For example, assume that a correction relation is entered with a date and time. A second correction relation is entered with a subsequent date and time. At some intermediate date and time, assume that the gage height is 4.23 ft. Correction values are determined from each of the two correction relations for a gage height of 4.23 ft, resulting in two correction values, one at the start of the proration period, and one at the end of the proration period. The correction that applies to the intermediate date and time, for the gage height of 4.23 ft., is determined by time interpolation between the two correction values.

5.4.3 Numbering Correction Relations

Parameter variable correction relations should be numbered for ease of identification, reuse, and archiving. A simple consecutive number sequence for each year is preferred, such as 1997.1, 1997.2, 1997.3, and so forth.

5.4.4 Additive Corrections

Sometimes, more than one correction for the same period of unit values may be needed. For instance, a datum correction may be needed during the same period of time that a parameter variable correction relation is needed. If both corrections are defined, and the dates and times overlap, the electronic processing system automatically should apply both corrections simultaneously for the overlapping period. In other words, all corrections that are defined for the same date and time, or for the same type of correction, become additive. There should be no limit as to the number of corrections that can be used for a given date and time, but it is not likely that more than two or three would be required.

5.4.5 Identification of Corrections

The electronic processing system should provide the option to identify the separate corrections entered by the user. It is recommended that a standard group of correction types be defined as (1) instrument error, (2) datum error, (3) datum adjustment, (4) velocity drawdown error, and (5) other. When a correction is entered by the user, one of these types can be selected to describe the correction. Each type should have provision to enter additional descriptive text, if necessary.

5.4.6 Flagging of unit values

Corrections cannot always be determined for unit values, and in fact, corrections are not always desired for unit values. For certain situations it is recommended that daily values be estimated rather than attempting to correct, or estimate, unit values. In these situations, the user should be able to mark, or flag, specific unit values to specify the reason they are not used. The flags also will be an indicator in other parts of the electronic processing system, such as the primary computations, to ignore the unit values for certain kinds of computations. The following flags are recommended.

- Affected—This flag is for unit values that are correct and representative of the true stage (or other parameter), but because of some irregular condition the rating is severely affected and may not be applicable. This flag should be used for severe conditions of backwater from irregular downstream conditions, backwater from ice, and other conditions. The flag should not be used for normal shifting control conditions.
- Erroneous—This flag is for incorrect unit values. For instance, the float is resting on mud in the stilling well, and the recorded unit values do not represent the stage in the stream.
- Missing—This flag is reserved for situations where unit values were expected, but because of some malfunction of equipment where no data were recorded.
- Estimated—This flag is used for estimated unit values. It should be automatically attached to unit values that are changed by the user.

The first three types of flags defined above are intended primarily for the original, archivable, unit values. These flags will document, for historical purposes, the evaluation and interpretation of the validity of the recorded unit values. They also should be carried forward for the analysis and computation of records. In the analysis and computations, it may be desirable to estimate unit values in certain situations. The fourth type of flag is reserved for estimated values, which may replace affected, erroneous, or missing data. The estimated flag only wll be used for unit values in data sets generated subsequent to the original data set. Unit values flagged as affected or erroneous should not be used in the primary computations.

6. Verification and Analysis of Field Measurement Data

Field measurement data and information that are entered into the electronic processing system include discharge measurements, gage datum leveling measurements, crest-stage gage data, channel and control cross-section data, and miscellaneous field notes. All of these data usually are entered by keyboard, except that some discharge measurements are entered from electronic field computers. Various computations and comparisons should be made to verify the accuracy and insure the consistency of the information. Sections 6.1.1 through 6.1.3 describe some of the verification, computations, and cross checking that should be performed with the electronic processing system. Errors resulting from data entry and incorrect computation should be corrected by the user.

It is important to emphasize that measurement *data* should not be deleted or erased from the original notes, which in most cases are the paper note sheets. Editing of data that are entered from paper notes to the electronic processing system is permitted, provided the data were entered by keyboard. This editing allows for correction of keyboard entry errors without compromising the integrity of the original paper notes. On the other hand, data entered electronically, such as from an electronic field computer, should not be edited, changed, or deleted because once they are entered to the electronic processing system they become the original copy which will be used for archiving. It is assumed that no errors occur during an electronic transfer. All *information* in measurement notes (for example, computed values such as area, velocity, width, discharge, and others) may be edited and changed regardless of the entry method. Obviously, these values should be arithmetically correct and based on the original data.

6.1 Discharge Measurement Analysis

All discharge measurements should be checked wherever possible for arithmetic errors, logic errors, and other inconsistencies, with the electronic processing system. In addition, the electronic processing system should compute the standard error for regular current meter measurements. If a rating is available for the gaging station, the electronic processing system should compute the shift, or deviation, of the measurement from the rating. The shift analysis would apply to stage-discharge, slope, rate-of-change in stage and velocity-index ratings.

Most of the following checking and computation steps apply only to standard current meter measurements. See section 6.1.5 for other types of measurements where checking procedures differ.

6.1.1 Arithmetic Checking

A summary of the numerical results of a discharge measurement is entered to the electronic processing system from what usually is referred to as the *front sheet* of the measurement. Most of these numbers are computed from the field measurement data, that are part of the *inside* body of the measurement. For discharge measurements recorded on paper forms, the computations are made by the hydrographer in the field with a calculator. If an electronic field notebook was used for recording the discharge measurement data, then the computations were made automatically by the field notebook, and little or no arithmetic checking is required.

When original computations are made on paper forms, the following checks of the inside part of the measurement should be made with the electronic processing system:

- Subsection width—The width for a subsection is computed as one-half the distance between the preceeding vertical stationing and the succeeding vertical stationing. For verticals at the edge of a channel or bridge pier, the subsection width is computed as one-half the distance to the adjacent vertical.
- Point velocities—If a current meter rating or equation has been entered for the current meter used in making the discharge measurement, then each point velocity should be checked.
- Mean velocity for each vertical—The mean velocity for each vertical is computed as follows:

  For the one-point method, the mean velocity is equal to the point velocity at the 0.6 depth. If the point velocity was measured at a depth other than the 0.6 depth, then the mean velocity for the vertical is computed by multiplying the point velocity by the method coefficient. If a method coefficient has not been entered for the vertical, then the electronic processing system should warn the hydrogapher and provide an opportunity to enter a method coefficient. The user can choose to ignore the warning.

  For the two-point method, the mean velocity is equal to a mean of the point velocities for the 0.2 and 0.8 depths.

  For the three-point method, the mean velocity is equal to a weighted mean of the 0.2 depth velocity, the 0.6 depth velocity, and the 0.8 depth velocity, where the 0.6 depth velocity is given double weight.

- Subsection mean velocity—The mean velocity for each subsection is computed as the product of the mean velocity of the vertical and the horizontal angle coefficient. If a horizontal angle coefficient is not entered for the vertical, then the electronic processing system should assume a value of 1.00.
- Subsection area—The area for each subsection is computed as the product of the subsection width and the depth at the vertical.
- Subsection discharge—The discharge for each subsection is computed as the product of the subsection area and the subsection mean velocity.
- Total width—The total width for each channel is computed by summing the subsection widths.
- Total area—The total area for each channel is computed by summing the subsection areas.
- Total discharge—The total discharge for each channel is computed by summing the subsection discharges.
- Total number of verticals—The total number of verticals for a measurement is simply a count of the number of verticals, and includes the beginning and ending points where depth often is equal to zero.
- Average velocity—The average velocity for each channel is computed by dividing the total discharge by the total area.
- Totals for multiple channels—When the discharge measurement has two or more channels, such as for a braided stream, or a flood measurement that has a main channel and one or more overflow channels, the grand total of width, area, discharge, and number of verticals is computed. These grand totals are the values used to summarize the discharge measurement on the *front* sheet. The average velocity for the measurement is the grand total of discharge divided by the grand total of area.

6.1.2 Logic and Consistency Checking

Information entered to the electronic processing system from one part of the discharge measurement notes should be automatically compared and cross checked with information from other parts of the measurement to verify that it is logical and consistent. The electronic processing system should alert the user when inconsistencies occur and provide an opportunity to make a change. In addition, when specific information items are entered, the electronic processing system then should limit the entry of other items so that the choices are consistent among themselves. For instance, if the type of measurement is entered as a *wading* measurement, then the choices for equipment entry would be limited to the various types of wading rods. A listing of some of the possible logic and consistency checks are given below:

- *Compare measurement sequence number with measurement date and time*—Measurement numbers generally are in sequential order according to date and time.
- *Compare measurement mean gage height(s) to gage readings*—The mean gage height should be a value that falls between the lowest and highest gage readings recorded during the course of making the discharge measurement.
- *Compare gage-height change to gage readings*—The gage-height change should be the difference between the gage heights at the start and end of the discharge measurement.
- *Compare gage-height change time to start and end time*—The gage-height change time should be the difference between the start and end time of the discharge measurement.
- *Compare stream width on summary input to stream width for inside note input*—The stream width on the summary input should be exactly the same as the stream width computed and entered for the inside note input. For multiple channels the stream width should be the sum of individual channel widths.
- *Compare stream area on summary input to stream area for inside note input*—The stream area on the summary input should be exactly the same as the area computed and entered for the inside note input. For multiple channels the stream area should be the sum of the individual channel areas.
- *Check mean velocity*—The mean velocity should be checked by dividing the measured discharge by the stream area.
- *Compare number of sections on summary input to number of section for inside note input*—The number of sections should be the total number of verticals used for making the discharge measurement. This total includes each end section of the measurement, even though depth and velocity at these points may be zero. For multiple channels, the number of sections should be the sum of the sections for individual channels.
- *Check adjusted discharge*—If an adjusted discharge is entered, the electronic processing system should compute an adjusted discharge based on the adjustment method, if stated. This computed value should be compared to the entered value.
- *Check average time of point velocities*—The average time of point velocities on the summary input should agree with the average of the time of current-meter revolutions entered for the inside note input.
- *Compare gage height of zero flow to gage readings*—The gage height of zero flow should be less than the mean gage height of the discharge measurement,

and less than the gage heights in the gage-height table, except in the cases of a zero flow measurement.

6.1.3 Computation of Measurement Error

The standard error of regular open-water, current-meter discharge measurements can be computed based on the method described by Sauer and Meyer (1992). Specific information needed to make this computation includes current-meter type (Price AA or Pygmy), current-meter rating type (standard or individual), streambed conditions, suspension method, average observation time of individual velocities, average channel depth, average velocity, number of verticals, horizontal angle information, and velocity measurement method (one-point, two-point, and so forth). Much of this information is part of the regular entry of discharge measurement data. The discharge measurement entry form should allow for the entry of any missing items of information, and when all requirements are met the electronic processing system should automatically compute the measurement standard error and display it on the measurement entry form.

The standard error computation described above only can be used for regular open-water, current-meter discharge measurements, according to the limitations described by Sauer and Meyer (1992). It should not be used for ice measurements, moving boat measurements, and acoustic velocity measurements, indirect measurements, portable flume measurements, dye dilution measurements, volumetric measurements, and discharge estimates.

6.1.4 Shift Analysis

Discharge measurements are used primarily to check rating curves to insure that currently used rating curves still are applicable and have not changed. The electronic processing system should automatically compute the shift information for each discharge measurement The shift information should, by default, be computed on the basis of the rating curve applicable for the time and date of the discharge measurement; however, the user should be allowed to specify a different rating curve for which the shift information is computed. If, at a later date, a new rating curve is prepared, then the shift information should be automatically updated for all measurements that fall within the period of time that the new rating is applicable. Shift information, as noted in sections 6.1.4.1 through 6.1.4.4, should be displayed as part of the output for each discharge measurement.

Sections 6.1.4.1 through 6.1.4.4, respectively, describe the methods of computing shift information for discharge measurements made at stage-discharge stations, slope stations, rate-of-change in stage stations, and velocity-index stations. Shifts are not computed or used for structure stations and BRANCH model stations. Definition of shift curves, use of partial or average shifts, and other aspects of shift application are described in section 8.

All shift information should be computed on the basis of standard rounding for discharge measurements, which usually is three significant figures for discharge and hundredths of a foot for gage height. Percent differences should be rounded to tenths of a percent.

6.1.4.1 Shifts for Stage-Discharge Ratings

The shift information that should be computed for discharge measurements applicable to stage-discharge rating curves is as follows:

- *Rating shift, S_r*—This shift is the numerical difference between the gage height, G_r, that corresponds with the rating curve discharge for the measurement, and the gage height, G_m, of the discharge measurement. The resulting algebraic sign should be observed. The equation is

$$S_r = G_r - G_m \qquad (1)$$

- *Measurement percent difference, $D_{\%}$*—This is the percent difference between the measured discharge, Q_m, and the rating curve discharge, Q_r, that corresponds to the gage height of the discharge measurement. This represents the difference between the measured discharge and rating discharge if no shift is applied. The equation is

$$D_{\%} = 100\,(Q_m - Q_r)/Q_r \qquad (2)$$

- *Shifts for the gage height of zero flow, S_0*—If the gage height of zero flow, G_0, is determined either when a regular discharge measurement is made, or independently during a visit to the gaging station, then it is possible to compute a shift for that gage height if the rating curve is defined down to zero flow. This information can be very useful as an aid in defining the low end of a shift curve. The equation for computing the shift for the gage height of zero flow is similar to equation 1 for computing the rating shift, and is

$$S_0 = G_r - G_0 \qquad (3)$$

Because the discharge corresponding to G_0 is by definition zero, it is not possible to compute a measurement percent difference.

6.1.4.2 Shifts for Slope Ratings

Slope ratings usually are referred to as complex ratings because they involve two sites for measuring gage height (a base gage and an auxiliary gage) and three individual ratings of different parameters. The required ratings are (1) a stage-discharge rating, (2) a stage-fall rating, and (3) a fall ratio-discharge ratio rating. The use of these ratings for computing discharge are described in section 9.1.4. The purpose of this section is to describe how shift information is computed for individual discharge measurements at stations with slope ratings.

The stage-discharge rating is the only rating of the three slope station ratings that is allowed to be shifted, and shift information is referenced to this rating. If either the fall rating or the ratio rating change, then new ratings should be prepared. It also should be noted that slope ratings only may apply to certain ranges of stage, and in some cases only when the fall is less than a specified amount.

For slope ratings, the measured discharge, Q_m, is considered the true discharge. The adjusted discharge, Q_{adj}, is an adjustment of the measured discharge that is computed by using the observed stages at the base gage and the auxiliary gage, the observed fall, which is the difference between the two observed stages, and the defined rating curves. This adjusted discharge is used for comparison to the rating discharge, Q_r, to determine shift information. If no shift is present, then Q_{adj} and Q_r will be equal. The method for computing Q_{adj} and shift information is given in the following paragraphs.

- *Adjusted discharge, Q_{adj}*—Compute the measured fall, F_m, as the difference between the observed mean gage height for the measurement at the base gage, G_b, and the auxiliary gage, G_a. The equation is

$$F_m = G_b - G_a \tag{4}$$

1. If the auxiliary gage is upstream from the base gage, reverse the order of G_b and G_a in equation 4.
2. Determine the rating fall, F_r, that corresponds to the base gage height, G_b, from the stage-fall rating.
3. Compute the fall ratio, R_f, of the measured fall to the rating fall. The equation is

$$R_f = F_m / F_r \tag{5}$$

4. Determine the discharge ratio, R_q, corresponding to R_f from the ratio rating.
5. Compute the adjusted discharge, Q_{adj}, based on the measured discharge, Q_m, and the discharge ratio, R_q, is

$$Q_{adj} = Q_m / R_q \tag{6}$$

- *Stage-discharge rating shift, S_r*—Determine the gage height, G_r, corresponding to the adjusted discharge, Q_{adj}, from the stage-discharge rating.
  Compute the shift, S_r, based on the observed gage height, G_b, for the base gage and the rating gage height, G_r. The equation is

$$S_r = G_r - G_b \tag{7}$$

- *Measurement percent difference, $D_{\%}$*—The percent difference, $D_{\%}$, between the adjusted discharge, Q_{adj}, and the rating discharge, Q_r, also should be computed. This percentage represents the error of the adjusted discharge from the rating discharge if no shift is applied. The equation is

$$D_{\%}=100(Q_{adj}-Q_r)/Q_r \tag{8}$$

6.1.4.3 Shifts For Rate-of-Change In Stage Ratings

Rate-of-change in stage ratings are complex ratings that include a stage-discharge rating, and a rating of stage and the factor, $1/US_c$. This type of rating is referred to as the Boyer method (see Rantz and others, 1982), and applies for streams where rapid changes in stage affect the stage-discharge rating. The term $1/US_c$ is a measure of flood-wave velocity, U, and the constant discharge stream slope, S_c. This term usually is defined empirically from the discharge measurements. The greatest effect of changing stage occurs on streams having relatively mild slopes, and rapid changes in discharges. Frequently, this effect will happen when the flow regime of a stream has been changed artificially, such as below a dam when releases are made quickly, or in urban areas where basin development causes rapid increases in flow rates for a stream that was previously sluggish.

Shift information for Boyer ratings should be computed only for the stage-discharge rating. The rating of stage-$1/US_c$ should not be shifted. If this rating changes, then a new rating should be prepared. The shift and percent difference should be based on the rating discharge, Q_r, and the adjusted discharge, Q_{adj}.

The method for computing the adjusted discharge and the shift information for Boyer ratings is as follows.

- *Adjusted discharge, Q_{adj}*—Compute the change in stage, dG, for the discharge measurement as the difference between the ending gage height, G_e, and the starting gage height, G_s. For rising stages the difference is positive, and for falling stages the difference is negative. The equation is

$$dG = G_e - G_s \tag{9}$$

1. Compute the elapsed time, dt, for the discharge measurement as the difference between the ending time, t_e and the starting time, t_s. The equation is

$$dt = t_e - t_s \tag{10}$$

2. Compute the rate-of-change in stage, dG/dt, for the discharge measurement.
3. Determine the factor, $1/US_c$, for the mean gage height of the discharge measurement, from the stage-$1/US_c$ rating.
4. Compute the adjustment factor, F_{adj}, using

$$F_{adj} = 1 + \sqrt{\left\langle\frac{1}{US_c}\right\rangle\left\langle\frac{dG}{dt}\right\rangle}\,. \tag{11}$$

5. Compute the adjusted discharge, Q_{adj}, as

$$Q_{adj} = Q_m / F_{adj} \tag{12}$$

6. The adjusted discharge, Q_{adj}, represents the discharge that would be computed from the two ratings and the observed gage height if no shift is applied.
   - *Rating shift, S_r*—Determine the rating gage height, G_r, corresponding to the adjusted discharge, Q_{adj}, from the stage-discharge rating.
     Compute the shift, S_r, as the difference between the rating gage height, G_r, and the measured gage height, G_m, as

$$S_r = G_r - G_m \tag{13}$$

   - *Measurement percent difference, $D_{\%}$*—Determine the rating discharge, Q_r, from the stage-discharge rating using the measured mean gage height, G_m.
     Compute the percent difference, $D_{\%}$, between the adjusted discharged, Q_{adj}, and the rating discharge, Q_r, as

$$D_{\%} = 100(Q_{adj} - Q_r)/Q_r \tag{14}$$

This percent difference represents the error between the Boyer adjusted discharge and the rating discharge if no shift adjustment is applied.

6.1.4.4 Shifts for Velocity-Index Stations

Ratings at gaging stations with velocity index as part of the rating system are considered complex ratings, and in some cases can be extremely complex if two or more velocity meters are in use. Stream channels may be subdivided either vertically or horizontally, with each subdivision having a specific set of ratings, or in some cases the individual meters may be averaged for use with one set of ratings. Also, for some stations discharge measurements may be made so that only the total discharge is computed, with no accurate method of subdividing the measured discharge into the various rating components. Because of this variability in the way velocity-index stations are processed, it is not possible to describe all of the ways that rating shifts are computed. The electronic processing system should provide an interactive mode that allows the user to define the shifts and the shifting method.

Shift information for a basic velocity-index rating is described in the following paragraphs. A basic velocity-index rating includes a single rating of stage and cross-section area, a single rating of index velocity and mean velocity, and in some cases an optional rating of stage and a velocity correction factor. The rating discharge, Q_r, is computed by multiplying the cross-section area, A_r, from the area rating, times the mean velocity, V_r, from the velocity rating, and times the velocity correction factor, K_r, from the stage-factor rating. If the velocity correction factor is not used, it is set to a default value of 1.00. The basic velocity-index equation for discharge is

$$Q_r = A_r \times V_r \times K_r \tag{15}$$

Shifts are allowed only for computation of V_r from the velocity rating. The stage-area and stage-factor ratings should not be adjusted through the use of shifts. If either the stage-area or the stage-factor ratings change, then new ratings should be prepared.

It also should be noted that a standard cross section *must* be used for the ratings and for computing shifts. That is, a specific cross section in the stream channel should be designated as the rating section. This cross section may be the same section as used for making discharge measurements or it may be a different section. All computations should be related to and based on the standard cross section. For instance, the mean stream velocity, as used for rating purposes, should be computed by dividing the measured discharge by the cross-section area determined from the stage-area rating of the standard cross section. This mean stream velocity is the velocity that should be used to check or define the velocity rating, and the one to be used for plotting purposes on the velocity rating, for those sites where a stage-factor rating is not used. If a stage-factor rating is used, then this velocity should be adjusted by dividing it by the applicable factor before using it to check or define the velocity rating.

The order of computations for shift determinations is important because two, and in some cases three, ratings are involved. The following step-by-step procedure should be used:

Standard cross-section area, A_r—Determine the cross-sectional area, A_r, of the standard cross section from the stage-area rating, using the mean gage height, G_m, of the discharge measurement.

Velocity correction factor, K_r—Determine the velocity correction factor, K_r, from the rating of stage and velocity correction factor, using the mean gage height, G_m, of the discharge measurement. If this rating is not used, then set the velocity correction factor to a default value of 1.00.

Adjusted mean stream velocity, V_m—Compute the mean stream velocity, adjusted for the velocity correction factor, for the standard cross section using

$$V_m = \frac{Q_m}{A_r \times K_r}, \tag{16}$$

where Q_m is the measured discharge, and the other variables are as previously defined.

Rating index velocity, V_{ir}—Determine the rating index velocity from the rating of index velocity and mean stream velocity, by entering the rating with the adjusted mean stream velocity, V_m, as computed in equation 16.

Index velocity shift, S_v—Compute the index velocity shift as the difference between the rating index velocity, V_{ir}, and the mean measured index velocity, V_{im}, for the discharge measurement. The shift, S_v, is defined by

$$S_v = V_{ir} - V_{im}\ . \tag{17}$$

S_v should retain the resulting algebraic sign (+ or -) for application purposes. When the computed shift is applied to the measured index velocity, V_{im}, it will yield a corrected index velocity to use for entry to the velocity rating when determining the rating mean velocity, V_r.

- *Measurement percent difference, $D_{\%}$*—The measurement percent difference is the percentage of error between the measured discharge, Q_m, and the discharge computed by using the ratings without shifts. To compute this unshifted rating discharge, Q_r, first determine the standard cross-section rating area, A_r, corresponding to the observed stage of the discharge measurement. Then determine the rating mean velocity, V_r, corresponding to the index velocity observed for the discharge measurement. If a factor rating is used for the site, determine the rating factor, K_r, corresponding to the observed stage of the discharge measurement. If a factor rating is not used for the site, the rating factor defaults to 1.00. Finally, compute the rating discharge, Q_r, using equation 15.

The measurement percent difference is computed as

$$D_{\%} = 100(Q_m - Q_r)/Q_r \, . \tag{18}$$

6.1.5 Special Procedures for Other Types of Discharge Measurements

Some discharge measurements are made under conditions that require computational procedures that are different than the standard open-water, current-meter discharge measurement described in preceding sections. In some cases, the differences are minor, but in other cases the measurement method is completely different. Also, some measurement methods use highly specialized equipment and recording methods that differ entirely from those of standard discharge measurements. The following sections describe some of the verification, editing, and computations that should be performed with the electronic processing system for each of the various types of measurements.

6.1.5.1 Ice Measurements

Ice measurements, in most respects, are the same as a standard open-water discharge measurement. All of the same arithmetic checking, logic and consistency checking, and shift analysis should be performed on ice measurements. Differences between computations for a standard discharge measurement and an ice measurement are listed below:

- *Computation of effective depth*—The inside body of the discharge measurement notes for ice measurements contains two additional columns of data and information. One of the extra data columns is a field measurement of the vertical distance between the free water surface and the bottom of the ice (solid or slush ice). These measurements should be compared to the total depth for each vertical, and if in any given vertical the depth from the water surface to the bottom of the ice is found to be greater than the total depth, a warning message should be issued by the electronic processing system to the user.

The second additional column is effective depth, d_e, for each vertical and is computed as the difference between the total depth, D, and the vertical distance, d_i, between the free water surface and the bottom of the ice. The equation is

$$d_e = D - d_i \tag{19}$$

- *Computation of subsection area*—The area of each subsection is computed by multiplying the subsection width times the effective depth, d_e, of the vertical.
- *Velocity coefficient*—For verticals where the 0.6 depth method is used to observe velocity, it is frequently necessary to apply a velocity coefficient to correct for the ice effect on the vertical velocity distribution. This velocity coefficient is similar to the use of a method coefficient for computing the mean velocity in a vertical, as described in section 6.1.1 on *arithmetic checking*. The mean velocity in the vertical is computed by multiplying the velocity coefficient times the point velocity observed at the 0.6 depth. If a velocity coefficient is not given, then it should default to 1.00. If the two-point method (0.2 depth/0.8 depth) is used to observe velocity, then no velocity coefficient is necessary.
- *Shift computations*—Shifts are not usually computed for ice measurements, but in some cases may be desired. The user should have the option to specify if shifts should be computed, and if so, they should be computed just as they are for a regular open-water measurement.
- *Percent difference from rating curve*—The difference, in percent, between the measured discharge and the rating curve should be computed for all ice measurements, based on the same method as described in section 6.1.4.1 for standard discharge measurements.
- *Discharge ratio*—For some gaging stations, the discharge-ratio method is used for computing ice records. The user should have the option to specify the computation of the ratio if it is used. The electronic processing system then should compute the ratio, K_i, for each ice measurement as the ratio of the measured discharge, Q_m, to the open-water rating discharge, Q_r, that corresponds to the mean gage height of the measurement as

$$K_i = Q_m / Q_r \, . \tag{20}$$

6.1.5.2 Measurements With Vertical Angles

Depth measurements of deep, swift streams that are made with cable suspension equipment from bridges, cableways, and boats cannot always be made directly. Frequently, the sounding weight is carried downstream by the current, and consequently the observed depth is greater than the true vertical depth. In such cases, corrections must be made to the observed depth in the field at the time the measurement is made. The body of the field notes for these measurements contain additional columns for recording air-line vertical distance, observed depth, vertical angle, and computed vertical depth. The corrections, which usually are not recorded in the field notes, account for an air-line correction and a wet-line correction of the sounding cable. In some cases, such as when sounding line tags are used, the air-line correction may be eliminated or reduced to a negligible amount.

The electronic processing system should contain the air-line correction table and the wet-line table so that the computed vertical depth can be checked. These tables are given by Rantz and others (1982), which also provides a detailed description of the computation methods. A brief summary of the procedure is listed below.

1. Determine the air-line correction based on the observed air-line vertical distance between the sounding equipment and the water surface, the observed vertical angle, and the air-line correction table.
2. Subtract the air-line correction (if used) from the uncorrected observed depth of water. This subtraction must be made before determining the wet-line correction.
3. Determine the wet-line correction based on the air-line corrected observed depth, the observed vertical angle, and the table of wet-line corrections.
4. Compute the true vertical depth by subtracting the wet-line correction from the air-line corrected observed depth.
5. Air-line and wet-line corrections should be interpolated from their respective tables to the nearest tenth of a foot.

All other computations and checking are essentially the same for measurements with vertical angles as they are for standard discharge measurements, including the computation of measurement standard error.

6.1.5.3 Moving Boat Measurements

Two types of moving boat measurements utilize a horizontal axis current meter. The primary difference between these two types of measurements is the data-recording method and the computation method. The original type of moving boat measurement is defined here as the manual method, and the more recent type is defined as the automatic method. In the manual method, some of the data are acquired by visual observation and recording on paper field notes as the measurement progresses across the stream. All computations in the manual method are performed by hand calculator and look-up tables. In the automatic method, almost all data collection, data recording, and computations are performed by an on-board computer. The manual method is still in use at the time of this report (2001), however, it is rapidly being replaced by the automatic method. Also, some moving boat measurements now utilize an acoustic Doppler current profiler (ADCP) for measurement of stream velocity. This method is described in section 6.1.5.5.

6.1.5.3.1 Moving Boat Measurement, Manual Type

The discharge measurement front sheet (summary) for the manual type of moving boat measurement is different than the standard current meter front sheet, but the differences are minor and for practical purposes can be considered the same. Therefore, entry of summary data and information for a manual type of moving boat measurement should use the same entry form as the standard current meter measurement (see table 4). A few special items that show on the front sheet can be entered as part of the inside of the measurement described below.

The inside notes of the manual type of moving boat measurement are considerably different than those of a standard discharge measurement. A typical inside note sheet is shown in figure 2. The *data* columns required are as follows.

- *Angle, α*—The horizontal angle of the current meter is read visually from an angle indicator as the boat progresses across the stream.
- *Depth*—Depths at each vertical are taken from an acoustic sounding chart.
- *Pulses per second*—These readings are instantaneous values of current meter response, related to velocity, taken visually from the rate indicator at each vertical.
- *Remarks*—The remarks column provides data and information that relate to the individual verticals and subsections.

Angle α	L_b	Dist. from initial point	Width	Depth	Pulses per second	V_v	**Sin α**	V_v **Sin α**	Area	Dis-charge	Remarks
IP		0									IP to LEW=28’
LEW		28.0	19.5	0					0		
20	39.0	67.0	36.0	9.0	250	4.50	.342	1.54	324	499	
25	33.1	100.1	48.2	39.0	340	6.09	.423	2.58	1880	4850	(1/2 count)
30	63.2	163.3	63.5	38.0	370	6.62	.500	3.31	2410	7980	
29	63.8	227.1	60.2	37.5	340	6.09	.485	2.95	2260	6670	
39	56.7	283.8	56.3	37.0	340	6.09	.629	3.83	2080	7970	
40	55.9	339.7	57.8	35.0	330	5.91	.643	3.80	2020	7680	
35	59.8	399.5	57.8	35.5	330	5.91	.574	3.39	2050	6950	
40	55.9	455.4	52.4	33.0	330	5.91	.643	3.80	1730	6570	
48	48.8	504.2	48.8	32.5	350	6.27	.743	4.66	1590	7410	
48	48.8	553.0	50.6	32.0	340	6.09	.743	4.52	1620	7320	
44	52.5	605.5	50.2	31.5	340	6.09	.695	4.23	1580	6680	
49	47.9	653.4	48.4	31.0	320	5.74	.755	4.33	1500	6500	
48	48.8	702.2	52.4	30.0	330	5.91	.743	4.39	1570	6890	
40	55.9	758.1	53.8	28.5	320	5.94	.643	3.69	1530	5650	
45	51.6	809.7	52.5	26.5	300	5.38	.707	3.80	1390	5280	
43	53.4	863.1	54.2	27.0	330	5.91	.682	4.03	1460	5880	
41	55.1	918.2	50.5	27.0	350	6.27	.656	4.11	1360	5590	
51	45.9	964.1	51.3	26.0	330	5.91	.777	4.59	1330	6100	
39	56.7	1020.8	55.0	25.0	320	5.74	.629	3.61	1380	4980	
43	53.4	1074.2	54.6	25.0	320	5.74	.682	3.91	1360	5320	
40	55.9	1130.1	57.4	25.0	330	5.91	.643	3.80	1440	5470	
36	59.0	1189.1	51.4	24.5	330	5.91	.588	3.48	1260	4380	
53	43.9	1233.0	48.2	23.5	320	5.74	.799	4.59	1130	5190	
44	52.5	1285.5	53.8	22.5	320	5.74	.695	3.99	1210	4830	
41	55.1	1340.6	58.8	22.5	330	5.91	.656	3.88	1320	5120	
31	62.6	1403.2	60.8	22.0	330	5.91	.515	3.04	1340	4070	
36	59.0	1462.2	55.4	22.5	320	5.74	.588	3.38	1250	4220	
19	51.8	1514.0	55.4	12.0	340	6.09	.326	1.99	665	1320	(3/4 counts)
REW	59.0	1573.0	29.5	0					0		
FP		1596.0									REW to FP=23’
	1545.0		1544.7						42,039	157,369	
									x1.022	x1.022	Width/Area
	Width/Area Adjustment Coefficient: 1579 1545=1.022										Adj. Coef.
									43,000	160,831	
										x .91	Vel.Corr.Coef.
										146,000	

Figure 2. Discharge measurement inside notes for manual type of moving boat measurement.

All other columns in the inside notes are computed and/or determined from look-up tables. These are considered *information*, not *data*, and after verifying that the data have been entered correctly, the information columns should be checked with the electronic processing system. This checking will require that the electronic processing system have access to the tables and equations used for moving boat measurements. Following are the information columns required.

- *Boat travel distance, L_b*—Most of the L_b values are determined from the look-up table, based on the angle, α, and range number used for the control panel during the moving boat measurement. Special methods apply for the determination of L_b values at the beginning and end of each run. The first L_b value, corresponding to the first measured angle, is an actual field measurement of the distance from the edge of water to the float marker. This measurement is a field data value, and should not be changed. The second L_b value, corresponding to the second measured angle, always is entered as one-half of the table value. The next-to-last L_b value is entered on the basis of the proportion shown in the remarks column of the field notes. The last L_b value is an actual field measurement, and should not be changed. All L_b values between the two points at each end of the measurement are determined directly from the look-up table. The total boat travel distance should be computed as the sum of all subsection distances.
- *Distance from initial point*—These distances mostly are computed values, and should begin at the edge of water on one side of the stream and end at the edge of water at the other side of the stream. The water edges usually are designated LEW (left edge of water) and REW (right edge of water). All distances are referenced to an initial point (IP), which usually is designated as having a distance of zero (0). A final point (FP) also is included in the notes. The distance for the edge of water at the beginning of the measurement is based on the actual field measurement of the distance from the IP to the edge of water. All other distances are computed by adding Lb to the preceding distance.
- *Width*—These are incremental widths for each subsection, and are computed just as they are in a standard current meter measurement, based on one-half the distance from the preceding vertical to one-half the distance to the next vertical. The total width should be computed as the sum of all subsection widths.
- *Vector velocity, V_v*—These are instantaneous vector velocities, and are determined from the rating table (or equation) for the current meter, and correspond to the pulses per second recorded for each vertical.
- *Sine of angle, Sine α*—These values are the sine function values corresponding to the angle, α, for each vertical.
- *Product of V_v and Sine α*—The stream velocity normal to the cross section, for each vertical, is computed as the product of V_v and sine α.
- *Area*—The subsection area is computed as the product of the subsection width and the vertical depth, just as in a standard current meter measurement. The total area also should be computed as the sum of all subsection areas.
- *Discharge*—The subsection discharge (unadjusted) is computed as the product of the subsection area and the normal stream velocity (see above). The total unadjusted discharge also should be computed as the sum of all unadjusted subsection discharges.

A number of individual data items and computations are included in the inside note sheet, and should be entered to the electronic processing system and/or checked for computational accuracy. These items and computations are listed below and grouped as data items and computations.

Data items:

- *Run number*—This number indicates the run number for a series of runs.
- *Control panel range number*—This number is used to determine the correct look-up table for determining L_b.
- *Measured width*—This is the total measured width of the stream, water's edge to water's edge.
- *Velocity adjustment coefficient, k_v*—This is the vertical velocity coefficient used to adjust the total discharge for the effect of velocity measurements taken near the stream surface.
- *Distance from IP to beginning edge of water*—This is a measured distance.
- *Distance from ending edge of water to FP*—This is a measured distance.
- *Distance from beginning edge of water to initial float*—This is a measured distance.
- *Distance from final float to ending edge of water*—This is a measured distance.

Computations:

- *Width/area adjustment coefficient, k_b*—This coefficient is a computed value equal to the ratio of the measured stream width to the computed stream width.
- *Total adjusted area*—The total adjusted area is computed by multiplying the total unadjusted area times the coefficient, k_b.
- *Total adjusted discharge*—The total adjusted discharge is computed by multiplying the total unadjusted discharge times the coefficient, k_b, and times the coefficient, k_v.

6.1.5.3.2 Moving Boat Measurement, Automatic Type

Moving boat measurements increasingly are being made with integrated computerized equipment, including an on-board computer that is used for recording all data and fully computing the discharge measurement. The body (inside) of the measurement is stored in electronic format, and should be transferred directly to the electronic processing system. The summary front sheet information is similar to a standard discharge measurement and can be entered by keyboard, except for those items that can be transferred to the summary from the inside body of the measurement. The same entry form, as for a regular current meter measurement, should be used (see table 4).

6.1.5.4 Acoustic Doppler Current Profiler (ADCP) Measurements

The ADCP is used to define the complete (or nearly complete) velocity profile in a stream vertical. This velocity profile provides a much more accurate measure of the mean stream velocity than other techniques where only one or two measuring points are used, and sometimes adjusted by velocity coefficients. The ADCP can be incorporated into the moving boat method of measurement, providing a fast, accurate type of discharge measurement for wide and deep streams. This type of measurement is fully computerized, with all data collected and computed automatically.

Data and information from the ADCP measurement should be transferred to the electronic processing system through an interface. These data and information become the original, archivable record. Summary information for the measurement is much the same as for a regular discharge measurement and can be entered using the same entry form (table 4).

6.1.5.5 Indirect Measurements

Indirect discharge measurements include slope area, contracted opening, critical depth, culvert, step backwater, and flow over dams and embankments. These types of measurements are almost always made after a flood event, rather than at the time of the flood event. Data collection, recording of field notes, and computation procedures are appreciably different than standard measurements made during a flood event. For most indirect measurements, special computer programs are used for the computations and detailed reports are prepared. Entry of information from indirect measurements to the electronic processing system should include only the summary information. The same entry form can be used as for a standard discharge measurement (table 4).

6.1.5.6 Portable Weir and Flume Measurements

Measurements of low discharge can be made using a portable weir or flume. Various types of weirs and flumes are available for these measurements and usually are rated in the laboratory so that coefficients and discharge ratings are defined for each. Field setup and measuring methods are described by Rantz and others (1982), and are relatively simple and easy to follow. After the weir or flume is installed and a sufficient period of time is allowed for streamflow to stabilize, a series of upstream head measurements are taken for a period of about 3 minutes. The average of these head measurements is used to determine the discharge, either from a rating table (flume measurement) or from an equation (weir measurement). Downstream head measurements usually are not taken because the flume or weir is installed so that free fall or minimum backwater results; thus, negating the need for downstream head measurements.

Entry of the inside body of the discharge measurement is relatively simple and includes only the weir or flume head data, and the determined discharge. Some hydrographers enter this information on the front sheet of the measurement, rather than in the inside body. Regardless of where these notes are recorded, the electronic processing system should provide a form for entering the basic data and computations, and should check the computations. The data and information required are as follows.

- *Head measurements*—These are the individual observations of head. The recommended number of observations is about seven, one observation every 30 seconds for a period of 3 minutes. However, this number can vary and in some cases only one observation will be recorded. The electronic processing system should allow for at least 10 entries.
- *Average head, h*—This is an unweighted average of the individual head observations. The electronic processing system should calculate the average head, h, and compare it to the entered value. If the two values are different, a message to this effect should be given to the user. The user should be allowed to select the average head value for use in computing discharge.
- *Discharge, Q*—The discharge should be calculated, either from a rating table or from an equation. Rating tables and/or equations for standard weirs and flumes should be included in the electronic processing system. However, if they are not directly available, the user should be allowed to enter one.

Entry of front-sheet information for weir and flume measurements greatly is abbreviated from that of a standard discharge measurement and is described in table 4.

6.1.5.7 Tracer-Dilution Measurements

Tracer-dilution discharge measurements are highly specialized techniques that utilize one of a number of different tracers, different types of measurement equipment, and different measurement methods. Data collection, recording, and calculation of measurement information varies depending on the method and tracer used. Details of each type of tracer-dilution measurement are described by Rantz and others (1982). Although the methods are well standardized, it is not recommended that complete details of tracer-dilution measurements be entered to the electronic processing system. Summary information from each measurement should be entered, according to the details given in table 4.

6.1.5.8 Volumetric Measurements

Low flows sometimes are measured by diverting the flow into a calibrated container, and measuring the time required to fill, or partially fill, the container. If the container is filled completely, the flow volume equals the container volume. If the container is partially filled, the flow volume equals the difference of the ending volume and the starting volume. This procedure usually is repeated 3-4 times to improve accuracy of the measurement. The discharge, in cubic feet per second, is computed by dividing the total volume (sum of the volume measurements from each repetitive run), in cubic feet, by the total time of diversion (sum of the time measurements from each repetitive run), in seconds.

Data entry from the inside field notes includes the following:

- Total container volume, in cubic feet.
- Starting volume, in cubic feet, for each repetitive run—This value should be equal to or greater than zero, but less than the total container volume.
- Ending volume, in cubic feet, for each repetitive run—This value should be greater than the starting volume, and equal to or less than the total container volume.
- Flow volume, in cubic feet, for each repetitive run—This is the difference between the ending volume and the starting volume, and must be equal to or less than the total container volume.
- Fill time, in seconds, for each repetitive run.
- Total volume, in cubic feet—This is a summation of the individual flow volumes of each repetitive run.
- Total time, in seconds—This is a summation of the individual fill times of each repetitive run.
- Discharge, in cubic feet per second—This is the total volume divided by the total time.

The electronic processing system should make the checks and computations indicated above, and report any discrepancies.

The procedure described above is used where the total flow can be easily diverted into a container. In some cases, such at a broad-crested weir or dam the flow may be too shallow to measure using conventional methods, but volumetric measurements may be applicable to small segments (samples) of the flow. This is the volumetric-incremental sampling method. In this method, volumetric flow measurements are made as described in the preceding paragraphs at 5-10 subsections along the weir or dam. The flow rate of each sample is increased by the ratio of the subsection width to the sampled width to obtain a flow rate for each subsection. The total flow of the stream is the summation of the discharge rates of each subsection. The electronic processing system should perform these computations from the input data and report any discrepancies.

Front sheet information is an abbreviated version of the standard discharge measurement. Details are given in table 4.

6.1.5.9 Discharge Estimates

Low flows sometimes are estimated when no suitable measuring method is available. Various techniques for estimating the flow are used, which usually are described in the paper field notes. It is not recommended that the details of making the estimate be entered into the electronic processing system, because they generally cannot be checked or verified, and the paper notes are considered the original archivable record. A summary of the measurement can be entered using the standard discharge measurement entry form (see table 4), but abbreviated considerably to accommodate only the information pertinent to the estimate.

6.1.6 Rounding and Significant Figures

All data (actual field measurements) for discharge measurements should be entered to the electronic processing system with the same precision and significant figures as recorded in the field notes. Table look-up values and calculated values should be rounded to standard significant figures (table 2), unless specified otherwise by the user. Exceptions to the standard significant figures are required for calculations of the subsection values of width, area, and discharge in the inside body of the field notes, as follows.

- *Subsection width*—The width of each subsection should be used and displayed as an unrounded value.
- *Subsection area*—Each subsection area should be rounded and displayed with one additional significant figure from that of the expected total area. For instance, if the total area is expected to be between 10.0 and 99.9 ft^2, the individual subsection areas should be rounded and displayed to hundredths of a square foot.
- *Subsection discharge*—Each subsection discharge should be rounded and displayed with one additional significant figure over that of the expected total discharge, similar to that described above for subsection area. For instance, if the total discharge is expected to be between 100 and 999, then each subsection discharge should be rounded and displayed to the nearest 0.1 ft^3/s.

All summary information for discharge measurements should be rounded and displayed with significant figures that conform to those listed in table 2, unless specified otherwise by the user.

6.1.7 Summary of Discharge Measurements

Discharge measurement information and data from all types of discharge measurements should be summarized in chronological order, and grouped by water year, to provide a history of the measurements. The basic format of the summary output form should conform closely to the historical USGS standard form 9-207. The items required for this form are listed in table 10. In addition to the summary format (short-form) of discharge measurements, an output format (long-form) that includes all of the data and information entered for each measurement, as shown in table 10, should be available to the user. The user also should be able to define a custom output format that only would include selected items.

Table 10. Discharge measurement items that should be shown in U.S. Geological Survey long-form output and in short-form output (historical form 9-207)

Item	Long-Form Output	Short-Form Output (9-207)
Station identification number	X	X
Station name	X	X
Measurement sequence number	X	X
Date of measurement	X	X
Mean time of measurement	X	X
Time zone	X	X
Party	X	X
Mean gage height, inside gage	X	X
Mean gage height, outside gage	X	
Gage-height change	X	X
Gage-height change time	X	X
Stream width	X	X
Stream area	X	X
Mean velocity	X	X
Number of sections	X	X
Measured discharge	X	X
Rating number	X	X
Shift adjustment	X	X
Percent difference	X	X
Adjusted discharge	X	X
Adjustment method	X	X
Number of channels measured	X	
Measurement type	X	
Measurement location	X	
Observation method	X	X
Accuracy rating (field assigned)	X	X
Computed accuracy	X	X

Table 10. Discharge measurement items that should be shown in U.S. Geological Survey long-form output and in short-form output (historical form 9-207)—Continued

Item	Long-Form Output	Short-Form Output (9-207)
Control conditions	X	X
Control cleaned	X	
Time of control cleaning	X	
Gage-height change from cleaning	X	
Maximum stage indicator	X	
Minimum stage indicator	X	
Air temperature (degrees Celsius)	X	
Water temperature (degrees Celsius)	X	X
Base flow (Yes or No)	X	
Gage height of zero flow	X	X
Gage height of zero flow accuracy	X	X
Mean index velocity	X	
Mean auxiliary gage height	X	
Remarks	X	X

6.2 Gage Datum Analysis

The gages at streamgaging stations are referenced to a permanent datum (zero level) that must be maintained as accurately as possible throughout the lifetime of the station. In order to maintain this accuracy, leveling is performed periodically to check the gages and reference marks for vertical movement, so that if appreciable movement is detected, corrections can be made. Generally, leveling at gaging stations is performed once every 2 to 4 years, but the time frame varies according to gage stability conditions and other factors. For complete details of leveling procedures for gaging stations, see Kennedy (1990).

Complete gage levels are recorded on paper field notes that include all turning point elevations, instrument setup heights, elevations of gage reference marks, and other miscellaneous gage features. These notes also may include various adjustments required to account for instrument error and closure error. In some instances, the field notes may include more than one level circuit, and a summary field note sheet is included that shows average elevations for benchmarks, reference marks, and other gage features. These paper field notes are the original leveling notes, and are archived as part of the permanent record. It is not required that the complete field notes be entered to the electronic processing system.

The electronic processing system should provide for the entry of a summary of the field notes for gage- datum leveling. Data and information that should be entered to the electronic processing system from leveling notes are listed in table 6. In addition, established elevations should be entered for each benchmark, reference mark, and other gage feature for reference and comparison purposes. For each set of level notes the electronic processing system should perform datum error comparisons as described in section 6.2.2.

6.2.1 Established Elevations

All benchmarks, reference marks, reference points, gage features, and other permanent points that may be referenced to the gage datum should be included in a gage datum reference list. Each mark, feature, and point should be given a short, abbreviated name that conforms with the usual surveying terminology, such as BM1 (Benchmark No. 1), BM2 (Benchmark No. 2), RM1 (Reference Mark No. 1), WWCB (Wire Weight Check Bar), IGRP (Inside Staff Gage Reference Point), and OGRP (Outside Staff Gage Reference Point). For each gaging station, the list will be different and the user should be allowed to establish the initial list and add new points at any time. In addition to the abbreviated names, an optional, short description of each point should be included for easy reference. This description also would provide a place to document the status (active, abandoned, destroyed, and others) of benchmarks, reference marks, reference points, and other gage features.

Established elevations should be provided for each benchmark, reference mark, reference point, and gage feature. These elevations generally are the initial elevation defined by levels for each point when the gaging station was first established. However, as new points and features are established at later times in the life of the gaging station, these new established elevations should be added to the reference list. Also, it is sometimes found that the elevation of a point or feature may have changed so that the new elevation is considered reasonably permanent. The user should be allowed to make a change to the established elevation, but the electronic processing system should maintain a history of all elevation changes, along with dates of change, and names of persons making the change. An optional "remarks" entry should be allowed for the purpose of describing the reason for making an established elevation change. Established elevations should be maintained as permanent "known," or "given" elevations, and changes should not be made arbitrarily. These elevations become the basis for datum error comparisons, as described in section 6.2.2, and are the basis for making datum corrections to gage readings.

6.2.2 Datum Error Comparisons

One of the permanent benchmarks or reference marks at a gaging station usually is defined and referred to as the *base* benchmark. This is the benchmark at the station considered to be the most stable of the various marks that may be used for leveling purposes. Leveling at the station usually will start at this benchmark, using it as the base, and all other elevations are computed from that base. The base benchmark should be maintained as a permanent base so long as it remains stable.

For each set of levels, comparisons should be made between established elevations and elevations determined by leveling, for each benchmark, reference mark, reference point, and gage feature. The first, and primary, comparison should use the *base* benchmark as the starting point for all computations.

6.2.2.1 Base Benchmark Comparisons

The first, and sometimes the only, comparison between established elevations and elevations determined by leveling is made using the established base benchmark as the starting point to compute the elevations of other benchmarks, reference marks, reference points, and gage features. This method of comparison almost always conforms to the way the levels were run, and the way level data are entered to the electronic processing system. The electronic processing system should compute the difference between the established elevation and the elevation found by leveling, for each benchmark, reference mark, reference point, and gage feature. These differences should be retained as part of the permanent record, and should be displayed to the user as part of the gage-datum summary.

If levels are field computed and entered to the electronic processing system using a benchmark that is not designated as the base, the user should be alerted. Various reasons may be present as to why a designated base benchmark is not used. One reason could be that the benchmark may have been damaged or destroyed so that it is no longer a reliable mark. The user should be given the option to allow the levels to remain as entered, with no recomputation, or to designate a recomputation using the established base benchmark if the base was included in the levels.

6.2.2.2 Alternate Benchmark Comparisons

Instances may result where comparative elevations, using alternate benchmarks as a base, are desired, even though the designated base benchmark is still being used. The user should be allowed to designate an alternate benchmark as a base, and the electronic processing system should compute and display all other elevations on this basis. These elevations should be considered temporary, or work-sheet computations for comparative analysis only. If such comparisons reveal that a different benchmark should be designated as a new base, then the user should be allowed to make the change, and the elevations computed using this new base should be retained.

Recomputation of elevations cannot be made using the original rod readings and instrument heights because these are not entered to the electronic processing system. Therefore, the recomputation must be based on relative differences between the entered elevations of each benchmark, reference mark, and other feature.

6.2.2.3 Rounding and Significant Figures

All elevations of benchmarks, reference marks, and gage features usually are shown to thousandths of a foot in level notes and level-note front sheets. This degree of precision may not be justified for some gage features, gage heights of zero flow, and ground elevations. It is recommended that the precision and significant figures conform to the commonly used values shown in tables 4 and 5; however, the precision and significant figures are optional and the electronic processing system should retain the precision and significant figures entered by the user.

6.2.2.4 Gage Datum Summary

A historical summary of benchmarks, reference marks, and gage features should be maintained with the electronic processing system. This summary should include the name and abbreviation of each feature, a designation for the base benchmark, the original established elevations for all benchmarks and features, the elevations determined by leveling for each set of levels, the difference between the established elevation and the elevation determined by leveling, and remarks for each feature. The summary should be updated each time a new set of levels is entered, showing the date of leveling, and the names of the leveling party. An example of a datum summary is shown in figure 3.

6.3 Crest-Stage Gage Analysis

Crest-stage gages are vertical pipes containing a rod or wooden stick, and powder or dust such as cork dust. When water enters the intakes at the bottom of the pipe, it rises to a level corresponding to the outside water level until it reaches the peak stage and then recedes, leaving a line of cork dust on the rod/stick at the peak water level. The gage is designed so that measurements, either from the top of the rod/stick or the bottom of the rod/stick to the line of cork dust, can be used to compute the peak stage. Sometimes, more than one peak will occur between gage visits; thereby, leaving more than one crest mark on the rod/stick. Special paper field notes are used to record the information for a crest-stage gage.

Crest-stage gages may be the primary gage at a site where only peak stage data are collected. A crest-stage gage also may be used as an auxiliary gage at a continuous record gage site. In either case, the same paper field note form is used at both types of gage sites. The paper field notes are the original data used for archiving. A summary of the data and information on the notes should be entered to the electronic processing system as shown in table 7. Checking and comparisons should be performed as indicated in sections 6.3.1 and 6.3.2.

History and summary of gaging station levels

99111100 (Station ID Number) Example creek near Timbucktoo, SC (Station name)

[B=Base benchmark; (xxx)=Difference from gage reading; R=Gage reset; BM=Benchmark; RM=Reference mark; RP=Reference point; OG=Outside gage; IG=Inside gage; WWT=Wire-weight gage; Elev.=Elevation; —=No data]

Date of levels	10-12-42	06-18-44	03-21-47				
Party	DJS, VBS	VBS, MBS	JDC, DJS				
Benchmarks	Original Elev.	Elevation	Elevation	Elevation	Elevation	Elevation	Elevation
BM1	12.235	12.240	12.242				
RM1	2.468 (B)	2.468 (B)	2.468 (B)				
RM2	2.992	2.990	2.994				
RP1	15.334	15.333	15.331				
USC&GS 275	25.451	25.448	25.449				
Other…							
Gage Features							
Instrument shelf	16.43	16.44	16.43				
Bottom of well	0.34	0.37	0.33				
Lower door sill	5.89	5.89	5.88				
Lower intake	0.75	0.76	0.76				
Upper intake	1.79	1.79	1.80				
Point of zero flow	0.23	0.30	0.20				
Orifice	—						
Gages							
OG 3.3 - 6.8	4.500 (-0.002)	4.501 (+.001)	4.530(+.030) 4.504(+.004)R				
IG 0.0 - 6.8	3.480 (+0.004)	3.492 (+.012)	3.478 (-.002)				
WWT check bar	19.673	19.660	19.662				
Elec. tape index	16.532	16.532	16.530				
Steel tape RP	16.687	16.691	16.688				
Other…							
Remarks	Gage establ.		OG reset				

Figure 3. Example of a streamflow station datum summary.

6.3.1 Arithmetic Checking

Only one type of computation is made for crest-stage gages on the field notes. This is the computation of the peak stage for each crest mark entered on the form. The electronic processing system should check this computation by adding the measured distance of the crest mark to the index gage height for gages where the index mark is at the bottom of the rod/stick. If the index mark is at the top of the rod/stick, the measured distance of the crest mark should be subtracted from the index gage height. The calculated crest-gage height should be compared to the entered crest-gage height; if a difference is found the user should be alerted so that changes can be made, if necessary.

6.3.2 Logic and Consistency Comparisons

The electronic processing system should make the following comparisons to confirm that the data and information entered for each crest mark are consistent and logical for the given gage setup.

- *Date comparison*—The date estimated for the crest mark normally should fall between the date of the previous and current gage visit. The electronic processing system should make this comparison, and if the estimated date does not fall between the two visits, the user should be alerted and given the opportunity to make a change. It is not mandatory that the estimated date fall between the two visits. Circumstances may result to cause the apparent discrepancy.
- *Maximum gage-height comparison*—The computed crest-gage height should be compared to the maximum possible gage height for the crest-stage gage. If the computed gage height is greater, the user should be alerted and given the opportunity to make necessary changes.
- *Minimum gage-height comparison*—The computed crest-gage height should be compared to the minimum possible gage height for the crest-stage gage. If the computed gage height is less than the minimum, the user should be alerted and given the opportunity to make necessary changes.
- *Crest sequence comparisons*—The cork dust marks that are deposited on the rod/stick are fairly fragile, and can be erased by subsequent peaks that exceed a mark. When two or more marks are entered from one set of field notes, the electronic processing system should make a sequence comparison. The highest crest-gage height should have the earliest estimated date of occurrence, the second highest crest-gage height should have an estimated date that is later than the highest crest-gage height, and the third highest crest-gage height should be later than the previous one. The lowest crest-gage height in the sequence should have the latest estimated date. Although the previous description is the normal sequence of marks, circumstances can result where a mark still may be visible that is exceeded by a higher peak, and may be measured and entered in the field notes. The electronic processing system should alert the user about any sequence discrepancies and given the opportunity to make changes.

6.3.3 Rounding and Significant Figures

The precision of crest-gage heights usually is hundredths of a foot. However, some marks may be measured only to the nearest tenth of a foot. In such cases, the precision of individual marks should be retained as entered to the electronic processing system.

6.3.4 Summary of Crest-Stage Gage Measurements

A summary of all crest-stage gage measurements should be listed in chronological order, and grouped by water year. The summary listing should include all items shown in table 11.

6.4 Cross Sections

Cross-section data have various uses, but are primarily intended as an aid in rating-curve analysis. One or more cross sections may be entered with specific identifying information that make them unique to a particular gage site. The data and information entered for each cross section are listed in table 8. Some of the checking and computations that should be performed with the electronic processing system are listed in sections 6.4.1 through 6.4.3.

6.4.1 Logic and Consistency Checking

Cross-section entry consists mainly of transverse stationing along the line of the cross section, and ground elevations at each station. Station distances are measured from an initial point located on the left bank of the stream. The electronic processing system should check that each station distance is equal to or greater than the preceding station distance. The electronic processing system also should insure that ground elevations are provided for each station. Negative values of stationing and ground elevations are acceptable.

6.4.2 Graphical Review

The user should be required to view a graphical plot of each cross section to review and edit for inconsistencies and data-entry errors. The plot should be drawn to a scale ratio of 5 horizontal to 1 vertical, with an option to change the scale, if necessary. The plot should include all ground points, vertical subdivision boundaries, if entered, horizontal roughness boundaries, if entered, and Manning roughness coefficients, if entered. A typical cross-section plot is shown in figure 4.

Table 11. Crest-stage gage items that should be shown in the summary output form

[Items 9–12 should be arranged in tabular format, with multiple entries, if necessary, to accommodate multiple highwater marks.]

1. Station identification number
2. Station name
3. Party
4. Date of crest-stage gage inspection
5. Crest-stage gage identification (for example, upstream gage, downstream gage, and others)
6. Gage height on date of inspection
7. Time of gage-height reading
8. Time zone
9. Type of gage read (for example, outside gage, inside gage, wire weight, and others)
10. Elevation of crest-stage gage reference point (top of rod/stick, bottom pin, and others)
11. Measured distance from crest-stage gage reference point to high watermark
12. Highwater mark elevation (calculated from items 9 and 10)
13. Highwater mark elevation, determined from outside highwater marks
14. Estimated date of highwater mark
15. Remarks

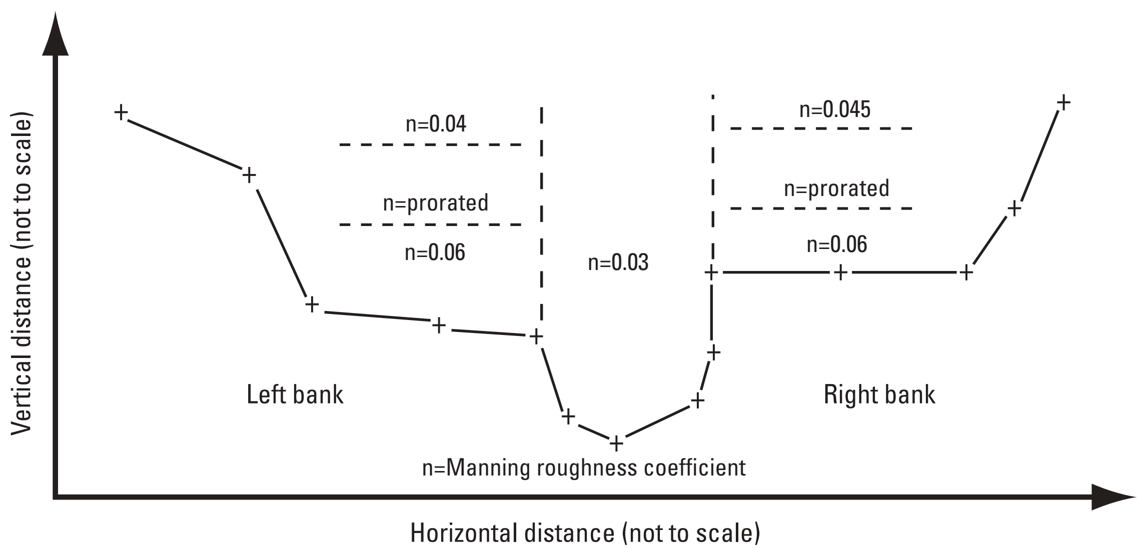


Figure 4. Typical stream cross-section plot.

6.4.3 Computation of Cross-Section Hydraulic Properties

The electronic processing system should provide for computation of cross-section hydraulic properties, using standard WRD methods, as described by Dalrymple and Benson (1967). A computer program such as Hydraulic Information Exchange (HYDIE), developed by Fulford (1993), can be used to compute cross-section properties. These computations should be optional, and not required for every cross section. The details for computing the various cross-section properties will not be described here, however, a typical summary listing of cross-section properties is shown in table 12.

Table 12. Summary of calculated cross-section properties that should be listed in tabular format

[ft, foot]

1.	Station identification number
2.	Station name
3.	Date of cross-section survey
4.	Party
5.	Cross-section identification number (a sequential number unique for each cross section)
6.	Location of cross section (longitudinal stationing, in feet, relative to the gage)
7.	Type of control that cross section represents, if applicable (for example, section control or channel control)
8.	Gage height, incremented according to user specifications (for example, 0.5 ft intervals, 1.0 ft intervals, 2.0 ft intervals) Number of sub-areas
9.	Total cross-section top width
10.	Total cross-section area
11.	Total cross-section conveyance
12.	Wetted perimeter
13.	Hydraulic radius
14.	Critical discharge
15.	Maximum depth (for natural sections), or head (for weirs and flumes).
16.	Mean depth
17.	Remarks

NOTE—For each cross section, items 8–12 should be arranged in tabular format, beginning with the lowest specified gage height and incremented at the specified interval to the highest specified gage height.

6.4.4 Rounding and Significant Figures

All data entered for cross sections should conform to the precision given in table 1, and all computed information for cross sections should be rounded to the precision given in table 2. The user should have the option to change the standard precision, as required, and numbers entered with a non-standard precision should be retained as entered.

7. Rating Curves

Rating curves are relations between dependent and independent variables. For instance, a rating curve expressing the mathematical or graphical relation between stage (independent variable) and discharge (dependent variable) is referred to as a stage-discharge relation. The processing of most surface-water records requires the application of one or more rating curves. This section of this report will describe the various types of rating curves, the methods of rating curve development, the methods of rating curve entry to the electronic processing system, and other related aspects of rating curves as they apply to the electronic processing system.

Rating curves are an integral part of the computation of most streamflow records, and become a part of the permanent records for each station. However, the electronic processing system also should allow the entry, development, and display of rating curves independent of computing streamflow records for specific gaging stations. That is, the user should be allowed to use the rating curve aspects of the electronic processing system and choose any one of the rating types listed below for entering, editing, developing, refining, and experimenting with the data.

7.1 Types of Rating Curves

A number of rating curve types are available for the processing of surface-water records. Following is a brief description of each type.

- *Stage-discharge relation*—This type of rating is the most common rating used for the processing of surface-water records. It is a relation between water-surface gage height and the rate of flow of the stream. Much of the descriptive information about rating curves that follow in this report will be discussed in terms of stage-discharge relations; however, many of the basic principles, entry procedures, plotting procedures, and other processing methods also are applicable to the other types of ratings. For stage-discharge ratings, the minimum allowable discharge is zero. Also, discharge values always should increase as gage height increases.

- *Stage-area relation*—This is a relation between gage height and area for a standard cross section of the stream. This type of rating commonly is used for velocity-index methods of computing discharge. Cross-section area always should increase as gage height increases. The minimum value of area is zero, and negative values of area are not permitted.
- *Velocity-index and mean velocity relation*—This is a relation between an index velocity (electromagnetic, acoustic, and others) and the mean velocity for a standard cross section of the stream. This type of rating commonly is used for velocity-index methods of computing discharge. The mean velocity usually increases as the index velocity increases, but sometimes may decrease. Negative values of either parameter, the velocity index or the mean velocity, are permitted; most velocity ratings of this type will extend into the negative range. For this reason, logarithmic ratings are seldom used for this type of rating.
- *Stage and velocity factor relation*—This is a relation between gage height and an adjustment factor used in the velocity-index method of computing discharge. The adjustment factor almost always increase as stage increases, but in some instances it will decrease. It always should be a positive value.
- *Stage-fall relation*—This is a relation between gage height and the water-surface fall between the base gage and an auxiliary gage. This relation is used in the slope method of computing discharge. Fall may increase or decrease as stage increases, but it always should be a positive value. Negative values of fall should not be allowed.
- *Fall ratio and discharge ratio relation*—This is a relation between the fall ratio, F_m/F_r, and discharge ratio, Q_m/Q_r, as used in the slope method of computing discharge. The discharge ratio always should increase as the fall ratio increases. Neither ratio should be negative. The upper limit of both ratios usually is less than 1.5, but in rare cases may exceed 1.5.
- *Stage-1/US_c relation*—This is a relation between gage height and a flood-wave factor, $1/US_c$, and is used in the rate-of-change in stage method of computing discharge. The flood-wave factor may increase or decrease as stage increases, however, it always should be a positive value.
- *Elevation and reservoir contents relation*—This is a relation between the water-surface elevation of a reservoir and the contents of the reservoir. The reservoir contents always should increase as elevation increases, and always should be a positive value. The minimum allowable value for reservoir contents is zero. This rating should allow for large numbers, with reservoir contents sometimes exceeding 4,000,000 acre-feet and elevation sometimes exceeding 6,000 ft above sea level. Elevation usually is shown to a precision of hundredths of a foot (for example, 2,345.67).

Gaging stations at control structures such as dams require a number of different rating curves and rating equations for spillways, gates, turbines, and other flow conveyances. These ratings specifically are designed for each individual structure and are a part of the structure computation program, as described by Collins (1977).

The BRANCH model method for computation of streamflow records does not require the use of individual rating curves. That model has internal calibration procedures as described by Schaffrannek and others (1981).

All ratings may be defined as logarithmic plots, linear plots, or equations. A summary of rating curve characteristics, limitations, and requirements is given in table 13. All ratings should be tested with the requirements and limitations listed in table 13.

Table 13. Rating curve characteristics, limitations, and requirements

[$1/US_c$, Boyer coefficient]

Computation Method	Rating Type	Independent Variable / Dependent Variable	Plot Scale Preference	Minimum Value Allowed	Maximum Value Allowed	Negative Values Allowed	Rating Reversals Allowed
Stage—discharge	Stage—discharge	Gage height	Ordinate	No limit	No limit	Yes	No
		Discharge	Abscissa	Zero	No limit	No	
Velocity	Stage—area	Gage height	Ordinate	No limit	No limit	Yes	No
		Area	Abscissa	Zero	No limit	No	
	Index velocity and mean velocity	Index velocity	Ordinate	No limit	No limit	Yes	Yes
		Mean velocity	Abscissa	No limit	No limit	Yes	
	Stage and velocity factor	Gage height	Ordinate	No limit	No limit	Yes	Yes
		Velocity factor	Abscissa	Zero	No limit	No	
Slope[1]	Stage—fall	Gage height	Ordinate	No limit	No limit	Yes	Yes
		Water-surface fall	Abscissa	Zero	No limit	No	
	Fall ratio and Q ratio	Fall ratio	Abscissa	Zero	1.5	No	No
		Discharge ratio	Ordinate	Zero	1.5	No	
Change in stage[1]	Stage—$1/US_c$	Gage height	Ordinate	No limit	No limit	Yes	Yes
		Factor, 1/USc	Abscissa	Zero	No limit	No	
Reservoir	Elevation—contents	GHt or elevation	Ordinate	No limit	No limit	Yes	No
		Reservoir contents	Abscissa	Zero	No limit	No	

[1]Requires a stage-discharge rating in addition to rating types shown.

7.2 Rating Selection Default Procedure

When a user is working on a specific gaging station with a specific computation method defined, and where ratings may, or may not, already be defined, the electronic processing system automatically should default to the rating type applicable to the defined computation method. For instance, if the computation method is *stage-discharge*, then the electronic processing system should default to a stage-discharge rating, or if a slope computation method is required, then the electronic processing system should default to the three rating types applicable to slope stations (stage-discharge, stage-fall, and fall ratio-discharge ratio ratings). The electronic processing system should not allow a rating type to be entered for a gaging station other than those applicable to the defined computation method for that station.

Stage-discharge ratings are the most commonly used ratings, and should, therefore, be the default rating of choice when the rating procedure is used independently; that is, not in conjunction with a specific gaging station.

7.3 Entry of Rating Curve Information

Rating curve information required for defining the relation between the independent and dependent variables, such as gage heights and discharges, can be entered into the electronic processing system using various methods, including tabular, equation, and graphical methods. *Tabular entry* is the use of a table of descriptor data pairs, each representing a specific location of the rating curve. *Equation entry* is the use of a mathematical expression to define the rating curve algebraically. *Graphical entry* is a method whereby a series of points are entered directly on a rating curve plot displayed on the computer monitor, and the electronic processing system automatically evaluates the points, connects the points, and displays the rating curve.

Tabular entry and graphical entry are similar in that both utilize user-defined descriptor points. The primary difference is that tabular entry is based on descriptor points that are hand picked from a paper rating curve plot, whereas graphical entry is based on descriptor points defined on the computer monitor, thus, negating the need for a paper plot. An individual rating curve can be entered by using only one or the other of these two entry modes, or in combination. However, the electronic processing system should not allow either of these entry modes to be used in combination with the equation mode of entry. The requirements for each type of entry mode are described in sections 7.3.1 through 7.3.3.

7.3.1 Tabular Entry

Rating curves may be entered to the electronic processing system by keyboard as a series of descriptor points, sometimes referred to as point pairs. Each point pair contains the independent variable and the corresponding dependent variable for one position on the rating curve. The electronic processing system should not limit the number of point pairs that can be entered. Point pairs always should be entered in ascending order of the independent variable, starting with the lowest point on the rating curve. If the user incorrectly enters a point pair in which the independent variable is not ascending, the electronic processing system immediately should issue a warning message to alert the user that an entry error was made. This checking method also should be used for the dependent variable for those ratings where the dependent variable is not allowed to decrease. A similar warning message also should be given if negative values are entered for ratings where they are not allowed.

Rating curves that are entered as linear scale ratings will require only the table of point pairs. No other descriptive information is needed for either plotting or expanding (interpolating) a linear scale rating.

Rating curves entered as logarithmic scale ratings will require entry of scale offset information, in addition to the table of point pairs. A scale offset is a value that is subtracted from the independent variable before interpolating between point pairs of the rating. It is important that the scale offset entered at this point is the same as the one used for the plotted rating curve. Because there is no way to verify that the offset used for a paper plot and the entered offset are the same, the electronic processing system should include a reminder at the point of offset entry, that states, “Offsets entered here must be identical to offsets used for the rating curve plot to provide exact duplication in the rating table.” If the user does not enter a scale offset for a logarithmic rating, the electronic processing system should not accept the rating, and should prompt the user that an offset is required.

The electronic processing system should allow one, two, or three scale offset values for each logarithmic rating curve, with each respective offset applicable to a designated range, or segment, of the rating. The offsets should be entered starting with the lowest rating curve segment and progressing upward, with a defined breakpoint between successive offsets. The breakpoint is the value (usually gage height) of the independent variable above which the succeeding offset should be used. The following combinations of offsets and breakpoints are allowable.

- *One offset, no breakpoints*—In this case, a single offset is used throughout the range of the rating.
- *Two offsets, one breakpoint*—In this case, the first offset is used for all values of the independent variable that are less than or equal to the breakpoint value. The second offset is used for all values of the independent variable that are equal to or greater than the breakpoint value.
- *Three offsets, two breakpoints*—In this case, the first offset is used for all values of the independent variable that are less than or equal to the first breakpoint value. The second offset is used for all values of the independent variable that are equal to or between the first and the second breakpoints. The third offset is used for all values of the independent variable that are equal to or greater than the second breakpoint value.

A point pair entry in the table of point pairs is required at each breakpoint of the rating. If the user omits the point pair corresponding to a breakpoint, the electronic processing system should issue a warning message and should not accept the rating unless this requirement is met. The point pair at each breakpoint is used as the ending point for the rating-curve segment below the breakpoint, and the beginning point for the rating-curve segment above the breakpoint This process insures continuity of the rating-curve segments. Scale offsets are described in more detail in section 7.7.6.2.

7.3.2 Equation Entry

Some ratings may be easily expressed in equation form, and if so, they may be entered to the electronic processing system as a mathematical expression. Such ratings usually are of simple form, consisting of a smooth curve or straight line, with no unusual shapes or sharp bends. For all equation ratings, a basic format as given in equation 21 should be used.

$$Y = a + b(X - e)^c \tag{21}$$

where

Y = dependent variable (usually discharge),
X = independent variable (usually gage height),
a = equation constant (default value is zero),
b = multiplier (default value is 1),
e = scale offset (default value is zero),
c = exponent (default is 1).

Equation 21 can be used for rating curves interpolated either linearly or logarithmically. Other types of equations, such as parabolic equations, are not recommended for surface-water rating curves.

Upper and lower equation limits also should be required as part of the input for equation ratings. These limits should, by default, be in terms of the independent variable; however, the user should have the option to specify the limits in terms of the dependent variable. When extrapolation of equation ratings is needed, and can be justified, a modification of the approved limits should be allowed. The electronic processing system automatically should not extrapolate the equation beyond the approved specified limits.

The electronic processing system should allow up to three equations for the definition of a rating curve. Breakpoints, in terms of the independent variable, between two consecutive equations are required to define the exact point of the ending of one equation and the beginning of the next equation. Consecutive equations must intersect at the given breakpoint. The electronic processing system should calculate the dependent variable at the breakpoint by using each equation, and if the two calculated values of the dependent variable are not identical the electronic processing system should alert the user and not accept the equations until appropriate changes are made. These checks and modifications should be made at the time of equation entry, and before application of the equations.

When multiple equations are used to define a rating curve, a lower limit should be specified for the lower equation, and an upper limit should be specified for the upper equation. The same rules and guidelines apply to these limits as stated previously for single equation limits.

7.3.3 Graphical Entry

Graphical input of rating curves is presently the most automated and preferred method of entering a rating curve to the electronic processing system. Historically, rating curves have been drawn manually on paper work sheets, and descriptor points visually are read from the plot. The electronic processing system should provide a method whereby the user can automatically plot, from the electronic processing system files, selected discharge measurements and other rating curve information on the computer monitor, and then fit a rating curve to the plotted points directly on the monitor. The fitting process will be done by specifying a series of descriptor points, either directly on the computer monitor or in a table displayed on the monitor. After the user is satisfied with the accuracy and smoothness of the rating curve, the electronic processing system should automatically transform the plotted rating curve into a rating table.

7.4 Rating Tables

The rating table is primarily for the purpose of displaying values of the dependent variable for the complete range of the independent variable. Rating tables should be generated with the electronic processing system for all rating curves. The tables are populated by interpolating values of the dependent variable for the complete range of the independent variable, at intervals equal to the stated precision of the independent variable or other user-defined interval. For instance, if the independent variable is gage height, and its stated precision is hundredths of a foot, then values of the dependent variable (for example, discharge) would be computed for every hundredth of a foot of gage height for the full range of gage height defined by the limits of the rating. The interpolation methods and other requirements of producing rating tables are described in sections 7.4.1 through 7.4.5.

7.4.1 Interpolation Methods

The method used to interpolate between rating input points should be based on the method used to develop the rating. Rating curves defined as linear scale ratings should be interpolated between input points using a simple linear interpolation method.

Rating curves defined as logarithmic scale ratings should be interpolated between log-transformed input points using a linear interpolation method. The applicable scale offset must be subtracted from all input values of the independent variable before making the logarithmic transformations. If the rating is defined with two or three scale offsets, then each offset only should be applied within the range defined by the respective breakpoints.

It is very important that the interpolation process use the same offset, or offsets, that are used for the development of the rating curve plot, so that the resulting rating table precisely duplicates the plotted curve. If the rating is plotted on the electronic processing system monitor, the rating curve automatically is converted to a rating table, and the offset will automatically be the same for both the plotted curve and the resulting table. If the rating curve is entered as a table of descriptor points, then the interpolation method must use the scale offset, or offsets, entered with the descriptor points. The user is responsible for insuring that the offsets are identical.

Note that the subtraction of the scale offset from the independent variable is made only for the purpose of transformation and interpolation. The subtraction should not alter the original values of the independent variable that are displayed in the rating table or plotted on rating curve plots.

The dependent variable (for example, discharge) for many rating curves has a minimum value of zero, which theoretically cannot be transformed to a logarithm. A simple linear interpolation between the zero point and the next larger input value of the dependent variable should be used for logarithmic ratings beginning with zero. To avoid appreciable distortion of the low end of the rating, it is recommended that the input value of the dependent variable that follows the zero input value be equal to or less than 0.1. The electronic processing system should issue a warning message to the user if 0.1 is exceeded, and provide an opportunity to make changes.

The independent variable (for example, gage height) can sometimes be zero or negative at the low end of a rating curve. This value is permissible only when subtraction of the scale offset from the independent variable results in a positive number. See section 7.7.6.2.1 for additional details.

Rating curves defined by one or more equations also should be transformed into rating tables. This is a simple method of computing the dependent variable for the entire range of each equation, as defined by the breakpoints and input limits.

7.4.2 Rating Table Precision and Significant Figures

Rating tables should be defined and displayed using either standard precision or expanded precision methods. Standard precision involves using only the number of significant figures required for each variable as defined in tables 1 and 2. Expanded precision involves the addition of one additional significant figure for the dependent variable. For instance, if the standard number of significant figures for the dependent variable (for example, discharge) is three, then standard precision would display three significant figures and expanded precision would display four significant figures.

7.4.3 Rating Table Smoothness Analysis

One method of analyzing the smoothness of a rating curve and/or rating table can be done by studying the differences between successive values of the dependent variable. To make this task easy for the user, the rating table should display the computed differences (traditionally referred to as first differences) of the dependent variable between every tenth value of the independent variable displayed in the rating table. For instance, if gage height is incremented every 0.01 ft in the rating table, then the difference between discharges corresponding to gage heights at 0.1 ft intervals should be computed and displayed.

7.4.4 Other Rating Table Information

The rating table should include descriptive information that identifies the gaging station, type of rating, period of use, and other items that are unique for that rating. At a minimum, the following items should be included in the table.

- *Station number*—The downstream order number that identifies the station.
- *Station name*—The official name of the station.
- *Rating table number*—The unique number assigned to identify the rating table.
- *Processing information*—The time and date the rating was entered, and name of the person making the entry. If the rating is edited (minor changes only) or extrapolated and the rating number is not changed, then additional times, dates, and names should be shown that identify when these changes were made. Information explaining a change, or extrapolation, can be given in the narrative rating description (see descriptions below).
- *Type of rating*—The rating type, such as stage-discharge, stage-area, and others. This rating type also will identify the input parameter (independent variable) and the output parameter (dependent variable). The units of measurement (for example, feet, cubic feet per second, square foot, and so forth) should be shown for the independent and dependent variables.
- *Method of rating definition*—The method by which the rating is defined, either logarithmic plot, linear plot, or equation.
- *Scale offset, or offsets (for logarithmic ratings only)*—The scale offset(s) used for the working plot of the rating.
- *Scale offset breakpoints (for logarithmic ratings only)*—The value of the independent parameter that defines the point of change from one scale offset to the next. Breakpoints only are required if the rating is defined with more than one scale offset.
- *Period of use*—The date, time, and time zone that identifies the beginning and ending of the period of time for which the rating is to be used. If the rating is still in use, then the ending date, time, and time zone should be left open.
- *Rating description (optional)*—A narrative description of the rating definition. This is an optional entry at which point the user can describe how the rating was defined, the number of measurements used, strong and weak points of the rating, how the rating was extrapolated (if done), use of theoretical methods in developing the rating, and any other information that might qualify the rating.
- *Significant figures*—The use, or non-use, of expanded precision should be identified.
- *Input values*—If the rating was entered using descriptor points, each of the entered points should be identified in the body of the table. This traditionally has been done by flagging each entered point with an asterisk (*).

An example of an expanded rating table for a logarithmic stage-discharge rating curve is shown in figure 5. This sample rating table illustrates the header information and a typical arrangement of table information.

7.5 Rating Curve Numbers

Every rating curve for a specific gaging station should be identified with a number. The preferred numbering system should be a simple, consecutive number, with the earliest used rating as number 1, the next rating number 2, and so forth. Although not recommended, alpha-numeric numbers should be permitted, as well as decimal number combinations such as 3a.2 or 4.2b. Gaging stations with long periods of record may have old ratings that either are identified only by dates of use, or consecutive numbers. These older ratings may no longer be in use, and in many cases may not be entered to the electronic processing system. It is recommended, however, that the old numbers be retained whenever possible, and that newer ratings that are entered to the electronic processing system be numbered in the same sequence. Changing original rating numbers, breaking the numbering sequence, or using duplicate numbers for different ratings at a gaging station, should be avoided, if possible.

UNITED STATES DEPARTMENT OF THE INTERIOR—GEOLOGICAL SURVEY—WATER RESOURCE DIVISION
EXPANDED PRECISION RATING TABLE TYPE: LOG
RATING NO: 001 [10-01-1996] Scale offset=1.00
USGS 99410000 COMPUTER PROCESSED: 03-20-1997 BY vbsauer
Alabama River stage-Q test site

BASED ON ___DISCHARGE MEASUREMENTS, NOS___, AND ___, AND IS___WELL-DEFINED BETWEEN___AND___CFS
RATING ANALYSIS BY ____________________DATE_________RATING
DESCRIPTION____

GAGE EIGHT (FEET)	DISCHARGE, IN CUBIC FEET PER SECOND										DIFF IN Q PER TENTH FT
	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	
3.00	2.000*	2.086	2.175	2.267	2.362	2.460	2.561	2.666	2.773	2.884	.998
3.10	2.998	3.115	3.236	3.360	3.489	3.620	3.756	3.895	4.039	4.186	1.339
3.20	4.337	4.493	4.653	4.817	4.985	5.158	5.336	5.518	5.705	5.896	1.756
3.30	6.346	6.294	6.501	6.713	6.930	7.152	7.379	7.613	7.851	8.096	2.253
3.40	8.346	8.602	8.864	9.132	9.406	9.687	9.974	10.27	10.57	10.87	2.844
3.50	11.19	11.51	11.83	12.17	12.51	12.86	13.21	13.58	13.95	14.33	3.520
3.60	14.71	15.11	15.51	15.92	16.34	16.77	17.20	17.65	18.10	18.56	4.320
3.70	19.03	19.51	20.00	20.50	21.01	21.53	22.05	22.59	23.14	23.69	5.230
3.80	24.26	24.84	25.43	26.02	26.63	27.25	27.88	28.53	29.18	29.84	6.260
3.90	30.52	31.21	31.91	32.62	33.34	34.08	34.83	35.59	36.36	37.15	7.430
4.00	37.95	38.76	39.58	40.42	41.28	42.14	43.02	43.92	44.82	45.75	8.730
4.10	46.68	47.63	48.60	49.58	50.58	51.59	52.61	53.66	54.71	55.79	10.20
4.20	56.88	57.98	59.10	60.24	61.40	62.57	63.76	64.97	66.19	67.43	11.81
4.30	68.69	69.97	71.26	72.58	73.91	75.26	76.63	78.02	79.42	80.85	13.61
4.40	82.30	83.76	85.25	86.75	88.28	89.83	91.39	92.98	94.59	96.22	15.57
4.50	97.87	99.54	101.2	103.0	104.7	106.5	108.2	110.0	111.9	113.7	17.73
4.60	115.6	117.5	119.4	121.4	123.3	125.3	127.4	129.4	131.5	133.6	20.10
4.70	135.7	137.8	140.0	142.2	144.4	146.7	149.0	151.3	153.6	156.0	22.70
7.80	158.4	160.8	163.2	165.7	168.2	170.7	173.3	175.9	178.5	181.1	25.40
4.90	183.8	186.5	189.2	192.0	194.8	197.6	200.5	203.4	206.3	209.3	28.50
5.00	212.3	215.3	218.3	221.4	224.5	227.7	230.9	234.1	237.3	240.6	31.70
5.10	244.0	247.3	250.7	254.1	257.6	261.1	264.6	268.2	271.8	275.5	35.20
5.20	279.2	282.9	286.6	290.4	294.3	298.2	302.1	306.0	310.0	314.1	38.90
5.30	318.1	322.2	326.4	330.6	334.8	339.1	343.4	347.8	352.2	356.6	43.00
5.40	361.1	365.7	370.2	374.8	379.5	384.2	389.0	393.8	398.6	403.5	47.30.
5.50	408.4	413.4	418.4	423.5	428.6	433.8	439.0	444.2	449.5	454.9	51.90
5.60	460.3	465.8	471.3	476.8	482.4	488.1	493.8	499.5	505.3	511.2	56.80
5.70	517.1	523.1	529.1	535.1	541.3	547.4	553.6	559.9	566.3	572.7	62.00
5.80	579.1	585.6	592.1	598.8	605.4	612.1	618.9	625.8	632.7	639.6	67.50
5.90	646.6	653.7	660.8	668.0	675.2	682.6	689.9	697.3	704.8	712.4	73.40
6.00	720.0*	725.9	731.9	737.9	743.9	750.0	756.1	762.2	768.4	774.6	60.80
6.10	780.8	787.1	793.4	799.7	806.1	812.5	819.0	825.4	832.0	838.5	64.30
6.20	845.1	851.7	858.4	865.1	871.8	878.6	885.4	892.2	899.1	906.0	67.90
6.30	913.0	920.0	927.0	934.1	941.2	948.3	955.5	962.7	970.0	977.3	71.60
6.40	984.6	992.0	999.4	1007	1014	1022	1029	1037	1045	1052	75.40
6.50	1060*	1068	1076	1083	1091	1099	1107	1115	1123	1131	80.00
6.60	1140	1148	1156	1164	1173	1181	1189	1198	1206	1215	83.00
6.70	1223	1232	1241	1249	1258	1267	1276	1284	1293	1302	88.00

Figure 5. Example of expanded precision rating table.

Ratings that are defined with two or more segments (for example, a rating defined with three equations that intersect at specified breakpoints) should be considered as one rating and only have one assigned number. In other words, the individual equations that define that one rating should not have different numbers.

A separate numbering sequence for each rating type should be used for gaging stations that require two or more ratings of different parameters. For instance, a velocity-index station may have a stage-area rating, another rating of velocity index and mean velocity, and a third rating of stage and velocity factor. Each of these ratings should be numbered within their own sequence of numbers, and consequently, in many cases each of the three ratings would have the same number. The ratings would be distinguished by *rating type* and *rating number*, not only by number.

7.6 Updating and Renumbering Existing Rating Curves

Rating curves occasionally may require updating, or revision. Updates usually are composed of extrapolating either the low end or the high end of the rating. If no change is made to the available part of the rating, and it is simply extrapolated (either end, or both ends), then the electronic processing system should retain the rating with no change in the rating number. However, the user should have the option to renumber the rating, if desired. Revisions to an existing rating, or to a segment of an existing rating, require renumbering, and revision of the period of use. In effect, a new rating is established.

All updating and revisions of rating curves should be made a part of the record processing notebook, as described in section14.1. The date, users name, nature of the update, and reason for updating should be required input to the log.

7.7 Rating Curve Plots

A graphical presentation of a rating curve is useful to the user. Rating curves plotted on paper graphs traditionally have been used for studying the relation between parameters (mainly gage height and discharge), and very high standards have been established for this purpose. For the relation between stage and discharge, for instance, the hydraulics of the stream and control are expressed in the rating curve plot. Therefore, the user can make basic interpretations regarding the stream hydraulics if the plot is made by observing specific guidelines. Details of rating curve analysis and interpretation can be found in various reports, and specifically by Rantz and others (1982), and by Kennedy (1984).

Rating curves may be plotted either to linear scales or logarithmic scales. Certain types of ratings are better plotted with linear scales, whereas other rating types are best plotted with logarithmic scales. Preferences are frequently subjective, with either type of plot as acceptable. The most frequently used rating is the stage-discharge, and for hydraulic analysis purposes the working plot should be done with logarithmic scales.

The electronic processing system should provide the capability to display more than one rating on the same plot. These plots allows the user to compare ratings easily. Each rating displayed on a plot should be identified with rating number and dates of application.

7.7.1 Reversal of Ordinate and Abscissa

A peculiarity of most rating curve plots is that the parameters plotted along the ordinate and abscissa scales are interchanged from the standard engineering practice. For rating curves where gage height is the independent variable, gage height always is plotted as the ordinate, and the dependent variable as the abscissa. This designation allows gage height, which is measured in a vertical direction, to be plotted in a vertical direction. The rating curve slope for this method of plotting is defined as a horizontal distance divided by a vertical distance. The plotting scale preference for other ratings is given in table 13.

7.7.2 Electronic Processing System Monitor Plots

The electronic processing system should provide for plotting of rating curves on the electronic processing system monitor with interaction by the user to manipulate, draw, and define ratings electronically. The requirements for electronic processing system monitor plots are essentially the same as for paper plots, as described in sections 7.7.3 through 7.7.8. These monitor plots should be a highly flexible part of the electronic processing system and also should provide the capability to produce a paper plot of the same rating, if required.

7.7.3 Paper Plots

The electronic processing system should be able to produce a paper plot of rating curves that are entered either through the use of descriptor points or equations. Paper plots also should be producible from system monitor plots. Requirements for paper plots are described in sections 7.7.4 through 7.7.8.

7.7.4 Plotting Forms for Paper Plots

The electronic processing system should develop and print the entire plotting form for a paper plot. It should print the grid as well as the rating curve and other rating curve information. Preprinted plotting forms are not advised. The combination linear and log-log plotting form that traditionally has been used for stage-discharge ratings (see fig. 6) should be included as a paper plot option.

7.7.5 Linear Scale Plots

An arithmetically divided, linear, plotting scale is the simplest type of rating curve plot. Linear scale plots are convenient

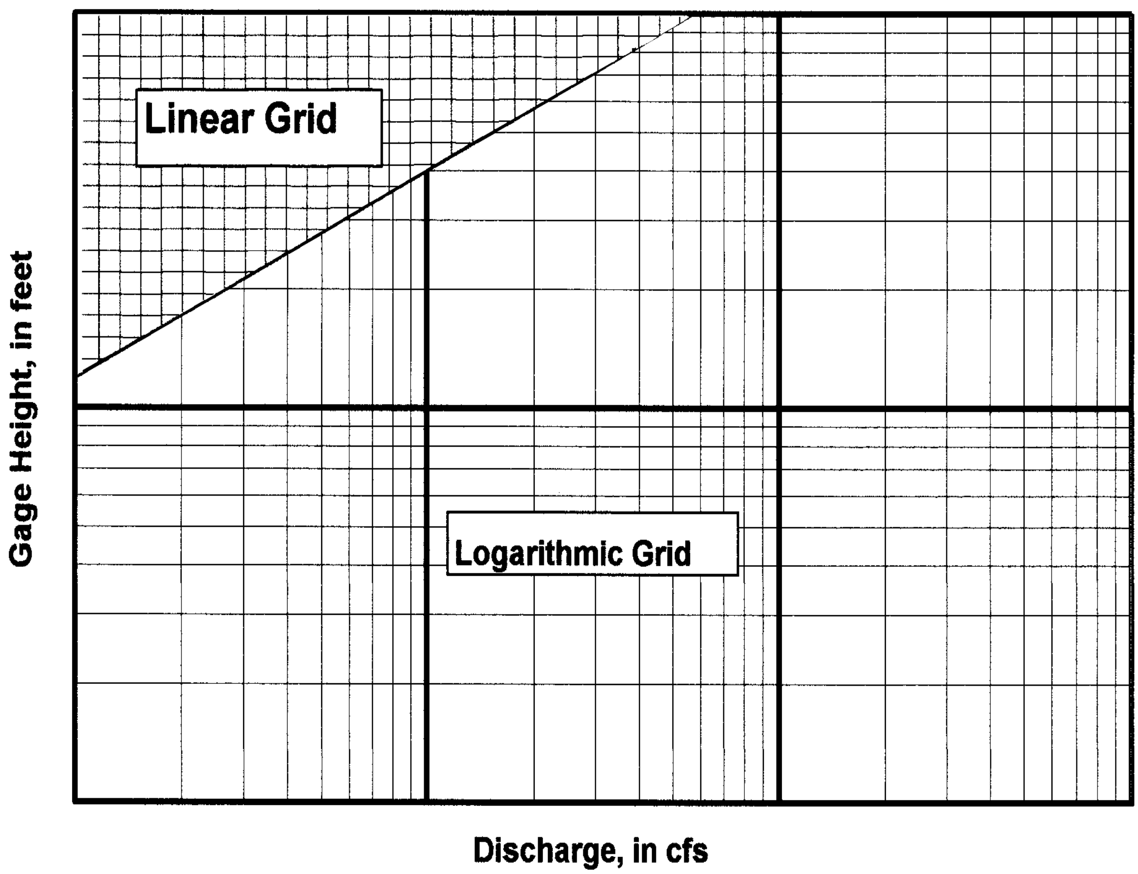


Figure 6. Linear and log-log combination plotting form.

to use and easy to read. Zero values can be plotted on the arithmetic scale, whereas these values cannot be plotted on logarithmic scales. For this reason, linear scale plots frequently are used for analyzing the low end of stage-discharge ratings. However, for detailed hydraulic analysis linear scale plots have little or no advantage over logarithmic scale plots. A stage-discharge relation plotted to a linear scale is almost always a curved line, concave downward, which can be difficult to shape correctly if only a few discharge measurements are available. Logarithmic scale plots, on the other hand, have a number of analytical advantages as described in section 7.7.6.

Linear scale plots are excellent for displaying a rating curve. Usually, a rating curve is first drawn on a logarithmic scale plot for shaping and analysis, then transferred to a linear scale plot for display, (usually a paper plot). The electronic processing system should make this process simple and easy.

7.7.5.1 Linear Scale Selection Procedure

Linear scale subdivisions should be established to cover the complete range of the independent and dependent variables, or a selected range. If only part of the rating is to be plotted, the user should specify the range of either the independent variable or the dependent variable for the desired plot. The electronic processing system should make an initial determination of scales, subdivided in uniform, even increments that are easy to read and interpolate. The scales also should be chosen so that the plotted rating curve is not very steep or very flat. Usually, the curve should follow a slope of between 30 and 50 degrees. The user should be able to change the scales easily and quickly so that various plots can be viewed. The electronic processing system should replot all measurements and rating curve information each time a scale change is made.

7.7.5.2 Linear Scale Breaks

If the range of the variables is large, it may be necessary to break the plotting scale and plot the rating curve in two or more segments to provide scales that are easily read with the necessary precision. This method may result in separate curves for low water, medium water, and high water. Although two or three separate curves are plotted, they should be plotted within the same plotting form, if possible. The electronic processing system should arrange the individual plots on the form so that they are separate and distinct, properly scaled, and not overlapping. Optionally, the separate curves could be plotted on separate forms.

7.7.6 Logarithmic Scale Plots

Many rating curves, and especially the relation between gage height and discharge, can be analyzed best by plotting the rating on logarithmic scale plots. Hydraulic characteristics that are evident in logarithmic plots relate to the type of control, the stream cross section, cross-section shape changes, and shifting control patterns as described by Rantz and others (1982), and by Kennedy (1984).

7.7.6.1 Logarithmic Scale Selection Procedure

The electronic processing system should plot rating curves and rating curve information to logarithmic scales, by default, if the rating is defined as a logarithmic rating. Ratings defined as linear ratings, or equation ratings, may be plotted to logarithmic scales at the users option. The initial plot should cover the full range of the rating, or a selected range if defined. A normal logarithmic scale (no offset) always should be used for the abscissa, or dependent variable. However, the ordinate scale should be adjusted, by default, by an amount equal to the offset defined for the primary rating being plotted. If multiple offsets are defined with this rating, and the user chooses to plot a continuous rating for the complete range of all segments, then the electronic processing system should default to the offset corresponding to the lowest segment of the rating to make the initial plot. If this is a plot for a new rating, where no other rating is to be plotted, then the electronic processing system should define the ordinate scale as a normal log scale (no offset), or use an offset selected by the user. Although default scale selections and offsets are prescribed, the user should be allowed to override the defaults and provide his/her own selections.

Generally, it is advised that full log cycles be used for logarithmic scale plots; however, the user should have the option to set lower and/or upper limits so that only partial log cycles are used at each end of the scales. The setting of scales should be highly flexible and easily changed so the user can plot and position the rating to the best advantage.

Logarithmic scale cycles always should be square. That is, the linear measurement of a log cycle, both horizontally and vertically, *must* be equal. Unless this requirement is met, it is impossible to hydraulically analyze the resulting plot of the rating.

7.7.6.2 Scale Offsets

Many rating curves, and especially stage-discharge rating curves, are analyzed and drawn on logarithmic scale plots, using a scale offset for the ordinate, or gage-height scale. A scale offset is a constant value that, when subtracted from the independent variable (gage height), changes the plotting relation between the dependent and independent variables. The results are a change to the curvature of the line of relation. If the offset value is too large, the line will plot as a curve concave downward. Conversely, if the offset value is too small, the curve will plot concave upward. Theoretically, a segment of a rating curve that is controlled by a specific cross section, or specific channel reach, only one scale offset will cause that segment of rating to plot as a straight line on a logarithmic scale plot. This specific scale offset is referred to as the effective gage height of zero flow for that specific segment of rating. For the extreme low end segment of a stage-discharge relation, the scale offset frequently will be equal to the true gage height of zero flow. Defining the best scale offset for each segment of a rating curve is a goal in rating curve analysis because it allows the rating curve segment to be drawn as a straight line, which is easier and usually more precise than drawing a curved line. The electronic processing system should allow up to three scale offsets for each rating curve. This procedure conforms to many stage-discharge rating curves, where three major segments are present; (1) the extreme low water segment that usually is controlled by a section control, (2) the within bank segment that can be either a section control or channel control, and (3) the overbank segment that usually is channel control. Short transition curves that join major rating segments usually are curved lines that will not plot as a straight line, regardless of the scale offset.

7.7.6.2.1 Scale Offset Limitations

Scale offsets must be limited to values that are less than the lowest value of the independent variable for the rating curve, or segment of a curve, being defined. Otherwise, the mathematics would produce zero or negative results, for which logarithms cannot be determined. The electronic processing system should not accept scale offsets that are equal to or greater than the lowest value of the independent variable for the range in which the offset applies.

Negative scale offsets are acceptable. A negative offset for the low segment of a stage-discharge relation would indicate that the gage height of zero flow is negative. Although such a condition usually is not advised, this condition can result at some gaging stations.

7.7.6.2.2 Determination of Best Scale Offset

When drawing a new rating curve, or rating curve segment, the best value for the scale offset is not always apparent. A trial-and-error procedure usually is used, and therefore, the electronic processing system should provide an easy method to change the scale offset and quickly produce a new plot of the measurements and rating curve. In this way, the user can work with different scale offsets to find the one best suited for the rating curve in question. Three or four trials usually are sufficient to find the best offset, but the electronic processing system should not limit the number of trials.

The electronic processing system should provide an option to compute a scale offset. The computation method is one defined by Johnson (1952), and is further described by Kennedy (1984) and Rantz and others (1982). The following computation steps are required for the procedure.

1. Choose two points on the rating curve segment for which a computation of the scale offset, e, is desired. One of the chosen points should be near the lower end of the segment,

and one point should be near the upper end of the segment. The two point coordinates are G_1, Q_1, and G_2, Q_2.

2. Compute a value, Q_3, based on Q_1 and Q_2, and the equation

$$Q_3 = \sqrt{Q_1 Q_2} \tag{22}$$

3. Determine a value, G_3, from the rating curve that corresponds to Q_3.
4. Compute the value, e, based on the equation

$$e = \frac{G_1 G_2 - G_3^{\ 2}}{G_1 + G_2 - 2G_3} \ . \tag{23}$$

5. Round the resulting value of the scale offset, e, to one that easily is used for the logarithmic plot.

7.7.6.3 Rating Curve Shaping

Stage-discharge rating curves usually are shaped by fitting a curve or straight line to a series of plotted discharge measurements. For paper plots, this fitting is easily performed by hand with straight edges and preformed plastic curves. For electronic processing system monitor plots, a method, or methods, should be provided whereby the user similarly can fit a smooth curve or straight line to points plotted on the electronic processing system monitor. This should be a highly interactive process between the electronic processing system and the user.

Certain helps should be made available for electronic processing system plots to ensure that stage-discharge ratings are hydraulically correct. One such help is to plot a theoretical rating based on the control properties and the governing hydraulic equations. The computations and plotting of theoretical ratings should be performed with the electronic processing system, but will require interaction with the user. Methods of computing theoretical ratings will be described in more detail in section 7.8. The theoretical ratings are used primarily for defining the rating shape, and not necessarily for locating the rating position. The user must use such ratings with caution, and should make discharge measurements to verify these ratings whenever possible.

Another help, when working with logarithmic scale ratings for stage-discharge stations, is to measure the slope of straight line rating segments for comparison to theoretical slopes that correspond to various control conditions. Rating slope computations should be done automatically with the electronic processing system on command. The user first should designate the end points of the segment of rating where slope is to measured. The electronic processing system should check to be sure the selected rating curve segment is reasonably close to a straight-line segment. This checking can be done by computing percentage differences of discharge between the actual rating and the straight line defined by the selected end points, at intermediate points along the rating segment. If any difference exceeds + or - 1 percent (default value), the rating segment should be considered curvilinear and the slope should not be computed. The electronic processing system should issue a statement to the user to this effect, and simultaneously provide an opportunity for the user to select a different percentage to use for checking the differences, or to select a different rating segment to check. On the other hand, if the rating segment is found to be a straight line (within the default, or selected, percentage difference), then the slope should be computed and displayed. When displaying a computed slope, the electronic processing system also should include the statement "*section control*" for slopes greater than 2.0, and "*channel control*" for slopes less than 2.0.

The slope of a logarithmic rating is computed as the run (horizontal distance) divided by the rise (vertical distance). The run and rise are measured as linear distances on logarithmic plotting scales. They should not be measured in terms of the independent and dependent variables, but rather in terms of the logarithms of these variables. For a straight-line segment, two points [(Q_1, G_1) and (Q_2, G_2)] on the segment can be used to compute the slope using

$$c = \frac{\log Q_2 - \log Q_1}{\log(Y_2 - e) - \log(Y_1 - e)} , \tag{24}$$

where
c = the rating curve slope, and
e = the scale offset for the independent variable.

7.7.7 Mathematical Fitting of Rating Curves

As previously stated, rating curves are hydraulic functions that should conform to the laws of hydraulics. For this reason, rating curves should not be defined with statistical methods, such as regression techniques, or by fitting curves with mathematical methods such as quadratic equations. All measurements used in a mathematical or statistical derivation are assumed to lie on the same rating curve. Frequently, this is an incorrect assumption, especially for streams with shifting controls.

7.7.8 Measurement Plotting

Selected field measurements and other computed parameters should be plotted with the electronic processing system on rating curve plots. The rating type will govern the parameters to be plotted. For each respective rating, these may be measurements of stage and discharge, stage and fall, index velocity and mean velocity, stage and area, or elevation and reservoir contents. Computed parameters such as discharge ratio and fall ratio for slope ratings, velocity factor and stage for index velocity ratings, and $1/US_c$ and stage for change-in-stage ratings also should be plotted as required.

7.7.8.1 Selection of Measurements

The user should have considerable flexibility in the selection of measurements and computed parameters to be plotted. The selection criteria should be based on measurement number, measurement date, independent variable, dependent variable, and measurement type (for example, ice measurement, control condition, and others). Various combinations of the selection parameters also should be permitted; however, the electronic processing system should not allow unlimited selection of all possible combinations. Unlimited selection could lead to conflicting and sometimes biased plotting standards. Various selection criteria are given below.

1. Plot all measurements with numbers greater than a specified number, less than a specified number, and (or) between two specified numbers.
2. Plot all measurements with dates subsequent to a specified date, prior to a specified date, and (or) between two specified dates.
3. Plot all measurements where the independent variable exceeds a specified value, is less than a specified value, or between two specified values.
4. Plot all measurements where the dependent variable exceeds a specified value, is less than a specified value, or between two specified values.

Plot combinations of the above selection criteria as follows:

1. Combinations of (1) and (3).
2. Combinations of (1) and (4).
3. Combinations of (2) and (3).
4. Combinations of (2) and (4).

Other combinations of plotting criteria are not recommended.

For each of the above selection criteria and combinations, the user should be allowed to select various types of measurements, namely selected control conditions and measurement method.

7.7.8.2 Selection of Independent Variable

Gage height is used as the independent variable for most of the rating curve types, such as gage height and discharge, or gage height and area. For these rating types, the selection of *inside* or *outside* gage height becomes an important consideration for rating curve plots. It is common practice that both an inside gage reading and an outside gage reading will be measured. Frequently, these readings are identical, and either gage height can be used. However, the inside and outside gages do not read the same at some stations, sometimes by small amounts of only .01 or .02 ft, but in other cases where drawdown is present the difference could be large.

The electronic processing system should, by default, select the *inside* gage height for those ratings that use gage height as the independent variable. The user should have the option to change the default to *outside* gage height, if desired. Rating curve plots clearly should label the gage-height scale as "Inside Gage Height" or "Outside Gage Height," whichever is applicable.

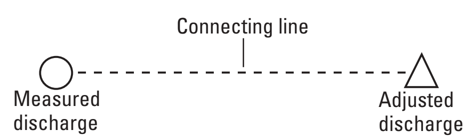
The electronic processing system should not allow a mixture of inside and outside gage heights to be plotted on the same rating curve plot. Such a practice could lead to confusion and improper rating analysis.

Only two rating types use independent variables other than gage height (or elevation). For velocity stations, the rating of index velocity and mean velocity uses the mean index velocity during the period of time of the discharge measurement. For slope stations, the rating of fall ratio and discharge ratio uses the computed value of the fall ratio at the time of the discharge measurement as the independent variable.

7.7.8.3 Selection of Dependent Variable

The dependent variable is selected according to the type of rating being plotted, as indicated in table 13. The dependent variable for each rating type is given below.

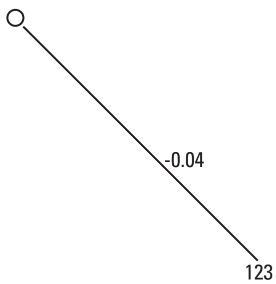
- Stage-discharge rating—Discharge is the dependent variable and should be plotted for all discharge measurements. For discharge measurements where a measured discharge and an adjusted discharge are entered in the discharge measurement file, they both should be plotted, but with different symbols. A connecting line between the measured discharge and the adjusted discharge, as indicated below, should be shown on the rating to indicate that the two discharges are for the same measurement.



- Stage-area rating—The area measured at the standard cross section is the dependent variable.
- Index velocity-mean velocity rating—The mean velocity in the standard cross section at the time of the discharge measurement is the dependent variable.
- Stage-velocity factor rating—The mean velocity adjustment factor is the dependent variable.
- Stage-fall rating—The mean fall between the base gage and the auxiliary gage at the time of the discharge measurement is the dependent variable.
- Fall ratio-discharge ratio rating—The computed discharge ratio, Q_m/Q_r, at the time of the discharge measurement is the dependent variable.
- *S*tage-1/USc rating—The flood wave factor, $1/US_c$, is the dependent variable.
- Elevation-contents rating—The reservoir contents is the dependent variable.

7.7.8.4 Identification of Measurements on Rating-Curve Plots

Each measurement plotted on a rating curve should be identified by measurement number. The identification method should conform to the traditional USGS method used for paper plots, where the measurement point is shown as a small circle, a 45 degree line, 1-in long, is drawn from the measurement point, and the measurement number is shown at the end of the line. For some discharge measurements, an optional feature should allow the user to show the rate of change in stage, in feet per hour, on the measurement line. The following sketch illustrates these concepts.



7.7.8.5 Other Rating-Curve Plot Information

The rating curve plot should include information that identifies the gaging station by number and name, the rating type, the period of use for each rating plotted, the selection criteria of the plotted measurements, the date of rating development and approval for each plotted rating, the name of the user responsible for developing each plotted rating, and the name of the person approving each rating. Each rating shown on the plot should be clearly identified by rating number. Scales should be labeled with the correct parameter name, and the units of measurement for the parameter.

The rating plot sheet should contain a disclaimer statement that alerts the user that direct application of the rating may lead to errors if undefined shifts and/or backwater occur. The wording of the disclaimer statement should be designed to fit the specific gaging station and the type of rating. A typical statement for a stage-discharge rating is

> "This rating curve is applicable only for stream conditions unaffected by backwater, ice, debris, scour, and other undefined changes to the control."

7.8 Rating Curve Development Procedures

Rating curves traditionally have been developed by hand plotting of measurements and manually drawing curves of best fit. Complex ratings, such as slope ratings and velocity-index ratings, have been developed through a combination of hand calculations and plotting methods. All of these methods are time-consuming and tedious. The computer development methods that can assist the user in rating curve shaping and definition are given in Sections 7.8.1 through 7.8.4.

7.8.1 Stage-Discharge Ratings

Stage-discharge ratings are graphical relations between stream stage and stream discharge. These ratings can be developed within the electronic processing system using the plotting and curve drawing functions described in section 7.7. However, the user should use care in ensuring that the ratings are hydraulically correct. The electronic processing system can be used in providing computations that aid in the correct hydraulic shaping of the rating curves. Three such methods, section control, channel control, and step-backwater, are described in sections 7.8.1.1 through 7.8.1.3.

7.8.1.1 Section Control Methods

Rating segments that are controlled by a specific cross section of the stream, such as a sand bar, rock outcropping, manmade weir, or other stream feature, can be approximated by flow computations based on a surveyed cross section of the control and the weir equation. The input of cross-section data and the computation of cross-section properties are given in Section 6.4.

Flow computations can be made for the section control by using the cross-section properties, a coefficient of discharge, C, and the weir equation. For purposes of defining the theoretical rating shape (not exact rating position), the method defined here is simplified and some of the more detailed intricacies of weir computations are not accounted for in the method.

The general form for the weir equation to be used for section control computations is as follows:

$$Q = CLh^{1.5}, \tag{25}$$

where

Q = discharge, in cubic feet per second,
C = the discharge coefficient,
L = the top width, in feet, of the water surface at the control section and for the gage height of interest, and
h = the head, in feet, (difference between the gage height and lowest point of the control section).

The discharge coefficient, C, used in the weir equation may be input directly by the user at the time the cross-section data are entered. A value of C should be required for the lower limit of gage height for the computations and for the upper limit of computations. Optionally, C- values may be specified for intermediate gage heights. The electronic processing system should use linear interpolation, based on gage height, for intermediate values of C.

For control sections where C is not known, the user may choose to obtain estimates of the C values computed from discharge measurement data. The electronic processing system should allow the user to designate specific discharge measurements for which a C value would be computed, based on the gage height and discharge of the measurement, the cross section, and the weir equation. The computation of C would be based on the weir equation

$$C = \frac{Q}{Lh^{1.5}} \tag{26}$$

The electronic processing system should display the computed values of C in tabular format for each of the discharge measurements. The user can use this information to choose values of C to input as described above. The electronic processing system should allow the user the option to plot gage height and C, and draw a smooth curve of relation. This curve could be used for defining C for the range of theoretical rating curve computations.

The range of theoretical computations for a given cross section should be specified by defining the lower and upper limit gage height. Intermediate computations should be spaced at 0.1 intervals of gage height. The theoretical rating curve should be plotted on the rating curve plot, and clearly identified as theoretical.

7.8.1.2 Channel Control Methods

Rating curve segments that are controlled by channel conditions such as cross-section area, channel slope, channel shape, and roughness of the bed and banks, can be defined by theoretical computations using the Manning equation and a typical cross section near the gage. Such computations can define the correct hydraulic shape of the rating, but not necessarily the correct position of the rating. Computations of this type have been historically referred to as the *conveyance-slope* method as described by Rantz and others (1982).

The Manning equation is

$$Q = \frac{1.486}{n} A R^{2/3} S^{1/2}, \tag{27}$$

where

Q = discharge, in cubic feet per second,
n = the Manning roughness coefficient,
A = the cross-section area, in square feet,
R = the hydraulic radius, in feet, computed as the area, A, divided by the wetted perimeter of the cross section, and
S = the energy slope, in feet/feet.

The first part of the equation, consisting of the n, A, and R terms, commonly is referred to as channel conveyance, K, and can be computed from the channel cross section and visual estimates of the roughness coefficient, n. The equation for conveyance, K, is

$$K = \frac{1.486}{n} A R^{2/3}. \tag{28}$$

Some cross sections may be subdivided into two or more subsections because of channel shape and (or) roughness variability. For such cross sections, the conveyance, K, should be computed for each subsection, and a total conveyance, K determined as a summation of the individual subsection K's. Points of subdivision are defined at the time the channel cross-section data are entered.

The energy slope, S, can be estimated from various sources such as topographic maps and highwater marks. It also can be computed from the Manning equation, the surveyed cross section, and discharge measurements. The equation for computing slope, when the discharge is known, is

$$S = [Q/K]^2 \tag{29}$$

The electronic processing system should allow the user to designate specific discharge measurements for which slope, S, is computed. These computed values of S should be displayed in tabular format, from which the user can choose values to input at the lower and upper limits of the conveyance-slope computations. The electronic processing system should use linear interpolation to determine intermediate values of slope.

The electronic processing system should provide an option for the user to plot the computed values of slope and gage height so that a curve of relation can be drawn. This curve then would be used to determine values of S for the conveyance-slope computations.

The range of theoretical computations for a given cross section using the conveyance-slope method should be specified by defining the lower and upper limit gage height. Intermediate computations should be spaced at 0.5 ft intervals of gage height, by default. The user should be allowed to specify other intervals if desired. The theoretical rating curve should be plotted on the rating curve plot, and clearly identified as theoretical.

7.8.1.3 Step-Backwater Method

Step-backwater is a water-surface profile computation method that requires a minimum of two cross sections, but generally four or more cross sections are required to produce accurate results. The details of the method are described by Shearman (1990) and will not be discussed in this report. It is an excellent method to define the shape, and position of the rating curve, and sometimes is used instead of discharge measurements when they are difficult to obtain. Cross-section data and other information necessary for step-backwater computation are entered in the step-backwater program.

The step-backwater method computes water-surface elevations at each cross section in the stream reach downstream from the gage. The computation depends on a given discharge in the reach and on an assumed water-surface elevation at the downstream end of the reach. Two or more downstream elevations are used to verify that the results at the gage will define a unique stage-discharge relation. The electronic processing system should provide an option to plot the profiles of water-surface elevations for the various starting elevations for each selected discharge. This type of plot is referred to as a convergence plot that is useful in evaluating the accuracy of the step-backwater results.

The electronic processing system should have a direct link to the step-backwater software so that results can be transferred easily to the rating analysis for a gaging station. Generally, a series of discharges is selected and for each discharge in the series the step-backwater method will compute a gage height at each cross section used in the computations. The parameters that are required to be transferred are the discharges and the corresponding computed gage heights for the cross section at the gage. Each transferred pair (gage height at the gage and corresponding discharge) should be plotted on the rating curve and identified as a step-backwater computation.

The step-backwater program also computes the water-surface elevation for critical depth of flow for each discharge at each cross section. The user should have the option to select a cross section and plot the critical water-surface elevation (gage height) computed for that section, and the corresponding discharge on the rating plot. This is an additional method to define the shape of a rating where section control is effective.

7.8.2 Slope Ratings

Slope ratings are used for stations with channel controls where variable stream slope downstream from the base gage affects the position of the stage-discharge relation. Variable stream slope usually is caused by a downstream condition, such as a reservoir, tributary stream, or overbank storage. In reality, the term “slope rating” is a misnomer, because these ratings do not use actual stream slope as a rating parameter. Instead, an index of stream slope is used, which usually is the water-surface fall measured between the base gage and an auxiliary gage downstream from the base gage. For some slope stations, the auxiliary gage may be located upstream from the base gage, but a better index of stream slope can be obtained if the auxiliary gage is located downstream from the base gage.

The rating method for slope stations involves a complex relation of three separate rating curves, (1) stage-discharge, (2) stage-fall, and (3) fall ratio-discharge ratio. These ratings are described in section 7.1, and a detailed description of slope ratings can be found in Kennedy (1984) and Rantz and others (1982). Slope ratings usually are classified into three specific types: (1) unit fall ratings, (2) constant fall ratings, and (3) limiting fall ratings. Although these different fall ratings are treated separately in the literature, they can be treated as one rating for computational purposes. This treatment is accomplished by defining the stage-fall rating to fit the specific fall rating type. For instance, if a unit fall rating is desired, then the fall rating is defined so that fall equals 1 ft for all gage heights. If a constant fall rating is desired, for a fall other than unity, then the fall rating is defined so that the desired constant fall is computed for all gage heights. Finally, if a limiting fall rating is desired, then the stage-fall rating is defined so that a variable fall is computed, which is dependent on gage height.

The development of slope ratings must be defined empirically, using discharge measurements, simultaneous measurements of fall, and a trial-and-error method to position and shape the individual rating curves. This procedure traditionally has been done by hand plotting and hand computing methods, a slow and tedious process. The electronic processing system should provide an interactive process, whereby the user makes the decisions regarding the curve positions and shape, and the system makes the routine computations and plots.

7.8.3 Index Velocity Ratings

Index velocity ratings, like slope ratings, can be used for gaging stations where variable backwater precludes the use of a stage-discharge rating. For index velocity stations, some method of recording a point or line velocity is required. This recording normally is accomplished with separate gages, such as vane gages, electromagnetic gages, or acoustic gages.

A stage-discharge rating is not used at gaging stations where index-velocity ratings are used. Instead, ratings are developed for index velocity and mean stream velocity, gage height and cross-section area, and gage height and velocity factor (optional). Each of these ratings are developed for a standard cross section of the stream. Development of the ratings is fairly straight forward, but may require some amount of trial- and -error fitting, especially if the stage and velocity-factor rating is used. The electronic processing system should provide an interactive process that allows the user to fit and test the ratings so that the best combination of ratings can be attained.

The methods described here for index velocity ratings refer to a single channel rating situation. However, these methods can be used where the stream is subdivided into two or more subsections, either horizontally or vertically. In such cases, each subsection has its own set of ratings, and is computed separately. The total discharge is the sum of the subsection discharges.

7.8.4 Rate-of-Change-in-Stage Ratings

Rate-of-change-in-stage ratings sometimes are used at gaging stations where changing discharge causes a variable stream slope. These ratings are used for stations with a condition frequently referred to as loop ratings. The Boyer method in Water Supply Paper 2175 (Rantz and others, 1982) usually is used to determine the rating at a station with this condition. This method requires two ratings: (1) a stage-discharge rating, and (2) a stage-1/US_c rating. An empirical, trial-and-error method, is used to develop these ratings, and requires a number of discharge measurements. Like other complex ratings, this rating traditionally has been done using hand computations and hand-plotting methods. The electronic processing system should provide an interactive method so the user can quickly and easily develop a Boyer rating. The user should be allowed to fit and test trial ratings until the best combination is attained.

8. Shift Adjustments

Shifts are gage-height adjustments used to account for temporary changes to rating curves, without having to re-define the rating curve. The method for computing shift information for the various types of discharge measurements is described in Section 6.1.4, *Shift Analysis*. For surface-water computations, shift adjustments are added to unit values of the input parameter to yield temporary unit values that are applied to the rating curve for computation of the output dependent variable. The algebraic sign of the shift must be maintained correctly, as defined in section 6.1.4. When measurements plot above a rating curve, that is, when the actual gage height for a given discharge is higher than indicated by the rating curve, the sign of the shift is negative. When measurements plot below a rating curve, the sign of the shift is positive. Also, it is important to note that a shift is a temporary correction, used only for computational purposes. It does not permanently alter the input unit value.

Although most shifts will apply to stage-discharge ratings, they also may be defined and applied to the index velocity and mean velocity rating for index-velocity stations. Shifts should not be allowed for any other types of rating curves except stage-discharge ratings and index velocity and mean velocity ratings. Because shifts are predominantly used for stage-discharge ratings, the shift discussions in this section will relate to that type of rating.

Shifts usually are applied only when discharge measurements deviate from a rating curve by more than a specified percentage. The specified percentage frequently is based on the accuracy of discharge measurements that can be made at the gaging station. For instance, if discharge measurements can be made with 5 percent or better accuracy, then shifts will be used only when measurements deviate more than 5 percent from the rating. Otherwise, if more than 2 or 3 consecutive discharge measurements consistently plot on one side of the rating a shift curve may be used for these measurements even though they are within the specified shift percentage. See the following section (Shift Curves) for methods for defining shift curves.

8.1 Shift Curves

Shift-variation diagrams (a plot of gage height and shift, and commonly known as V-diagrams) that have been used in previous computing systems, such as in the Water Data Storage and Retrieval System, WATSTORE, (Hutchinson and others, 1977), or the Automated Data Processing System, ADAPS, (Dempster, 1990), should not be considered the primary method of defining and applying shifts. Shift curves, as defined here, become the primary method of defining and applying shifts. Shift-variation diagrams and tables are not eliminated from the system, but used more for an evaluative tool as described in subsequent sections.

A *shift curve* is defined as a shifted-rating curve, and has all of the basic characteristics of a rating curve. A few common characteristics of shift curves are

- Shift curves have the same independent and dependent variables as the parent rating curve.The *parent rating curve* is defined as the original, primary rating curve that is being shifted.
- Shift curves should have the same basic shape as the parent rating curve.
- The algebraic difference between independent variables of a parent rating curve and a shift curve, for any given dependent variable, is defined as the shift that applies to the independent variable of the shift curve. For application purposes, shift curves should be translated with the electronic processing system into temporary adjustments (shifts) of unit values of gage height used to compute unit values of discharge.
- Shift curves defined for a given control segment (for example, section control) of the rating usually apply only to that segment of the rating. For example, a shift curve defined for a low-water section control should be merged with the parent rating at or near the transition to a channel control segment of the rating, unless discharge measurements or other information show otherwise.
- Shift curves may be time-interpolated as described in section 8.4.4.

8.1.1 Input of Shift Curves

Shift curves should be an integral part of rating curves, and may be defined graphically or by tabular input, using as a guide, a screen displayed plot of the current rating curve, the last used shift curve, and selected discharge measurements. The electronic processing system should allow the user to draw and shape a shift curve on the screen in a similar manner to drawing and shaping rating curves on the screen. The current, or parent, rating curve should be displayed, by default, at the time shift curves are defined. However, the user should be allowed to display any other defined rating curve or previously used shift curves, simultaneously or individually.

8.1.2 Shift Curve Tables and Diagrams

For each shift curve defined graphically, a summary table of the independent variable (usually gage height) and corresponding shift should be produced automatically with the electronic processing system. The user may choose to enter shifts in the table prior to defining a shift curve graphically. Therefore, the tabular entries automatically should be displayed as a shift curve on the rating plot. This table will aid the user in defining and smoothing the shift curve. The table should begin with the lowest gage height of the shift curve and end with the highest gage height of the shift curve. The tabular listing should include all points along the shift curve that were specified by the user during the process of defining the shift curve.

A plot of gage height and shift, or shift-variation diagram, for all points in the shift curve table should be an option. This diagram should not be considered the basic method of defining a shift curve, but it can be useful in evaluating the shift definitions and applications.

The shift curve table and diagram should be displayed simultaneously with the shift and rating curve plot. The table and diagram should be linked directly to the shift curve plot, so that a graphical change made to the plotted curve automatically would be reflected in the table and diagram. Likewise, a change made in the table automatically should be reflected in the plotted curve. A typical shift curve plot, shift diagram, and shift curve table are illustrated in figure 7.

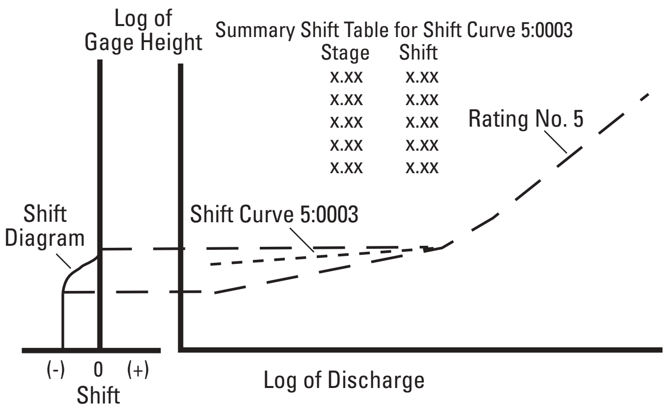


Figure 7. Typical rating curve, shift curve, shift table, and optional shift diagram.

8.1.3 Period of Use for Shift Curves

Each shift curve must be given a starting date and time. An ending date and time may or may not be required, depending on how the shift curve is to be applied. When both starting and ending dates, and times are given for a specific shift curve, then that shift curve will be applied directly throughout the defined period of time.

If an ending date and time for a specified shift curve is not given, then that shift curve will be time-interpolated to the succeeding shift curve, if one is given. If a succeeding shift curve is not given, then the last specified shift curve will be used directly until it is terminated either with an ending date and time, or with a succeeding shift curve. Additional details on time-interpolation of shift curves are given in section 8.4.

8.1.4 Extrapolation of Shift Curves

Shift curves should be extrapolated parallel to the parent rating curve below their lowest defined gage height and above their highest defined gage height. For example, if the shift curve is 0.20 ft above the parent rating curve at the highest defined gage height of the shift curve, then a constant shift of 0.20 ft should be used for all gage heights greater than the highest defined gage height of the shift curve. Likewise, a shift equal to the shift for the lowest defined gage height should be used for all gage heights below the lowest defined gage height. The electronic processing system automatically should make these extrapolations when they are needed for computing a discharge record. It should distinguish the extrapolated part of a shift curve on the shift curve plot with a dashed line.

8.2 Shift Curve Numbering

Each defined shift curve should be numbered automatically with the electronic processing system. Numbers should be referenced to the rating curve for which the shift curve applies. A two part number is recommended, with the first part being the rating curve number, and the second part a sequential shift curve number that is determined in the order that the shifts curves are defined. Shift curves should retain its number once assigned, and not be renumbered. The two parts of the shift curve number should be separated by a colon (:). Following are two examples of shift curve numbers.

1. The second shift curve defined for rating number 5 would be numbered *5:0002*.
2. The third shift curve defined for rating number 12b.2 would be numbered *12b.2:0003*.

8.3 Shift Curve Error Analysis

An error analysis should be performed with the electronic processing system for each discharge measurement to show the effects of shifting or not shifting. In effect, this analysis is an extension of the computations described in section 6.1.4 (Shift Analysis). The error analysis should show the optimum shift and the percent difference of the discharge measurement without shifting, as described in section 6.1.4. Also, the analysis should show the percent difference between the measured discharge and the discharge computed by using the optimum shift. In addition, it should show the shift actually applied at the exact date and time of the discharge measurement based on the defined shift curve and the interpolation method, if used. It also should show the percent difference between the measured discharge and the discharge computed on the basis of the applied shift. The shift analysis also should show the range of uncertainty for each discharge measurement, based on the assigned accuracy of the measurements. This range of uncertainty is referred to as the *uncertainty bars* for a measurement.

The electronic processing system should produce a table of discharge measurements showing the results of the error analysis and identifying information about each discharge measurement, such as measurement number, date, gage height, measured discharge, and measurement accuracy. The table normally should cover the period of time for a water year[1], and

[1]The water year is the period of time from October 1 through the following September 30.

include the last measurement of the previous water year, and the first measurement of the subsequent water year. It also can cover a period of time defined by the user. An example of a table of this type is shown in figure 8.

8.4 Shift Curve Application

Shifts are applied to all unit values of gage height (or other input parameter) on the basis of defined shift curves, as described in sections 8.4.1 through 8.4.4. These methods can be used for constant shifts, time interpolation of shifts, stage interpolation, and a combination of time and stage interpolation.

8.4.1 Individual Shift Curves

An individual shift curve can be used when it is desired to apply a constant shift, or a shift varied with stage for a period of time without varying the shift curve. The individual shift curve can be applied to a specified period of time by defining the starting date and time, and the ending date and time. If an ending date and time are not defined, then the shift curve will be used indefinitely until such time as an ending date and time are defined.

A constant shift that does not vary with stage or time can be accomplished by defining an individual shift curve with a single point. When a single point on a shift curve is used to define that shift curve, the shift will automatically be extrapolated below and above the specified gage height using the same shift entered for the specified gage height. This sometimes is referred to as a shift curve parallel to the rating curve. It is considered parallel because the shift is constant throughout the range of application.

An individual shift curve also can be used to apply shifts that are varied by stage only (not varied by time). This method defines an individual shift curve drawn so that it will have different shifts at different gage heights. This is a shift curve that is not parallel to the rating curve.

8.4.2 Multiple Shift Curves

Two or more shift curves can be used in combination to apply shifts to unit values so that the shifts are varied either by time only, or by both stage and time. Varying the shift in this way is accomplished by defining a shift curve and assigning it a starting date and time, but no ending date and time. A second shift curve is defined with a subsequent starting date and time. If the two shift curves are defined so that each one has a different constant shift (not varied with stage), then the electronic processing system will interpolate between these two shifts based on time only. This procedure commonly is referred to as time interpolation of shifts.

If two consecutive shift curves are entered so that one or both of them have shifts that vary by stage, then the electronic processing system will interpolate shifts based on both stage and time for all unit values between the two assigned shift curves. The interpolation method is described in section 8.4.4.

Two or more consecutive shift curves entered with starting dates and times only (no ending dates and times) will be interpolated for intermediate dates and times. In this manner, the user can vary shifts by stage and time, or time only, from one shift curve to another, and even between a shift curve and the base rating.

8.4.3 Additive Shift Curves

The electronic processing system should not allow two or more shift curves to be added. If overlapping dates and times are entered for two shift curves, the electronic processing system should issue a warning message to this effect, and require that corrections be made.

Measurement						Rating Shift Analysis					Uncertainty Bars					Applied Shift		
						Optimum Shift			Without Shift		Low		Optimum Shift	High				
Number	Date	Stage	Discharge	RTD	PCT UNC (+/-)	Shift	Discharge	% Diff	Discharge	% Diff	Shift	Discharge		Shift	Discharge	Shift	Discharge	% Diff
213	09/15/1992	2.18	115.0	P	10.0	-0.03	116.1	-0.9	123.3	-6.7	-0.08	103.5	-0.03	0.01	126.5	-0.02	118.1	-2.6
214	10/01/1992	2.40	178.0	F	8.0	-0.01	177.5	0.3	180.2	-1.2	-0.06	163.8	-0.01	0.04	192.2	-0.01	177.5	0.3
215	11/02/1992	1.91	60.40	F	8.0	-0.03	60.94	-0.9	65.84	-8.3	-0.06	55.57	-0.03	0.00	65.23	-0.01	63.80	3.1
216	03/23/1993	1.63	24.60	F	8.0	-0.01	25.10	-2.0	26.15	-5.9	-0.03	22.63	-0.01	0.00	26.57	-0.01	25.10	-2.09
217	04/29/1993	2.08	93.50	F	8.0	-0.03	92.95	0.6	99.72	-6.2	-0.06	86.02	-0.03	0.01	101.0	-0.02	95.10	-1.7
218	05/18/1993	3.58	563.0	F	8.0	-0.04	561.2	0.3	576.7	-2.4	-0.15	518.0	-0.04	0.08	608.0	-0.04	561.2	0.3
219	06/29/1993	2.79	276.0	F	8.0	-0.06	276.9	-0.3	295.8	-6.7	-0.13	253.9	-0.06	0.01	298.1	-0.04	283.1	-2.5
220	08/11/1993	2.09	99.80	F	8.0	-0.01	99.72	0.1	102.0	-2.2	-0.05	91.82	-0.01	0.03	107.8	-0.01	99.72	0.1
221	10/22/1993	1.78	44.40	F	8.0	-0.01	44.24	0.4	45.79	-3.0	-0.03	40.85	-0.01	0.01	47.95	-0.01	44.24	0.4

Figure 8. Example of shift-analysis table [RTD, measurement rating; P, poor; F, fair; G, good; E, excellent; PCT UNC, percent uncertainty; %DIFF, percent difference].

8.4.4 Shift Interpolation Procedure

Shift curves are defined and numbered as a means of describing and tracking specific shifting characteristics at specific points in time. Each shift curve usually is based on one or more discharge measurement and other field observations that define a change in the position of the rating curve, and this change usually is considered a temporary change. To estimate shifts at other times, intermediate to the defined shift curves, a linear-interpolation procedure is used.

Individual shifts, and not entire shift curves, should be interpolated. That is, only those shifts needed to adjust unit values should be determined by interpolation, and not those outside the range of recorded unit values. Likewise, the interpolation process should be continuous in time, so that a shift interpolation is performed for each unit value to which shifts are to be applied.

The interpolation procedure is described in the following step-by-step example.

1. Two shift curves, 001 and 002, are defined graphically for use at dates and times, t_1 and t_2, respectively.
2. An interpolated shift, S_n, is required for unit value, G_n, at an intermediate date and time, t_n.
3. The electronic processing system computes the shifts, S_1 and S_2, corresponding to the unit value, G_n, from each of the shift curves, 001 and 002, respectively.
4. The electronic processing system performs an unweighted, linear time interpolation of shifts S_1 at time t_1, and S_2 at time t_2, to obtain the shift, S_n, at time t_n.
5. The same interpolation procedure is used to estimate shifts for all other unit values resulting between times, t_1 and t_2.

8.4.5 Rounding and Significant Figures

All computed shifts and interpolated shifts should be rounded to two significant figures to the right of the decimal (for example, all shifts should be rounded to hundredths). Rounding should be performed before any application process.

8.4.6 Unit Value Graphical Comparisons of Shifts

Shifts that are applied to a time series of unit values should be displayed with the electronic processing system in a graphical plot. The graphical comparison should show a time-series plot of the unit values of gage height (or other independent variable) and a superimposed plot of the unit values of shifts. Scales for the two plots should be used so that each plot is easily discernible and readable. The user should have the option to change either or both of the scales. An example plot is shown in figure 9.

8.4.7 Shift Curve Tracking Procedure

The electronic processing system should summarize each shift curve that was used for computing discharge records for a water year. This provides a record of shifting instructions, and it should be presented in tabular format so that the user can easily review all shift curves in chronological order. A new record of shifting should be started at the beginning of each water year, and it should include the last shift curve used in the previous water year as the first entry. Entries to the table should be made automatically each time a new shift curve is developed and put into use during the current water year. The table should include only defined information, not extrapolated parts of the shift curve. The table should be accessible at any time. It should include, at a minimum, the following items for each shift curve.

- Shift curve number
- Beginning date and time
- Ending date and time (if used)
- Minimum gage height
- Shift corresponding to minimum gage height
- Maximum gage height
- Shift corresponding to maximum gage height
- Name of user
- Date shift curve entered

9. Primary Computations

Primary computations are the functions that convert input data, such as gage height, velocity index, and other auxiliary data, into time series of unit values, daily values, monthly values, and annual values of discharge, mean velocity, reservoir contents, and other output parameters. The conversion process is dependent on the type of gaging station and, except for stage-only stations, always will require the use of at least one rating

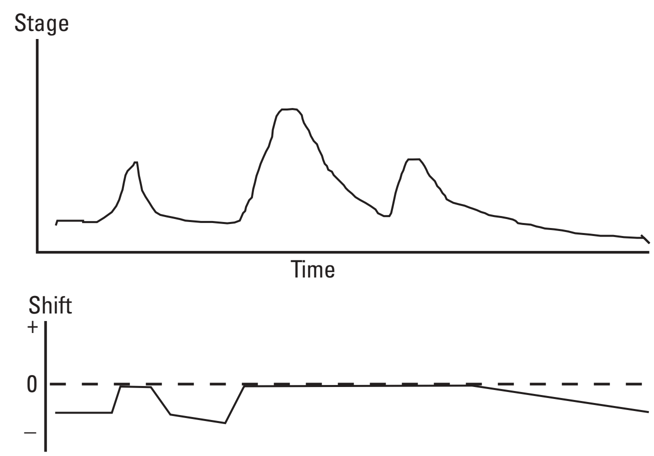


Figure 9. Example plot of time-stage and series shifts.

curve. To carry out the conversion process, previously developed data and information will be required, such as time series of input variables, correction diagrams, shift curves, and rating tables. The conversion should be carried out with minimal interaction from the user, and should produce files of information that can be used to produce tables and graphs that commonly are referred to as primary output.

9.1 Unit Value Computations

Unit value files of uncorrected input parameters, such as gage height and velocity index, are entered to the electronic processing system as described in section 4.1. Also, specific information such as parameter correction diagrams, shift curves, and rating curves are entered as described previously. The primary computations should produce additional unit values files of specific output parameters, dependent on the station type. These unit values and their associated time tags are saved for the purpose of computing daily mean values, various statistics, and for archiving. The unit values files that should be computed for each type of station are described in sections 9.1.1 and 9.1.9.

Most gaging stations use *gage height* as the input parameter, however, some stations use elevation above NGVD as the input parameter (for example, reservoir and tide stations). For some of these stations, the original data are recorded as gage heights above an arbitrary datum, and then converted to elevation as described in section 5.4.1.2. The computations in terms of either gage height or elevation, depending on the most common usage at each type of gage are described in sections 9.1.1 through 9.1.9.

Rating curves are used extensively in the conversion of input parameters to unit value files of output parameters. Occasionally, the range of the input parameter may exceed the range of the defined rating. In such cases, the electronic processing system should not automatically extrapolate the rating curve, but rather, should insert a flag at points in the unit values file where the rating is exceeded to alert the user. The user then may make necessary extrapolations, and perform a new primary computation to complete the files.

9.1.1 Stage-Only Stations

Stage-only stations are those stations where unit and daily mean values of gage height, and associated statistics, are required. For this type of station, only the unit values files of gage-height data and the gage-height correction information are needed. Primary computations should create the following unit values files. Unless otherwise noted, each unit value file should be saved for further use, and for archiving.

- *Gage-height corrections*—The electronic processing system should evaluate and compute the gage-height correction that corresponds to each input value of gage height. gage-height corrections include instrument errors, gage datum errors, and gage datum conversions (for example, conversion to NGVD), as described in section 5.4. The computations should use each correction and correction diagram, as defined by the user, and as described in section 5.4. The corrections and correction diagrams should be interpolated by time and stage, as required, and according to the interpolation procedure described in section 5.4.2.3. If two or more corrections or correction diagrams apply to the same time period, the gage-height correction should be determined from each one independently for each time step, and summed to produce the cumulative correction for each time step. All gage-height corrections should be rounded to standard gage-height precision (usually hundredths of a foot, unless specified otherwise) before using them in further calculations. The resulting time series of cumulative gage-height correction values should be saved as a working file, and for later archiving.
- *Corrected gage heights*—A unit values file of corrected gage heights should be computed by adding the cumulative gage-height correction (see above) to the input unit values of gage height for each time step. This file of corrected gage heights is considered the final, and most accurate, gage-height record for the gaging station. The file also should be saved for further computations, and for archiving.

9.1.2 Stage-Discharge Stations

Stage-discharge stations are those stations where unit and daily values of discharge are computed, based on unit values of gage height and a stage-discharge rating curve. This station is the most common type of gaging station, and requires unit values files of gage height and information defining gage-height corrections and shift adjustments. Unless otherwise noted, each unit value file should be saved for further use, and for archiving.

- *Gage-height corrections*—A file of unit values of cumulative gage-height corrections should be computed and saved for each unit value of gage height, as described for stage-only stations in section 9.1.1.
- *Corrected Gage Heights*—A file of unit values of corrected gage heights should be computed and saved, as described for stage-only stations in section 9.1.1.
- *Shift Adjustments*—Unit values of shifts should be computed for each unit value of corrected gage height. These shifts should be based on the shift curves defined by the user, and for the applicable time period. Interpolation of shifts by time and stage should be performed with the electronic processing system, according to the method described in section 8.4.4. All unit values of shifts should be rounded to standard gage-height precision, usually hundredths of a foot, before using them in further computations. The computed unit value shifts

for each gage height and time step should be saved in a unit values file for further use, and for archiving.

- *Discharge*—Unit values of discharge should be computed by temporarily adding the shift adjustment to the corrected gage height for each time step. The corrected and shifted gage height then should be used to determine the corresponding discharge from the applicable rating curve. The shift-adjusted gage height is a working value only, and should not permanently alter the gage height. It is not required that the shift-adjusted gage heights be saved. The computed unit values of discharge, however, should be saved for later use, and for archiving.

For the low end of the rating, and if the rating is defined to zero discharge, all shift-adjusted gage heights that are lower than the gage height of zero flow will be assigned a unit value discharge of zero. If the rating is not defined to zero flow, and a shift adjusted gage height is below the lowest gage height of the rating, a flag should be set indicating the rating was exceeded on the low end. Rating extrapolations can be made by the user at a later point in the processing.

9.1.3 Velocity Index Stations

Velocity index stations are those stations where unit values of discharge are computed on the basis of unit values of gage height, cross-section area, an index velocity, mean stream velocity, and a velocity adjustment factor (optional). At least two rating curves are required, (1) a stage-area rating, and (2) an index velocity and mean stream velocity rating. A third rating sometimes is used, relating stage to a velocity adjustment factor. Information defining gage-height corrections, index-velocity corrections, and index-velocity shift adjustments also are required.

Two unit value input files are used for velocity index stations, (1) an input file of unit values of gage height, and (2) an input file of unit values of index velocity. For various reasons, these files may not have corresponding and simultaneous time steps, which is required for the unit value computations of discharge. If the time steps for the two files do not correspond, the electronic processing system should automatically interpolate each file to provide estimated unit values corresponding to all recorded times of both files. That is, the gage-height file should be interpolated so that an estimated gage height is available for all time steps of the index velocity file, and conversely, the index velocity file should be interpolated so that an index velocity is available for all time steps of the gage-height file. Therefore, this method doubles the size of each of the input unit values files. The electronic processing system should flag, save, and archive all estimated unit values, together with the recorded unit values.

Unit value files should be computed with the electronic processing system for the following parameters. Unless otherwise noted, each unit value file should be saved for further use, and for archiving.

- *Gage-height Correction*—A file of unit values of cumulative gage-height corrections should be computed and saved for each unit value of gage height (including estimated values), as described for stage-only stations in section 9.1.1.
- *Corrected Gage Heights*—A file of unit values of corrected gage heights should be computed by adding the gage-height corrections to the corresponding unit values of gage heights.
- *Velocity Adjustment Factor*—If a rating of gage height and velocity adjustment factor is used for the gaging station, a velocity adjustment factor should be computed from that rating for each unit value of corrected gage height. Shift adjustments are not applied to gage height for use with the velocity adjustment factor rating. If a velocity factor rating is not used for the station, then the velocity adjustment factor of 1.00 is used for all gage heights. Velocity adjustment factors should be rounded to two decimal places for application purposes.
- *Cross-Section Area*—The cross-sectional area should be computed for each unit value of gage height, using the stage-area rating.
- *Index Velocity Correction*—Correction values should be computed for each input value of index velocity (including estimated values), based on the index velocity correction value diagrams, and the methods of interpolation described in section 5.4. All index velocity correction values should be rounded to standard velocity precision, usually hundredths of a foot per second.
- *Corrected Index Velocity*—Each input value of index velocity should be corrected by adding the index velocity correction value to the corresponding value of the input index velocity.
- *Index Velocity Shifts*—Shifts for each value of the corrected index velocity should be computed based on the velocity shift curves, and the interpolation procedure described in section 8.4. All velocity shifts should be rounded to standard velocity precision, usually hundredths of a foot per second, before applying to further computations.
- *Mean Rating Velocity*—The mean rating velocity should be computed for each shift adjusted value of the corrected index velocity by using the rating of index velocity and mean velocity.
- *Mean Stream Velocity*—The mean stream velocity should be computed for each time step by multiplying the mean rating velocity times the velocity adjustment factor.
- *Discharge*—The unit values of discharge should be computed by multiplying each unit value of cross-sectional area times the corresponding value of mean stream velocity.

For some velocity index stations, two or more horizontal subsections may be present, each of which has its own set of unit values. For these stations, unit values files are computed for each subsection as described above. Unit values of the total discharge for the stream for each time step is computed as a summation of the corresponding unit values of the subsection discharges. If time steps for the subsections do not correspond, interpolation of unit values will be required.

For streams where two or more index velocity meters are positioned to measure velocity at different vertical positions, a velocity averaging procedure should be used to compute an average index velocity for the stream. Various averaging procedures are possible, depending on the gage configuration and the number of index velocity gages that are used. The electronic processing system should provide for user-defined equations to compute average index velocity. The ratings for such a station are based on the average index velocity. All other aspects of computing unit values of discharge for the stream are the same as described above.

9.1.4 Slope Stations

Slope stations are those stations where discharge is computed on the basis of a stage-discharge relation that is adjusted for variable water-surface slope. Water-surface slope cannot be measured directly, so the water-surface fall between the base gage and an auxiliary gage is used as an indicator of slope. The auxiliary gage preferably is located downstream from the base gage, at a distance that provides a measurable fall but does not introduce hydraulically appreciable channel changes or tributary inflow. For some sites, the auxiliary gage may be located upstream, but this is not advised because the water-surface slope in the upstream reach is not as representative of backwater conditions as it is in the downstream reach.

Computation of discharge at a slope station requires unit values of gage height at the base gage and the auxiliary gage. Three ratings are required: (1) stage-discharge, (2) stage-fall, and (3) fall ratio and discharge ratio. Information defining gage-height corrections for the base gage and the auxiliary gage, and shift adjustments for the base gage, also are required.

Timing accuracy of unit-value data is very important at each gage, because water-surface fall computations require that time synchronous stage data be available for the base gage and the auxiliary gage. Even with the best timers and time-correction methods, it is not always possible to obtain this kind of accuracy, and stage data will sometimes be recorded and/or time corrected to different time steps for the two gages. For such situations, the stage data for the base gage should be interpolated so that estimated stage values are available for each corresponding stage value at the auxiliary gage. Likewise, the stage data at the auxiliary gage should be interpolated so that estimated stage values are available for each corresponding stage value at the base gage. This procedure effectively doubles the number of stage values at each gage, half of which are measured values, and half are estimated values. The electronic processing system should flag, save, and archive all estimated unit values, together with the recorded unit values.

Computations of discharge using the slope method are subject to constraints that should be checked and applied for each unit value computation. These constraints are listed below.

1. Slope ratings should not be used if the measured fall values are negative. In these cases, discharges should not be computed and the electronic processing system should issue a warning that negative fall values have been encountered.
2. Slope affected ratings may apply throughout the range in stage measured at a station, or they may apply only for a specific range in stage. The user should be allowed to designate the lower and upper limits of the slope rating by entering a minimum gage height and a maximum gage height, below and above which the slope rating procedures should not be used. Discharge should be computed directly from the stage-discharge rating for gage heights that are outside these limits.
3. Slope ratings may, in some situations, have maximum fall constraints. That is, for measured fall values exceeding a designated amount, or for measured fall exceeding the fall from the stage-fall rating, no slope adjustments should be applied. The user should be allowed to enter a maximum fall so that when measured falls exceed this value, slope adjustments will not be made. Likewise, the user should be allowed to designate that when measured fall exceeds the rating fall slope adjusted computations will not be made. For both of these situations, unit values of discharge should be computed by direct application of the stage-discharge rating.
4. For some slope stations, constraints 2 and 3 both may apply, and should be checked.

Unit value files should be computed with the electronic processing system for the following parameters, subject to the above constraints. Unless otherwise noted, each unit value file should be saved for further use and archiving.

- *Gage-height Corrections, Base Gage*—A file of unit values of cumulative gage-height corrections for the base gage should be computed and saved for each corresponding unit value of gage height (including estimated values), as described for stage-only stations in section 9.1.1.
- *Corrected Gage Heights, Base Gage*—A file of unit values of corrected gage heights for the base gage should be computed by adding the gage-height corrections for the base gage to the corresponding unit values of gage heights.
- *Gage-height Corrections, Auxiliary Gage*—A file of unit values of cumulative gage-height corrections for the auxiliary gage should be computed and saved for each corresponding unit value of gage height (including estimated values), as described for stage-only stations in section 9.1.1.

- *Corrected Gage Heights, Auxiliary Gage*—A file of unit values of corrected gage heights for the auxiliary gage should be computed by adding the gage-height corrections for the auxiliary gage to the corresponding unit values of gage heights.
- *Measured Water Surface Fall*—A file of unit values of measured water-surface fall should be computed by subtracting each unit value of gage height at the auxiliary gage from the corresponding gage height at the base gage. If the auxiliary gage is located upstream from the base gage, fall should be computed by subtracting the base gage height from the auxiliary gage height.
- *Shift Adjustments*—For slope stations, shift adjustments are used only for the stage-discharge rating for the base gage. A unit values file of shift adjustments should be computed for each base gage height, including estimated values, by using the defined shift curves and the time/stage interpolation procedures described in section 8.4. If shift curves are not applicable for specific time periods, shifts should default to zero for that time period.
- *Rating Discharge*—Unit values of rating discharge are computed for each unit value of shift adjusted gage height for the base gage, using the stage-discharge rating for the base gage. The rating discharge is an unadjusted discharge value, and does not represent the true discharge of the stream.
- *Rating Fall*—Unit values of rating fall are computed for each unit value of gage height (not shift adjusted) for the base gage, using the stage-fall rating for the base gage.
- *Fall Ratio*—Unit values of fall ratio are computed by dividing the measured water-surface fall by the rating fall.
- *Discharge Ratio*—Unit values of the discharge ratio are computed using the rating curve of fall ratio and discharge ratio.
- *Discharge*—Unit values of discharge are computed by multiplying the rating discharge times the discharge ratio. The resulting discharge represents the true discharge of the stream.

9.1.5 Rate-of-Change-in-Stage Stations

Rate-of-change-in-stage stations are those stations where discharge is computed on the basis of a stage-discharge relation that is adjusted for variable rates of change in stage. Computation of discharge is based on the Boyer Method and requires unit values of gage height. Two ratings are required, (1) a stage-discharge rating, and (2) a stage-1/US_c rating. Information defining gage-height corrections and shift adjustments also are required.

Computation of discharge using the Boyer Method is subject to constraints that should be checked and applied for each unit value computation. These constraints are as follows.

1. Rate-of-change-in-stage ratings apply only to high discharges where channel control conditions are effective. The user should be allowed to specify a minimum gage height and a maximum gage height, below and above which the rate-of-change-in-stage computations should not be applied. Discharge should be computed directly from the stage-discharge relation when the stage is outside these limits.
2. Rate-of-change-in-stage computations are frequently not made when the Boyer adjustment factor results in only a small change of the rating discharge. The electronic processing system should use default values of 0.96 to 1.04 as the range of Boyer adjustment factors for which adjustments would not be made.The user should be allowed to change these values, if necessary (for example, to achieve smoothness of the computed unit values of discharge).

Unit value files should be computed with the electronic processing system for the parameters listed below, subject to the above constraints. Unless otherwise noted, each unit value file should be saved for further use and archiving.

- *Gage-height Corrections*—A file of unit values of cumulative gage-height corrections should be computed and saved for each corresponding unit value of gage height, as described for stage-only stations in section 9.1.1.
- *Corrected Gage Heights*—A file of unit values of corrected gage heights should be computed by adding the gage-height corrections to the corresponding unit values of gage heights.
- *Rate of Change in Stage*—A rate-of-change in stage (dG/dt) should be computed for each unit value of corrected gage height that is within the range of gage heights defined by the minimum and maximum constraint. First, the difference in stage is computed by subtracting the *previous* unit value of corrected gage height from the next unit value of the corrected gage height. This difference in gage height is converted to the rate-of-change in stage, in feet per hour, by dividing it by the time difference of the *previous* and *next* unit values. This method of computation provides an average rate-of-change-in-stage for the time period extending one time interval before and one time interval after the current unit value of gage height. The algebraic sign of the computed rate-of-change-in-stage should be retained as computed. A positive sign indicates a rising stage, and a negative sign indicates a falling stage.
- *Shift Adjustment*—For rate-of-change-in-stage stations, shift adjustments are used only for the stage-discharge rating. A unit values file of shift adjustments should be computed for each corrected gage height by

using the defined shift curves and the time/stage interpolation procedures described in section 8.4. If shift curves are not applicable for specific time periods, shifts should default to zero for that time period.

- *Rating Discharge*—Unit values of rating discharge are computed for each unit value of shift adjusted gage height using the stage-discharge rating. The rating discharge is an unadjusted discharge value, and does not represent the true discharge of the stream for periods when rate-of-change adjustments are applicable.
- *Boyer Factor, $1/US_c$*—The Boyer Factor should be computed for each corrected gage height (not shift adjusted) that is within the range of gage heights defined by the minimum and maximum constraint, by application of the stage-$1/US_c$ rating.
- *Discharge Adjustment Factor*—Unit values of the discharge adjustment factor, F_{adj}, are computed based on the Boyer Factor and the rate-of-change-in-stage, by using the following equation. Discharge adjustment factors should be computed only for gage heights that are within the range of gage heights defined by the minimum and maximum constraint as

$$F_{adj} = \sqrt{1 + \left(\frac{1}{US_c}\right)\left(\frac{dG}{dt}\right)}. \qquad (30)$$

- *Discharge*—Unit values of discharge are computed by multiplying the rating discharge times the discharge adjustment factor. All unit values of discharge that are based on adjustment factors from 0.96 to 1.04, by default, should not be used unless overridden or otherwise specified by the user. Instead, the rating discharges based on the shift adjusted gage heights should be used directly.

9.1.6 Reservoir Stations

Reservoir stations are those stations where unit and daily values of reservoir elevation and reservoir contents are required. If only reservoir elevation is required, no rating is needed. However, if reservoir contents are required, then a rating of reservoir elevation and contents is needed. Input requires unit values of elevation and information defining elevation corrections. Generally, for reservoir stations, the term *elevation* is used rather than gage height because the elevation above National Geodetic Vertical Datum (NGVD) is used for many reservoir gages. However, gage heights are allowed and used at many reservoir stations. Unit values files should be computed with the electronic processing system for the parameters listed below. Unless otherwise noted, each unit value file should be saved for further use and archiving.

- *Elevation Correction*—A file of unit values of cumulative elevation corrections should be computed and saved for each corresponding unit value of elevation, as described for stage-only stations in section 9.1.1.
- *Corrected Elevations*—A file of unit values of corrected elevations should be computed by adding the elevation corrections to the corresponding unit values of elevations.
- *Reservoir Contents*—A file of unit values of reservoir contents should be computed by application of the corrected elevations to the elevation-contents rating.

9.1.7 Tide Stations

Tide stations are those stations located in estuaries and along tidal affected rivers and streams to provide the daily information on diurnal and/or semi-diurnal variations of surface-water levels in those areas. Tide stations may be set to an arbitrary datum or to an elevation based on the National Geodetic Vertical Datum (NGVD). When an arbitrary datum is used, unit values of elevation are determined by adding a constant datum conversion to the unit values of gage height. No other conversions to other parameters are required, therefore, no ratings are required. Information defining gage height or elevation corrections also is required. Each unit value file should be saved for further use and archiving.

- *Gage-Height or Elevation Correction*—A file of unit values of cumulative gage height or elevation corrections should be computed and saved for each corresponding unit value of gage height or elevation as described for stage-only stations in section 9.1.1. This correction value is separate from the datum-conversion value used to convert gage height to NGVD.
- *Corrected Gage Height or Elevation*—A file of unit values of corrected gage heights or elevations should be computed by adding the gage-height or elevation corrections to the unit values of gage heights or elevations.

9.1.8 Hydraulic Structure Stations

Hydraulic structure stations are those stations where unit and daily values of discharge are computed using special ratings and equations for spillways, gates, turbines, pumps, siphons, and other controlled conveyances. A special software program developed by C.L. Sanders, USGS, South Carolina District, (written communication, 1997) is available for this purpose. The basic theory and concepts are described by Collins (1977). Input data may include unit values of headwater gage heights, tailwater gage heights, individual gate openings for each gated conveyance, turbine pressures, lockages, and other variables as required for a specific site. Hydraulic structure gaging stations are extremely complex and may have many sub-units (individual gates, turbines, and others) for which unit values of discharge are computed. Unit values of total discharge are computed as a summation of the individual subunits. Because of the complexity and variability of hydraulic structure gages, a listing of unit values files will not be given here. However, the electronic processing system should save all unit values files for further use and archiving.

9.1.9 BRANCH Model Stations

A BRANCH model gaging station utilizes a calibrated digital computer model for simulating the unsteady flow in a channel reach, usually affected by variable backwater. The model calibration requires basic field data, principally cross-section definition at a number of locations in the gaged reach, roughness coefficients, calibration discharge measurements, and gage-height data at the upstream and downstream end of the gaged reach. Details of calibration and computation are given by Schaffrannek and others (1981). Primary computations require unit values of gage height at the upstream and downstream ends of the reach, as given below. Information defining gage-height corrections for the upstream and downstream gages is required.

- *Gage-height Corrections, Upstream Gage*—A file of unit values of cumulative gage-height corrections for the upstream gage should be computed and saved for each corresponding unit value of gage height (including estimated values), as described for stage-only stations in section 9.1.1.
- *Corrected Gage Heights, Upstream Gage*—A file of unit values of corrected gage heights for the upstream gage should be computed by adding the gage-height corrections for the upstream gage to the corresponding unit values of gage heights.
- *Gage-height Corrections, Downstream Gage*—A file of unit values of cumulative gage-height corrections for the downstream gage should be computed and saved for each corresponding unit value of gage height (including estimated values), as described for stage-only stations in section 9.1.1.
- *Corrected Gage Heights, Downstream Gage*—A file of unit values of corrected gage heights for the downstream gage should be computed by adding the gage-height corrections for the downstream gage to the corresponding unit values of gage heights.

BRANCH model gages have a unique characteristic, in that the parameters of gage height, mean stream velocity, and discharge are computed for each cross-section location, as well as at the upstream and downstream gage locations. For this reason, unit values of each of these parameters, for each cross section, can be saved for future use and archiving, if desired. The electronic processing system should allow the user to designate which output parameters, and for which cross sections and gage sites, should be saved for future use and archiving.

9.2 Daily Value Computations

Various kinds of daily values are computed for each station type, and are based on the unit values files described in section 9.1. Daily values for the various parameters consist of mean values, minimum instantaneous values, maximum instantaneous values, and instantaneous values at selected times. Daily values for a gaging station usually are computed for the local time zone designation, for the location of the gaging station. This computation includes the use of daylight savings time wherever applicable. However, the electronic processing system should allow computation of daily values for any other time zone, as selected by the user. For additional information on time zones, see sections 5.1 and 5.2.

The electronic processing system should allow the user to compute daily values for temporary use and study, without requiring that they be saved and archived. Such files of daily values could be used for review and comparisons before finalization of the records.

9.2.1 Daily Mean Values

Daily mean values, frequently referred to as daily values, consist of a time-weighted arithmetic mean of selected parameters, and are computed from the files of unit values. Daily mean values may be computed for the following parameters.

- Gage height
- Discharge
- Cross-section area (index velocity stations)
- Index velocity
- Mean stream velocity
- Fall (slope stations)
- Elevation (reservoir and tide stations)
- Contents (reservoir stations)

A file of all computed daily mean values should be saved for future use and archiving.

The time-weighted arithmetic method of computing daily mean values is referred to as the *trapezoidal method*. The trapezoidal method is a mathematical integration of the unit value hydrograph and provides an accurate computation of the mean parameter value. With a large number of instantaneous values for each day, the trapezoidal method closely approximates actual integration.

The trapezoidal method assumes that all unit values are instantaneous values, and that each unit value has a specific, designated time of occurrence. The time interval between unit values may be constant or variable. The file of unit values used for the computation of the daily mean value by the trapezoidal method must include a unit value at the midnight time for each day. If actual values are not recorded for the midnight time, a unit value should be interpolated based on the recorded unit values on either side of the midnight time. These interpolated midnight values should be flagged as interpolated, and should be retained in the unit values file for future use and archiving. The equation for the trapezoidal method is

$$Q = \frac{\left(\frac{q_0 + q_1}{2}\right)(t_1 - t_0) + \left(\frac{q_1 + q_2}{2}\right)(t_2 - t_1)\ldots + \left(\frac{q_{(n-1)} + q_n}{2}\right)(t_n - t_{(n-1)})}{t_n - t_0} \qquad (31)$$

where

Q = daily mean parameter value (In the above equation, Q represents discharge; however, the same equation can be used for any other parameter, such as gage height, velocity, and others)

q_0 = the parameter unit value at the midnight time at the beginning of the day,

q_1, q2....., $q(_{n-1})$ = consecutive unit values of the parameter during the day,

q_n = the parameter unit value at the midnight time at the end of the day,

t_0 = midnight time at the beginning of the day, or zero time,

t_1, t_2......, $t(_{n-1})$ = consecutive times corresponding to the parameter unit values during the day, and

t_n = midnight time at the end of the day, or 24.00 hour time. Note that all times must be expressed in hours and decimal parts of a hour.

Daily values will not be computed for days when time gaps exceed a value specified as the abort interval. The abort interval, by default, is 2 hours; however, the user should be allowed to change this interval to any other value less than 24 hours.

9.2.2 Daily Minimum and Maximum Values

The minimum and maximum values for some of the parameters are required for each day. These values are determined from the unit value files for the various parameters, and the selection process should consider all recorded and interpolated unit values for each day, including the midnight values at the beginning and end of each day. For some parameters, corresponding values of other parameters also should be determined.

The parameters requiring maximum and minimum values for each day and for each station type, and the corresponding unit values required for each maximum and minimum are shown in table 14. Not all tidal stations are included in table 14. Tidal stations require special computations to determine peak and trough elevations for semi-diurnal, diurnal, and mixed tidal cycles. The computation procedures for determinations at tidal stations are described in section 9.2.4.

9.2.3 Daily Values at Selected Times

Some stations require additional daily values at selected times for some parameters. For instance, reservoir stations sometimes require daily elevation and contents at specific times, such as 0800, 1200, or 2400. If unit values are not available at the specified times, interpolated values should be used. The user should be able to specify the parameter and time for which selected daily values are required, for all station types.

9.2.4 Daily Values for Tidal Stations

Tidal stations require the determination of the gage heights or elevations of tidal peaks and troughs for diurnal and semi-diurnal variations of the water-surface level. The unit values file of the corrected gage height or elevation data are examined sequentially to determine the two high tides and the two low tides for each day for semi-diurnal fluctuations. The procedure for computing daily values for tidal stations also recognizes diurnal and mixed fluctuations when they occur. The following discussion is excerpted from Hutchinson and others (1977).

> "In order to find true tidal peaks and troughs which occur once or twice in relation to the lunar day rather than the solar day, the record is NOT broken up into groups of observations in a calendar day before processing. Instead, the whole record is scanned continuously for successive peaks and troughs within periods of given length following the time of the previous extreme. After each extreme is found, the calendar day in which it occurred and time is determined. This completely eliminates any confusion with inclusion or exclusion of extremes occurring just before or just after midnight.
>
> "The method of finding successive tidal peaks and troughs is to look for an opposite extreme in a selected time period (normally 10-1/2 hours) following each recognized peak or trough. That is, when a tidal peak is found (and its date and time are stored) a search is made for the lowest stage in the selected time period following the time of the previous tidal peak. Then having found the time of this tidal trough, a search is made for the highest stage in the selected time period following the time of the previous tidal trough. Comparison of two peaks found within a calendar day and two troughs found within the same calendar day are used to assign each as a HIGH-HIGH, a LOW-HIGH, a HIGH-LOW, or a LOW-LOW for the day.

Table 14. Parameters requiring daily maximum and minimum values computed for various station types

Station Type	Parameter Requiring Maximum and Minimum	Corresponding Values for Parameters
Stage only	Corrected gage height	Gage-height correction
Stage—discharge	Corrected gage height	Gage-height correction, shift
	Discharge	—
Velocity—index	Corrected gage height	Gage-height correction, velocity factor, area, corrected index velocity, mean stream velocity, discharge
	Corrected velocity index	Index velocity correction, index velocity shift
	Mean stream velocity	—
	Discharge	—
Slope	Corrected base gage height	Gage-height correction, shift, measured fall, rating fall, fall ratio, discharge ratio, discharge
	Corrected auxiliary gage height	Gage-height correction
	Measured fall	—
	Discharge	—
Rate-of-change in stage	Corrected gage height	Gage-height correction, shift, rate-of-change, Boyer factor, discharge adjustment factor, rating discharge, discharge
	Discharge	—
Reservoir	Corrected elevation	Elevation correction
	Contents	—
Hydraulic structure	Corrected headwater gage height	Gage-height corrections for headwater
	Corrected tailwater gage height	Gage-height corrections for tailwater
	Discharge	—
BRANCH	Corrected upstream gage height	Gage-height corrections for upstream gage
	Corrected downstream gage height	Gage-height corrections for downstream gage
	Discharge	—

“Although the normal tide on most of the United States coastline is semi-diurnal, at a few places the tides are diurnal or are mixed semi-diurnal. This program tries to give meaningful results in a situation by the following logic. Starting each search for a peak or trough, a normal, semi-diurnal tidal cycle is assumed and the length of the selected time period for the search is set at about 10-1/2 hours (0.44 day). This length of the search period was picked so as to be long enough to include the normal time of occurrence of the next peak or trough for a semi-diurnal tide (which should occur about 6-1/2 hours after the preceding trough or peak) and short enough to avoid confusion with the advance side of the next following tidal wave if the two tidal waves are of greatly different magnitude. (If a 12-hour search period were used, confusion could occur such as when the second tidal wave of the day is so much higher than the first that the water level 12 hours after the previous tidal trough is rapidly rising and already higher than it was at the time of the first real peak which occurred about 6-1/2 hours after the previous tidal trough).

"In order to be able to produce meaningful results for sites where the tide is actually diurnal or is a mixture of semi-diurnal and diurnal, an additional test is made after each search for the next apparent extreme. If the next extreme is found to occur in the last hour of the 10-1/2 hour search period, it is assumed that this extreme is not a true tidal peak or trough in a semi-diurnal cycle but is instead falling toward a trough or rising toward a peak in a diurnal tidal cycle. Then in order to find the real tidal peak or trough in this longer cycle, that particular search period is extended by another 12 hours and the new results used as the next peak or trough. However, after finding the next tidal peak or trough, the following search is again made for an initial period of 10-1/2 hours so that a change back from a diurnal tide to a semi-diurnal tide is not missed."

The daily values of HIGH-HIGH, LOW-HIGH, HIGH-LOW, and LOW-LOW determined in the above procedure should be saved for further use, and for archiving. In addition, the cumulative elevation correction values corresponding to each of the peak and trough elevations should be saved and archived. The daily mean gage height and/or elevation also may be computed for a tidal station, as is done for a stage only station, and these values should be saved and archived.

9.3 Summary of Primary Computations

Primary computations include the determination of unit values and daily values for numerous parameters, as described in sections 9.1 and 9.2. It is important and necessary to summarize the results in tables that can be used for review, analysis, and for publication. Standard formatted tables include unit values, primary computations, diagnostics, and daily value tables. The electronic processing system should allow for the design of other summary tables, as needed, and as specified by the user.

9.3.1 Unit Values Tables

The electronic processing system should provide a flexible array of unit values tables to allow for the analysis and review of individual parameters, or selected groups of parameters. For instance, a unit values table may show only the final, corrected values of gage height for a selected period of time; or the unit values table may show the final gage-height values and the corresponding discharge values. The user should select the input parameters to a unit values table. The unit values should be displayed in chronological order, and generally grouped by day, month, and year. The user also should specify selected time intervals for a unit values table. For instance, an hourly table may be selected, even though 15-minute unit values are available or, even-hour unit values may be selected that require interpolation of unit values that are not recorded on the even-hour.

9.3.2 Primary Computations Tables

Primary computations involve the application of various user instructions to derive the final discharge record (or other parameter such as reservoir contents, tide, and others) for a gaging station. These instructions include gage-height corrections, shifts, and rating curves. The computations should be displayed in a table that shows input data, and various computed information so that they can be easily reviewed. Traditionally, two formats have been utilized for displaying primary computations, (1) the historical format, and (2) the standard format. Selection of either format is optional.

The main difference between the historical format and the standard format of a primary computation is that the historical format shows hourly values of input data (for example, gage heights). The standard format provides more information than the historical format regarding the computations. Other differences are present between the formats, but these are mainly in the arrangement of the data and information.

Each gaging station type, such as stage-discharge, slope, velocity-index, and others, will have primary output formats specifically designed for the station type. A listing of items, by station type, that should be included in a primary computation form, is shown in table 15. Arrangement of the information is not critical. A slightly modified version of a traditional historical primary output is shown in figure 10, and a standard format is shown in figure 11, each for a stage-discharge station. Primary computation tables for other gaging station types should be similarly designed.

Table 15. Items required for primary output tables for various gaging station types

Item	Gaging-StationType								
	Stage Only	Stage-Dis-charge	Velocity Index	Slope	Rate-of-Change in Stage	Reser-voir	Tide	Structure	BRANCH Model
Header Information									
Station identification number	X	X	X	X	X	X	X	X	X
Station name	X	X	X	X	X	X	X	X	X
Water year information	X	X	X	X	X	X	X	X	X
Date of primary processing	X	X	X	X	X	X	X	X	X
Name of responsible user	X	X	X	X	X	X	X	X	X
List of ratings used		X	X	X	X	X			
Unit value recording interval	X	X	X	X	X	X	X	X	X
Station type (for example, processing method)	X	X	X	X	X	X	X	X	X
Datum conversion (if applicable)	X	X	X	X	X	X	X	X	X
Tabular Information									
Date	X	X	X	X	X	X	X	X	X
Hourly gage heights for base gage	X	X			X	X	X		
Daily maximum gage height	X	X	X	X	X	X			X
Time of maximum gage height	X	X	X	X	X	X			X
Shift corresponding to maximum gage height		X		X	X				
Gage-height correction corresponding to maximum gage height	X	X	X	X	X	X			X
Daily minimum gage height	X	X	X	X	X	X			X
Time of minimum gage height	X	X	X	X	X	X			X
Shift corresponding to minimum gage height		X		X	X				
Gage-height correction corresponding to minimum gage height	X	X	X	X	X	X			X
Daily mean gage height	X	X	X	X	X	X			X
Daily maximum discharge		X	X	X	X			X	X
Time of maximum discharge		X	X	X	X			X	X
Daily minimum discharge		X	X	X	X			X	X
Time of minimum discharge		X	X	X	X			X	X
Daily mean discharge		X	X	X	X			X	X
Hourly discharges			X	X				X	X
Daily maximum index velocity			X						
Time of maximum index velocity			X						
Shift corresponding to maximum index velocity			X						
Index velocity correction for maximum index velocity			X						
Daily minimum index velocity			X						
Time of minimum index velocity			X						

Table 15. Items required for primary output tables for various gaging station types—Continued

Item	Gaging-StationType								
	Stage Only	Stage-Dis-charge	Velocity Index	Slope	Rate-of-Change in Stage	Reser-voir	Tide	Structure	BRANCH Model
Index velocity correction for minimum index velocity			X						
Daily mean index velocity			X						
Daily maximum cross-section area			X						
Time of maximum cross-section area			X						
Daily minimum cross-section area			X						
Time of minimum cross-section area			X						
Daily mean cross-section area			X						
Daily maximum stream velocity			X						
Time of maximum stream velocity			X						
Daily minimum stream velocity			X						
Time of minimum stream velocity			X						
Daily mean stream velocity			X						
Daily maximum reservoir contents						X			
Time of maximum reservoir contents						X			
Daily minimum reservoir contents						X			
Time of minimum reservoir contents						X			
Daily mean reservoir contents						X			
Reservoir gage height at specified time						X			
Gage-height correction at specified time						X			
Reservoir contents at specified time						X			
Daily high-high gage height without datum conversion							X		
Daily high-high gage height with datum conversion							X		
Time of daily high-high gage height							X		
Correction for daily high-high gage height							X		
Daily low-high gage height without datum conversion							X		
Daily low-high gage height with datum conversion							X		
Time of daily low-high gage height							X		
Correction for daily low-high gage height							X		
Daily high-low gage height without datum conversion							X		
Daily high-low gage height with datum conversion							X		
Time of daily high-low gage height							X		
Correction of daily high-low gage height							X		

Table 15. Items required for primary output tables for various gaging station types—Continued

Item	Gaging-StationType								
	Stage Only	Stage-Dis-charge	Velocity Index	Slope	Rate-of-Change in Stage	Reser-voir	Tide	Structure	BRANCH Model
Daily low-low gage height without datum conversion							X		
Daily low-low gage height with datum conversion							X		
Time of daily low-low gage height							X		
Correction for daily low-low gage height							X		
Daily mean tide gage height without datum conversion							X		
Daily mean tide gage height with datum conversion							X		
Daily maximum gage height at auxiliary gage				X					X
Time of maximum daily gage height				X					X
Gage-height correction corresponding to maximum auxiliary gage height				X					X
Daily minimum gage height at auxiliary gage				X					X
Time of daily minimum gage height				X					X
Gage-height correction corresponding to minimum auxiliary gage height				X					X
Daily mean gage height at auxiliary gage				X					X
Daily maximum fall				X					
Time of daily maximum fall				X					
Daily minimum fall				X					
Time of daily minimum fall				X					
Maximum rate-of-change in stage					X				
Time of maximum rate-of-change in stage					X				
Maximum adjustment factor					X				
Time of maximum adjustment factor					X				
Minimum adjustment factor					X				
Time of minimum adjustment factor					X				

```
1                       UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY - WATER RESOURCES DIVISION       STATE 23  DIST 23
                                      PRIMARY COMPUTATIONS OF GAGE HEIGHT AND DISCHARGE                        RATINGS USED --
 01034000                              DATE PROCESSED: 09-10-1997 @ 12:10 BY auser01                         INPUT 0002 01/01/80 (0001)
 Piscataquis River at Medford, Maine                                                                         STNRD    5 10/01/92 (0015)
 OUTPUT PARAMETER 00060    STORE STATISTIC(S) 00003
 PROVISIONAL DATA FOR WATER YEAR ENDING SEPT. 30, 1993                                   TEST DIFF:******    PUNCH INTERVAL:  15 MIN

          MAX GH  MIN GH                                                        STAGE, IN HUNDREDTHS OF FEET, AT INDICATED HOURS
   DATE   /DISCH  /DISCH   MEAN            MEAN      SHIFT    DATUM   0100 0200 0300 0400 0500 0600 0700 0800 0900 1000 1100 1200
  ------  <TIME>  <TIME>   GH              DISCH      ADJ      CORR   1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400

 08/11/93   1.53    1.51   1.51            203P               0.00
          209     203                                                     151  153  151  151  151  151  151  151  151  151  151
          <1500>  <1400>
 08/12/93   1.51    1.51   1.51            203                0.00    151  151  151  151  151  151  151  151  151  151  151  151
          203     203                                                 151  151  151  151  151  151  151  151  151  151  151  151
          <0000>  <0000>
 08/13/93   1.51    1.51   1.51            203                0.00    151  151  151  151  151  151  151  151  151  151  151  151
          203     203                                                 151  151  151  151  151  151  151  151  151  151  151  151
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 08/14/93   1.51    1.51   1.51            203                0.00    151  151  151  151  151  151  151  151  151  151  151  151
          203     203                                                 151  151  151  151  151  151  151  151  151  151  151  151
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 08/15/93   1.51    1.51   1.51            203                0.00    151  151  151  151  151  151  151  151  151  151  151  151
          203     203                                                 151  151  151  151  151  151  151  151  151  151  151  151
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 08/16/93   1.51    1.50   1.50            201                0.00    151  151  151  151  151  151  151  151  150  150  150  150
          203     200                                                 150  150  150  150  150  150  150  150  150  150  150  150
          <0000>  <0844>
 08/17/93   1.66    1.50   1.54            211                0.00    150  150  150  150  150  150  150  150  150  150  150  150
          252     200                                                 150  150  150  150  154  161  166  165  164  162  159  158
          <1859>  <0000>
 08/18/93   1.59    1.51   1.52            207                0.00    156  158  158  156  154  153  152  152  152  152  151  151
          227     203                                                 151  151  151  151  151  151  151  151  151  151  151  151
          <0214>  <1029>
 08/19/93   1.78    1.51   1.69            267                0.00    152  154  156  158  160  162  165  167  169  170  172  173
          301     203                                                 174  175  176  176  177  177  177  178  178  178  178  178
          <1958>  <0000>
 08/20/93   1.78    1.72   1.75            288                0.00    178  178  178  177  177  177  177  176  176  175  175  175
          301     275                                                 174  174  174  173  173  173  172  172  172  173  173  173
          <0000>  <1743>
 08/21/93   1.97    1.73   1.82            320                0.00    174  174  174  174  174  175  175  176  177  177  178  179
          403     279                                                 180  181  182  183  186  188  189  191  193  195  196  197
          <2343>  <0000>
 08/22/93   1.99    1.91   1.97            400                0.00    198  198  199  199  199  199  199  199  199  198  198  198
          415     366                                                 198  197  197  196  195  195  194  193  192  192  191  191
          <0258>  <2243>
 08/23/93   1.91    1.78   1.84            329                0.00    190  190  189  188  187  187  186  185  185  184  184  183
          366     301                                                 183  183  182  182  181  181  180  180  179  179  179  178
          <0000>  <2358>
 08/24/93   1.78    1.73   1.75            290                0.01    178  178  177  177  178  177  177  177  176  176  176  175
          301     279                                                 175  175  175  174  174  174  174  173  173  173  173  173
          <0000>  <1957>
 08/25/93   1.74    1.71   1.72            276                0.01    173  173  173  173  173  173  173  173  173  173  172  172
          284     271                                                 172  172  172  172  171  171  171  171  171  171  171  171
          <0112>  <1657>
```

Figure 10. Example of a historical primary output of primary computations table.

10-01	2.35	.02	0000	2.21	.02	2120	2.26	.02	705	0000	591	2120	629
10-02	2.22	.02	1820	2.17	.02	0920	2.20	.02	599	1820	561	0920	580
10-03	2.27	.02	2400	2.10	.02	1035	2.15	.02	636	2400	508	1035	545
10-04	2.45	.02	2249	2.27	.02	0000	2.39	.02	794	2249	636	0000	741
10-05	2.53	.02	2019	2.44	.02	0449	2.48	.02	864	2019	786	0449	816
10-06	2.53	.02	0000	2.39	.02	1249	2.43	.02	864	0000	740	1249	776
10-07	2.42	.02	0000	2.27	.02	1334	2.33	.02	768	0000	638	1334	687
10-08	2.31	.02	0000	2.25	.02	2400	2.28	.02	671	0000	624	2400	649
10-09	2.25	.02	0000	2.20	.02	1918	2.22	.02	624	0000	583	1918	598
10-10	2.26	.02	2218	2.20	.02	0348	2.22	.02	630	2218	583	0348	600
10-11	2.29	.02	2248	2.17	.02	1133	2.23	.02	655	2248	561	1133	604
10-12	2.30	.02	0018	2.18	.02	2003	2.26	.02	663	0018	568	2003	631
10-13	2.63	.02	2348	2.26	.02	0000	2.49	.02	955	2348	629	0000	827
10-14	3.02	.02	1417	2.63	.02	0000	2.93	.02	1370	1417	955	0000	1260
10-15	2.97	.02	0000	2.65	.02	2332	2.81	.02	1310	0000	974	2332	1140
10-16	2.65	.02	0000	2.46	.02	2400	2.54	.02	974	0000	804	2400	875
10-17	2.58	.02	2317	2.45	.02	0202	2.51	.02	909	2317	794	0202	848
10-18	2.57	.02	0000	2.38	.02	2400	2.51	.02	899	0000	732	2400	848
10-19	2.54	.02	1531	2.38	.02	0002	2.44	.02	872	1531	732	0002	788
10-20	2.52	.02	0331	2.40	.02	2031	2.45	.02	855	0331	749	2031	794
10-21	2.56	.02	2400	2.34	.02	0831	2.38	.02	889	2400	697	0831	734
10-22	4.04	.02	2316	2.56	.02	0000	3.44	.02	2840	2316	889	0000	1960
10-23	4.06	.02	0131	3.89	.02	1401	3.98	.02	2880	0131	2580	1401	2730
10-24	3.95	.02	0000	3.66	.02	1645	3.81	.02	2680	0000	2210	1645	2460
10-25	3.70	.02	1130	3.56	.02	2345	3.65	.02	2280	1130	2070	2345	2200
10-26	3.56	.02	0000	3.44		2159	3.47	.01	2070	0000	1890	2159	1940
10-27	3.44		0000	3.38		1258	3.40		1890	0000	1810	1258	1830
10-28	3.39		0057	3.37		1810	3.39		1830	0057	1800	1810	1820
10-29	3.37		0000	3.33		2153	3.35		1800	0000	1750	2153	1770
10-30	3.33		0000	3.28		2051	3.30		1750	0000	1680	2051	1710
10-31	3.29		0250	3.08		2400	3.25		1690	0250	1440	2400	1650
11-01	3.29		1317	2.94		1916	3.13		1690	1317	1280	1916	1500
11-02	3.37		2059	3.15		0000	3.30		1800	2059	1520	0000	1710
11-03	3.51		1412	3.22		2027	3.37		1990	1412	1610	2027	1800
11-04	3.25		0000	3.24		1210	3.25		1640	0000	1630	1210	1640
11-05	3.32		1952	3.25		0000	3.28		1730	1952	1640	0000	1680
11-06	4.47		2400	3.14		0506	3.65		3670	2400	1510	0506	2270

9.3.3 Diagnostics Tables

Diagnostics tables provide a means to review every computation for each time step of the primary computations. The table should be a line item listing, in chronological order of the time steps, showing all input and computed values for each time step of each day. Items required in the diagnostics table for each type of gaging station are listed in table 16.

Table 16. Items required for diagnostics tables

Item	Gaging-Station Type								
	Stage Only	Stage-Discharge	Velocity Index	Slope	Rate-of-Change in Stage	Reservoir	Tide	Structure	BRANCH Model
Header Information									
Station identification number	X	X	X	X	X	X	X	X	X
Station name	X	X	X	X	X	X	X	X	X
Water year information	X	X	X	X	X	X	X	X	X
Date of primary processing	X	X	X	X	X	X	X	X	X
List of ratings used		X	X	X	X	X		X	
Station type (for example, processing information)	X	X	X	X	X	X	X	X	X
Tabular information									
Date	X	X	X	X	X	X	X	X	X
Time	X	X	X	X	X	X	X	X	X
Base gage height, without corrections or adjustments	X	X	X	X	X	X	X	X	X
Base gage-height correction	X	X	X	X	X	X	X	X	X
Base gage-height datum adjustment	X	X	X	X	X	X	X	X	X
Base gage height, with corrections and adjustments	X	X	X	X	X	X	X	X	X
Base gage-height shift		X		X	X				
Index velocity, without correction			X						
Index velocity correction			X						
Index velocity, with correction			X						
Index velocity shift			X						
Index velocity adjustment factor			X						
Mean stream velocity			X						X
Cross-section area			X						X
Discharge (mean stream velocity times cross-section area)			X						
Auxiliary gage height, without correction or adjustment				X				X	X

Table 16. Items required for diagnostics tables—Continued

Item	Gaging-Station Type								
	Stage Only	Stage-Discharge	Velocity Index	Slope	Rate-of-Change in Stage	Reservoir	Tide	Structure	BRANCH Model
Auxiliary gage-height correction				X				X	X
Auxiliary gage-height datum adjustment				X				X	X
Auxiliary gage height with correction and adjustment				X				X	X
Measured Fall				X					
Rating Fall				X					
Fall ratio				X					
Discharge ratio (from ratio rating)				X					
Rating discharge		X		X	X				
Discharge, adjusted for slope				X					
Rate-of-change in stage					X				
Factor 1/USc					X				
Discharge adjustment factor					X				
Discharge, adjusted for rate-of-change-in-stage					X				
Reservoir contents						X			
Number of gates								X	
Discharge through gates								X	
Number of turbines								X	
Discharge through turbines								X	
Spillway discharge								X	
Weir discharge								X	
Pump discharge								X	
Siphon discharge								X	
Lockage discharge								X	
Leakage discharge								X	
Other discharge								X	
Total discharge, hydraulic structure station								X	
Discharge computed by BRANCH model									X

[1]For structures' gaging stations, base gage is headwater gage and auxiliary gage is tailwater gage.

9.3.4 Daily Values Tables

A daily values table is a listing of the daily values for each day of the year, for selected parameters at a gaging station. Generally, daily values are the daily mean discharges for a gaging station, but other parameters such as stage, elevation, reservoir contents, or other statistics such as daily maximum, daily minimum, and daily unit value at a specific time, may compose a daily values table. The user should be allowed to specify time periods in the daily values table, and to include multiple parameters in one table. In addition, the daily values table should show monthly and annual totals, means, and extremes, as appropriate. See section 13 for computation of monthly and annual values.

9.3.5 Unit Values and Discharge Measurement Comparison Table

A table where primary computation unit values are compared to measured discharge should be produced for all gaging stations where discharge measurements are made. This table will be used to review the final results after the primary computations are completed, and to verify that all shifts, corrections, and adjustments were applied correctly. The comparison should be made using the mean time of the discharge measurement. At a minimum, this table should include the following items.

- Date of discharge measurement
- Mean time of discharge measurement
- Measured discharge
- Computed unit value of discharge for same date and time (interpolated, if necessary)
- Difference between measured discharge and computed unit value discharge, (Q_m - Q_{uv})
- Percent difference of measured discharge and computed unit value discharge, $100(Q_m - Q_{uv})/Q_{uv}$

10. Hydrograph Plots

Hydrographs are useful for graphical viewing, verification, editing, and comparisons of streamflow information, including most of the basic information that contributes to the primary computation of streamflow records. Hydrograph plots of unit values of discharge, along with comparative plots of other parameters, such as gage height, velocity, and shifts, and supplementary data such as peak discharge, peak stage, and discharge measurements, provide an excellent means of reviewing and editing the primary computations. Likewise, hydrograph plots of daily discharge records can be combined with hydrograph plots of other station records, precipitation records, and temperature records for review and editing purposes, as well as providing a graphical summary of the records for visual presentation and publication. Hydrograph requirements for other purposes such as review and editing of unit value input (section 5.3.4) and estimation of missing record (section 13.2.1) are consistent with hydrograph requirements stated in this section for review of primary computations.

All hydrograph plots, both unit value and daily value, should be viewable on the computer monitor. In addition, the user should have the option to plot all hydrographs on paper plots. All scales and grid lines should be generated by the electronic processing system. Preprinted plotting forms are not advised.

10.1 Unit Values Hydrographs

The electronic processing system should allow the user to choose any of the unit values files for hydrograph plotting. Generally, hydrographs showing unit values of discharge will be of most interest, but other unit values hydrographs, such as gage height, elevation, and reservoir contents also may be required. Other unit values files of supplementary information, such as for shifts, gage-height corrections, auxiliary gage information, and others should be superimposed on the same plot if these additional parameter plots are specified. Also, unit value information from other gaging stations, precipitation stations, and temperature stations should be superimposed on the same plot, as specified by the user.

When more than one unit values file is shown on a unit values hydrograph plot, each should be clearly identified by a distinctive plotting symbol. Individual scales should be shown for each parameter, labeled with the correct parameter name and units of measurement.

The abscissa scale for a unit values hydrograph plot is a time scale, with hours being the primary unit of subdivision. Each day, month, and year are shown as secondary subdivisions. The ordinate scale should conform to the parameter being plotted. Discharge scales should default to logarithmic, but should be changeable to linear if specified. All other scales, such as for gage height, elevation, shifts, rainfall, temperature, and others, should default to linear scales. The range of the ordinate scale should default to one that will include the full range of the plotted unit values file, but should be changeable to any specified range.

10.2 Daily Values Hydrographs

A daily values hydrograph is a traditional USGS method for displaying the results of streamflow computations for a gaging station. This hydrograph usually is an annual plot showing the daily values for a water year, but can be for any other period of time as selected by the user. Daily value hydrographs usually are plots of daily mean discharge for a gaging station, with comparative hydrograph plots of daily mean discharge for one or more nearby gaging stations. For some stations, the daily values hydrograph also may include daily values of precipitation and/or temperature. Daily values hydrographs also can be used to display other parameters, such as gage height, elevation, and reservoir contents.

When more than one daily values file is shown on a daily values hydrograph plot, each should be clearly identified by a distinctive plotting symbol. Individual scales should be shown for each parameter, labeled with the correct parameter name and units of measurement.

The abscissa scale for daily values hydrographs is a time scale, with days being the primary subdivision. Months and years are secondary subdivisions. The ordinate scale should be logarithmic for discharge plots, unless otherwise specified by the user. Other daily values parameters should be plotted using linear scales. The range of the ordinate scale for the primary parameter should default to one that will include the full range of the daily values for the time period being plotted.

10.3 Supplementary Hydrograph Information

A few items of supplementary information are required, or are optional, for both unit value and daily value hydrograph plots. These include hydrograph identification information (required), discharge measurement data (optional), and peak information (optional).

- *Station Number and Name*—Each hydrograph plot should include a heading that shows the station number and name of the parameter of primary interest. If supplementary hydrographs are plotted on the same plot, they should be identified separately within the grid area, using an explanation.
- *Time Period of Hydrograph*—The hydrograph heading should state the time period covered by the plot. For instance, water year 1996, calendar year 1996, January 1996 through June 1996, and others. The same period of time is identified on the abscissa scale.
- *Discharge Measurements*—All discharge measurements made during the time period of the hydrograph plot should be plotted if specified by the user. Discharge measurements should be plotted at the mean time of each discharge measurement. The measured discharge always should be plotted, and the adjusted discharge also should be plotted if one is available. Discharge measurements should be plotted as a small open circle and identified with the measurement number adjacent to the circle. Adjusted discharges should be plotted with a distinctive symbol.
- *Peak Measurements*—For unit value stage and elevation hydrographs, peak stages and/or elevations (from crest-stage gages and high water marks) may be plotted if specified by the user. Peak stage values should be shown as a short horizontal line at the estimated time and date, and at the stage or elevation of the peak, and identified as CSG or HWM.

For daily value discharge hydrographs, each instantaneous peak discharge that is greater than the base discharge should be plotted as a distinctive symbol on the day of occurrence. It should be identified as PAB (peak above base). If peaks above a base are not used for the gaging station, the annual peak should be plotted. The user should have the option to specify a temporary base level to be used only for plotting purposes.

11. Computation of Extremes

For most gaging stations, it is required that the maximum peak stage and discharge, the secondary peak stages and discharges, and the minimum discharge be computed for each water year. The maximum peak stage and discharge, and the minimum discharge, are referred to as the annual peak and annual minimum. Guidelines for these computations are given in sections 11.1 through 11.4.

11.1 Annual Peak Stage and Discharge

The annual peak stage and discharge are defined as the highest instantaneous (unit value) gage height and discharge associated with the highest flood peak that occurred during the water year. The annual peak stage and discharge, and the associated date and time, should be determined with the electronic processing system. If the highest gage height and discharge was at the beginning or end of the water year as a result of a recession from or rise to a peak that occurred in the previous or following water year, they should not be included as an extreme. For some gaging stations, the user may designate that the maximum daily discharge be used rather than the maximum instantaneous discharge.

The annual instantaneous maximum gage height may sometimes occur at a different time than the annual instantaneous maximum discharge. In these cases, the annual maximum instantaneous discharge should be determined, and also the gage height corresponding (at the same date and time) to this discharge. In addition, the annual maximum instantaneous gage height should be determined, and also the discharge corresponding (at the same date and time) to this gage height. Dates and times for both pairs of values should be determined.

11.2 Secondary Peak Stages and Discharges

Secondary peak stages and discharges are those peaks that are less than the annual peak stage and discharge, but greater than a specified base discharge. Furthermore, the secondary peaks must conform to guidelines that insure their independence. That is, to provide reasonable certainty that a peak has not been influenced, or affected, by another peak. These guidelines are described by Novak (1985), and are given as follows.

> "Two peaks are considered independent if the hydrograph recedes to a well-defined trough between the peaks. Publish both peaks if the instantaneous discharge of the trough is equal to or less than 75

percent of the instantaneous discharge of the lower peak; otherwise publish only the higher peak.

For small, highly responsive watersheds, only the highest peak discharge resulting from an obvious single storm event should be reported regardless of the trough configuration or magnitude between peaks.

For periods of diurnal peaks caused by snowmelt, report only the highest peak during each distinct period of melting, if such periods can be identified, even though other peaks may meet the preceding criteria. Identification of each distinct period of melting is largely a matter of individual judgment, but the principle as explained in paragraph 1 above for instantaneous discharges can be applied to daily discharges as an identification guide."

All secondary peak stages and discharges should be determined with the electronic processing system. In addition, the date and time for each secondary peak should be determined.

11.3 Annual Minimum Discharge

The annual minimum discharge is defined as the lowest instantaneous (unit value) discharge that results during the water year. For some gaging stations, the user may specify that the lowest daily discharge be determined as the annual minimum discharge. In either case, the electronic processing system should determine the annual minimum discharge, and the associated date and time (if applicable), for the water year.

11.4 Summary of Annual Extremes

A tabular listing of the annual peak gage height and discharge, secondary peak gage heights and discharges, annual minimum discharge, and all associated dates and times should be produced with the electronic processing system. The user should review this report on the system monitor, and select items from it for publication and other applications.

12. Navigation Paths

This report describes the individual processes required for the computation and analysis of gaging station records. A *navigation path*, as described here, is a concept whereby the electronic processing system would lead the user through the processing routines that are specific to the various gaging station types. The user would be prompted for input and decisions along the way, but much of the information transfer and record processing would be automatic. As each processing step is completed, the electronic processing system automatically would go to the next step defined for that particular gaging station type. The electronic processing system tracks the progress through the navigation path and can reinitiate processing at the point necessary if processing is interrupted. In addition, when data are entered and stored, those data automatically are transferred to processing steps where they are needed. As an example, maximum stages entered from discharge measurement notes, crest-stage gage notes, and highwater mark notes, automatically are transferred to the verification and editing routines for unit values of gage height so that recorded peak stages can be verified. A navigation path, combined with automatic information transfer, increases the efficiency of record processing, removes processes that are not needed for a specific type of station, arranges the processing logically, reduces the need to manually search for data and information, reduces the likelihood of errors, and increases the probability that all relevant data and information will be used.

12.1 Basic Navigation Path

Navigation paths for the various types of gaging stations are similar in many, but not all, respects. The basic processing steps required for a navigation path are shown in figure 12. Some steps must be repeated for each parameter type, and some steps will not apply for certain station types.The specific navigation path for each station type should be derived from the basic steps shown in figure 12.

The same basic steps shown above would be used for any gaging station type, but with some modification. For instance, an index velocity station would do steps 5 through 9 for the unit values file of stage *and* the unit values file of index velocity. The index velocity station also would require a shift analysis and shift application (steps 10 and 11) for the index velocity-mean velocity rating.

The choice of the correct navigation path to use for a specific gaging station should be automatic. When a gaging station initially is created in the electronic processing system, the method of processing (for example, stage-discharge, slope, index-velocity, and others) is defined, which automatically should establish the appropriate navigation path to use. Subsequent access to the processing routines for that station would use that same navigation path. If the station is multi-purpose in that various parameters are measured, such as streamflow, water quality, and/or sediment, then the user would need to specify the parameter that is to be processed so that the correct navigation path is used.

12.2 Navigating Through a Navigation Path

The user should be allowed to enter a navigation path at any point, as well as to back-track, if necessary. New data would be entered by starting at the initial point of the navigation path. If a period of record has not been completely processed, the user should be able to start at the point where processing ended during the prior processing session. Finally, the user should be able to enter or back-track to a step in the navigation path that already has been processed, and do a recomputation.

The electronic processing system should display a complete list of the processing steps contained in the active navigation path, showing the status of each for the period of record being processed.

12.3 Auxiliary Processing Functions

Certain processing steps are not part of regular navigation paths because they are not routine processes that are performed each time a gaging station record is processed. These auxiliary functions include preparation of station descriptions, station analyses, and publication manuscripts. The functions also include definition and analysis of rating curves, estimation of missing records, computation of various statistics, quality-assurance reports, and data archival. All of these functions are described in other sections of this report.

13. Estimating Missing Records

Complete records of daily discharges, and other parameters, are necessary in order to compute monthly and annual totals and other statistics. Complete records also are needed to compute total runoff from a drainage basin, to calibrate runoff models, and to compute total monthly and annual chemical and sediment loads. Data sometimes are missing because of instrument failures and other reasons; thus, not permitting the normal computation of daily records. Also, normal computation methods may not be applicable at all times, such as during backwater from ice, debris, or other abnormal stream conditions. Therefore, it is necessary to make estimates of discharge or other hydrologic parameters for these periods of missing record.

The electronic processing system should allow the user to estimate both unit values and daily values. However, estimation of missing records should be kept to a minimum, and usually should be limited to those parameters that will be published in the USGS annual data reports *and* to those parameters that may be required for the purpose of computing a published parameter. For example, in some cases it may be reasonable to estimate unit values of gage height for the purpose of computing daily values of discharge, provided the gage heights can be estimated with reasonable accuracy. The electronic processing system should provide estimating methods that commonly are accepted, but the user must be able to interact and apply unique site specific information and procedures in order to make the best estimate of missing records.

Also, it is important that only *one* estimate of discharge (or other hydrologic parameter) be saved and archived. Although the user may make various preliminary estimates for evaluation and comparison purposes, only the best estimate should be saved.

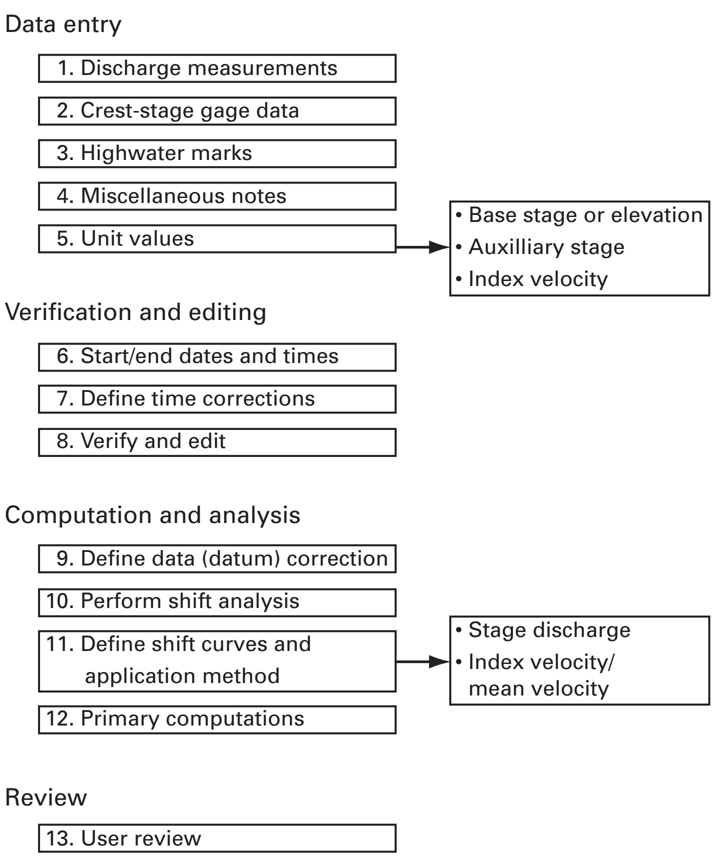

Figure 12. Basic navigation path requirements.

13.1 Estimating Discharge Records

A number of methods potentially are available to assist the user in estimating discharge for periods of missing record. Six such methods that can be adapted to computer application, are described in sections13.1.1 through13.1.6. The electronic processing system should allow the use of one or more of these methods, as well as other site specific methods, to make and compare discharge estimates.

13.1.1 Hydrographic and Climatic Comparison Method

The hydrographic and climatic comparison method, as described by Rantz and others (1982), is the most common method used to estimate discharge during periods of missing record and ice-affected periods. A semilogarithmic hydrograph of daily discharge is plotted, encompassing the period of missing record, and valid records for periods prior to and after the missing record period. Other data and information, as shown below, may be superimposed on this plot to aid in the estimation procedure.

- Hydrographs of nearby stations (reference sites)
- Hydrographs based on the direct application of ice-affected gage heights to the rating (without correction for ice-induced backwater)
- Daily or hourly precipitation

- Daily temperature, and/or daily maximum and minimum temperatures
- Discharge measurements
- Recession curves for station being estimated
- Notes and observations (for example, observed ice conditions)

The electronic processing system should allow vertical and horizontal repositioning of the hydrograph of the reference site (or sites) until it corresponds as closely as possible to the available good record of the site to be estimated. When long periods of missing record must be estimated, this repositioning process may need to be performed various times, each time for a different segment of the missing period. Values of daily mean discharge are then estimated by using the reference site as a guide and drawing a hydrograph for the missing period, whereas taking into account all of the other available data and information, such as the discharge measurements, climatic data, and notes. This estimation process is performed by the user on the electronic processing system monitor, using a mouse or other suitable device. After the estimated hydrograph segment is completed and accepted by the user, the electronic processing system automatically should determine the daily values of discharge, flag the values as estimated, and insert them into the daily values file.

A period of missing record resulting during an unbroken recession can be estimated by connecting the adjacent periods of good record with a straight line or a smooth recession curve on a semilogarithmic plot. This procedure is improved if recession curves, within the range of discharge to be estimated, are available for the station in question to superimpose on the plot. Recessions also may vary by season; therefore, it is useful to categorize the recession curves by season of the year. The user should be able to re-position the recession curves vertically and horizontally to obtain the best fit of the recession curves. The electronic processing system should allow for the storage, and later recall, of recession curve data for this purpose.

13.1.2 Discharge Ratio Method

The discharge ratio method is used for estimating discharge during ice-affected periods, and is described by Rantz and others (1982). For this method, the equivalent open-water daily mean discharge is multiplied by a variable correction factor, K, to produce a discharge corrected for the effects of backwater from ice. The correction factor, K, is computed for each discharge measurement as the ratio of measured discharge, Q_m, to the open water discharge, Q_r. As changes occur in the ice cover throughout a winter period, the value of K for each day also will change, and intermediate values should be determined with the electronic processing system by time interpolation between K values determined from consecutive discharge measurements. Climatic data, such as temperature and precipitation, should be used to as a guide to modify the simple time interpolation procedure, as necessary.

The computed correction factors, K, for each discharge measurement should be displayed on a semilogarithmic plot, along with the equivalent open-water daily discharge hydrograph and the climatic data. The correction factor should be merged with a value of 1.00 on the day prior to and the day following each ice period. These dates are based on the observed, or estimated, beginning and ending of ice cover. Daily values files of the open-water discharge and the corresponding correction factors, K, should be saved and archived for all ice-affected periods.

13.1.3 Regression Method

Multiple, stepwise, regression is a useful method of relating time series discharge data of one gaging station to concurrent time series discharge data of one or more nearby reference gages. Regression equations can be developed for specific ranges of discharge, for instance, low flows, medium flows, and/or high flows. They also can be developed for seasonal periods and for ice-affected periods. The electronic processing system should provide a flexible method of developing regression equations, allowing the user to specify reference gage records, time periods, and discharge ranges. The regression equations should include the ability to time-lag reference gage records, and to use transformations of discharges (for example, logarithmic). Also, developed regression equations and their associated limitations, should be documented and archived for later use, if desired.

A regression equation can be applied to provide estimated discharges for periods of missing record. In addition, the same regression equation should be used to compute discharge values for short time periods adjacent to the estimated period where discharges are known. These adjacent periods sometimes can be used for verifying the accuracy of the regression results, and for adjusting the estimated discharges during the period of missing record to more closely fit the adjacent known records.

13.1.4 Water-Budget Method

A gaging station located just upstream from a reservoir, for the purpose of measuring inflow to the reservoir, can have missing discharge records estimated using the water-budget method if accurate records are available for the outflow from the reservoir and the change in contents of the reservoir. The daily inflow to the reservoir is equal to the daily outflow plus or minus the change in reservoir contents. In some cases, where the flow at the inflow station may not represent the total inflow to the reservoir, an adjustment may be required. The adjustment may be simply the application of a drainage area ratio, or other multiplication factor supplied by the user. The adjustment factor can also be estimated by applying the water-budget equation during periods when inflow, outflow and storage records are all available. The water-budget method is

$$Q_i = K(Q_o + \Delta C) \ , \tag{32}$$

where

Q_i = flow at inflow gage,

Q_o = outflow from reservoir,

K = inflow adjustment factor, and

ΔC = change in contents of reservoir, computed as midnight contents on current day minus midnight content on previous day.

The same principle can be used to estimate missing outflow records, for gaging stations located just downstream from a reservoir. Equation 32 simply is rearranged to solve for outflow, Q_o.

13.1.5 Mathematical Translation Method

The mathematical translation method is a set of various mathematical functions that can be used to translate streamflow records for other gaging stations (referred to as reference gages) into estimates of streamflow for the gage.site where missing records result. Some of these functions are similar to the regression method described in section13.1.3, but are defined independently from regression methods. The selection of reference gages to use for making an estimate is important because the reference stations should be hydrologically related to the station for which estimates are made. For this reason, reference stations usually are nearby stations, have similar runoff characteristics, and are sometimes stations on the same stream. The user should use considerable care and judgment in selecting stations to use with the mathematical translation method. This method includes the following mathematical functions.

- Combining two streamflow records by addition, subtraction, multiplication, or division.
- Transforming a streamflow record into a different record using

$$Q_e = a + b(Q_r + c)^d \, , \tag{33}$$

where

Q_e = estimated discharge,

Q_r = discharge at reference gage, and

a, b, c, and d, are constants defined by the user.

- Offsetting a reference gage record by a specified time period. The offset record can be mathematically combined with another reference record, or can be transformed by an equation. Two or more reference records can be offset with the same, or different, offsets.
- Transformation of reference gage records into log10, and inverse log10. These transformations can be made prior to performing any of the above mathematical functions.

13.1.6 Flow Routing Methods

Various flow routing models can be used to route a streamflow record from a reference gage to a downstream location on the same stream, thereby providing an estimate of the flow at a downstream gage site. However, these models are used external to the electronic processing system, and the results must be imported to the streamflow data base. Generally, it is not expected that such models will be used very often for estimating streamflow records because of the complex and intense efforts needed for calibration and application.

13.2 Estimating Gage Height and Other Hydrologic Parameters

Discharge is the primary parameter for most gaging stations, and discharge estimates usually are made for missing periods so that a complete record is available for each year. Complete records of other secondary, hydrologic parameters, such as gage height or stream velocity, are not always required and estimates are not usually made when missing records result. However, in some cases estimates of these secondary parameters are necessary.

Gage height (or elevation) can be reliably estimated only for short periods of missing record, and even then, only when gage-height changes are small during the period. Therefore, it is recommended that gage-height (or elevation) records not be estimated, unless specifically required for publication or for computation of another parameter when no other reliable method of estimating that parameter is available. For instance, it usually is easier and more accurate to make direct estimates of discharge than it is to estimate gage height for the purpose of computing discharge.

When gage-height record must be estimated, subjective judgment and interpolation between periods of good record should be used. The user should use all available information, such as miscellaneous gage readings, peak and minimum stage information, and comparison with nearby gage sites to aid the estimation process.

13.3 Comparison of Estimation Results

It is important that all estimated discharge records, and other parameter estimates be compared with known records and with estimates made by various methods for the same time period. The best method of comparison is by plotting the hydrograph that includes the estimated records. In this way the estimated records can be compared visually to the observed records on either side of the estimated period. Likewise, two or more estimated records for the same period can be compared visually for consistency and accuracy. The comparison procedure should allow the user to make changes and revisions to the estimated record as appropriate. Finally, the user should select the best estimate for incorporation of the records into the data base.

13.4 Flagging and Archival of Estimation Results

All estimated values of discharge and other hydrologic parameters should be flagged in the data file as *estimated*. If estimates are made by one or more of the named estimating procedures, this information automatically should be written to the record processing notebook (see section15.1) for use in preparing the station analysis (section15.3). The estimated values and the applicable flag should be archived with the observed data.

In some cases, where a parameter such as discharge is computed from estimated values of another parameter, such as gage height, the computed parameter should be flagged as "*computed from estimated values of* _____." The wording of this flag should be varied to fit the situation.

14. Monthly and Annual Value Computations

Monthly and annual values of stage, elevation, discharge, runoff, reservoir contents, and tidal lows and highs should be computed for each station as required or as designated. The required and designated monthly and annual values will vary with station type and with specific stations. All computations of monthly values should be based on the rounded results of daily values, and all computations of annual values should be based on rounded results of either daily or monthly values, as indicated. This results in consistent agreement of the daily, monthly, and annual values.

At least two sets of annual values should be computed for each gaging station, (1) for the calendar year, January through December, and (2) for the water year, October through September. In special cases, the user may designate additional or alternative types of years, such as the climatic year, April through March.

14.1 Monthly and Annual Values of Stage

Monthly and annual values of stage should be computed for those stations where stage routinely is measured for defining the gage-height fluctuations of a stream. For some stations, the stage may be the primary end product, such as for a stage-only station. In other instances the stage may be measured for the purpose of computing other parameters, such as discharge.

The monthly stage values that should be computed are the following.

- *Monthly mean stage, in feet*—The arithmetic mean of all daily mean stages for each month.
- *Monthly minimum daily stage, in feet*—The lowest daily mean stage for each month.
- *Monthly maximum daily stage, in feet*—The highest daily mean stage for each month.

The annual stage values that should be computed are the following.

- *Annual mean stage, in feet*—The arithmetic mean of all daily mean stages for the water year and calendar year.
- *Annual minimum daily stage, in feet*—The lowest daily mean stage for the water year and calendar year.
- *Annual maximum daily stage, in feet*—The highest daily mean stage for the water year and calendar year.

14.2 Monthly and Annual Values of Discharge

Monthly and annual values of discharge should be computed for gaging stations where daily discharge is routinely computed, such as for a stage-discharge station, a slope station, a velocity-index station, or other station types where streamflow is the parameter of primary interest. Some of the monthly and annual values are required, whereas others are optional, and are computed only for specific gaging stations. The optional computations generally are designated on the basis of streamflow conditions, drainage basin size, natural runoff conditions, degree of regulation, and other factors that may affect the hydrologic value and need for the computed parameters.

The monthly discharge values that are required are the following.

- *Monthly total discharge, in cubic feet per second-days*—Total of all daily mean discharges for each month.
- *Monthly mean discharge, in cubic feet per second*—The mean of all daily mean discharges for each month, and is computed by dividing the monthly total discharge by the number of days in the month.
- *Monthly minimum daily discharge, in cubic feet per second*—The lowest daily mean discharge for each month.
- *Monthly maximum daily discharge, in cubic feet per second*—The highest daily mean discharge for each month.

The monthly discharge values that are optional are as follows.

- *Monthly runoff volume, in acre-feet*—This is the monthly total discharge, converted to a volume, in acre-feet, and represents the total number of acres that would be covered to a uniform depth of 1 ft by the total discharge for that month. The monthly runoff volume, in acre-feet, is computed by multiplying the monthly total discharge, in *cubic feet per second-days*, times the conversion constant, 1.983471.
- *Monthly runoff depth, in inches*—The monthly total discharge volume, converted to a depth, in inches, that would uniformly cover the drainage basin. The monthly total runoff depth, in inches, is computed by multiplying the monthly total discharge, in *cubic feet per*

second-days, times the conversion constant, 0.03719, divided by the drainage area, in square miles.

- *Monthly mean unit runoff, in cubic feet per second per square mile*—The monthly mean flow that would emanate from 1 mi^2 of drainage area, if the flow were uniformly distributed throughout the drainage basin. Monthly mean runoff, in *cubic feet per second per square mile*, is computed by dividing the monthly mean discharge, in cubic feet per second, by the drainage area, in square miles.

The annual discharge values that are required are as follows.

- *Annual total discharge, in cubic feet per second-days*—The total of all daily mean discharges for the year.
- *Annual mean discharge, in cubic feet per second*—The mean of all daily mean discharges for the year, and is computed by dividing the annual total discharge by 365, or by 366 for leap years.
- *Annual minimum daily discharge, in cubic feet per second*—The lowest daily mean discharge for the year.
- *Annual maximum daily discharge, in cubic feet per second*—The highest daily mean discharge for the year.

The annual discharge values that are optional are as follows.

- *Annual runoff volume, in acre-feet*—The annual total runoff volume, in acre-feet, is computed by summing the monthly values of runoff volume for the year.
- *Annual runoff depth, in inches*—The annual total runoff depth, in inches, is computed by summing the monthly values of runoff depth for the year.
- *Annual mean unit runoff, in cubic feet per second per square mile*—The annual mean runoff, in cubic feet per second per square mile, is computed by dividing the annual mean discharge, in *cubic feet per second*, by the drainage area, in square miles.

14.3 Monthly and Annual Values for Reservoirs

The computation of monthly and annual values for reservoir stations is varied and highly dependent on the type of daily values that are used for the station. Reservoir stations may require daily mean elevations, daily mean contents, elevation at a specific time (for example, at 0800, 1200, 2400, or other time), or contents at a specific time. The choice of daily values that are used, and published, for a reservoir station is dependent on user requirements, and consequently, the monthly values that should be computed will be based on these same requirements. The list of monthly and annual values that can be computed is fairly long (see below), but generally only a few of these values will be chosen for a given reservoir station. The choice will be partially based on the daily values used for the station, and partly on other considerations that relate to the anticipated use of the monthly and annual values.

The monthly reservoir values that may be computed are as follows.

- *Monthly minimum value*—The lowest value during the month of one or more of the following parameters:
  - daily mean gage height
  - daily mean elevation
  - daily mean contents
  - daily maximum gage height
  - daily maximum elevation
  - daily maximum contents
  - daily minimum gage height
  - daily minimum elevation
  - daily minimum contents
  - daily gage height at a specified time
  - daily elevation at a specified time
  - daily contents at a specified time

The full parameter name is formed by preceding the selected name(s) by “monthly minimum”; for example, “monthly minimum daily maximum elevation.”

- *Monthly maximum value*—The highest value during the month of selected parameters. The possible choices are the same as listed above for monthly minimum values, and the full parameter name is formed as explained above.
- *Monthly mean value*—The mean of all daily values during the month of one or more of the following parameters:
  - daily mean gage height
  - daily mean elevation
  - daily mean contents

The full parameter name is simply monthly mean gage height, elevation, or contents.

- *End of month contents*—The reservoir contents at time 2400 hours of the last day of the month.
- *Monthly change in contents*—The change in reservoir contents during the month. It is computed by subtracting the end of month contents for the previous month from the end of month contents for the current month. The change in contents may be shown in units of *acre feet, cubic feet,* or in units of *equivalent cubic feet per second,* or all three. Equivalent cubic feet per second is computed by dividing the change in contents, in cubic feet, by the number of seconds in the month.

The annual reservoir values that may be computed as follows.

- *Annual Minimum value*—The lowest value during the year of selected parameters. The possible choices are the same as listed above for monthly minimum values.
- *Annual maximum value*—The highest value during the year of selected parameters. The possible parameters are the same as listed above for monthly minimum values.
- *Annual mean value*—The mean of all daily values of selected parameters during the year. The possible parameters are the same as listed above for monthly mean values.
- *End of year contents*—The reservoir contents at time 2400 hours of the last day of the year.
- *Yearly change in contents*—The change in reservoir contents during the year. It is computed by subtracting the end of year contents for the previous year from the end of year contents for the current year. The change in contents may be shown in units of acre feet, cubic feet, or in units of equivalent cubic feet per second, or all three. Equivalent *cubic feet per second* is computed by dividing the change in contents, in cubic feet, by the number of seconds in the year.

14.4 Monthly and Annual Values for Tidal Stations

Tidal stations require the computation of various monthly and annual values as described below. For tidal stations that use an arbitrary gage-height datum and a datum-conversion constant to convert the gage heights to NGVD, the monthly and annual values should be computed for both datums.

The monthly tide values that may be computed as follows.

- *Monthly mean stage and/or elevation, in feet*—The mean of all daily mean stages and/or elevations for each month.
- *Monthly mean high tide, in feet*—The mean of all daily HIGH-HIGH tide stages and/or elevations for each month.
- *Monthly mean low tide, in feet*—The mean of all daily LOW-LOW tide stages and/or elevations for each month.
- *Monthly minimum low tide, in feet*—The lowest of all daily LOW-LOW tide stages and (or) elevations for each month.
- *Monthly maximum high tide, in feet*—The highest of all daily HIGH-HIGH tide stages and (or) elevations for each month.

The annual tide values that may be computed as follows.

- *Annual mean stage and/or elevation, in feet*—The mean of all daily mean stages and (or) elevations for the year.
- *Annual mean high tide, in feet*—The mean of all daily HIGH-HIGH tide stages and/or elevations for the year.
- *Annual mean low tide, in feet*—The mean of all daily LOW-LOW tide stages and/or elevations for the year.
- *Annual minimum low tide, in feet*—The lowest of all daily LOW-LOW tide stages and/or elevations for the year.
- *Annual maximum high tide, in feet*—The highest of all daily HIGH-HIGH tide stages and/or elevations for the year.

15. Documents

The operation and maintenance of gaging stations, and the analysis and publication of gaging station records, requires a number of documents to describe each gage and to document the records for that gage. In an automated electronic processing system these documents can be easily prepared using prescribed formats, automatic transfer of information, and a word-processing system. Four basic documents, (1) record processing notebook, (2) station description, (3) station analysis, and (4) station manuscript should be incorporated and formatted for each surface-water record. Additional, miscellaneous documents, such as the documentation of an indirect measurement, can be prepared, as needed, using the word-processing system.

15.1 Record Processing Notebook

The record processing notebook is an open comment file that can be accessed at any point during the processing of a gaging station record. The notebook provides the user a place to record comments pertaining to the data and information, the reasoning for various analytical steps such as shifts, data corrections, rating changes, and others, and other information that should be retained for future use. One of the main uses for the notebook is the preparation of the annual station analysis (described in section15.3) where it will allow quick and easy recall of the analytical steps used during the preceding year. All comments recorded in the notebook automatically should be categorized into defined subjects, patterned primarily according to the format of the station analysis. In addition, all comments should be dated automatically according to the date of entry, and automatically signed with the name of the user making the entry. All processing steps should fit into one of the comment categories listed below.

- *Equipment*—All comments pertaining to field equipment such as recorders, gage structures, artificial controls, cableways, and other field measuring devices should be saved as an equipment category. Most comments in this category will be derived from field notes such as discharge measurements, level notes, crest-stage gage notes, and miscellaneous notes.
- *Unit values data*—All comments pertaining to unit values of gage height, elevation, index velocity, and other unit values field data should be saved in this cate-

gory. These comments generally will relate to the completeness and accuracy of the input unit values files, and will include information such as periods of missing record, reasons for missing record, substitute record, estimated record, time corrections, and others. Most comments for this category will be derived during the entry, verification, and editing of unit values files.

- *Unit values data corrections*—Comments in this category will relate to unit values data corrections, including datum corrections resulting from gage leveling. These comments should describe any gage problems that caused erroneous (but correctable) unit values to be recorded, the method of making corrections, and changes in gage datum. Most comments for this category will come from the parameter value corrections processing step and the gage datum analysis step.
- *Rating analysis*—Comments in this category will relate to all phases of rating analysis, including the development of new ratings, revision of old ratings, use of cross-section data to define ratings, control conditions, shift analysis, shift application, rating curve plots, shift curve plots, and any other aspect of rating curve analysis.
- *Discharge computations*—Comments in this category will relate to the methods of producing unit and daily discharge records. These comments will include methods of direct computation and methods of estimating record during periods of missing record, ice, backwater, and other conditions. Comments for this category should be derived during the primary computation phase and missing record estimation phase of record processing.
- *Quality assurance and accuracy*—Comments in this category will relate to any phase of record processing that provides special applications of quality control and quality assurance. Comments also should be included for any condition that may affect the accuracy of the records. Comments for this category may be derived at any point during the process of producing a streamflow record from the initial entry of field data through the final computation steps.
- *Miscellaneous*—Comments in this category will be miscellaneous comments that do not fit in any of the other categories.

15.2 Station Descriptions

The station description is a narrative of the features and characteristics of a gaging station. A basic format containing specified topics is used for most station descriptions; however, deviations from the basic format sometimes are needed to describe special gaging station installations. Most of the input for preparing or editing a station description is supplied by the user. Some items, however, should be supplied automatically from other parts of the electronic processing system. For instance, when new elevations of reference marks, benchmarks, and other gage features are entered in the electronic processing system, these elevations automatically should be transferred to the station description. Other automatic transfers should be made, as appropriate.

A complete station description usually is prepared when a new gaging station is established. The date of preparation, and the name of the preparer automatically should be attached to a new station description. After the station description is completed, generally it will not require complete rewriting for many years, unless there is a major change in the gaging station. However, minor changes or changes to one or two features of a station may occur from time to time, and the station description should be edited to reflect these changes. The electronic processing system should provide an easy and flexible method for making such changes. In addition, the date of editing, and the name of the person making the change, automatically should be attached to each change. Automatic updating, made with the electronic processing system, should be footnoted as such.

The following items are suggested for most station descriptions; however, some of these may not apply to a specific gaging station and should not be used. On the other hand, additional items may be required for some gaging stations. Also, some stations (such as slope stations) may have auxiliary gages and will require multiple entries for some items. See Kennedy (1983) for additional details.

- Station name
- Station ID
- Location and road log
- Establishment
- Drainage area
- Gage
- History
- Reference and benchmarks
- Channel and control
- Discharge measurements
- Floods
- Gage height of zero flow
- Winter flow
- Regulation and diversions
- Accuracy
- Cooperation
- Purpose of record and gage classification
- Land ownership
- Indirect measurement site
- Sketch
- Photographs
- Observer

15.3 Station Analyses

The station analysis is a narrative description of the methods used to analyze the gaging station records for a water year. The analysis includes information about station equipment, performance of the gage and related equipment, the rating, shifting control methods, computation of discharge, accuracy, and any other information about how the station records were produced. The station analysis is one of the most important documents produced for each year of gaging station records because it is the primary documentation for quality assurance and quality control of these records.

The station analysis for a gaging station usually is written and finalized at the end of each water year, however, parts of it may be written at any time during the year as information becomes available. The *record processing notebook* described in section 15.1 should be utilized to the fullest extent as an aid in writing the station analysis. The electronic processing system automatically should transfer information from the record processing notebook to the appropriate paragraphs of the station analysis.

The electronic processing system also should automatically transfer information from other parts of the electronic processing system to the station analysis phase to assist the user. Specific transfer items should include the following.

- Level and datum information should be transferred from the most recent level summary. This information should include the date of the latest levels, and information about datum differences of the various gages at the station.
- All periods (dates) of missing record, and the total number of days of missing record, should be transferred from the unit values files.
- The minimum and maximum gage heights recorded during the water year should be transferred from the unit values files.
- The number of discharge measurements made during the water year, and their corresponding sequence numbers, should be transferred from the measurement file. In addition, the lowest and highest measured gage height and discharge should be transferred from the measurement file.
- The comparison of measured discharges to computed unit values of discharge should be transferred from the table described in section 9.3.5.
- Methods of estimating missing records and ice records should be transferred from the electronic processing system documentation of estimating missing records for the water year.
- The listing of records used for hydrograph comparisons should be transferred from the electronic processing system documentation of hydrograph comparisons used for the water year. This listing should include station names, parameters compared, and periods of record compared.
- The sequence numbers for the rating curves and the shift curves used during the water year should be transferred from the rating curve file and the shift curve file.
- Any information relative to quality control should be transferred from field notes, record processing notebook, and comment files that have been documented in the electronic processing system.

The transferred information, both from the record processing notebook and the various other parts of the electronic processing system, then can be used to write the station analysis. The station analysis should include, at a minimum, the following items and paragraphs. For some gaging stations, other paragraphs may be required in order to adequately describe the computation methods. See Kennedy (1983) for additional details.

- Station name
- Station ID
- Water year
- Equipment
- Gage-height record
- Gage-height and datum corrections
- Rating
- Discharge
- Quality assurance and control
- Remarks
- Recommendations

The name of the user who writes the station analysis, and the date of preparation, automatically should be attached to the end of the station analysis. Also, the name of the reviewer (see section 16) automatically should be attached, along with the date of review completion.

15.4 Station Manuscripts

The station manuscript is the narrative part of the published page for each gaging station record for each water year. A standard format is used that consists of paragraphs, as required, taken from the following list.

- A heading consisting of the basin name, station number, and station name
- Location
- Drainage area
- Period of record
- Revised records
- Gage
- Remarks (includes statement on accuracy)
- Cooperation

- Extremes for period of record
- Extremes outside the period of record
- Extremes for current year
- Revisions

The station manuscript is combined with the table of daily, monthly, and annual values to form the final publication page for each gaging station. In addition, a number of statistics are determined for the current water year, the current calendar year, and the period of record. These statistics are arranged in such a way as to provide a comparative presentation of data for the gaging station. For some stations, multiple statistical summaries are included, such as separate summaries before and after regulation by a major reservoir. The final station manuscript is variable among gaging stations depending on the period of record, the parameter of interest, the statistical presentation, and other characteristics of each individual station. For details of station manuscript preparation, see Novak (1985).

A copy of the previous year's manuscript (if available) should be recalled for use as a guide and starting point for the preparation of the current year's manuscript. Information used for completion of some parts of the station manuscript automatically should be computed and transferred from other parts of the electronic processing system. The electronic processing system automatically should highlight any differences of information between the previous and the current manuscript.

16. Review, Approval, and Finalization of Records

Gaging station records are reviewed at various points during the process of entering, analyzing, interpreting, and computing the streamflow information. These records generally are referred to as working reviews that usually are made by the user as the records are processed. This report refers to a number of places during the process of producing a streamflow record where such reviews should be made. Working reviews are a normal function of the record production process, and the electronic processing system provides the user with numerous aids to make this process as easy as possible.

A formal review should be made after the records have been processed and the user is satisfied that the records are complete and accurate. This final review should be made by a senior reviewer who is designated to make such reviews. This review ultimately results in the approval and finalization of the records for publication and archival if the reviewer finds that the records are complete and accurate. If this review reveals deficiencies in the records, the reviewer can return the records to working status (see section 17.2).

The formal review should have access to all of the same review functions that are used in the record processing steps. These review functions would include all output tables, such as the discharge measurement summary tables, the level summary tables, the unit values tables, the primary computation tables, the diagnostics tables, the daily values tables, and any other table produced during the record processing. Of even greater importance, the final reviewer should have easy access to graphs such as the rating curves, shift curves, unit values hydrographs, and daily values hydrographs. The reviewer also should have access to the comments file and should be allowed to enter comments. If a station analysis has been prepared, the reviewer should be allowed to review and edit, as appropriate.

When the review is complete and the records are considered acceptable and accurate, they should be designated as approved. The electronic processing system should flag the records as approved and ready for publication and archiving. Records that are flagged as approved should be protected from any further changes or revisions. In the event that a change to an approved record is required, the records must be set back to working status (see section 17.2).

17. Status of Data and Information

All data and information will progress through a hiearchy of processing steps. These steps include (1) original data, (2) working data, (3) review, (4) approval, and (5) publication. Specific processing functions that pertain to each of these steps have been described in previous parts of this report. The status of the data and information as they progress through these steps are described in sections 17.1 through 17.5.

17.1 Original Data

Original data are defined as direct measurements of a field parameter such as gage height, velocity, depth, width, or other station variable. Direct field measurements are considered to be those made by the hydrographer while at the gage site. These include all measurements required to make a streamflow measurement, direct visual readings of gages, determinations of highwater marks and crest-stage gage readings, leveling data, and other data collected during the course of servicing the gage. Historically, these notes and measurements were recorded on paper field notes. Presently (2002), paper field notes are the accepted media by the USGS. Paper field notes are considered the original data, and should be preserved even though much of the data and information from these notes will be entered manually to the electronic processing system.

Electronic field notebooks presently are in the early operational stages for the purpose of recording direct field measurements. It is expected that these notebooks will be used extensively within the next 5 to 10 years, and may eliminate the need for some or all of the paper note recording. All field measurements recorded in electronic format should be electronically transferred to the electronic processing system. The first transfer of this type becomes the original data and should be preserved without alteration. Any supplemental paper field notes should be preserved separately as original data.

In addition to direct field measurements made by the hydrographer, most gaging stations have automatic recorders to continuously, or intermittently, record gage height, velocity, or other parameters. Some gages contain two automatic recorders that record duplicate data. Frequently, one recorder is designated the primary recorder and the second recorder is designated as a backup recorder. Data from the primary recorder should be considered the primary original data. Data from the backup recorder also are original data, but should be used only for filling in missing or erroneous periods of the primary record. The process of filling periods of missing data should not be performed on the original records, but should be done on the working records. Both the primary and backup original unaltered data should be set aside for archiving.

Various types of automatic field recorders are currently in use by the USGS, each having unique characteristics that relate to the definition of original data, as well as to the format and method by which the data will be preserved. The following text describe these characteristics.

- *Analog recorders*—Analog recorders are graphical recorders that record a pencil or pen trace on a paper chart. This chart is the original record and should be preserved. Various mechanical and electronic methods are available that can be used to digitize the graphical record into an electronic record suitable for entry to the electronic processing system. The digitized record is not considered an original record, and should be used only as a working record (see section 17.2 for a definition of working data).
- *Automated digital recorders*—Automated digital recorders record data as punched holes in a paper tape. These tapes cannot be read easily by eye, and usually are translated into an electronic format by paper tape readers. The first electronic unaltered translation of the tape is considered the original record and should be permanently preserved.
- *Electronic data loggers*—Electronic data loggers record data in various formats that must frequently be translated to engineering units through the use of special algorithms. The first translation to engineering units is considered to be the original record and should be preserved as such.
- *Data-collection platforms*—Data-collection platforms are systems whereby data are transmitted from the field site to an office by radio, telephone, or satellite. In addition, the data frequently are recorded at the field site by a data logger or other backup recorder. The primary original record may be either the field recorded data or the transmitted data, depending on the individual gage setup, or the specific policy of the office collecting the data. In either case, the designated primary original data and the designated backup record should be preserved.

All original data that are entered to the electronic processing system should be preserved unaltered with the electronic processing system, and should be set aside for permanent archiving. A duplicate copy of the original data files should be made for the working files.

17.2 Working Data

Copies of original data files are put into a status of *working data*. Working data files are processed with the electronic processing system based on prescribed computation routines and by interactive input by the user. Data and information in the working status generally follow a specific navigation path (see section 12) of transformations and computations that ultimately result in a record of discharge, reservoir contents, or other parameter that is published or used for various project work. While in the working status, data and information may be changed as deemed appropriate by the user, reworked if necessary at any point in the working process, and even completely deleted so that processing can be restarted. At some point, however, when the user is satisfied that the computations are complete and accurate, the working files are moved to a review status. At this point, changes can no longer be made unless the data files are moved back to working status at the direction of a designated reviewer.

17.3 Review

The process of review has been described in section 16. Review status is the point where a senior reviewer reviews the records and either accepts the records and recommends them for approval, or rejects the records and recommends a complete or partial reworking. Records that are in the review status may not be changed or altered in any way. If the review reveals the need for changes, the records must be moved back to working status as described in section 17.2.

17.4 Approval

The approval status is the step following review, and results from the final approval of records as described in section 17.3. Records that are approved are considered ready for publication.

17.5 Publication

The publication status refers to records that are published in USGS annual data reports, released as approved records for public access, or released for public use in an electronic media such as CD ROM or the World Wide Web. Published records may be revised, but the original published values must be retained and flagged as *superseded*. The new, revised values must be flagged as *revised*. Revisions to approved and published records must follow USGS guidelines for publication (Novak, 1985) of water-resources data.

18. Archiving

Data archiving is a complex subject that deals with the permanent retention, protection, and accessibility of original records, and other records that support published scientific studies and analyses. With the advent of electronic media for collection and analysis of hydrologic data and information, it has become increasingly difficult to define the method by which these records should be archived. A study group in the early 1990's addressed the problems of data archiving, and made recommendations that are given by Hubbard (1992). That report provides a comprehensive set of recommendations for the management and retention (archiving) of hydrologic data, both for hard copy and electronic data and information, and should be used as the basis for permanent archiving of all hydrologic data and information. Only a brief summary of the archiving recommendations for electronic data and information will be given here, as taken from Hubbard (1992).

The following list of electronic data and information is not all inclusive, but at a minimum these items should be placed in permanent electronic archives.

- All original data for automated data-collection sites, as defined in section17.1.
- Records of algorithms used to convert field values to conventional engineering units.
- All non-automated data collected in electronic format, such as discharge measurement notes, as defined in section 4.2.
- All approved files of edited and calculated data, such as unit values and daily values of gage height, velocity, correction values, shift adjustments, discharge, reservoir contents, and other parameters resulting from the processing of the gaging station records.
- All approved algorithms, rating curves, shift curves, and other transformation information required for the processing of the records.
- All documents specific to a gaging station, such as station descriptions, station analyses, station manuscripts, level summaries, and comment files.

19. Quality Assurance and Quality Control

Quality assurance and quality control (QA/QC) is the process of performing specific tasks that ensure that the input data, algorithms, transformations, computations, and final results are complete and accurate to the greatest extent possible. Much of the QA/QC process is automatic in that many arithmetic checks, cross checks, and logic checks are programmed into the electronic processing system software. When inconsistencies are found in field data, computed records, or other parts of the records, the electronic processing system alerts the user so that appropriate changes can be made. These automatic checking routines have been defined and explained in various sections of this report, but primarily in sections 5 and 6. In addition to the automatic QA/QC checking, the electronic processing system provides a number of places where the user or supervisor can review and compare the computations and final results. All of these tasks, both automatic and manual, are important to the quality-assurance and quality-control process.

In addition to the actual checking and review process, it equally is important that the QA/QC process and findings be documented. For streamflow and other surface-water gaging stations, the documentation traditionally has been known as an annual *station analysis*. The preparation of a station analysis is described in section 15.3. Automation and electronic processing provides an easy and efficient means by which data and information can be supplied to the writer of the station analysis. A number of different reports and information items that can be used for this purpose are described in the station analysis section (15.3). Some of these reports may be useful as QA/QC documentation.

In summary, the quality-assurance and quality-control process is a continuous process that starts when data are collected in the field, and continues throughout the data and information processing procedure. This section of the report does not define specific QA/QC tasks because these are imbedded within each of the many steps required to produce a surface-water record.

20. Summary

The USGS has been using automated data-processing methods in various electronic systems to process surface-water records since about 1963. This report describes standards for the processing, computation, and analysis of streamflow records using modern electronic computer methods. The traditional USGS methodology for streamflow data collection and analysis has been incorporated into these standards to the greatest extent possible. Although these standards are intended for use primarily by the USGS, they may be used by other organizations doing similar work. In addition, the high speed and versatility of present-day computers allow for the design of an electronic processing system that offers many new opportunities to expand and improve on the ways that some traditional USGS methods have been applied.

Surface-water *data* and surface-water *information* are defined for this report to distinguish between a variable that is measured and cannot be repeated (data), and a variable that is computed or changed in some way (information). For example, a measurement of gage height or a measurement of depth are considered data. Whereas, a computed value of discharge or cross-section area is considered information. The term *unit value* is defined as data or information that is associated with a specified time and date, and usually is part of a time-series. *Daily values* are data or information that is associated with a specific date, and the time of the daily value usually is not required.

One of the first steps for use of the electronic processing system is the entry of data and information. Unit values of data are obtained from various sources such as observer data, analog recorders, automated digital recorders, electronic data loggers and data-collection platforms. The time system for unit values is important, and is usually based on local time, which includes standard and daylight savings time. However, the electronic processing system should provide the capability to transform and store all times in Universal Coordinated Time (UTC). Field measurement data and information, such as discharge measurements, gage datum leveling, crest-stage gage data, and cross-section data also must be entered to the electronic processing system. These data and information may require manual entry from paper field notes or from electronic field notebooks.

All unit values entered to the electronic processing system should be verified and edited, if necessary. However, an electronic copy of the original values should be archived, and all data processing should be performed on a copy of the original values. Times and dates should be verified, and corrections and adjustments made, as necessary, to account for clock errors. UTC adjustments should be made following the time and date corrections. Parameter values, such as gage height, should be verified by making various comparisons such as threshold comparisons, rating-curve comparisons, direct-reading comparisons, and graphical comparisons. Corrections to parameter values should be made for any datum or instrument errors that may have occurred.

Field measurement data and information that are entered to the electronic processing system require various checks to verify correctness. Some field measurements also require special analyses for use in other parts of the electronic processing system. Discharge measurements should be checked for arithmetic errors, and for logic and consistency. The standard error of discharge measurements should be computed if applicable methods can be used. Shift analysis should be made according to the methods defined for stage-discharge ratings, slope ratings, rate-of-change-in-stage ratings, and velocity-index ratings. Special procedures for verification and analysis apply to some measurements, such as ice measurements, measurements with vertical angles, moving boat measurements, acoustic Doppler current profiler measurements, indirect measurements, weir and flume measurements, tracer-dilution measurements, volumetric measurements, and discharge estimates. Specific rounding and significant figures are defined for all discharge measurements.

Rating curves are an integral part of the computation of most streamflow records. The electronic processing system should accommodate the use of various rating curve types, including stage-discharge, stage-area, velocity-index, stage-velocity factor, stage-fall, fall ratio and discharge, stage-1/US_c, and elevation-reservoir contents. In addition, control structures require a number of different rating curves and equations. Ratings should be entered as tabular, graphical, or equations, and should be either linear or logarithmic. Scale offsets are an integral part of most logarithmic ratings, and the electronic processing system should provide flexibility in entering multiple scale offsets, and in computation of best scale offset.The user should be allowed to enter, draw, shape, and edit rating curves directly on the electronic monitor to avoid the time-consuming hand plotting and drawing of ratings. Finally, the electronic processing system should provide various rating development procedures based on stream hydraulics.

Stream channels change at times because of natural or manmade influences. For this reason, certain ratings may require temporary adjustments, called shift corrections. The ratings to which shifts may be applied are stage-discharge and velocity-index. All other ratings should be redrawn.

Primary computations are the functions that convert input data, such as gage height or velocity data into unit, daily monthly, and annual values of discharge or other output parameters.This part of the process should be carried out by the electronic processing system with minimal user interaction. It should produce tables, graphs, and files of information that commonly are referred to as primary output. Each station type has a specific primary computation process that produces specific information. However, the primary output for most gaging stations is to calculate stream discharge (unit, daily, monthly, and annual values) and some related information such as stage or velocity. Primary computations for reservoir stations produce reservoir elevation and contents. Primary computations for tide stations produce various tidal statistics such as high and low tide elevations.

Other functions that the electronic processing system should provide to the user include hydrograph plotting for both daily and unit values, and automatic determination of extreme values such as maximum and minimum stages and discharges for a water year and calendar year. The electronic processing system should provide navigation paths that guide the user through routine computation and analysis of the streamflow records for the various gage types. In order to produce complete records of daily streamflow and other parameters, estimating methods such as the hydrograph and climatic comparison method, discharge-ratio method, regression method, water-budget method, mathematical translation method, and the flow routing method are functions of the electronic processing system.

Various monthly and annual statistics should be computed for streamflow stations, reservoir stations, and tide stations.These statistics should conform to the traditional statistics that currently are published in USGS annual data reports. The electronic processing system should provide the user a place to enter and archive documents such as the record processing notebook, station descriptions, station analyses, and station manuscripts. Quality assurance and control should be a continuous process in the electroic processing system from data collection to archiving. Finally, the electronic processing system should allow easy access to the computed records for review, approval, finalization, and archiving.

21. References

Collins, D.L., 1977, Computation of records of streamflow at control structures: U.S. Geological Survey Water-Resources Investigations Report 77–8, 57 p.

Corbett, D.M., and others, 1943, Stream-gaging procedures: U.S. Geological Survey Water-Supply Paper 888, 245 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 Investigation, book 3, chap. A2, 12 p.

Dempster, George R., Jr., National water information system user's manual, v. 2, chap. 3, Automated data processing system: U.S. Geological Survey Open-File Report 90–116.

Fulford, J.M. (1993), User's guide to hydraulic information exchange program: A computer program for hydraulic properties computations. On file with the U.S. Geological Survey, at Stennis Space Center, MS 39529.

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.

Hutchison, N.E., and others, 1977, WATSTORE user's guide, v. 5, chapters I–IV: U.S. Geological Survey Open-File Report 77–729–I, 230 p.

Johnson, L.H., 1952, Nomography and empirical equations: New York, John Wiley, 150 p.

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

Kennedy, E.J., 1984, Discharge ratings at gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigation Report, book 3, chap. A10, 59 p.

Kennedy, E.J., 1990, Levels at streamflow gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigation Report, book 3, chap. A19, 31 p.

Novak, C.E., 1985, WRD data reports preparation guide: U.S. Geological Survey Open-File Report 85–480, 199 p.

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

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

Schaffrannek, R.W., Baltzer, R.A., and Goldberg, D.E., 1981, A model for simulation of flow in singular and interconnected channels: U.S. Geological Survey Techniques of Water Resources Investigation Report, book 7, chap. C3, 110 p.

Shearman, J.O., 1990, User's manual for WSPRO—A computer model for water surface profile computa tions: Federal Highway Administration Publication No. FHWA–IP–89–027, 177 p.