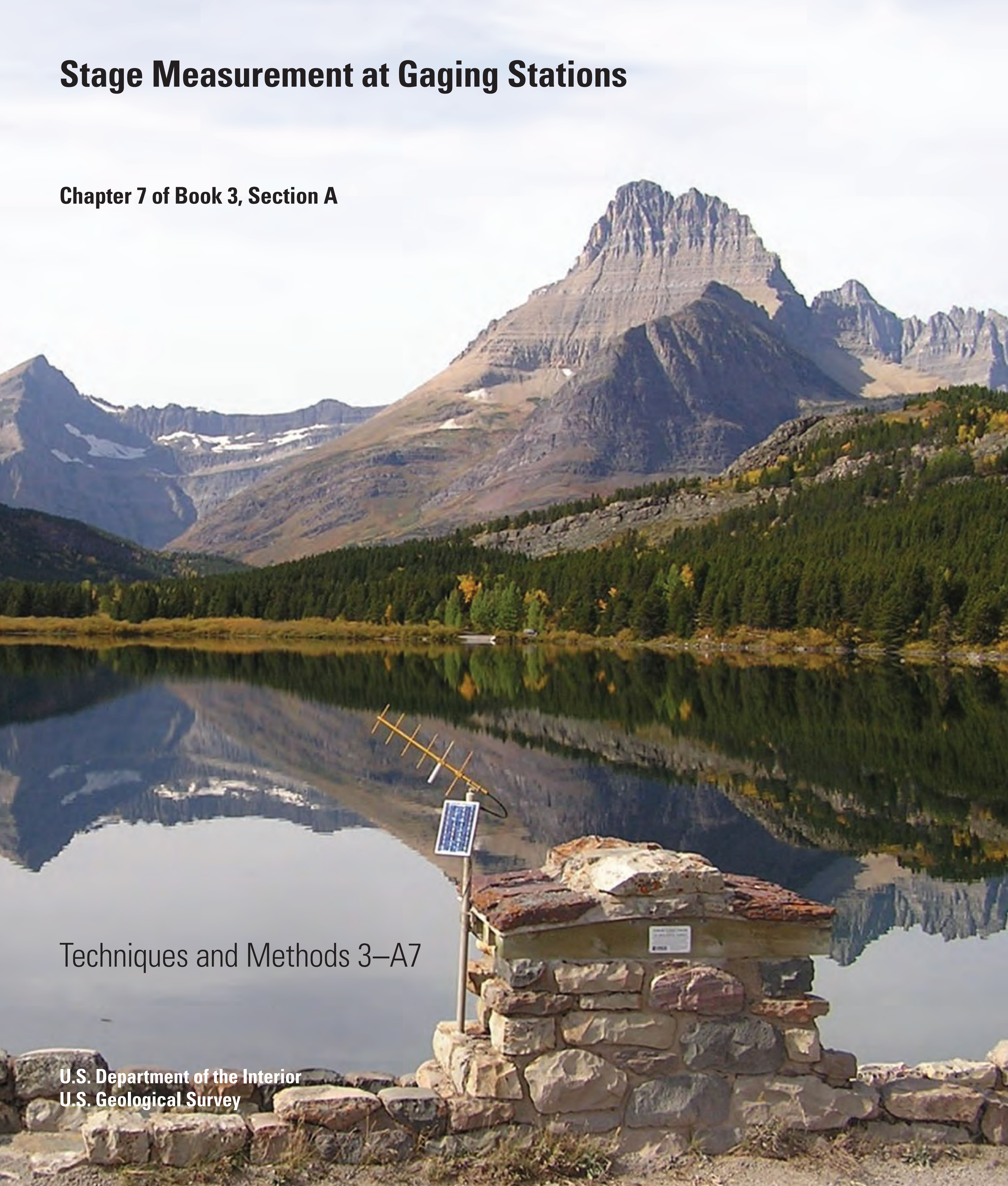
Stage Measurement at Gaging Stations

Chapter 7 of Book 3, Section A



Techniques and Methods 3–A7

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

Front cover: Looking upstream into Glacier National Park from Swiftcurrent Creek at Many Glacier, Mont. (U.S. Geological Survey station no. 05014500).
Back cover: On the top, hydrographer inspecting the streamgage at Prairie Dog Town Fork Red River near Canyon, Tex. (USGS station no. 07297500) in August 1925 (site is now discontinued). On the bottom, Streamgage construction crew at the Suwannee River at Ellaville, Fla. (USGS station no. 02319500), February 20, 1933.

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By Vernon B. Sauer and D. Phil Turnipseed

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

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Preface

This series of manuals on Techniques and Methods (TM) describes approved scientific and data-collection procedures and standard methods for planning and executing studies and laboratory analyses. The material is grouped under major subject headings called "books" and further subdivided into sections and chapters. Section A of book 3 is on surface-water techniques.

The unit of publication, the chapter, is limited to a narrow field of subject matter. These publications are subject to revision because of experience in use or because of advancement in knowledge, techniques, or equipment, and this format permits flexibility in revision and publication as the need arises. Chapter A7 of book 3 (TM 3–A7) deals with stage measurement at gaging stations. The original version of this chapter was published in 1968 as U.S. Geological Survey (USGS) Techniques for Water-Resources Investigations, chapter A7 of book 3. New and improved equipment, as well as some procedural changes, have resulted in this revised second edition of "Stage measurement at gaging stations."

This edition supersedes USGS Techniques of Water-Resources Investigations 3A–7, 1968, "Stage measurement at gaging stations," by T.J. Buchanan and W.P. Somers, available at *http://pubs.usgs.gov/twri/twri3a7/*, and supplements USGS Water-Supply Paper 2175, volume 1, 1982, "Measurement and computation of streamflow: Measurement of stage and discharge," by S.E. Rantz and others, available at *http://pubs.usgs.gov/wsp/wsp2175/html/WSP2175_vol1.html*.

This revised second edition of "Stage measurement at gaging stations" is published online at *http://pubs.usgs.gov/tm/tm3-a7/* and is for sale by the U.S. Geological Survey, Science Information Delivery, Box 25286, Federal Center, Denver, CO 80225.

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Pressure	
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)
ounce force per square inch (ozf/in^2)	110.316	kilopascal (kPa)
pound force per square foot (lb/ft^2)	0.0479	kilopascal (kPa)
	Density	
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter (kg/m^3)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Vertical coordinate information is referenced to the “National Geodetic Vertical Datum of 1929 (NGVD 29)” or the “North American Vertical Datum of 1988 (NAVD 88).”

Abbreviations and Acronyms

AC	alternating current power
ADAPS	U.S. Geological Survey National Water Information System Automatic Data Processing System
ADR	analog-digital recorder
ADVM	acoustic Doppler velocity meters
Accubar-3	Sutron Accubar Model 5600–0125–3
bps	baud rate expressed in bits per second
Bubbler	gas-purge Streamgaging system
CMP	corrugated metal pipe
CSG	crest stage gage
C type	Columbus type
DCP	data collection platform
DECODES	device conversion and delivery system
EDL	electronic data logger
FCC	Federal Communications Commission
GOES	Geostationary Operational Environmental Satellite
GPS	global positioning system
HDR	high data rate radio/transmitter
HIF	U.S. Geological Survey Hydrologic Instrumentation Facility
laser	light amplification by stimulated emission of radiation
LDR	low data rate radio/transmitter
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
NIST	National Institute of Standards and Technology
NOAA-NESDIS	National Oceanic and Atmospheric Administration’s National Environmental Satellite, Data, and Information Service
NOAA-NOS	National Oceanic and Atmospheric Administration’s National Ocean Service
NWS	National Oceanic and Atmospheric Administration’s National Weather Service
NSIP	U.S. Geological Survey National Streamflow Information Program
NWIS	U.S. Geological Survey National Water Information System
NWISWeb	U.S. Geological Survey National Water Information System Web site
OFR	U.S. Geological Survey Open-File Report
OSW	U.S. Geological Survey Office of Surface Water
PDA	portable digital assistant
PVC	polyvinyl chloride
radar	radio detection and ranging
TM	U.S. Geological Survey Techniques and Methods
TWRI	U.S. Geological Survey Techniques of Water-Resources Investigations
UPS	uninterruptable power supply
USGS	U.S. Geological Survey
WRD	Water Resources Division/Discipline
WWVB	National Institute for Standards and Technology time signal radio station near Fort Collins, Colo., that radio-controlled clocks throughout North America use to synchronize themselves

Definitions of Symbols

A_w	area of stilling well (in units of distance squared)
a_p	combined cross-sectional area of intake pipes (in units of distance squared)
d	average diameter of intake pipes (in units of distance)
$\frac{dh}{dt}$	rate of change of stage (in units of distance per unit time)
Δh	time lag of a stilling well's inside gage height (in units of distance)
g	acceleration of gravity (in units of distance per unit time squared)
K	*general loss coefficient to account for various intake pipe fittings*
K_v	3-way stem-cock valve loss coefficient, equal to 1.8 (do not use this coefficient if the intake is flush mounted or if a gate valve is used)
K_{sot}	side-outlet tee loss coefficient, equal to 1.1
K_{st}	static tube loss coefficient, equal to 1.6
L	average length of intake pipes (in units of distance)

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Abstract

Stream and reservoir stage are critical parameters in the computation of stream discharge and reservoir volume, respectively. In addition, a record of stream stage is useful in the design of structures that may be affected by stream elevation, as well as for the planning for various uses of flood plains. This report describes equipment and methodology for the observation, sensing, and recording of stage in streams and reservoirs. Although the U.S. Geological Survey (USGS) still uses the traditional, basic stilling-well float system as a predominant gaging station, modern electronic stage sensors and water-level recorders are now commonly used. Bubble gages coupled with nonsubmersible pressure transducers eliminate the need for stilling wells. Submersible pressure transducers have become common in use for the measurement of stage in both rivers and lakes. Furthermore, noncontact methods, such as radar, acoustic, and laser methods of sensing water levels, are being developed and tested, and in the case of radar, are commonly used for the measurement of stage. This report describes commonly used gaging-station structures, as well as the design and operation of gaging stations. Almost all of the equipment and instruments described in this report will meet the accuracy standard set by the USGS Office of Surface Water (OSW) for the measurement of stage for most applications, which is ±0.01 foot (ft) or 0.2 percent of the effective stage. Several telemetry systems are used to transmit stage data from the gaging station to the office, although satellite telemetry has become the standard. These telemetry systems provide near real-time stage data, as well as other information that alerts the hydrographer to extreme or abnormal events, and instrument malfunctions.

Introduction and Purpose

The stage of a stream or lake is the height or elevation of the water surface above an established datum plane. For rivers, lakes, reservoirs, coastal streams, estuaries, and surface-water bodies, the height of the water surface is usually referred to as an elevation measured above the North American Vertical Datum of 1988 (NAVD88), the National Geodetic Vertical Datum of 1929 (NGVD29), or some other citable datum.

The water-surface elevation for most rivers and streams is measured above an arbitrary or predetermined gage datum and is called the gage height of the river or stream. Gage height is often used interchangeably with the more general term stage, although the term gage height is more appropriate when used with a specific reading on a gage. Stage or gage height is usually expressed in feet and hundredths of a foot, or in meters and hundredths or thousandths of a meter.

A record of stream stage is useful in itself for designing bridges, embankments, levees, and other structures affected by stream elevations, or in planning for the use of flood plains. In streamgaging, gage heights are used as the independent variable in a stage-discharge relation to compute discharges. Reliability of the discharge record is therefore dependent on the reliability of the gage-height record, as well as the stage-discharge relation. Elevation records of lakes and reservoirs provide an index of lake-surface area and volume, as well as the elevation of the lake or reservoir.

Gage-height records may be obtained by systematic observation of a nonrecording gage, or with automatic water-level sensors and recorders. Various types of transmitting systems are frequently used to automatically relay gage-height information from remote gaging stations to office computers.

New technology, especially in the field of electronics, has led to a number of innovations in sensing, recording, and transmitting gage-height data. Whereas in the past, the majority of gaging stations used floats in stilling wells as the primary method of sensing gage height, the current trend is the use of submersible or nonsubmersible pressure transducers or radio detection and ranging (radar) sensors, which do not require a stilling well, are generally safer, and require less maintenance to operate. Unique to radar and optical [light amplification by stimulated emission of radiation (laser)] sensors, these instruments are usually operated out of the water, thus presenting a new set of uncertainties (for example, wind and waves, debris floating on the water surface, and air gaps), which are not encountered when the sensor is actually submerged or on the water surface.

Electronic data recorders and satellite transmission systems are now being used extensively. These new methods and equipment generally require only an instrument shelter with a simple bubble-orifice device in the stream, connected by tubing to a nonsubmersible transducer in the instrument shelter.

The purpose of this report is to describe the instrumentation and methods currently being used for the acquisition of gage-height data. This includes the traditional float/stilling-well method, and the newer methods utilizing pressure transducers, gas-purge systems, and radar sensors. The report first describes basic requirements necessary to all gages, such as gage-datum and stage-accuracy standards. Gage structures and the various types of instrumentation are described, such as reference and auxiliary gages, crest-stage gages, float gages, shaft encoders, bubble gages, recorders, telemetry systems, power supplies, submersible and nonsubmersible transducers, radar sensors, and other new instruments that are still in the development and testing phase. This report also describes various instrumentation configurations, methods of data retrieval, site selection, and gaging-station design and operation criteria.

Basic Requirements for Collecting Stage Data

The collection of stage data, either manually or automatically, requires various instrumentation, or components, established at a gaging site. For stage data to be useful for their intended purposes, requirements for maintaining a permanent gage datum and meeting specified accuracy limits are important. This section of the report provides definitions of the components, as well as the basic accuracy requirements. Descriptions of specific instrumentation are given in subsequent parts of this report.

Gage-Component Definitions

The reference gage for an automatic recording gaging station is a nonrecording gage used to set recorders, data loggers, or transmitters from which the primary gage-height record is obtained. The reference gage designated for this purpose is sometimes called the base gage, but this report uses the term “reference gage,” as defined by Rantz (1982). For gaging stations utilizing a stilling well, the reference gage is usually a staff gage, float-tape gage, or electric-tape gage located inside the stilling well. These gages are generally referred to as inside gages. For gages without stilling wells, such as a bubble gage, the reference gage is usually mounted directly in or over the stream, designated specifically to be the reference gage, and generally referred to as an outside gage. This may be a staff gage, wire-weight gage, chain gage, or other type of gage. For a nonrecording station, the reference gage is usually an outside gage, such as a staff gage, wire-weight gage, chain gage, or other type of gage read by an observer.

An auxiliary gage is any nonrecording gage other than the reference gage, and is used primarily for comparison and checking of the reference gage. For instance, where the inside gage is the reference gage, an outside gage is considered an auxiliary gage.

A stage sensor is a device that automatically determines (senses) the vertical position of the water surface. This may be a float riding on the water surface inside a stilling well. It may be a nonsubmersible pressure transducer coupled with a gas-purge bubbler orifice. It may be a submerged pressure transducer coupled with an electronic cable to transmit the vertical position of the water surface, and a venting tube to vent the submerged transducer to atmospheric pressure. Or it may be an acoustic, radar, laser, or optical pulse that reflects from the water surface to other instruments designed and calibrated for measuring or recording the gage height.

A stilling well and intake system consists of a closed well connected to the stream by intake pipes. It is designed so that an accurate water level of the stream can be determined inside the stilling well, even during rapidly rising or falling conditions, but without any appreciable surge or wave action. Stilling wells are generally used in conjunction with a float sensor, but can be used with gas-purge bubbler orifices.

A gas-purge bubbler orifice is a device placed in the stream, or sometimes near the bottom of a stilling well, to emit bubbles at a set rate. This device, when connected by a gas-fed tube to a gas-purge system and pressure transducer, becomes part of a bubble-gage stage-sensing system.

A pressure (or static) head, for the purposes of this report, is defined as the ratio between the pressure (pounds per square foot) and the density [pounds per cubic foot (lb/ft^3)] of a liquid, which for this report is typically the density of water (62.4 lb/ft^3). This is also known as the depth of the water at a given point.

Effective stage, for purposes of this report, is defined as the height of the water surface above an orifice, intake, or other point of exposure of the sensor to the water body.

A stage recorder is a graphical, digital, or electronic device that automatically records and stores gage-height readings sensed by a stage sensor. Graphical (analog) recorders produce a continuous chart of gage height. Digital and electronic recorders generally store gage heights at predetermined time intervals, such as every 5 minutes, 15 minutes, or 1 hour. Sometimes other uniform time intervals are used, as well as nonuniform time intervals based on preprogrammed conditions.

A gage-height retrieval is the means by which gage-height data are extracted from the recorder. This may be simply by manually removing a chart or paper-punch tape, by downloading the data from the recorder to a personal digital assistant (PDA) or field computer, or by removing an electronic memory device from the recorder.

A telemetry system, for purposes of this report, is the means by which gage-height and other environmental data are automatically transmitted from the field recorder to another location. Telephone, radio, or satellite communication may perform this function.

Gage Datum

The datum of the gage may be either a recognized datum, such as the North American Vertical Datum of 1988 (NAVD 88), the National Geodetic Vertical Datum of 1929 (NGVD 29), or an arbitrary datum chosen for convenience. NGVD 29 was the predominant datum used to establish lake and reservoir gages, and streamflow gages, including those located in tidal zones or coastal areas; however, with its inception, the NAVD 88 is currently the datum the USGS recommends as the vertical datum for the USGS streamgaging network. Where NAVD 88 exists, all gages referenced to other datums should be resurveyed or converted to NAVD 88. An arbitrary datum plane is usually used for streamgaging sites where it is desirable for all recorded gage heights to be relatively low numbers.

Select the arbitrary datum plane for a streamgaging site to avoid negative values of gage height. This requires the arbitrary datum plane to be below the lowest expected gage height, which will be at, or below, the elevation of zero flow on the control for all conditions.

Maintain a permanent gage datum, if at all possible, so that only one datum for the gage-height record is used for the life of the gaging station. For each gaging station, maintain a permanent datum that has at least three permanent reference marks that are independent of the gage structure. For gaging stations located at bridges, use at least one reference mark that is located away from the bridge structure, preferably out of the right-of-way easement. To make sure that the reference gage and the auxiliary gages have not changed relative to the established datum, and to determine the magnitude of any changes, run levels periodically to all gages and reference marks. Procedures for running levels at gaging stations are historically described by Thomas and Jackson (1981) and Kennedy (1990). With the publication of Kenney (2010), this is the standard for differential level surveys at USGS streamgaging stations.

The gage datum may need to be changed if there is excessive channel scour or a manmade channel change. Make such a change in increments of whole feet (or meters) so that the new datum can easily relate to the old datum. In some instances, the gage itself may need to be relocated to another site. The relation between the datum for the new gage site and the datum for the old gage site should be defined by leveling; however, it is not usually necessary to use the same datum at both sites. Keep a permanent record, or history, of all datum changes.

If you use an arbitrary datum plane for a gaging station, establish its relation to NAVD 88 by levels in order to maintain a national datum for the gage-height record. This can be done by using a Global Positioning System (GPS) survey, if it is not practical to do a level survey from a known established bench mark. This allows for recovery of the gage datum if the gage and local reference marks are destroyed.

Stage-Accuracy Requirements

Stage and elevation data are used primarily as an index for computing stream discharge and reservoir contents. The established methods require that stage data be measured and stored as instantaneous values rather than averaged values. Subsequent data processing and analysis will provide the means for any required averaging. The following paragraphs on accuracy requirements and stage-measurement error pertain to instantaneous stage values.

A number of factors enter into the specification of stage-accuracy requirements. For instance, the specific use for which the stage data are collected is an important factor. Stage data used to compute streamflow records must be significantly more accurate than stage data used for some design applications, or for certain flood-plain management applications. The primary use of stage data by the USGS is for computation of streamflow records; consequently, stage-accuracy requirements are stringent. In accordance with this primary use, and because the use of stage data cannot be predicted, the overall accuracy of stage data established for USGS gaging stations is either 0.01 foot or 0.2 percent of the effective stage, whichever is greater. For example, the required accuracy would be 0.06 ft at an effective stage of 30 ft, 0.02 ft at 10 ft, and 0.01 ft at all effective stages less than 7.5 ft. Effective stage is defined as the height of the water surface above the orifice, intake, or other point of exposure of the sensor to the water body. The instrument should be installed in the field with the orifice or intake only slightly below the zero-flow stage, or other defined low point of use.

The accuracy criteria stated above applies to the complete streamgaging station configuration, and is a composite of errors, or total error, from all of the components necessary for sensing, recording, and retrieving the data. See USGS Office of Surface Water (OSW) Technical Memorandum No. 93.07 (1992) and OSW Technical Memorandum 96.05 (1996a). The individual sources of stage-measurement errors are described in the next section of this report.

The same accuracy requirements apply at reservoirs, lakes, and estuaries as those for stream sites. Vertical accuracy is needed for the computation of storage changes in reservoirs, for computation of discharge using slope ratings and (or) unsteady-flow models.

When field conditions, such as high velocities, wave action, or channel instability, make it impossible to collect accurate stage data or to define an accurate stage-discharge relation, stage data should be collected with the greatest accuracy feasible. Select appropriate instruments and methods to fit the field conditions.

Sources of Stage-Measurement Errors

The measured stage of a stream or other water body at any given point in time is subject to numerous sources of incremental errors. The combined effect of these errors should be within the accuracy requirements stated in the preceding section. The accuracy requirement for any single component of a stage-measuring system will generally be more stringent than the requirement for the system as a whole; however, it is not always possible to isolate, or pinpoint, an error and attribute it to one specific component. This part of the report describes the various sources of error, in general. For additional descriptions, see Rantz (1982).

Datum Errors

The gage datum is described in a previous section of this report. Movement of a gage caused by uplift or settlement of the supporting structure can cause datum errors that can only be detected by running levels. Gage datum for reference gages should be maintained to an accuracy of 0.01 ft (Rantz, 1982), which can usually be achieved by running levels to established reference marks every 2 or 3 years. Where conditions are not stable, levels may be required at more frequent intervals. Generally, gages do not need to be adjusted unless datum discrepancies exceed 0.02 ft. Procedures for surveying differential levels at gaging stations are described by Kenney (2010).

Gage-Reading Errors

Errors can result from inaccurate gage readings, where it may be difficult to detect the water line against a staff gage because of poor lighting or very clear water. In other instances, accurate gage readings may be difficult to make because of water surge. These errors can be reduced or eliminated by careful observation, and in the case of surge, by averaging several observations. In almost all cases, read gages to the nearest 0.01 ft.

Stage-Sensor Errors

Stage sensors, such as floats, pressure transducers, and other stage-sensing devices, may introduce gage-height errors. The float in a stilling well may sometimes leak, the float-tape clamp may have slipped, or small animals or snakes may rest on the float. In most instances, problems with the float will cause it to float lower than originally set, causing gage readings to be too low. Stilling-well intake pipes may also become partly clogged, where the stage inside the stilling well lags in time behind the actual stage of the stream. Lagging intakes are discussed in depth in subsequent sections of this report.

Pressure transducers may have, or may develop, calibration errors. These errors can result in plus or minus deviations from the true gage height. The standard for acceptable errors in nonsubmersible pressure transducers is 0.01 ft or 0.10 percent of the effective stage, whichever is greater (see OSW Technical Memorandum No. 96.05, 1996). In other words, the acceptable error is 0.01 ft for an effective stage of 10 ft or less, 0.03 ft for 30 ft, and 0.05 ft for 50 ft. These are acceptable errors for the pressure transducer only, which is only one component of the overall stage-measuring system. Various makes and models of pressure transducers have been tested by the USGS Hydrologic Instrumentation Facility[1] (HIF) to determine if they meet these standards. The HIF also tests pressure transducers after they have been used in the field. [See Water Resources Division (WRD) Instrument News issue 90 (U.S. Geological Survey, 1998a).]

Noncontact radar sensors are available and are being used in many locations in the USGS national streamgaging network. These sensors have been tested at the HIF and some of them are within 0.01 ft of accuracy. But noncontact radar sensors come with a new set of uncertainties, such as wind, air gap between the sensor and the water surface, waves, and debris floating on the water surface. The HIF continues to strive to stay abreast of testing to determine if this genre of stage sensors meets vertical standards.

Other noncontact stage-measuring devices are available that use water-surface sensing methods, such as acoustic wave transmission and optical (laser) transmission systems. These methods have and continue to undergo testing and have shown potential. Under controlled conditions, some of these devices are accurate to within 0.01 ft. Sources of error include temperature variations, density variations, and compositional variations in the transmission column. In some cases, obstacles such as snow, rain, or dust can affect accuracy. The electronics of these systems can be very sensitive and affect accuracy.

Water Surface-to-Sensor-to-Recorder Errors

The communication link between the stream-water surface, the stage sensor, and the data recorder can sometimes develop problems, or have inherent problems that result in gage-height errors. For instance, for a stilling-well-and-float system, the intakes may become clogged, or excessive sediment may settle in the stilling well, or the float tape may hang. These are major problems that usually result in a complete loss of data. More subtle problems can also occur that are not so obvious, but may result in small gage-height errors. For instance, as the stage rises in a stilling well, the float tape that

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[1] Contact information for the HIF is available on their Web site home page at *http://wwwhif.er.usgs.gov/*.

connects the float to the data recorder via the float pulley is gradually transferred from one side of the float pulley to the other. This shift in weight can cause the float to ride slightly higher in the water, causing small positive errors in the recorded gage height. Rantz (1982) describes and quantifies this and other sources of error, such as float lag and submergence of the float-tape counterweight.

Likewise, for gas-bubbler systems, errors can result from gas friction in the line between the bubbler orifice and the nonsubmerged pressure transducer, the variation in weight of the gas column with stage, and the gas-bubble rate. Rantz (1982), Smith (1991), and Kirby (1991) discuss these error sources in detail, and quantify their magnitudes. Submersible pressure transducers show variation in measured water pressure because of water temperature, water density, and other factors.

In the case of electronic stage sensors, errors may occur as a result of converting an electrical signal to a numerical value of stage suitable for recording. In other instances, errors can happen when mechanical movement is converted to a numerical value of stage.

Noncontact gages have other sources of error. For instance, radar gages are often affected by waves on the water surface. Laser gages, although seldom used, are affected by the clarity of the water.

Hydraulically Induced Errors

High velocity in the stream near the outside end of the intake pipes can cause drawdown, or sometimes buildup, of the water surface inside a stilling well. A similar condition can occur when high velocity occurs near a bubble-gage orifice. For example, where a sensor is located on the downstream or upstream side of a pier, the drawdown or buildup can be very large during large flows, on the order of 0.5 ft or more. This condition should be investigated by making simultaneous readings of outside and inside auxiliary gages, or recorder readings, during periods of high stages and (or) high velocity. It can also be checked by determining outside and inside high-water elevations. (See a subsequent section of this report on “Maximum- and minimum-stage determinations”).

Hydraulically induced errors can be reduced or eliminated through the use of an intake-static tube, or in the case of a bubble gage, an orifice-static tube. Relocating the intakes or orifice to a zone of low velocity may also help. Where drawdown or buildup cannot be completely eliminated, it may be necessary to develop an inside-outside gage relation to use over the effective range in stage for correcting inside gage readings to represent the actual outside gage height.

Recorder Errors

Automatic stage recorders include analog (graphic) recorders, digital (punch tape) recorders, data collection platforms (DCPs), and electronic data loggers (EDLs). Analog and digital recorders are mechanical recorders that can have play within the drive chains, gears, and (or) other linkages. Graphic recorders may also experience paper expansion and (or) reversal errors that can lead to data errors. Electronic recorders can have play within the mechanical float wheels and chain drives connected to them. Some of these errors can be corrected with care, good maintenance, and proper verification.

DCPs and EDLs may record incorrect stage readings because of errors or inconsistencies in equations and algorithms that convert electrical signals to recorded stages. This is usually a programming problem that can be corrected. Extreme temperatures can cause recording errors; however, most EDLs are rated to record accurately from about -40° to +60° Celsius, and some data loggers are rated for even greater extremes. Tests indicate that in almost all cases, the data loggers record correctly at extreme temperatures.

Retrieval Errors

Retrieval errors resulting from DCPs and EDLs occur because downloading the data from the data logger to a field computer is an electronic process that can sometimes result in incorrect stage readings and lost data. An even more serious problem would be the complete loss of stage data. Data errors or loss can also occur when downloading the data from an EDL or DCP to a removable data card or to an office computer. (See subsequent sections of this report for a more detailed discussion of data retrieval.)

Verification Errors

Stage readings require frequent and consistent verification to ensure that errors are reduced or eliminated. Failure to perform proper verification standards can be the source of undetected, and possibly significant, stage errors. Verification procedures include frequent reading of independent auxiliary gages, comparison of inside- and outside-gage readings, observation of high-water marks, redundant recording of peaks and troughs by use of maximum/minimum stage-tape indicators (also referred to as Dahman indicators), use of crest-stage gages, and regular maintenance of gage datum by differential-level surveys. These checks should be augmented as appropriate for unusual field conditions. Hydrographers should notice and keep records of instrument performance, including comparisons of recorded stages with the reference gage reading, and any applied corrections.

Gage Structures

Stream and reservoir gages require some type of instrument shelter, and in the case of gages that use float sensors, they also require a stilling well. In many cases, these structures provide protection against vandalism, and from natural hazards such as rain, floods, wind, and lightning. The following sections describe the various structures used by the USGS. Streamgages identified as part of the USGS National Streamflow Information System (NSIP) are by mandate to be maintained above the 0.5 percent annual exceedance probability (200-year) flood stage. (See more discussion of NSIP streamgages in a subsequent section of this report.)

Stilling Wells

The stilling well protects the float and dampens the fluctuations in the stream caused by wind and turbulence, and perhaps could be considered the most accurate measure of stream stage. Stilling wells are made of concrete, reinforced concrete, concrete block, concrete pipe, corrugated-galvanized-steel pipe, aluminum pipe, PVC pipe and occasionally wood. They may be placed in the bank of the stream as shown in figures 1, 2, 3, and 4, but often are placed directly in the stream and attached to bridge piers or abutments, as shown in figures 5 and 6.

The stilling well should be deep enough for its bottom to be at least a foot below the minimum stage anticipated and its top above the level of the 2-percent annual-exceedance probability (50-year) flood [0.5-percent annual-exceedance probability (200-year) flood for NSIP streamgages]. The inside of the well should be big enough to permit free operation of all the equipment to be installed. Normally, a pipe 4 ft in diameter or a well with inside dimensions 4 by 4 ft is of satisfactory size, but pipes as small as 18 inches (in.) in diameter have been used for temporary installations where equipment

Figure 1. Reinforced concrete stilling well and shelter.

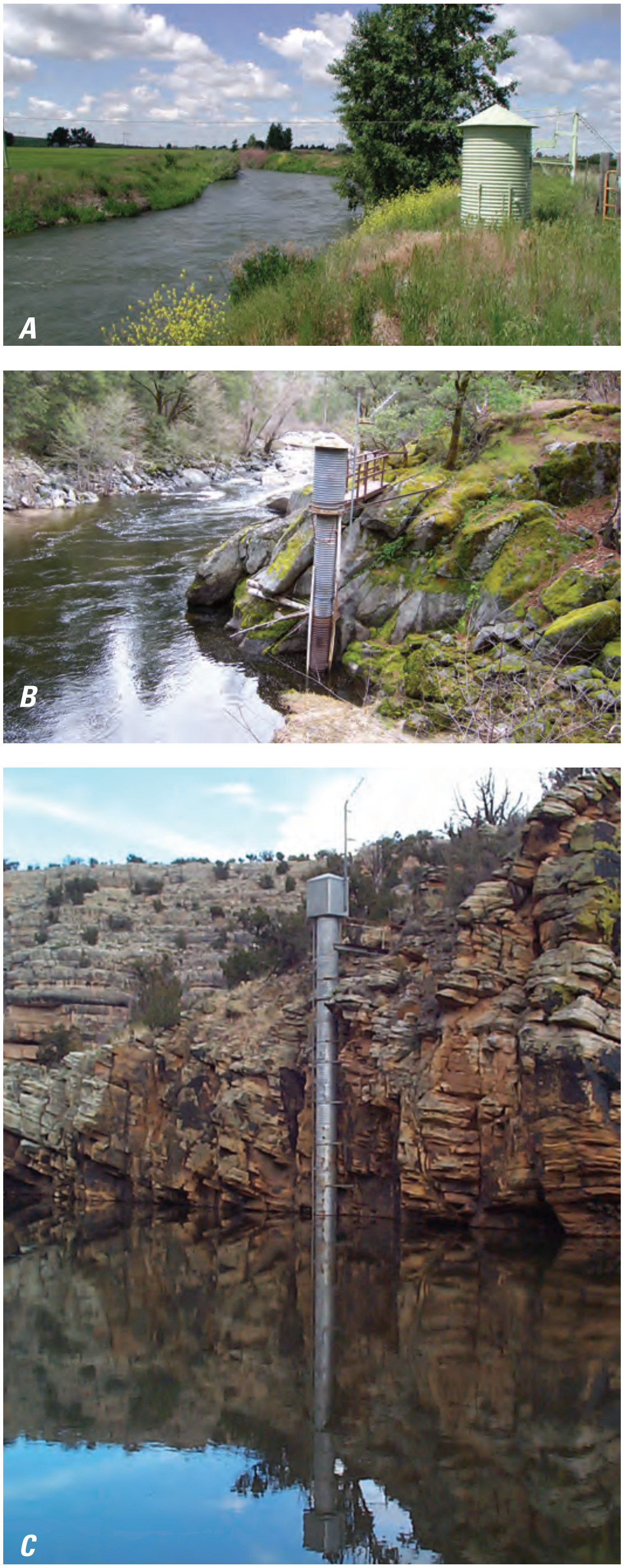

Figure 2. *A–C*, Corrugated-galvanized-steel stilling well and shelter.

Figure 3. Concrete pipe stilling well and shelter.

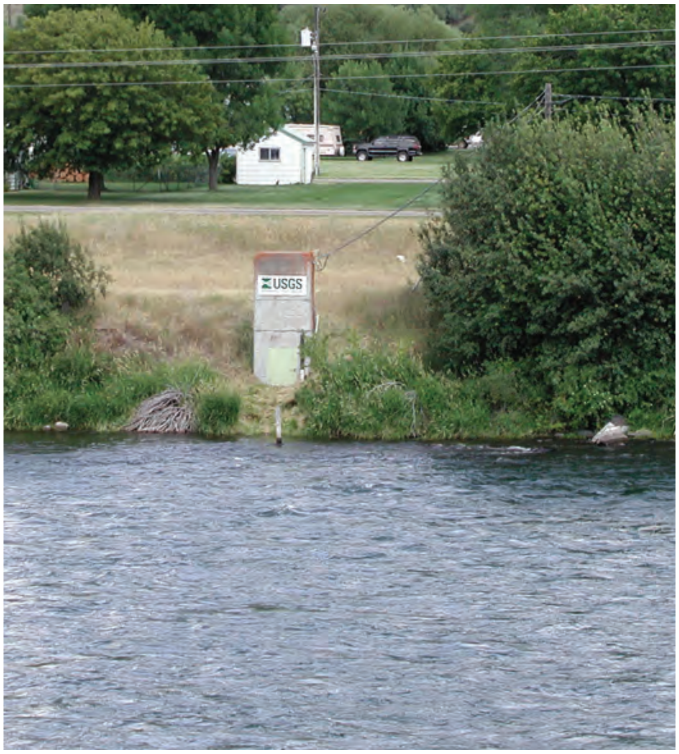

Figure 4. Concrete block stilling well and shelter.

Figure 5. *A*, Steel pipe stilling well and B, shelter attached to bridge abutment.

Figure 6. *A* and *B*, Corrugated-steel pipe stilling well and shelter attached to bridge pier.

requirements are not substantial. The 4-by-4-ft well provides ample space for the hydrographer to enter the well from the top, via a ladder, to clean it or to repair equipment. The smaller metal wells and the deep wells should have doors at various elevations to facilitate easy entry for cleaning and repairing. All personnel must follow appropriate safety rules and regulations when entering confined space, as defined in several official WRD memoranda, the latest being USGS WRD Technical Memorandum 2005.03 (2005). This memorandum also directs the hydrographer to other safety-related memoranda that specifically deal with safety guidelines for working in and around gaging stations. (See a subsequent section of this report on “Safety” for additional safety considerations.)

When placed in the bank of the stream, the stilling well should have a sealed bottom so that groundwater cannot seep into it nor stream water leak out of it. Water from the stream enters and leaves the stilling well through one or more intakes so that the water in the well is at the same elevation as the water in the stream. If the stilling well is in the bank of the stream, the intake consists of a length of pipe connecting the stilling well and the stream. The intake should be at an elevation at least 0.5 ft lower than the lowest expected stage in the stream, and at least 0.5 ft above the bottom of the stilling well to prevent silt buildup from plugging the intake. In cold climates, the intake should be below the frostline. If the well is placed in the stream, holes drilled in the stilling well may act as intakes, taking the place of pipe intakes. Some wells placed in the stream have a sloping hopper bottom that serves as an intake. These are designed to allow silt to slide out of the stilling well, thus preventing a buildup of silt that might cause a loss of gage-height record.

Two or more pipe intakes are commonly installed at vertical intervals of about 1 ft. During high water, silt may cover the stream end of the lower intakes while the higher ones continue to operate.

Most stations that have intakes subject to clogging are provided with flushing systems, as shown in figure 7, whereby water under several feet of head can be applied to the gage-well end of an intake. Ordinarily, a pump raises water from the well to an elevated tank. The water is then released through the intake by operation of a valve. Intakes without flushing systems may be cleaned with a plumber’s snake or rod, or by building up a head of water in the well with a portable pump to force an obstruction out of the intakes.

A silt trap is constructed at some stations where silt is a persistent and recurring problem. The silt trap is a

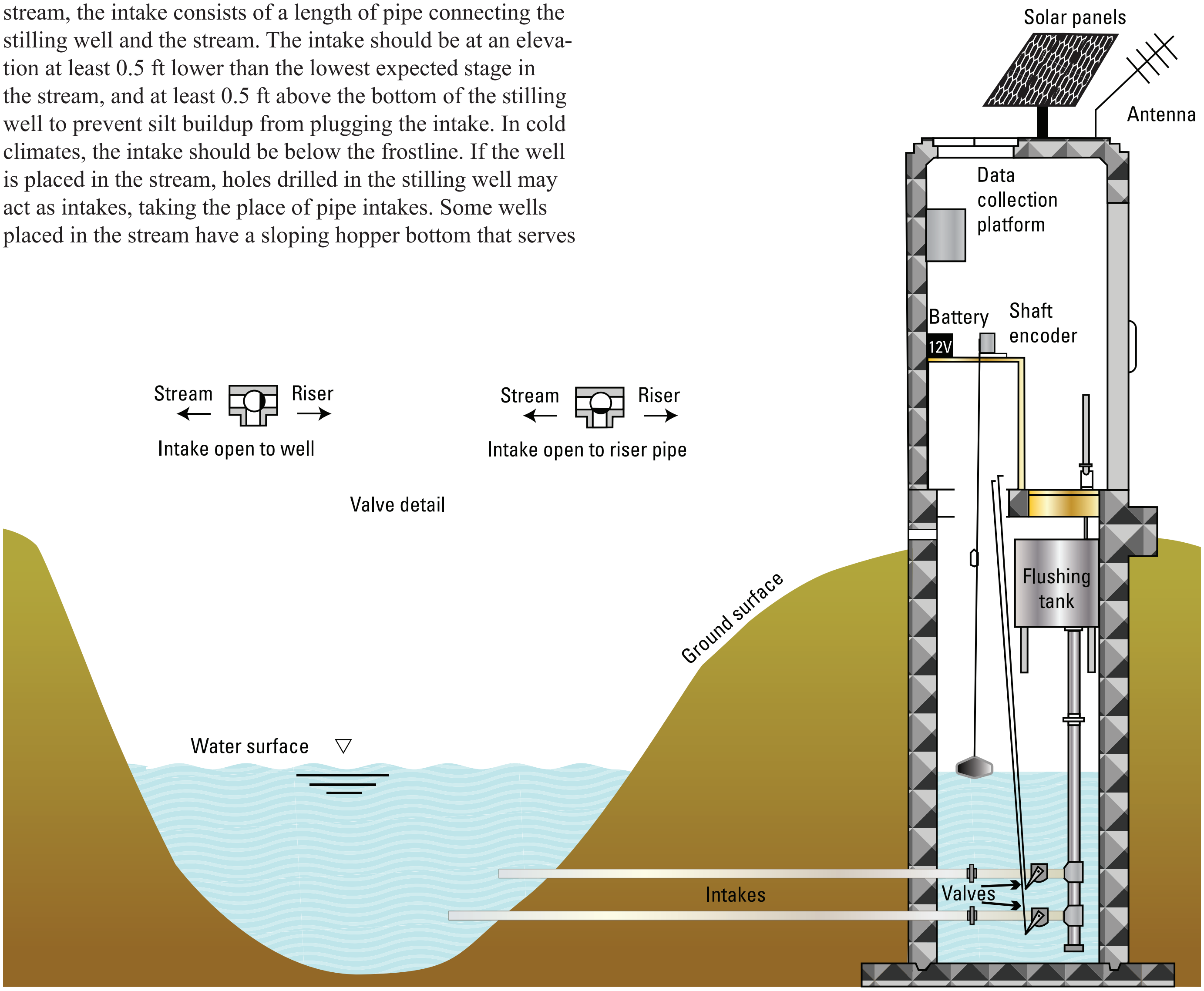

Figure 7. Schematic of typical flushing system for intakes.

low-elevation well located between the main stilling well and the stream, and through which the intakes pass before reaching the main stilling well. Baffles are sometimes placed in the silt trap to facilitate settlement of the silt before reaching the main stilling well, thereby leaving the main stilling well clear of silt so that it can function without clogging. The silt trap usually has a large entrance on top so that it can be accessed and cleaned easily. Figure 8 shows an installation with a silt trap, and figure 9 is a schematic illustrating a typical silt trap installation.

The intakes for stilling wells placed in the bank of the stream are usually galvanized-steel pipe. The most common size used is 2-in.-diameter pipe, but in some places up to 4-in.-diameter pipe is used. After the size and location of the well have been decided, the size and number of intakes should be determined. The intake pipes should be of sufficient number and size for the water in the well to follow the rise and fall of stage without significant delay. Smith, Hanson, and Cruff (1965) related intake lag to rate of change of stage of the stream, and to various components, such as valves, tees, and static tubes, which are used in the stilling-well intake system. Based on their studies, the following equation may be used to determine the approximate lag for an intake pipe (or pipes) for any given rate of change of stage. Keep in mind that there will always be some intake lag during a change in stage, but it can be minimized if sufficient intakes are provided. This equation, although not exact, will provide a reasonable indication of the lag that can be expected for various combinations of intakes and pipe fittings. An intake system designed to keep intake lag at 0.1 ft or less, for the maximum expected rate of rise or fall, is probably adequate.

Figure 8. In-bank stilling well and silt trap.

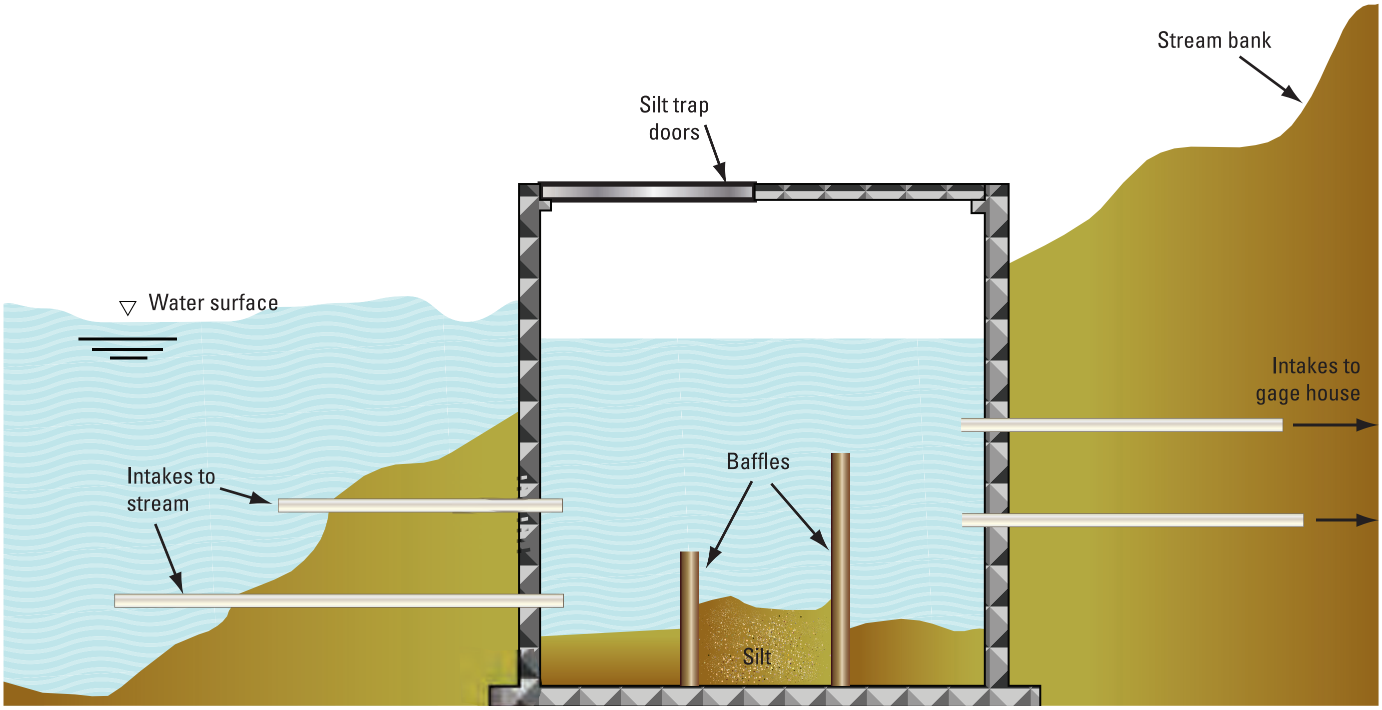

Figure 9. Schematic of typical in-bank silt trap.

$$\Delta h = \frac{1}{2g}\left(\frac{A_w}{a_p}\right)^2 \left(\frac{dh}{dt}\right)^2 \left(K + 1.5 + \frac{0.03L}{d}\right), \qquad (1)$$

where Δh = lag, in feet,
g = acceleration of gravity, in feet per second per second,
L = average length of intake pipes, in feet,
d = average diameter of intake pipes, in feet,
A_w = area of stilling well, in square feet,
a_p = combined cross-sectional area of intake pipes, in square feet,
$\frac{dh}{dt}$ = rate of change of stage, in feet per second, and
K = loss coefficient to account for various intake pipe fittings (see below).

The loss coefficient, *K*, is the summation of loss coefficients for various pipe fittings, as defined by Smith, Hanson, and Cruff (1965), and as given in the following equation:

$$K = K_v + K_{sot} + K_{st}, \qquad (2)$$

where K_v = three-way stem-cock valve loss coefficient, equal to 1.8 (do not use this coefficient if the intake is flush mounted or if a gate valve is used);
K_{sot} = side-outlet tee loss coefficient, equal to 1.1; and
K_{st} = static tube loss coefficient, equal to 1.6.

If there are two or more intakes of different sizes and lengths, use the average length and the average diameter of the pipes for *L* and *d*, respectively; however, use the total cross-section area of all of the pipes for a_p. If the intakes have different fittings, compute *K* for each pipe and use an average value of *K* for the system. These recommendations will not give exact results for intake lag, but will be approximately correct.

Place the intake pipes at right angles to the direction of flow where they are level. If the velocity past the ends of the intakes is high, drawdown or pileup of the water level in the stilling well may occur. To reduce the drawdown effect, attach static tubes to the stream end of the intake pipes. A static tube is a short length of pipe attached to an elbow or tee on the end of the intake pipe, extending horizontally downstream, as shown in figure 10. The end of the static tube is capped and water enters or leaves through holes drilled in the tube.

Use a special "orifice static tube" for a bubble-gage station equipped with a gas-purge system. Orifice static tubes will be described in subsequent sections of this report dealing with bubble gages.

Figure 10. Static tube for intake pipe.

The usual methods of preventing the formation of ice in a stilling well are insulating measures, such as subfloors and heaters. Subfloors are effective if the station is placed in the bank and has plenty of earth fill around it. If the subfloor is built in the well below the frostline in the ground, ice will not normally form in the well as long as the stage remains below the subfloor. Holes are cut in the subfloor for the recorder float and weights to pass through, and removable covers are placed over the holes. Subfloors prevent air circulation in the well and the attendant loss of heat that contributes to the formation of ice in the well.

An electric heater or heat lamps with reflectors may be used to keep the well free of ice. The cost of operation and the availability of electric service at the gaging station are governing factors. Heating cables are often placed in intake pipes to prevent ice from forming.

Oil (for example, mineral oil, vegetable oil, or Isopar M) is sometimes used in oil cylinders placed in the stilling well to prevent freezing; however, because of the danger of leakage of the oil from the cylinder to the stream, it is highly discouraged, as stated in USGS WRD Memorandum No. 77.49 (1977). If it is necessary to use an oil cylinder, the gage height reading must be corrected for the displacement the oil causes on the water column in the cylinder because of the density difference of the oil and water. Never put oil directly in the stilling well. Likewise, do not use an oil cylinder if there is a real danger that the oil could escape to the stream. Wherever possible, use an alternative measure, such as an insulated subfloor or heater. Pressure transducers and bubble gages, as described in subsequent sections of this report, are also alternatives.

Instrument Shelters

Instrument shelters are made of almost every building material available and in various sizes and shapes, depending on local custom and conditions. See figures 1–6 for examples of shelters placed on top of stilling wells. Instrument shelters are also required for gages, such as bubble gages, that do not require stilling wells. These may be placed on a concrete slab or other suitable foundation directly on a stream bank, on a bridge, or on some other structure located near the stream, as shown in figures 11–13. Most instrument shelters have an antenna for data transmission, and solar panels for maintaining battery charge. Some type of mast is usually required for these sites, but the solar panel may also function adequately mounted to the roof or wall of the shelter.

Figure 11. Instrument shelter located on a stream bank.

Figure 12. Instrument shelter located on a bridge abutment.

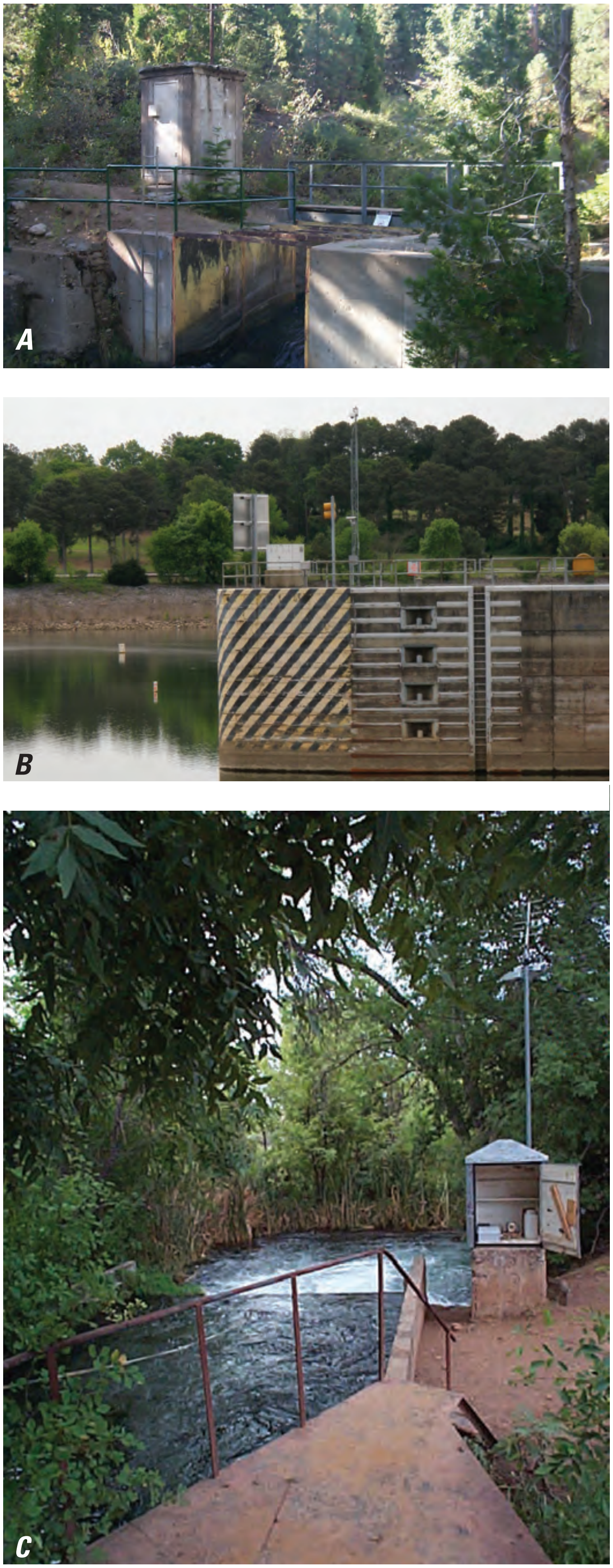

Figure 13. *A–C*, Instrument shelter located on a dam.

A walk-in shelter is the most convenient type of shelter, allowing the hydrographer to enter while standing and to be protected from the weather. A shelter with inside dimensions 4 by 4 ft with ceiling height 7 ft above the floor is about the ideal size, either for a stilling well gage or a bubble gage, where a stilling well is not required.

Look-in shelters are used at sites where a limited amount of equipment is to be installed and if a portable and inexpensive shelter is desired. Look-in shelters provide sufficient space for equipment such as bubblers. Figure 14 is an example of a look-in type of shelter.

Figure 14. Look-in type of instrument shelter.

In humid climates, shelters should be well ventilated and have a tight floor to prevent entry of water vapor from the well. Screening and other barriers should be used over ventilators and other open places in the well and shelter to help prevent the entry of insects, rodents, and reptiles.

Instrument shelters not requiring a stilling well, such as for a bubble gage, may be installed at any convenient location above the reach of floodwaters. Shelters similar to those in figures 11–14 would be adequate. Such a gage may be used to take advantage of existing natural or artificial features in a stream without costly excavation for well or intake and without need for any external structural support. The bubble orifice is placed at least 0.5 ft below the lowest expected stage in the stream. The plastic tube connecting the orifice and the instrument is encased in metal pipe or conduit, or buried to protect it from the elements, animals, and vandalism. The bubble gage is especially well suited for short-term installations because the entire station is readily dismantled and relocated with practically no loss of investment.

Lightning Protection

A lightning-protection system is needed for gaging structures to ensure uninterrupted data collection and to minimize expensive repairs to instruments and equipment that might otherwise be damaged by lightning. The best and most effective lightning protection for instruments, such as satellite data-collection platforms (DCPs), EDLs, stage sensors, telephone modems, computers, and other microprocessor-based instrument systems, is protection designed for and built into the instrument circuitry. Built-in protection can more closely match the protection needs of the circuitry than can protection that is added to the instrument after it is manufactured. Provide supplemental protection when built-in lightning protection is inadequate or not part of the equipment.

Supplemental protection includes alternating current power-line and telephone-surge suppressor devices. When telephone lines are used, but alternating current (AC) power is not part of a system, use a telephone-line-surge suppressor. Coaxial cables used for antennas should have a transient protector device to protect the DCP transmitter, not only from lightning, but also from voltage differences in an electrostatic discharge. Ground and protect sensor lines from induced lightning transients.

An effective, low-resistance grounding system is also required. Common-point grounding is necessary to keep the system components within the gage house at the same voltage potential relative to one another anytime the system becomes part of the lightning discharge circuit. Connect the common-point ground to a low-resistance (5-ohm) earth ground. A grounding rod buried below the soil frost line provides a year-round, uniform, low-resistance ground. In some cases, the stilling well may provide a low-resistance earth ground. An earth grounding kit can be obtained from the HIF, as described in WRD Instrument News issue 83 (U.S. Geological Survey, 1998b).

Use as many layers of lightning protection as possible. However, even with internal instrument protection and supplemental protection, a direct lightning strike will likely destroy the electronic components. An excellent, detailed description of providing lightning protection is given in WRD Instrument News issue 73 (U.S. Geological Survey, 1996b) and issue 75 (U.S. Geological Survey, 1996c).

Instrumentation

Many instruments are available for observing, sensing, recording, and transmitting stage data. Such instrumentation ranges from the simple nonrecording auxiliary gages to sophisticated water-level sensors, noncontact radar sensors, electronic data loggers, and telemetry systems, such as satellite data-collection platforms (DCPs). This section describes most of the currently available instruments used for stage data collection in open channels and reservoirs.

Nonrecording Gages

One method of obtaining a record of stage is by the systematic observations of a nonrecording gage. In the early days of the USGS, this was the means generally used to obtain records of stage, and is still used at a few gaging stations, but today water-level sensors and automatic water-stage recorders are the predominant instruments used at practically all gaging stations. Nonrecording gages are still in general use as auxiliary gages at water-stage recorder installations and serve the following purposes:

- *As an auxiliary or reference gage to indicate the water-surface elevation in the stream or reservoir*. This gage is referred to as the outside gage, and in the case where a stilling well is not used, this gage is usually the reference gage used for setting the automatic recorder.
- *As an auxiliary or reference gage to indicate the water-surface elevation in the stilling well*. This gage is referred to as an inside gage, and auxiliary gage readings in the stream are compared with the gage readings in the stilling well to determine whether outside stream stage is accurately transmitted into the stilling well via the intake pipes. The inside gage is usually considered the reference gage.
- *As a temporary substitute for the recorder when the intakes are plugged or there is an equipment failure*. The outside auxiliary gage can be read as needed by a local observer to continue the record of stage during the malfunction.

The types of nonrecording gages generally used are staff, wire weight, chain, float tape, and electric tape. Staff, wire-weight, and chain gages are normally used as outside auxiliary gages at recording gaging stations. Float- and electric-tape gages and the vertical-staff gage are normally used inside stilling wells. Staff gages are read directly, whereas the other four types are read by measurement from a fixed point to the water.

Staff Gages

The staff gage is either vertical or inclined. The standard USGS vertical-staff gage consists of porcelain-enameled iron sections 4 in. wide and 3.4 ft long and graduated every 0.02 ft. Figure 15 shows a vertical, outside staff gage. The vertical-staff gage is also used in stilling wells as an inside gage. Vertical-staff gages are set by leveling directly to the gages.

An inclined staff gage is used for an outside gage and usually consists of a graduated heavy timber securely attached to a permanent foundation. Inclined staff gages built flush with the streambank are less likely to be damaged by floods, floating ice, or drift than are projecting vertical staffs. Inclined-staff gages must be individually calibrated by leveling to several points along the length of the gage, interpolating intermediate points, and marking these points with a relatively permanent marking system. An inclined-staff gage is shown in figure 16.

Figure 15. Outside, vertical-staff gage, attached to 2-by-6-foot wood backing.

Figure 16. *A* and *B*, Inclined-staff gage.

Electric-Tape Gages

The electric-tape gage, as shown in figure 17, consists of a steel tape graduated in feet and hundredths, to which is fastened a cylindrical weight, a reel in a frame for the tape, and a voltmeter. Terminals are provided so that a voltmeter can be connected to a battery. The negative terminal of the battery is attached to a ground connection, and the positive terminal to the positive terminal of the voltmeter. The negative terminal of the voltmeter is connected to the weight, through the frame, reel, and tape. One of two power supplies may be used with electric-tape gages. Prior to 1989, electric-tape gages were manufactured with a 5-volt meter, which requires a 4.5-volt battery. After 1989, electric-tape gages were manufactured with a 15-volt meter, which requires a 12-volt battery. The old 5-volt meter can be replaced with a 15-volt meter so that the older model electric-tape gage can be connected to a 12-volt battery.

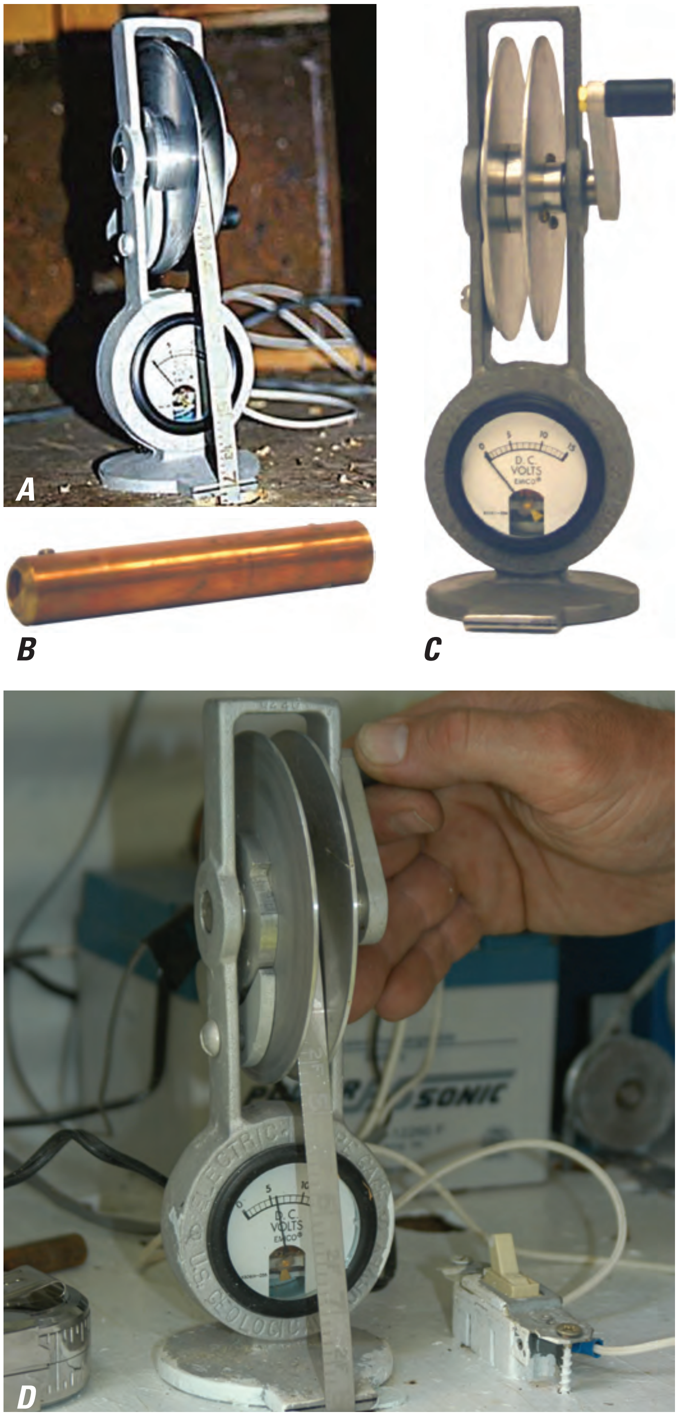

Figure 17. *A*, *C*, and *D*, Electric-tape gages and *B*, cylindrical weight.

Attach the electric-tape gage to the instrument shelf, and insulate it if the shelf is metal. Ground the negative terminal of the battery to the stilling well if the stilling well is metal, such as a corrugated metal pipe (CMP) or culvert-pipe well. If the stilling well is nonmetallic, attach the ground wire to a small metal plate placed on the floor of the stilling well. Attach the positive terminal of the electric-tape gage to the positive terminal of the battery.

Run differential-level surveys to determine the gage datum elevation of the index marker of the electric-tape gage. Lower the weight so that at the index marker, the tape reads an elevation somewhat less than the elevation of the index marker that was determined by levels. For example, lower the tape to read 1.00 ft less than the elevation of the index marker. Hold the tape at this position and adjust the position of the weight on the tape so that the bottom of the weight is exactly 1.00 ft below the index marker, as measured with a pocket tape or carpenter's rule. The electric-tape gage is now set to read water levels precisely to gage datum.

To determine the gage height of the water level, the weight is lowered until it barely contacts the water surface. This contact completes the electric circuit and produces a signal on the voltmeter. With the weight held in the position of first contact, observe the tape reading at the index marker, which is the gage height of the water level.

Wire-Weight Gages

The type A wire-weight gage is usually attached to a bridge handrail and is generally used as an outside auxiliary gage. At some sites it is used as a reference gage. A type A wire-weight gage consists of a drum wound with a single layer of cable, a bronze weight attached to the end of the cable, a graduated disc, and a Veeder counter, all within a cast-aluminum box. Figure 18 shows a type A wire-weight gage. The disc is graduated in tenths and hundredths of a foot and is permanently connected to the counter and to the shaft of the drum. The disk is adjustable by loosening the set screws and moving the disk to the desired setting. The cable is made of 0.045-in.-diameter stainless-steel wire, and is guided to its position on the drum by a threading sheave. The reel is equipped with a pawl and ratchet for holding the weight within about 0.1 ft of any desired elevation. The diameter of the drum of the reel is such that each complete turn represents 1 ft of movement of the weight. A horizontal checking bar is mounted at the lower edge of the instrument so that when the bar is moved to the forward position the bottom of the weight will rest on it.

The gage should be set by lowering the weight to a position a few feet above the water surface and where leveling can be used to determine the elevation of the bottom of the weight. Hold the weight at this position and set the Veeder counter and graduated disk to read the same elevation as determined by levels. The elevation of the check bar should be determined by levels, and also by setting the weight on the check bar and reading the elevation from the Veeder counter and dial. These two elevations should be identical; however, there will sometimes be a small difference, especially if the vertical distance between the gage and low water is large. Both check-bar elevations should be recorded, and the one determined from the dial reading should be used for future checking to verify that the gage adjustments have not changed. Some hydrographers record the correct check-bar elevation and the date it was determined inside the wire-weight gage box, so it is readily available anytime the gage is used.

The gage height of the water surface is determined by lowering the weight to the water surface until it just touches it. The Veeder counter and graduated dial are read to obtain the gage height. If there are waves or turbulence, it may be necessary to take several readings at the crest and trough, and use the average of these for the water-surface elevation. In very still water, it is sometimes difficult to tell when the weight touches the water. Various methods are used, such as creating a slight pendulum motion that will disturb the water surface at the low point of the swing. Another method is to lower the weight into the water a few hundredths of a foot, and raise it a hundredth at a time, each time making a quick upward movement of the weight. If the weight is in the water or just at the water surface, the quick vertical movement will create a visible disturbance of the water surface. If there is no noted disturbance, than the previous elevation is the water-surface elevation.

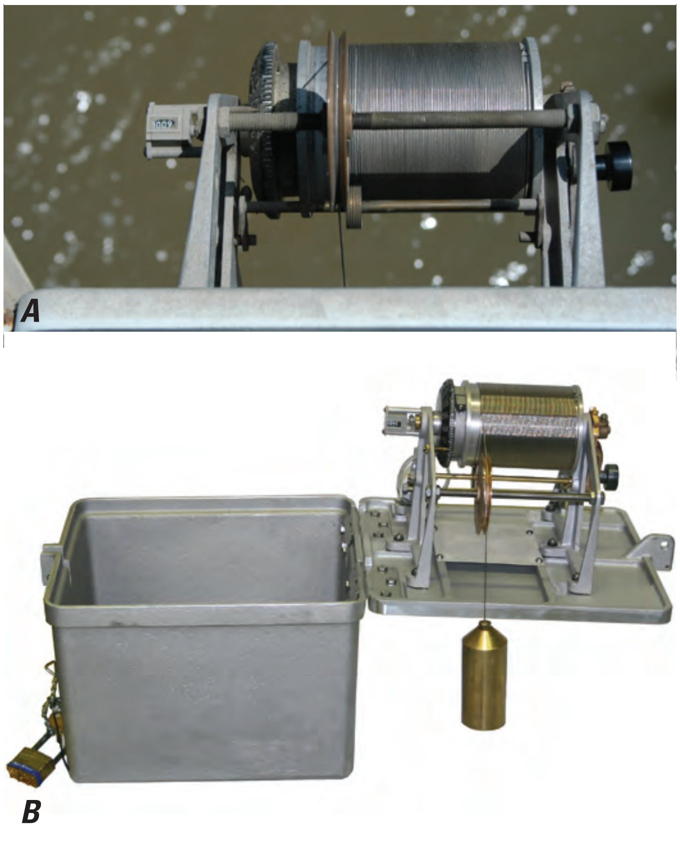

Figure 18. *A* and *B*, Type A wire-weight gage.

Cantilevered Wire-Weight Gages

A cantilevered wire-weight gage is sometimes used where outside staff gages are hard to maintain and where a bridge, dock, or other structure over the water is not available for the location of a wire-weight gage. A wire-weight gage can be mounted on a cantilevered arm that extends out over the stream, or which is made in such a way that it can be tilted to extend over the stream. Figure 19 shows a cantilevered wire-weight gage. To ensure no vertical movement, use a stable horizontal structure while using this instrument.

The cantilevered wire-weight gage consists of the cantilevered arm, which is held permanently in place, and a standard USGS wire weight, which runs over a pulley on the streamward end of the cantilever.

The wire-weight gage is set usually by leveling to the bottom of the weight, similar to the method described in the previous section for wire-weight gages. The wire-weight drum can be adjusted to read the correct elevation.

Stage is determined by lowering the weight until the bottom of the weight just touches the water surface, just as described previously for a wire-weight gage. The gage height is then read from the wire weight.

Figure 19. Cantilevered wire-weight gage.

Float-Tape Gages

Historically, the float-tape gage consisted of a float, a graduated steel tape, a lead or stainless-steel counterweight, and a pulley. The float pulley usually was a diameter of 6 in., was grooved on the circumference to accommodate the tape, and was mounted in a standard. An arm extended from the standard to a point slightly beyond the tape to carry an adjustable index. The tape was connected to the float by a clamp that also could be used for making adjustments to the tape reading, in case they were too large to be accommodated by the adjustable index.

Today, a float-tape gage is similar and typically consists of a float, a graduated steel tape, a stainless-steel counterweight, and a pulley wheel attached to an analog or SDI–12 shaft encoder as shown in figure 20. The float pulley is typically a diameter of about 4 in., is grooved on the circumference to accommodate the tape, and is mounted directly to the shaft of the encoder. The shaft encoder is connected to a DCP or EDL where timed measurements of stage are recorded. An arm typically mounted to a gage shelf extends to a point slightly beyond the tape to carry an adjustable index. The tape is connected to the float by a clamp that also may be used for making adjustments to the tape reading, in case the adjustments are too large to be accommodated by the adjustable index.

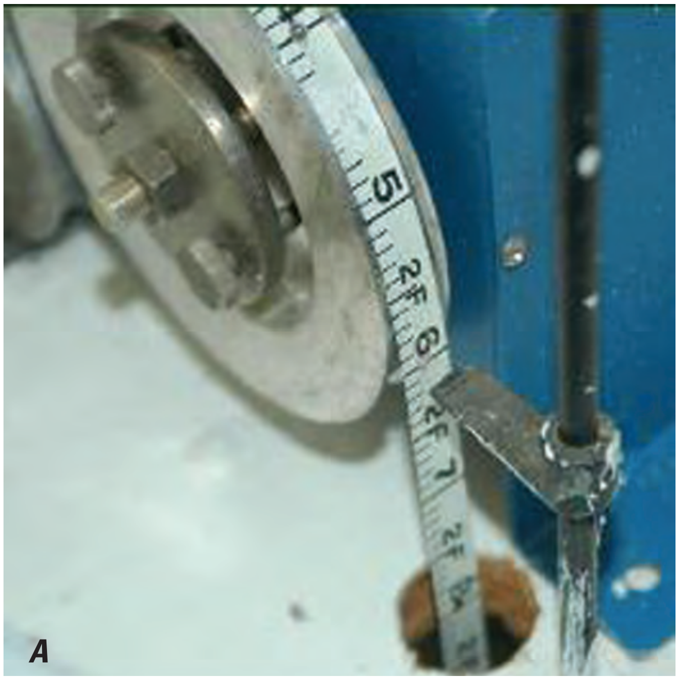

Figure 20. *A* and *B*, Float-tape gage with analog or SDI–12 shaft encoder.

Floats having diameters ranging from 2 to 12 in. are commonly made of plastic, although older floats were made of copper. The float-tape gage is used chiefly as an inside reference gage.

The float-tape gage can be an independent assembly, or it can be an integral part of an electronic encoder interfaced to a DCP or EDL, as shown in figure 20. In all cases, the index marker is set by determining the water-surface elevation in the stilling well by reading the inside auxiliary gage, and by setting the index marker to read the same on the float tape. Today roughly 40 percent of USGS streamgages still use float-tape assemblies in a stilling-well for the measurement and recording of river stage.

Float-Tape Maximum- and Minimum-Stage Indicators

An advantage of a float-tape gage is that maximum- and minimum-stage indicators can be used on the tape so that the maximum and minimum stage can be determined for the period between station visits. These indicators are wire clips (similar to a paper clip and also referred to as Dahman indicators), or small magnets that are attached to the float tape beneath the instrument shelf; however, magnets will not work on stainless-steel tapes. The clips or magnets are designed so they slide easily on the float tape, and are large enough that they will not pass through the float-tape hole in the instrument shelf. As the stage rises, the clip or magnet will come against the instrument shelf and slide along the tape until the stage reaches a peak and begins to recede. The clip or magnet will then retain its position on the tape, unless a higher stage occurs at a later date. During the inspection visit to the gage, the hydrographer can then raise the float until the clip or magnet just touches the instrument shelf, and read the tape indicator at that point to determine the peak stage. Alternately, the float-tape reading at the clip or magnet can be read, and a correction subtracted from this reading that will account for distance between the float-tape indicator and the bottom of the instrument shelf.

A wire clip or magnet, as described above, can also be used on the counterweight side of the float tape to determine the minimum stage that occurred since the last visit to the gaging station. The operation of the minimum-stage indicator is similar to the peak-stage indicator as described above. After obtaining the readings of both the maximum- and minimum-stage indicators, the clips or magnets should be reset on the float tape before leaving the station so they are against the bottom of the instrument shelf.

Crest-Stage Gages

The crest-stage gage is a simple, economical, reliable, and easily installed device for obtaining the elevation of the flood crest of streams. Although many different types of crest-stage gages have been tested, the most functional one is a vertical piece of 2-in. galvanized pipe containing a wood or aluminum staff held in a fixed position with relation to a datum reference, as shown in figure 21. The bottom cap has six intake holes located around its circumference so that when aligned correctly with the flow as shown in figure 21, drawdown or head buildup inside the pipe is kept to a minimum. Tests have shown that this arrangement of intake holes will be effective with velocities up to 10 ft per second, and at angles up to 30 degrees with the direction of flow. The top cap contains one small vent hole. For additional information, see Friday (1965) and Carter and Gamble (1963).

The bottom cap or a perforated tin cup or copper screening in a cup shape attached to the lower end of the staff contains regranulated cork. As the water rises inside the pipe, the cork floats on its surface. When the water reaches its peak and starts to recede, the cork adheres to the staff inside the pipe, thereby retaining the crest stage of the flood. The gage height of a peak is obtained by measuring the interval between the reference point on the staff and the flood mark. Scaling can be simplified by graduating the staff. The datum of the crest-stage gage should be checked by levels run from a reference mark to the top of the staff, or to the top of the bottom cap. Crest-stage gage pipes should be routinely checked for slippage.

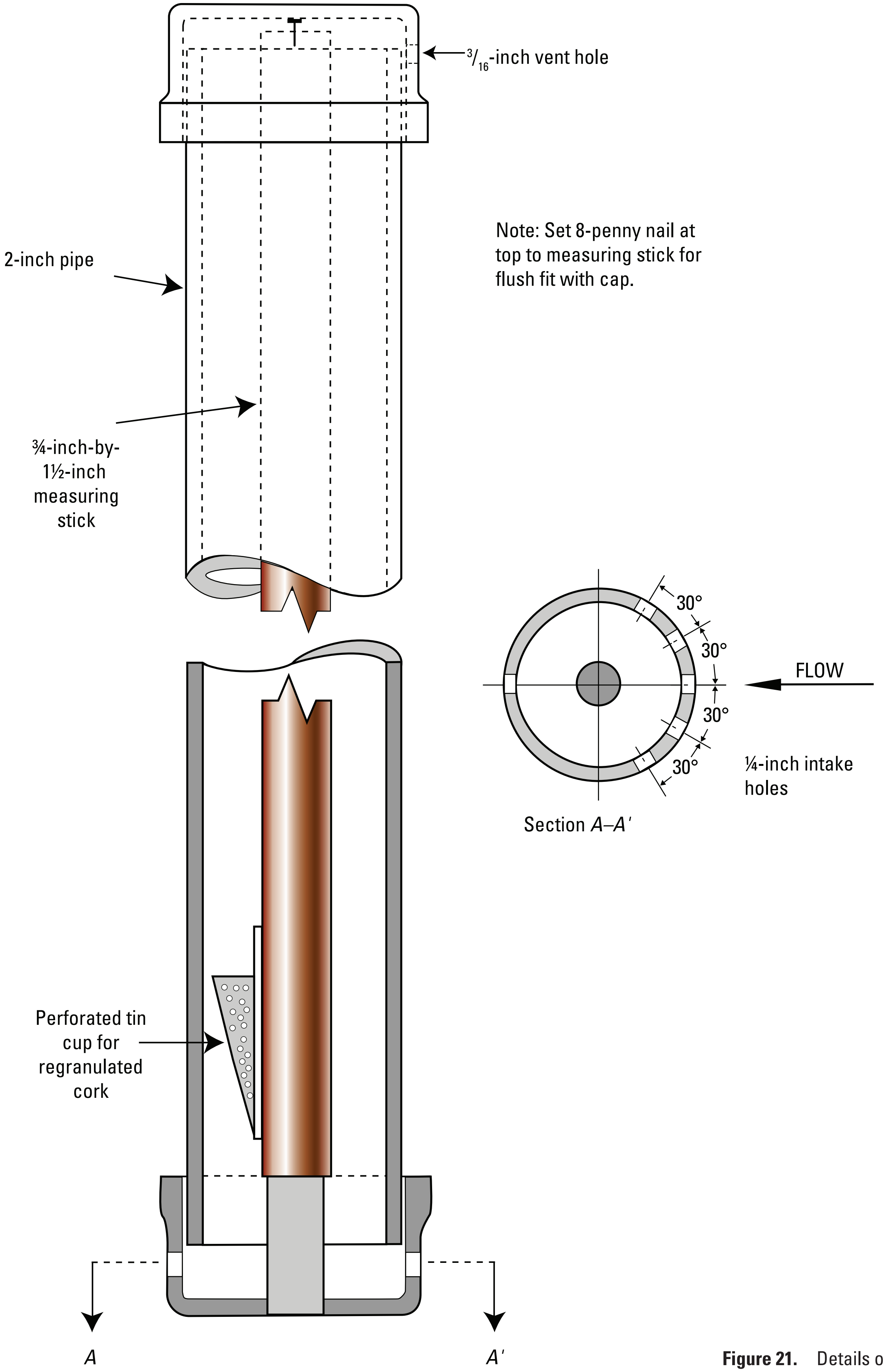

Figure 21. Details of a crest-stage gage.

Water-Level Sensors

A water-level sensor, or stage sensor, was defined in a previous section of this report as a device that automatically determines, or senses, the vertical position of the water surface. In reality, stage sensors are usually not a single device, but a combination of two or more components that work together to sense the water-level position. The two most commonly used stage sensors include float-driven systems and gas-purge (bubbler) systems. Other less commonly used stage sensors are submersible pressure transducers, and noncontact methods used are acoustic, radar, and optical (laser) systems. The following sections describe the various instruments used for automatically determining water levels.

Float-Driven Sensors

Basic Float System

The basic float sensor consists of a float resting on the water surface in a stilling well. The float is attached to a tape or cable passing over a pulley, with a counter weight attached to the other end of the tape or cable. This is identical to the float-tape reference gage described in a previous section of this report, and is shown in figure 20. The float follows the rise and fall of the water level, and if the system uses a graduated tape, the water stage can be read visually by using an index marker. For automatically recording the water stage, the pulley is typically connected to a digital shaft encoder and DCP or EDL.

Float and Shaft Encoder

A shaft encoder is a float-driven device that is connected with a shaft to the pulley of a basic float system. The shaft encoder interprets the rotational position and the number of revolutions of the shaft to determine the water stage. Shaft encoders may or may not have visual readouts to indicate the water stage. In addition, shaft encoders are programmable to transmit the encoded stage to an EDL or to a DCP based on user-specified instructions. Some shaft encoders have their own internal recording system, such as a computer memory card.

Several commercial manufacturers, such as Vaisala, Inc., Schmitz Engineering Liaison, and Design Analysis Associates, Inc., and others, make various models of shaft encoders that meet USGS accuracy standards. Figure 22 shows a Vaisala model 436A shaft encoder and a Sutron 5600–530 shaft encoder, both of which are designed to transmit water stages to an EDL or DCP. Figure 23 shows a WaterLOG model H–510 shaft encoder by Design Analysis Associates, Inc., which is designed to record water-stage data on an internal-computer memory card.

The float system that drives a shaft encoder must produce enough initial force to overcome the starting torque of the encoder. For example, when the float is displaced 0.01 ft, the driving force must be sufficient to produce movement of the encoder shaft. The driving force will vary, depending on the diameter of the float and on the diameter of the pulley attached to the encoder shaft. Table 1 shows the driving force and torque developed for 0.01-ft movement of various sizes of floats, and a 12-in.-diameter pulley. In order to allow for other sources of error, OSW Technical Memorandum 96.12 (1996d)

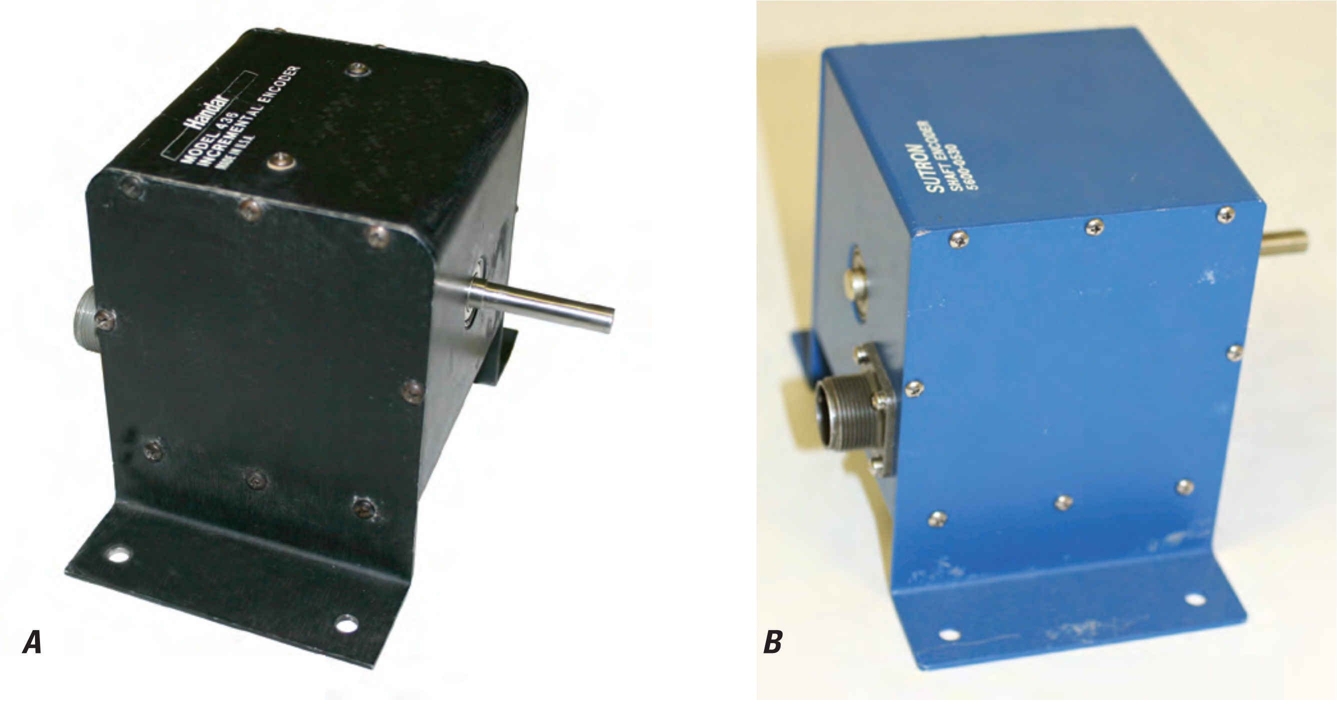

Figure 22. *A*, Vaisala Model 436A shaft encoder and *B*, Sutron 5600–530 shaft encoder.

recommends that the starting torque of shaft encoders be no more than one-third of the values shown in table 1. Also, it is recommended that shaft encoders should have a starting torque that meets the criterion for a 1.5-in. float [less than 0.08 inch-ounces (in-oz)]. This would allow interchange of shaft encoders among gaging sites where smaller floats might be used.

Figure 23. Design Analysis Associates WaterLOG Model H–510 shaft encoder and memory card.

Table 1. Driving force and torque developed when a float of the indicated size is displaced by 0.01 ft.

Float diameter, inches (in.)	12.00	10.00	2.50	1.50
Driving force, ounces (oz)	7.84	5.45	0.34	0.123
Driving torque, inch-ounce (in-oz) (12-in. pulley)	15.00	10.40	0.65	0.230
One-third of driving torque, inch-ounce (in-oz)	5.00	3.47	0.217	0.077

Float and Potentiometer

The stage potentiometer, as shown in figure 24, is designed as a stage sensor when used in combination with a basic float system. The stage potentiometer does not meet the accuracy requirements for primary stage records, and errors of ±0.05 ft are common. However, it is useful for noncritical applications with moderate accuracy requirements, and where low cost is an important factor. Stage potentiometers should not be used where continuous float motion (painting) occurs. Continuous movement of the water surface can cause wear of the internal contacts of the potentiometer, resulting in unreliable data.

Figure 24. Stage potentiometer.

Bubble Gages

The term bubble gage is a general term that refers to various configurations of instrumentation designed to measure, or sense, the water level and stage on the basis of pressure differentials. A gas, such as nitrogen or air, is forced (bubbled) through a fixed orifice mounted in the stream, and the water pressure at the orifice is transmitted through the gas tube to a pressure sensor located in the gage house where it is converted to a measurement of stream stage. Original bubble gages, first used in the early 1960s, used a mercury manometer to measure pressure differences. However, because of the hazardous nature of mercury, these manometers were banned in the late 1980s, and installation of new mercury manometers was prohibited. All existing mercury manometers in use by the USGS were removed over a period of a few years in the 1990s.

Modern day bubble gages use some type of nonsubmersible pressure transducer as the method of measuring pressure differentials. A number of different pressure transducers are available that meet USGS accuracy requirements; some are described in the following sections of this report.

Two essential components of a bubble-gage system, in addition to the pressure sensors, are (1) a gas-purge system, and (2) a bubble-gage orifice. These are described in the following sections.

Gas-Purge Systems

The gas-purge system is a critical component of a bubble-gas system. It is designed to feed a gas, usually nitrogen, through a system of valves, regulators, and tubing to an orifice located at a fixed elevation in the stream. The continuous formation of bubbles at the orifice transmits the pressure head (depth of water over the orifice) caused by the stream stage, by way of the connecting tubing, to the pressure sensor located in the gage house.

Several gas-purge systems are available for use with bubble gages. The standard USGS Conoflow bubbler system is a commonly used gas-purge system. Other gas-purge systems include the Hydrological Services Model HS–55 self-contained bubbler system, the Fluid Data Systems Safe Purge II unit, the Design Analysis Associates Model H–355, and the Sutron Accububbler.

The Conoflow bubbler system is shown in figure 25. The system consists of the Conoflow differential regulator, the sight-feed and needle-valve assembly, and various valves and tubing. The sight-feed and needle-valve assembly includes an oil reservoir where the bubble rate can be visually adjusted. One tube leads to the stream and orifice, and another tube leads to the pressure sensor. The Conoflow bubbler system is a proven method that meets USGS accuracy standards.

Figure 25. Conoflow gas-purge system.

The Hydrological Services Model HS–55 self-contained bubbler system is a gas-purge system that converts water-level head to pressure in conjunction with a water-level pressure-sensing instrument. This system is designed to supply a constant bubble rate by way of a regulator. Bubble rate is set by rotating a micrometer dial, thus eliminating the need for a sight glass and oil reservoir, as used in the Conoflow system. The unit has a gas-supply inlet for use with dry nitrogen, an instrument outlet for connection to a pressure-sensing device, and an orifice outlet for head-pressure measurement and system-purging operations. Tests have shown that it compares favorably with the Conoflow system. Figure 26 shows an HS–55 self-contained bubbler system.

Figure 26. Hydrological Services Model HS–55 self-contained bubbler system.

The Design Analysis Associates Model H–355 and the Sutron Accububbler model 5600–0131–1 are self-contained gas-purge systems with pressure sensors and controller units. They do not produce constant bubble rates; they purge the orifice line before each scheduled reading. These systems can be automatic and (or) manually controlled to purge the orifice line. They wait for the bubble turbulence to subside before taking a stage reading. These types of systems are considered an advantage in streams where sediment infiltration may cause clogging of the orifice lines. Tests have shown that they compare favorably to the Conoflow system. Figures 27 and 28 show the Design Analysis Associates Model H–355 self-contained gas-purging system and the Sutron Accububbler model 5600–0131–1 gas-purge units, respectively.

Figure 27. Design Analysis Associates Model H–355 self-contained gas-purge system.

Figure 28. Sutron Accububbler Model 5600–0131–1 self-contained gas-purge system.

Bubble-Gage Orifices

The gas-purge system bubbles a gas into the stream through an orifice. The standard USGS orifice is mounted in a 2-in. pipe cap so that it can be attached to a 2-in. pipe. Figure 29 is a detailed drawing of an orifice assembly, and figure 30 shows an inside and outside view of an actual standard USGS orifice assembly.

The orifice assembly is installed so that the orifice remains at a fixed elevation in the stream, and the proper placement in the stream is essential for obtaining an accurate record of stage. If possible, the orifice assembly should be installed where stream currents are not high, and where sediment accumulations are not likely to cover the orifice. If high velocities are expected to occur near the orifice, install it inside a static tube—a vertical mount perpendicular to the direction of flow.

Details of a standard orifice static tube are shown in figure 31. A more detailed description for the installation of a bubble-gage orifice is given by Craig (1983).

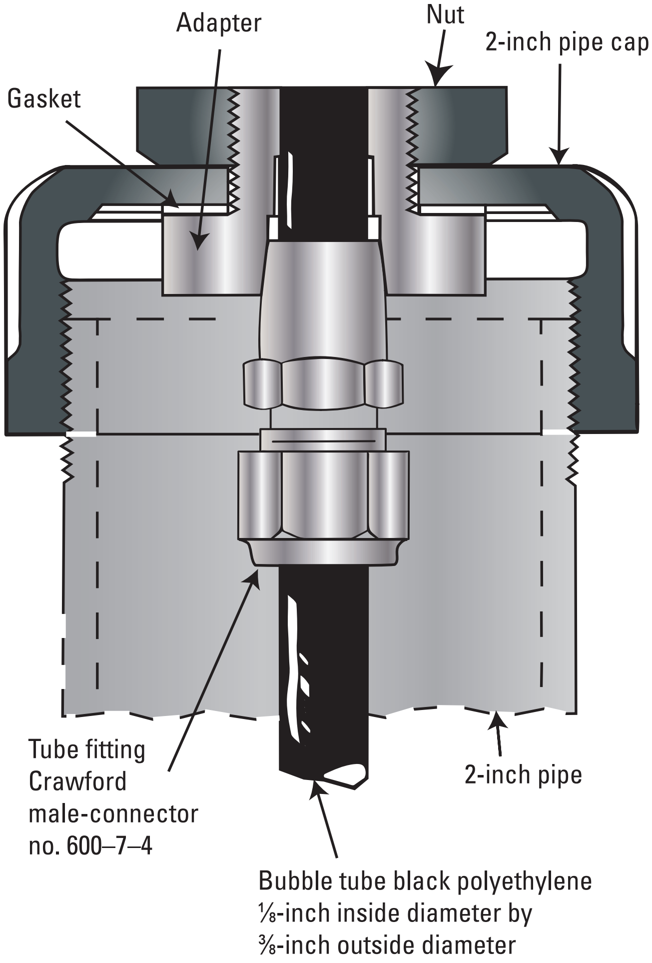

Figure 29. Details of a bubble-orifice assembly.

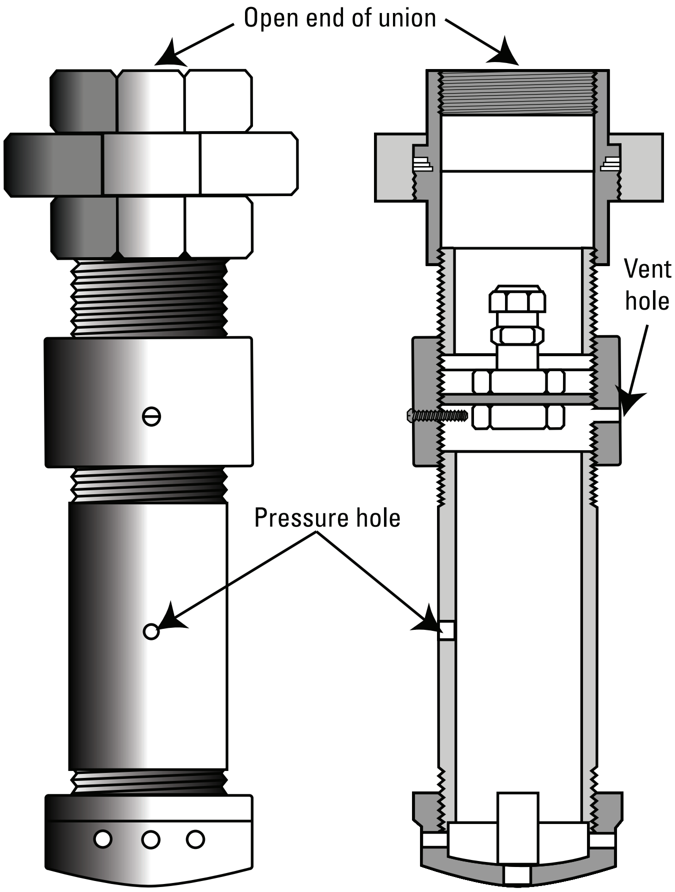

Figure 31. Details of a standard orifice static tube.

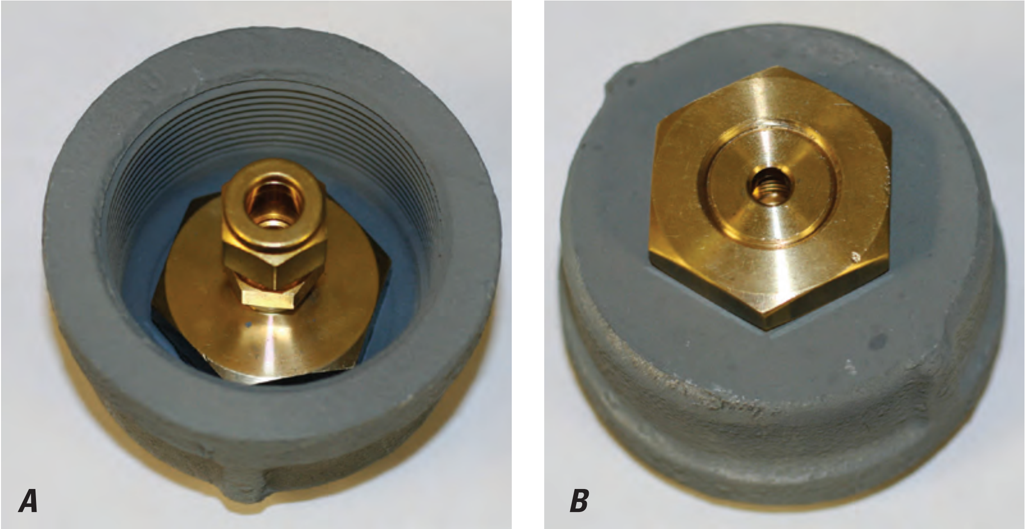

Figure 30. *A*, Inside and *B*, outside view of a bubble-orifice assembly.

Nonsubmersible Pressure Transducers

Nonsubmersible pressure transducers are generally used as the pressure sensor for bubble-gage systems. These transducers are connected to the gas-purge unit to receive the pressure input from the stream. The transducers are internally programmed to convert the gas pressure to units of water head (feet of water over the orifice), and to then transmit the data to an EDL or DCP by way of a serial digital interface, such as the SDI–12. Pressure transducers generally have internal compensation for temperature changes and various other adjustment provisions to compensate for water-density variations, purge-gas weight, local-gravity variations, and gage-datum adjustments.

Three nonsubmersible pressure transducers tested by the HIF, and found to meet USGS accuracy requirements, are (1) the Paroscientific Model PS–2, (2) the Sutron Accubar Model 5600–0125–3 (Accubar-3), and (3) the Design Analysis Associates Model H–350XL. These models are shown in figures 32, 33, and 34, respectively.

Figure 32. Paroscientific Model PS–2 nonsubmersible pressure transducer.

Figure 33. Sutron Accubar Model 5600–0125–3 (Accubar-3) nonsubmersible pressure transducer.

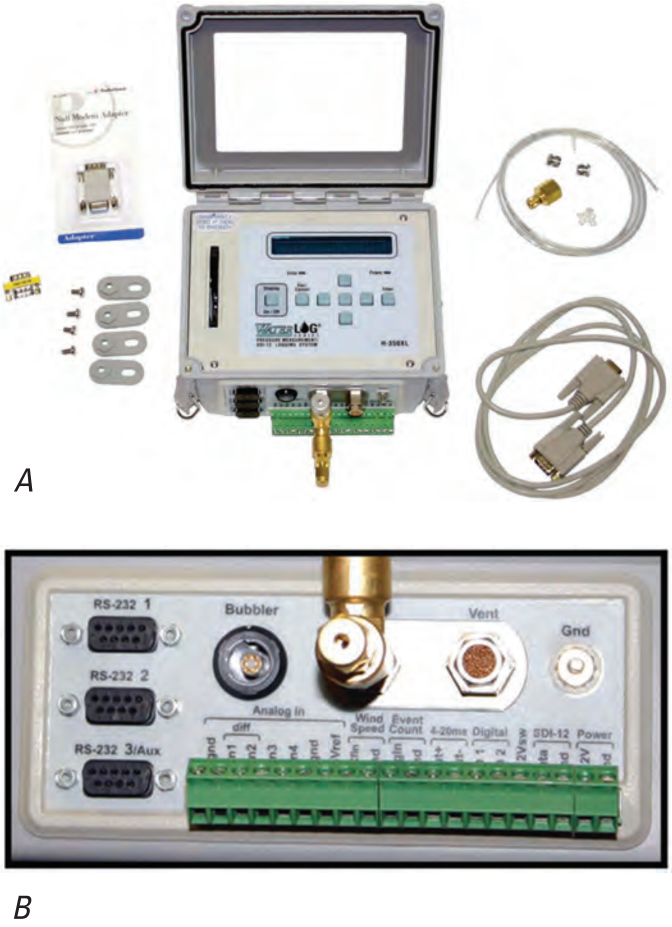

Figure 34. *A* and *B*, Design Analysis Associates Model H–350XL nonsubmersible pressure transducer.

Submersible Pressure Transducers

A number of submersible pressure transducers are commercially available for use, primarily in groundwater wells, although in a growing number of applications, they have been used for streams and reservoirs. Submersible pressure transducers are usually self-contained units having a transducer element and electronic circuitry. Some also contain a data logger and battery. These units can be mounted directly in the stream or reservoir. Temperature variations will affect the accuracy of submersible units; historically, these sensors generally have not met USGS accuracy requirements for primary stage records, although in recent years the HIF has tested several models that do meet OSW accuracy standards. Submersible units will be damaged or destroyed by freezing temperatures. Use of submersible pressure transducers may be acceptable in environments where temperature changes are small and where freezing is not a factor, such as in deep-reservoir installations. Tropical, subtropical, and temperate streams may also be acceptable locations, but without protection from freezing temperatures, these instruments are of limited use in the northern climates.

Submersible pressure transducers receive the pressure input from the water pressure of the stream above them and are internally programmed to convert pressure to units of water head (feet of water over the orifice). Units of water head then transmit the data to an EDL or DCP by way of a serial digital interface, such as the SDI–12.

Examples of submersible pressure transducers tested by the HIF, and found to meet USGS accuracy requirements, are: Design Analysis Associates Model H–312 submersible pressure transducer (0–22 psi; figure 35), the KPSI Model level and pressure transducer (0–15 psi; figure 36), and the YSI Model 600XL vented water-level submersible transducer (0–15 psi; fig. 37).

Submersible pressure transducers tested by the HIF, which did not meet USGS accuracy requirements, but may be applicable in certain environments, are: the Onset HOBO water-level data-logger models U20–001–01 and U20–001–02, and the In-Situ Aqua Troll 200. Two of these models are shown in figures 38 and 39.

Since September 2005, the OSW has actively pursued using submersible transducers, such as those shown in figures 35 through 39, for deployment in the track of hurricanes that come on shore in the United States. The data obtained from these transducers have helped modelers, decisionmakers, and emergency managers in the monitoring of storm surge caused by large hurricanes.

Figure 35. Design Analysis Associates Model H–312 submersible pressure tranducer.

Figure 36. KPSI Model level and pressure transducer (0–15 psi).

Figure 37. YSI Model 600XL vented water-level submersible transducer (0–15 psi).

Figure 38. Onset HOBO water-level data-logger models U20–001–01 (0–30 ft).

Figure 39. In-Situ Aqua Troll 200.

Storm tide levels, magnitude, and duration are critical parameters in the calibration of coastal models that depict and predict storm tides during hurricanes. This information is then used by emergency managers for the preparation, warning, and response to hurricanes. Since 2005, the OSW, in concert with USGS Water Science Centers, has planned and designed methods to collect a reliable time-series that can be used to construct a storm-surge dome model (that is, a three-dimensional image of the penetration, height, and abatement of the surge) for hurricanes that strike the U.S. coast. Such data yield valuable information for proactive design of coastal infrastructure, as well as emergency preparedness information for state departments of transportation and the National Weather Service. Data collected along beaches can help identify and describe wave dynamics and beach instability.

Based on the NOAA National Hurricane Center's 48-hour forecast of hurricane landfalls, USGS hydrographers rapidly deploy water-level sensors shown in figures 35 through 39. These sensors are installed specifically at the coastline or near shore estuaries to capture detailed tidal-stage wave-height data for use by emergency managers and hurricane modelers. Improving emergency preparedness and coastal protection is the USGS goal by optimizing the collection of time-series storm-surge data that can improve the predictive capability of hurricane-inundation models, help in the design of manmade infrastructure, and help protect coastal ecosystems. These sensors collect not only storm-tide levels but also can be programmed to collect wave data.

Noncontact Water-Level Sensors

Almost all of today's instrumentation for measuring water levels requires that some part of the stage-sensing element be in contact with the water. Recent developments using acoustic, radar, and optical methods are beginning to emerge with instrumentation that will eventually provide accuracy and convenience of measuring water surfaces without direct contact. Most of these types of instruments are still in the development stage and, consequently, are relatively expensive, and some are not yet able to achieve USGS accuracy standards. The following sections provide a brief description of noncontact water-level sensors. For a more detailed description, see issue 80 of WRD Instrument News (U.S. Geological Survey, 1998a).

Acoustic

The acoustic noncontact methodology for measuring stage generally uses a high-frequency acoustic transducer that propagates a sound wave through the air to the water surface. The reflected acoustic wave is received at the transducer, converted to an electrical signal, and processed into a water-surface stage. The transmitted and reflected signals are affected by air temperature and air density, which in turn affects accuracy, especially when the vertical distance between the transducer and the water surface is large (that is, greater than about 10 ft). Without compensating for air temperature and density, this acoustic method has limitations in meeting USGS accuracy standards for primary stage records.

One notable exception in the use of acoustic noncontact methodology for measuring stage is the acoustic sensor instrumentation developed in cooperation with Aquatrak Corporation by the National Oceanic and Atmospheric Administration's National Ocean Service (NOAA–NOS). The Aquatrak Absolute Liquid Level Sensor is an instrument based on sonic-pressure pulse comparison that is measured inside a 6-in. polyvinyl chloride (PVC) tube. The Aquatrak uses a fixed reference in its calibration tube approximately 4 ft below the sensor to compensate each reading for propagation speed changes due to variations in air temperature and density. This instrument in preliminary tests by the HIF shows promise as a water-level sensor. Initial tests by the HIF indicate the Aquatrak Absolute Liquid Level Sensor passes USGS standards for vertical accuracy (that is, ±0.01 ft or 0.2 percent of the effective stage). The Aquatrak Absolute Liquid Level Sensor is shown in figure 40 without the PVC housing and installed at an NOS station.

The Aquatrak sensor is used across the United States by NOAA–NOS as the standard for the collection of water-level data. NOAA–NOS operates over 200 permanent near-coast tidal and Great Lakes gages in the United States.

In-stream acoustic beams are used for the measurement of depth, typically on acoustic Doppler velocity meters (ADVMs) at index velocity streamgages. The USGS in recent years has built hundreds of index-velocity gages with an ADVM or other acoustic-velocity meter for the measurement of streamflow in reaches where unsteady (varied, nonuniform) streamflow is prevalent that prevents the development of a conventional stage-discharge rating. The ADVM measures point velocity and typically these gages include a dedicated stage sensor (for example, stilling well, nonsubmersible or submersible pressure transducer, or radar-level sensor) for the recording and computation of stage and discharge. However, ADVMs also now readily have available a separate in-stream acoustic beam or submersed pressure sensor for the measurement of depth. Some ADVMs have both an acoustic beam and a submersed pressure transducer for the measurement of depth. These measurements can readily be converted to stage with an offset. Currently (2010), the HIF has done only limited testing to determine the accuracy of these instruments for stage measurement, but the technology seems promising as long as temperature and density constraints within the vertical column of water being measured remain constant. Typically in the USGS, ADVM stage measurements are used as an auxiliary or backup stage for the primary stage sensor mentioned previously.

Figure 40. *A*, Aquatrak Absolute Liquid Level Sensor; *B*, sensor without polyvinyl chloride (PVC) housing; and *C* , installed at a National Oceanic and Atmospheric Administration National Ocean Service monitoring station with PVC housing.

Radar

Radar, or radio-frequency transmission, is a distance-measuring method that has been used since before World War II. A radio frequency is the propagation of an electromagnetic field, and therefore, is performed at the speed of light. The advantages of radar are that the signal is generally immune to weather conditions, such as snow and rain, and the radio wave used for this application is harmless to humans and wildlife. The usable sensor-to-water sensing range is minimally from near zero to about 66 ft, and can be greater, depending on the radar instrument. The technology for using radar for measurement of water levels is still new, although several commercially developed instruments are available. Some of these units are being tested by the HIF. Also, as in all radio-frequency transmissions, the radar frequency must meet approval from the USGS Office of Information Services and ultimately the U.S. Federal Communications Commission (FCC).

Several radar sensors are commercially available for use in streams and reservoirs. Radar sensors are usually self-contained units having typically a horn-like transmitting device and electronic circuitry. Radar sensors are internally programmed to convert radar-frequency reflections from units of distance to the water surface to stage.

To use these sensors, the hydrographer will usually have to provide a separate data logger and battery. These units are mounted directly above the stream or reservoir using a bridge handrail or other stable structure. In recent years, the HIF has tested several of these sensors that do meet OSW accuracy standards.

Typically, radar sensors used to measure stream stage have a beam angle of 8 degrees (table 2). This means at 25 ft of air gap, the footprint measured has a diameter of 7 ft on the water surface. If using one of these instruments for the measurement of stage, make routine checks to ensure the instrument footprint does not have obstructions that will affect the measurement of stage, such as debris, boulders, and other material in the stream.

Examples of radar sensors tested by the HIF, which meet USGS accuracy requirements, are: the Design Analysis Associates H–3611, the Ohmart Vega VegaPuls 61, the Ohmart Vega VegaPuls 62, and the Ott RLS radar level sensors. These sensors show promise in measuring stream stage although more research is needed to refine the uncertainties associated with noncontact radar sensors. Some of the manufacturers' specifications for three radar sensors tested by the HIF are presented in table 2. Three of the four sensors are shown in figures 41, 42, and 43.

Table 2. Sensor specifications for the Design Analysis H–3611 radar level sensor, the Ohmart Vega VegaPuls61 and VegaPuls62 radar gages, and the Ott RLS radar level sensor.

[TOF, time of flight; GHz, gigahertz; FCC, Federal Communications Commission; ft, feet; °, angular degrees; lb, pound; °C, degrees Celsius; mA, milliampere; V, volt; DC, direct current; mW, milliwatt]

Specification	Design Analysis	Ohmart Vega	Ohmart Vega	Ott
Model	H3611	Puls 61	Puls 62	RLS
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Frequency	26 GHz	26 GHz	26 GHz	24 GHz
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Range	0.75 to 72 ft	0.75 to 72 ft	0.75 to 72 ft	2.62 to 35 ft
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Beam angle	8° 10°	8°	8°	8°
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Weight	8 lb	~5 lb	8 lb	4.6 lb
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Supply voltage	10 to 16 V DC	Nominal 24 V DC	Nominal 24 V DC	12 to 24 V DC
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Operating temperature range	-40 to 80°C	-40 to 80°C	-40 to 80°C	-10 to 40°C
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Figure 41. Design Analysis Associates H–3611 Radar Level Sensor.

Figure 42. Ott RLS Radar Level Sensor.

Figure 43. Ohmart Vega VegaPuls62 Radar Gauge.

Rapid Deployment Gages

In recent years, the USGS has implemented a program whereby the HIF constructs and stores portable look-in shelters with stage sensors and preconfigured DCPs, batteries, solar panels, and other equipment to use in a rapid deployment during floods. Currently, the stage sensor for most of these gages is a noncontact radar-stage sensor. These portable gages are constructed and stored at the HIF, then quickly shipped to regions experiencing a flood or other environmental disaster, and when installed, provide near real-time access to stage and other hydraulic and hydrologic parameters to decisionmakers during emergency disasters (fig. 44). The equipment in these gages is typically a noncontact radar-stage sensor, a DCP, a Yagi antenna (top-of-pole-mount type), a 30-watt solar panel with custom bracket, and a GPS antenna. All cables are included and prewired, with two standard USGS padlocks for security.

Rapid deployment gages are useful where there is not an existing gage but there is a need to obtain information quickly, where a gage was destroyed by a flood, fire, or other cause, and perhaps for supplementing other gaging information at a site. These gages could also be used for wildfires, major chemical spills, and other natural and anthropogenic disasters. The need for rapidly deployable streamgages has grown sequentially over time.

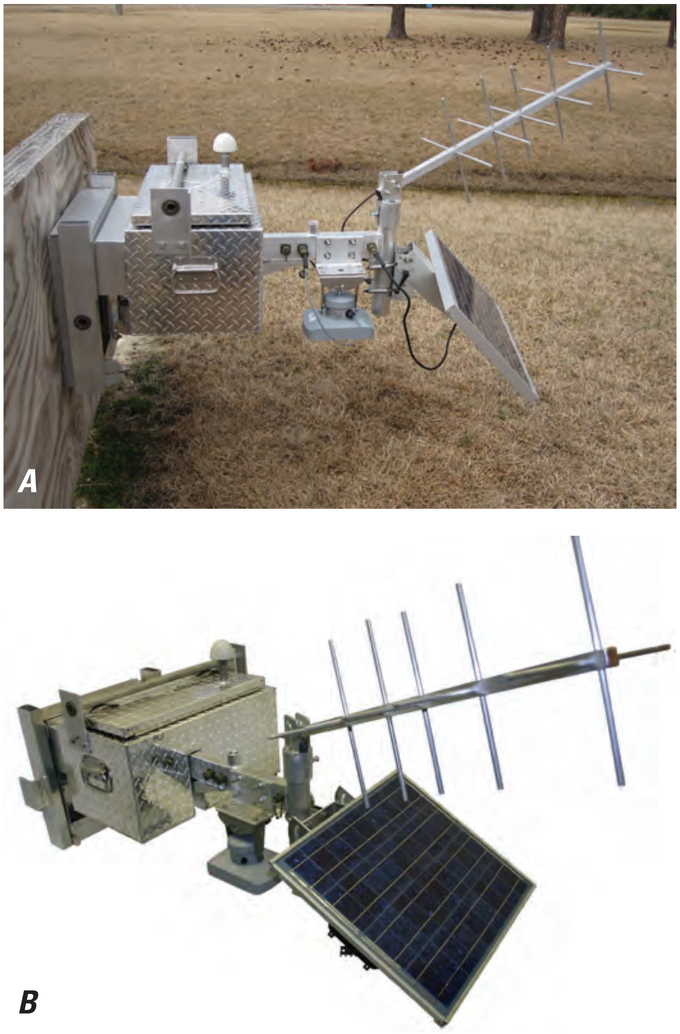

Figure 44. *A* and *B*, Typical USGS rapid deployment streamgage with a DCP and Ott RLS radar stage sensor.

Optical (Laser)

Optical methods of measuring distance are confined mainly to the use of laser, a technology that deserves further investigation for use in measuring water-level stage. Eye safety is a consideration with lasers because direct exposure of the eyes to a laser beam could be dangerous and cause permanent vision loss or other damage to the eyes. Generally, for water-level measurements, this will not be a problem because the power levels of the beam are well within safe standards. As with radar, a few commercially developed laser instruments are now available and are being considered for testing by the HIF. In general, existing lasers in industrial use are recommended for opaque and unclear liquids. There is currently a need to do further research in the use of laser technology before it can be evaluated for use in the measurement of stream stage.

Water-Level Recorders

A water-level recorder is an instrument that automatically records a continuous, or quasicontinuous, record of the water-surface stage with respect to time. Water-level recorders may be paper chart recorders (analog), paper punch-tape analog-digital recorders (ADRs), EDLs, or DCPs. The basic requirements for a recorder are to systematically and accurately keep a record of the gage height with respect to time so that a stage hydrograph of the fluctuations of the water surface can be produced for later archiving and analysis. Accuracy requirements are described in a previous section of this report.

Paper Chart Recorders

A paper chart recorder, also referred to as an analog or graphical chart recorder, provides a continuous graphical trace of water stage with respect to time. It was the primary type of stage recorder used by the USGS from about 1900 until the mid-1960s, when the ADR paper-punch tape recorder was introduced. The paper chart recorder is still used at some gaging stations, but in most instances it is used only as a backup recorder for verifying peak stages of hydrologic events. The Stevens A–35 strip-chart recorder, as shown in figure 45, is the most common analog recorder, but there are variations such as the gold strip-chart recorder, and the horizontal-drum recorder.

The Stevens A–35 recorder uses a roll of chart paper called a strip chart, which is driven by a clock at a uniform speed to provide the timing element of the stage hydrograph. Clocks are either spring driven or weight driven and are reasonably accurate if properly adjusted. Timing errors of 1 to 2 hours are normal over a period of several weeks; however, larger errors can sometimes occur. An ink pen and (or) pencil that rides on

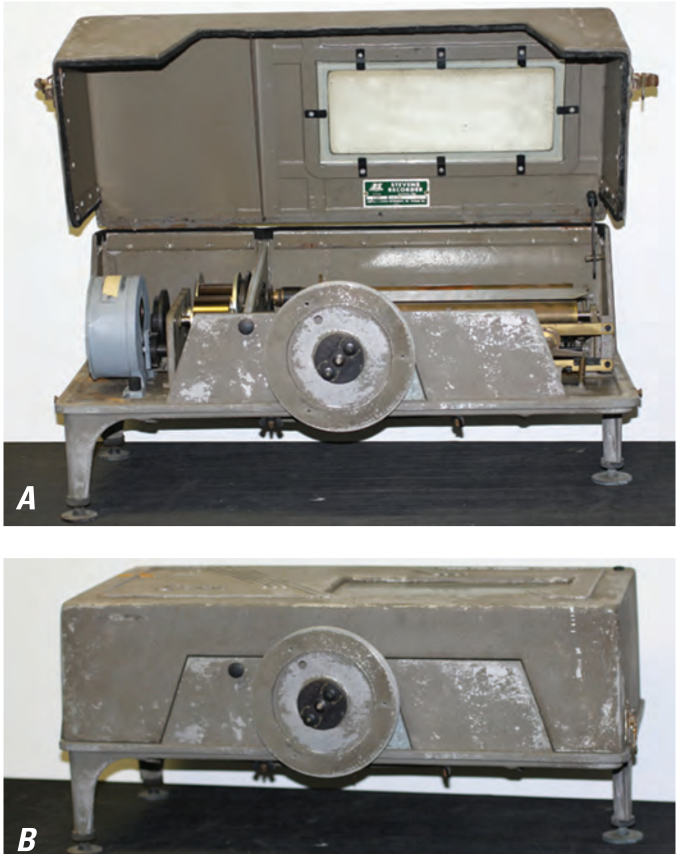

Figure 45. *A* and *B*, Stevens A–35 strip-chart recorder.

the strip chart is connected through a series of gear-and-chain linkages to the float wheel. As the stage rises and falls, the pen and (or) pencil draws a trace on the 10-in.-wide chart at a fixed scale, usually 1 ft of stage per 2 in. of chart scale, although other scales can be used. A reversal mechanism allows the pen and (or) pencil to reverse direction at the edge of the chart, thus providing a stage scale limited only by the vertical travel range of the float. Most strip-chart records will operate for several months without servicing, whereas the horizontal-drum recorder must be serviced at weekly intervals. Attachments are available for the strip-chart recorder to record water temperature or rainfall on the same chart with stage.

The Stevens A–35 recorder is a time-proven instrument that served as the primary method of recording stream stage for many years. A major advantage of this recorder is that it produces a graphical record of stage that gives a visual picture of the rise and fall of the stream. The graphical record also provides an easy means of spotting malfunctions, such as clogged intakes at stilling well streamgages. A disadvantage is that the graphical stage record cannot be easily scanned for electronic archiving and analysis.

Paper Punch-Tape Recorders

Paper punch-tape recorders, commonly referred to as ADRs, were introduced in the early 1960s as a replacement of the paper strip-chart recorders and used through the 1990s. The most common type of ADR used by the USGS is the Stevens digital recorder shown in figure 46. Recorders of this type have been replaced by EDLs and DCPs. A description of ADRs in this report is presented because of the many decades of service they provided and the billions of instantaneous stages that are still retained in hardcopy archives with the USGS.

The ADR (Carter, 1963) is a battery-operated, slow-speed, paper-tape recorder that punches a 4-digit number on a 16-channel paper tape at preselected time intervals. Stage is recorded in increments of a hundredth of a foot from zero to 99.99 ft and is transmitted to the instrument by rotation of the input shaft, which was generally driven by a basic float system, although these instruments were also geared to manometers. Shaft rotation is converted by the instrument into a coded punch-tape record that can be read visually from the tape, but is designed to be read by digital-tape readers for input to an electronic computing system.

The code consists of four groups of four punches each. In each group, the first punch represents “1,” the second “2,” the third “4,” and the fourth “8.” Thus, a combination of up to three punches in a group represents digits from one to nine, with a blank space for zero, and the four groups of punches represent all numbers from 1 to 9,999. Coding is done by means of two discs containing raised ridges in accordance with the punch code outlined above. One disc is mounted directly on the input shaft. The second code disc is connected to the first by a 100:1 worm gear so that 100 revolutions of the input shaft rotate the second, or high-order disc, one complete revolution. A paper tape is moved upward through a punch block that is mounted on a movable arm hinged at the base of the recorder. The punch

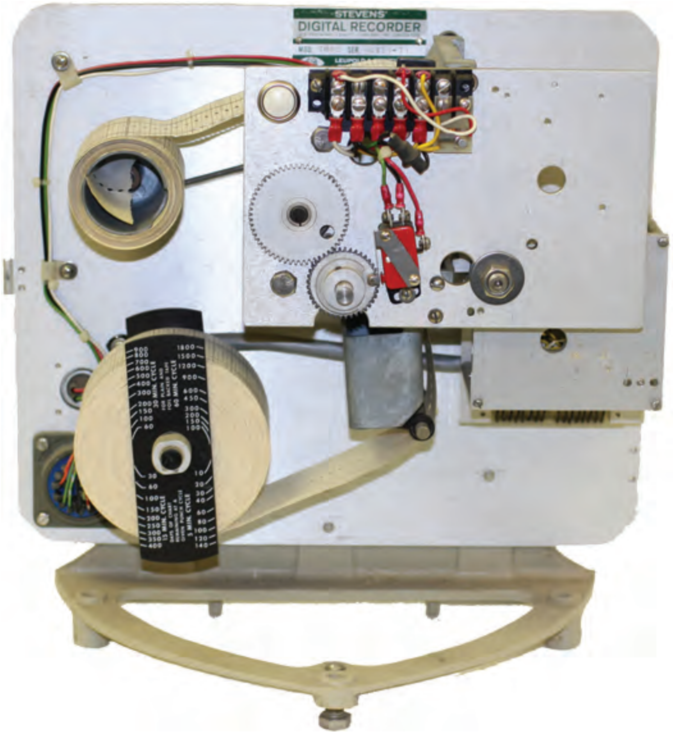

Figure 46. Stevens analog-digital recorder (ADR).

block contains a single row of 18 pins—16 pins for the information punches and 2 pins for punching feed holes.

Throughout decades of use, a major advantage of ADRs was that the paper-punch tapes could be automatically read into an electronic computing system for archiving and analysis; however, it was a slow and tedious process to read tapes by visual inspection. This made field inspection of the stage record difficult for spotting malfunctions of the gage. ADRs could also miss the absolute peak stage, especially on flashy streams. The mechanically punched tape of an ADR was very practical for field use under widely varying conditions of temperature and moisture.

Electronic Data Loggers

Electronic data loggers (EDLs) are devices that can be programmed to electronically record stage data (or other variables) on a specific, regular time interval, or on a user-defined schedule that may vary according to stage or other variable. There are a number of manufacturers and vendors of EDLs, which include Sutron, Coastal Environmental Systems, Campbell Scientific, Synergetics, Vaisala, Design Analysis Associates, Stevens, Unidata, and others. New models of current EDLs and new EDLs from new manufacturers are frequently offered. For this reason, it is not practical to provide a detailed description of specific manufacturers or models of EDLs in this report, as such listings and descriptions are subject to change in a short time. Descriptions and test results can be obtained from the HIF. EDLs are commonly combined with DCPs, which are described in the next section of this report. Table 3 contains a selected listing of currently available models of EDLs and DCPs that have been tested by the HIF.

Table 3. Summary of currently available data-collection platforms (DCPs) and electronic data loggers (EDLs).

Manufacturer	Model number	Primary function
Sutron	8200	EDL and DCP
	8200A	EDL and DCP
	8210	EDL and DCP
	8400	EDL
	9210	EDL and DCP
	7210	EDL and DCP
Vaisala	555A	EDL and DCP
Campbell Scientific	CR10[1]	EDL
	CR10X[1]	EDL
	CR 295	EDL and DCP
	CR 850	EDL
	CR 1000	EDL
Design Analysis	H-350[1]	EDL[2]
	H-522jr	EDL/DCP
	H-522+	EDL/DCP
	H-350XL[1]	EDL[2]
	H-500XL	EDL
	H-510	EDL
	DH-21	EDL[2]
Stevens	GS-93A[1]	EDL
	GS-93B[1]	EDL

[1] Not currently supported by the HIF.

[2] EDL and nonsubmersible pressure transducer (combination).

EDLs are usually powered by an external battery, which may be rechargeable. In many cases, the batteries are charged through the use of a solar panel. Where reliable AC power is available, power may be supplied from the AC source. EDLs also usually have internal batteries to maintain programming and data in the event of a power failure.

Electronic clocks used in EDLs can generally be relied upon to keep accurate time. See a subsequent section of this report on "Timers" about the method of setting the timers in EDLs.

The stage of a stream or reservoir is sensed by either a float-driven shaft encoder, by a bubble gage and nonsubmersible pressure transducer arrangement, by a submersible pressure transducer, or by a radar sensor. The encoded stage data are then relayed to the EDL through a hard-wired or wireless connection for storage and (or) transmittal to a remote site. See figure 47 for a typical installation of a float-driven shaft encoder and EDL.

EDLs store stage data either internally on a memory module, or the EDL may store the data on a removable

Figure 47. *A*, Typical installation of float-tape gage and *B*, electronic shaft encoder and electronic data logger (EDL).

memory card. Most EDLs allow for both methods of data storage. Data are retrieved either by downloading directly from the EDL to a PDA or other field computer, or by removing the memory card and transferring the data from the card to a PDA or other field computer. The portable memory card can then be carried to the field office for downloading. Data can also be retrieved by transmitting via telephone, radio, or satellite.

EDLs can store relatively large amounts of data without frequent servicing, and they can be programmed to collect data according to specific needs. They can be easily connected to transmitting devices, such as land-based radios, telephones, or satellite radio systems, so that data can be retrieved in near real-time mode. The internal electronic clocks of EDLs are generally accurate. A disadvantage is that usually the complete stage record cannot be easily viewed in the field by graphical methods without downloading the data to a PDA or portable field computer that has plotting software designed for stage-hydrograph viewing.

Data Collection Platforms

Data Collection Platforms (DCPs) are referred to in the commercial industry as a unit designed to acquire data and transfer the data to another location. Data may be transferred by a telephone modem (land-line based or cellular), a land based radio, or satellite. The USGS uses the term DCP in reference to devices that collect data and transfer it over the NOAA, National Environmental Satellite, Data, and Information Service (NOAA–NESDIS) Geostationary Operational Environmental Satellite (GOES). The GOES transmitter is considered an integral part of a DCP. High Data Rate (HDR) transmitters are now available and transmit at baud rates of from 300 to 1200 bits per second (bps). NOAA–NESDIS has mandated the replacement of all 100 bps radios with 300 or 1200 bps radios by 2013.

DCPs store relatively large amounts of data; some units may provide for storage modules or cards that can also store a relatively large amount of data. In some cases, the GOES transmitter may be an integral part of an electronic data logger, or may be connected to an EDL in such a way that large amounts of data can be stored as well as transmitted. Like EDLs, there are a number of makes and models of DCPs by some of the same companies listed in the previous section on EDLs. Descriptions and manufacturers' specifications of specific DCPs are not given in this report because currently available DCPs are subject to change, and new makes and models are frequently introduced. Descriptions and test results can be obtained from the HIF, and a summary of currently available units is given in table 3.

The power source for a DCP can be a rechargeable battery or a reliable AC electrical source. Solar panels are typically used to keep batteries charged, and the same battery may provide power to other instruments in the gage house.

Electronic timers are used for DCPs, and are generally very accurate. See a subsequent section of this report on "Timers" for a description of a device that can be used for setting the electronic clock of a DCP. HDR transmitters include internal atomic clocks.

DCPs receive stage (or other variable) data from a shaft encoder, submersible or nonsubmersible pressure transducer, radar water-level sensor, water quality sondes or other sensors, just as described previously for EDLs. The data are transmitted on a predefined schedule, such as a 1-, 3-, or 4-hour interval (after 2013, current plans are for 3- and 4-hour transmission to be phased out), thus providing near real-time access to the data. Overlapping periods of data are transmitted each time a transmission is made, providing a certain amount of redundancy; and this allows for the recovery of data that may sometimes be lost during a transmission. Redundant transmissions have proved a reliable means of plugging short gaps from data loss either through a missed transmission or brief malfunction of equipment.

DCPs typically are equipped with two channels for transmission. One channel is designated for normal transmissions (for example, at 1, 3, or 4 hours), and one for emergency transmissions (for example, typically transmitted at the recording interval of the DCP, such as at 5, 15, or 60 minutes). Emergency transmissions are random and usually triggered either by the stage reaching a predefined trigger, such as a NOAA National Weather Service flood stage, or a rate of change of stage, usually at flashy streams.

Telemetry Systems

The primary telemetry method used by the USGS is the GOES satellite transmission system, which is an integral part of DCPs, as described in the previous section of this report. Radio and telephone-transmitting systems are also used, primarily by agencies other than the USGS, but the USGS does have several flood-warning and real-time systems that are transmitted through radio and telephone systems. Through 2013, the GOES satellite transmission will allow transmission through low data rate (LDR) satellite transmitters. LDRs transmit typically at a baud rate of 100 bps. After 2013, agencies using the GOES are currently mandated to upgrade all LDR radios to high data rate (HDR) radios. HDR radios transmit at 300 or 1200 bps. A schematic of the flow of data from the streamgage to the Internet is provided in figure 48.

Other telemetry systems for transmitting data from a gaging station to a remote location include electronic modems, cellular telephone modems, land based radio systems, and new satellite technology, such as Meteor Communications Corporation systems, which uses ionized meteor trails as a means of radio signal propagation. These meteor trails exist in the 50- to 75-mile region above the Earth's surface. Some of these systems are relatively new, and still in the development stage. Wireless data-transmitting systems are in a rapid state of development with new systems on the horizon.

A short-range radio transmitter can be used to send data from a stage sensor, such as a float-tape gage or bubble gage, to a data logger. Two units are required—one for sending and one for receiving. An example of a radio system of this type is the Design Analysis Associates H–424–MS SDI–12 Radio Link, as shown in figure 49. This unit has a range of ⅛ to ¼

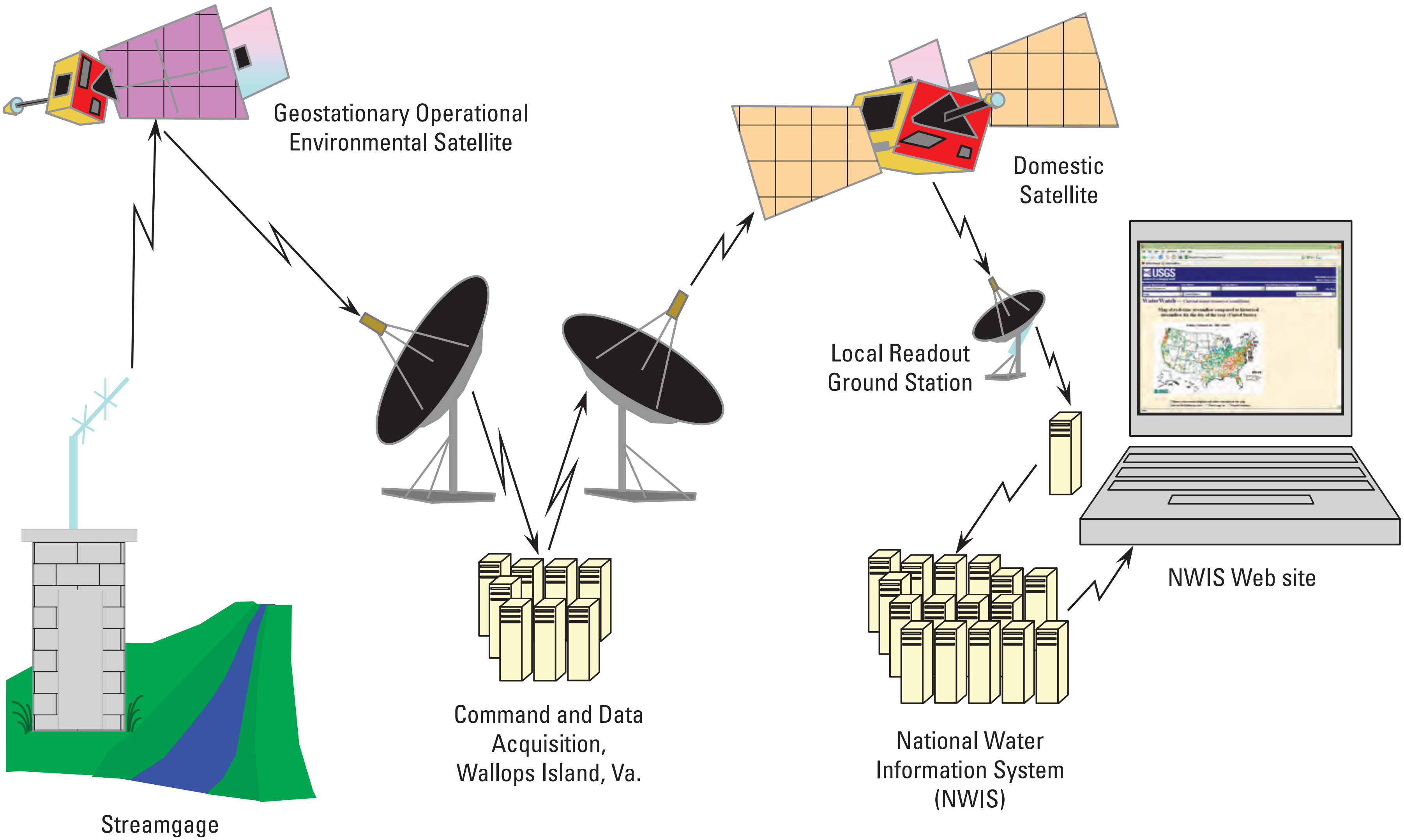

Figure 48. Schematic showing flow of hydrological data for a DCP transmission from a gaging station to the Internet.

mile; however, this range can be increased by substituting a directional antenna for the omnidirectional antenna that comes with the unit. It is basically a line-of-sight unit, but can tolerate minor obstructions. Other short-range radio transmitters are available from other manufacturers.

Figure 49. Design Analysis Associates H–424–MS SDI–12 Radio Link.

Timers

Timers for data recorders and data loggers range from mechanical clocks to highly sophisticated electronic clocks to GPS signals. These have been referenced in previous sections of this report that describe data recorders and DCPs. The accuracy of the time associated with each recorded stage is dependent on the accuracy of the timer, and the advent of electronic timers in recent years has resulted in highly accurate time records.

Portable, electronic clocks are still available that can be used for setting the time on EDLs, DCPs, and other instruments requiring an accurate time setting; however, most EDLs and DCPs come with GPS-corrected timers that are highly accurate. These clocks receive a radio signal directly from the Atomic Clock (WWVB) in Boulder, Colo. The units typically use an omnidirectional antenna, and reception of the signal automatically sets and displays the time, in hours, minutes, and seconds, on a liquid crystal display. They are typically accurate to 0.0001 of a second. In addition to the time, a.m. and p.m., the month, date, day of the week, time zone, and signal strength are also displayed. The clocks automatically adjust for daylight savings time, leap year, and Earth-rotation corrections. Future instrumentation will incorporate automatic calibration of internal timers, and manual setting of timers will not be needed.

With the advent of HDR transmissions, it is critical to be accurate within a second of true atomic time. As stated previously, HDR transmitters include internal atomic clocks.

Power Supplies

Most gaging stations require some type of electrical power, either AC or DC, to operate the various instruments. Dry cell and wet cell batteries are the usual DC power sources; however, if a reliable source of AC current is available, it can be used, usually with an AC-to-DC converter. Very few, if any, instruments operate directly from AC current. If a system is operating from AC power, it should be equipped with an appropriate uninterruptible power supply (UPS) and surge protector. Automatic battery chargers that operate from AC power can be used to keep rechargeable batteries fully charged. Where AC power is not available, solar panels are frequently used as the primary method of recharging batteries.

Typical Gaging-Station Instrumentation Configurations

The diversity of instrumentation available for sensing, recording, and transmitting stage-data results in several configurations of instrument setups provides stage data according to USGS standards for input to the National Water Information System (NWIS). In the following sections, four typical configurations are described. There are other possible and likely variations of these configurations.

Stilling Well, Float Sensor, Shaft Encoder, and Data-Collection Platform

The traditional, basic stage-recording system, used since the early 1900s, consisted of a stilling well located in or near the stream with a float used as the stage sensor. To this day, this method remains the most consistent and least uncertain method for the measurement of stream stage. The inside auxiliary gage is typically used as the reference gage for setting the recorder. This has proven to be a reliable system and is still used at about 4 of 10 USGS streamgaging stations today. Pictures of stilling wells are shown in figures 1–6 and 8. Nonelectronic recorders are shown in figures 45 and 46. This configuration with a shaft encoder and DCP is shown schematically in figure 50.

From the early 1900s through the 1990s, stage was recorded by a graphical or digital (nonelectronic) recorder. Since the 1990s, most of the instrumentation has been electronic for the logging, recording, and transmitting of stage data.

Figure 50 shows a stilling well and float sensor, an incremental shaft encoder (see figs. 22 and 23) and a DCP. The encoded stage, as determined by the float-actuated shaft encoder, is passed to the DCP by a hard-wired connection. The inside reference gage is used for setting the shaft encoder. The DCP transmits data through the GOES to the NWIS for reception, decoding, processing, analysis, and near virtual issuance of preliminary stage data to the NWIS World Wide Web (NWISWeb).

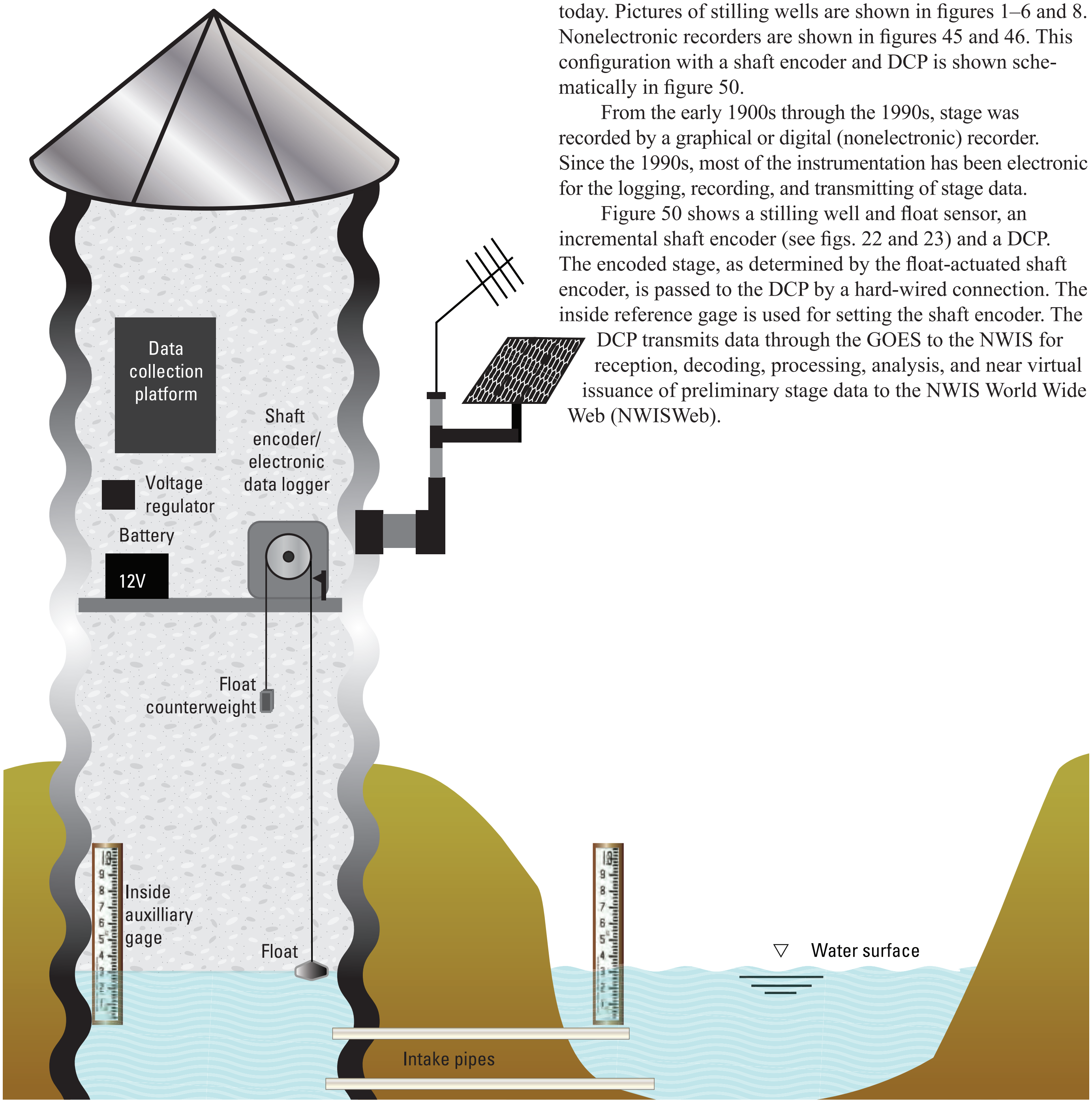

Figure 50. Schematic of stilling well, float sensor, incremental shaft encoder, and DCP.

Instrument Shelter, Bubble Gage, Nonsubmersible Pressure Transducer, and Electronic Data Logger/Data Collection Platform

At gage sites where a stilling well is not used or is not practical, stage may be sensed with a pressure transducer coupled to a compressed-gas-purge system (bubble gage). Use nitrogen gas or a self-contained air-compression apparatus as the bubbler and also to purge the orifice. Connect the gas-purge system with an orifice line (tubing) to a bubble-gage orifice that is located in the stream, and to the pressure transducer located in the instrument shelter. The stage, as sensed by the pressure transducer, is passed to the DCP by a hard-wired connection. The encoded stage is stored and later transmitted by the GOES transmitter. All instruments are housed in an instrument shelter. An outside reference gage is used for setting the pressure transducer. This configuration is shown in figure 51.

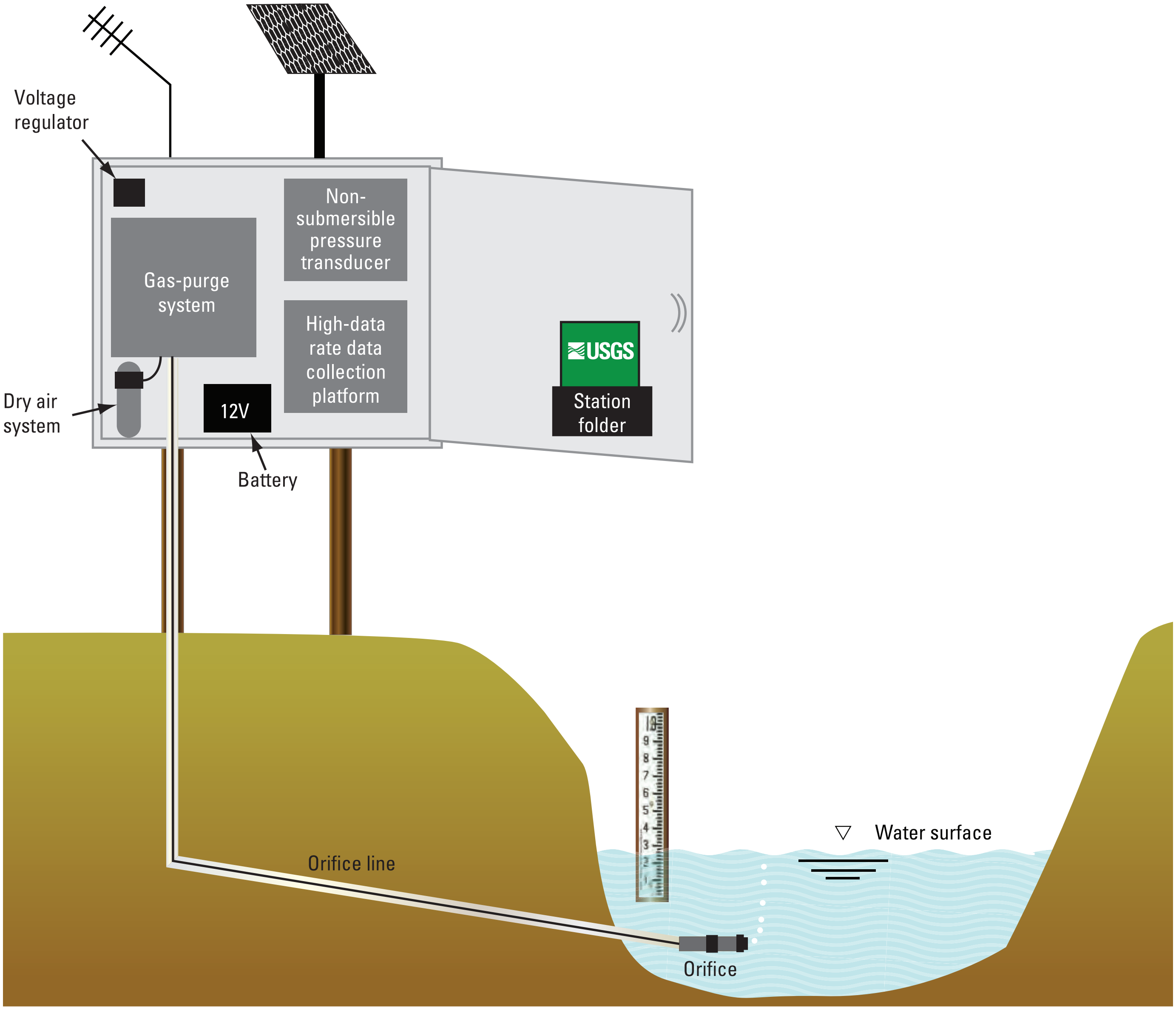

Figure 51. Schematic of bubble gage, nonsubmersible pressure transducer, EDL, and (or) DCP.

Instrument Shelter, Submersible Pressure Transducer or Noncontact Radar-Stage Sensor and Electronic Data Logger/Data-Collection Platform

At gage sites where neither a stilling well nor a nonsubmersible pressure transducer is used or is practical, stage may be sensed with a submersible pressure transducer or a noncontact radar-level sensor. Submersible pressure transducers can be mounted directly in the stream or reservoir. Temperature variations will affect the accuracy of submersible units, but several have passed the USGS standard for vertical accuracy (figs. 35–37). The ideal conditions for this sensor are typically a deep stream where temperature changes are minimal throughout the year. The stage, as sensed by the submersible pressure transducer, is passed to the DCP by a hard-wired connection, typically SDI–12. The encoded stage is stored and later transmitted by the GOES transmitter. All instruments, except the transducer, are housed in an instrument shelter. An outside reference gage is used for setting the pressure transducer.

Submersible pressure transducers are usually self-contained units having a transducer element and electronic circuitry. Some also contain a data logger and battery. These units can be mounted directly in the stream or reservoir, and with some planning in most locations, can be mounted so that maintenance and replacement can be accomplished without the hydrographer entering the water. As stated previously, temperature variations will affect the accuracy of submersible sensors, even those that meet USGS accuracy standards. Submersible units can be damaged or destroyed by freezing temperatures. Submersible pressure transducers receive the pressure input from the water pressure of the stream above them and are internally programmed to convert pressure to units of water head (feet of water over the orifice). Units of water head then transmit the data to an EDL or DCP by way of a serial digital interface such as the SDI–12. Use an outside reference gage for setting and maintaining stage measured with the pressure transducer.

The configuration for a submersible pressure transducer sensor is shown in figure 52.

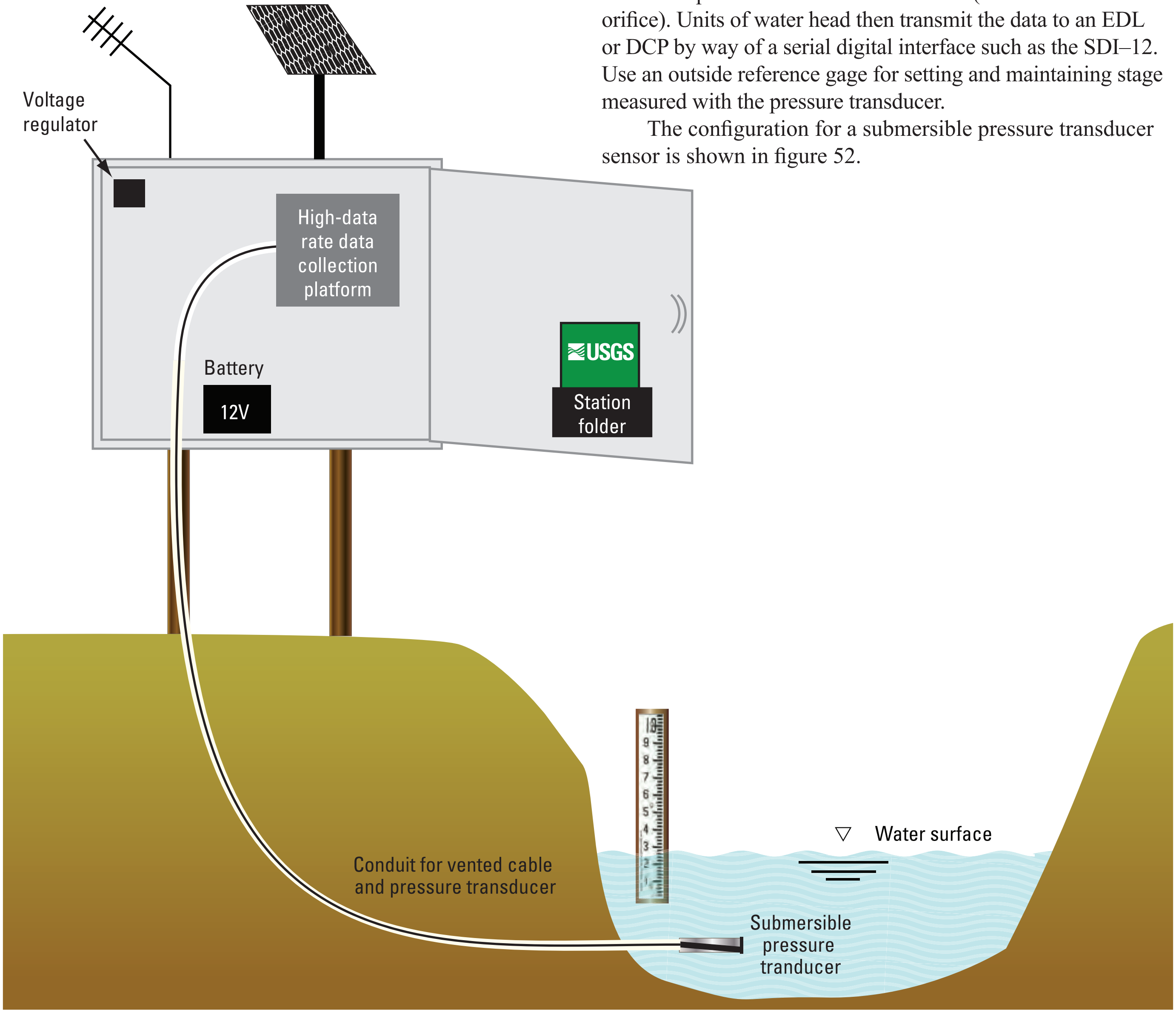

Figure 52. Schematic of a submersible pressure transducer used to measure stage with EDL and (or) DCP.

The noncontact radar-level sensor is mounted on a bridge handrail or other stable structure above the water surface. Radar-level sensors are generally immune to weather conditions, such as snow and rain, and the radio wave used for this application is harmless to humans and wildlife. The usable sensor-to-water sensing range is minimally from near zero to about 66 ft, and can be greater, depending on the radar instrument. Radar sensors are usually self-contained units having typically a horn-like transmitting device and electronic circuitry. Radar sensors are internally programmed to convert radar-frequency reflections from units of distance to the water surface to stage. The stage, as sensed by the radar, is transmitted to the DCP by a hard-wired connection, typically SDI–12. The encoded stage is stored and typically later transmitted by the GOES transmitter. All instruments, except the transducer, are housed in an instrument shelter. An outside reference gage is used for setting and maintaining stage in the noncontact radar-level sensor.

The configuration for a radar-level sensor is shown in figure 53.

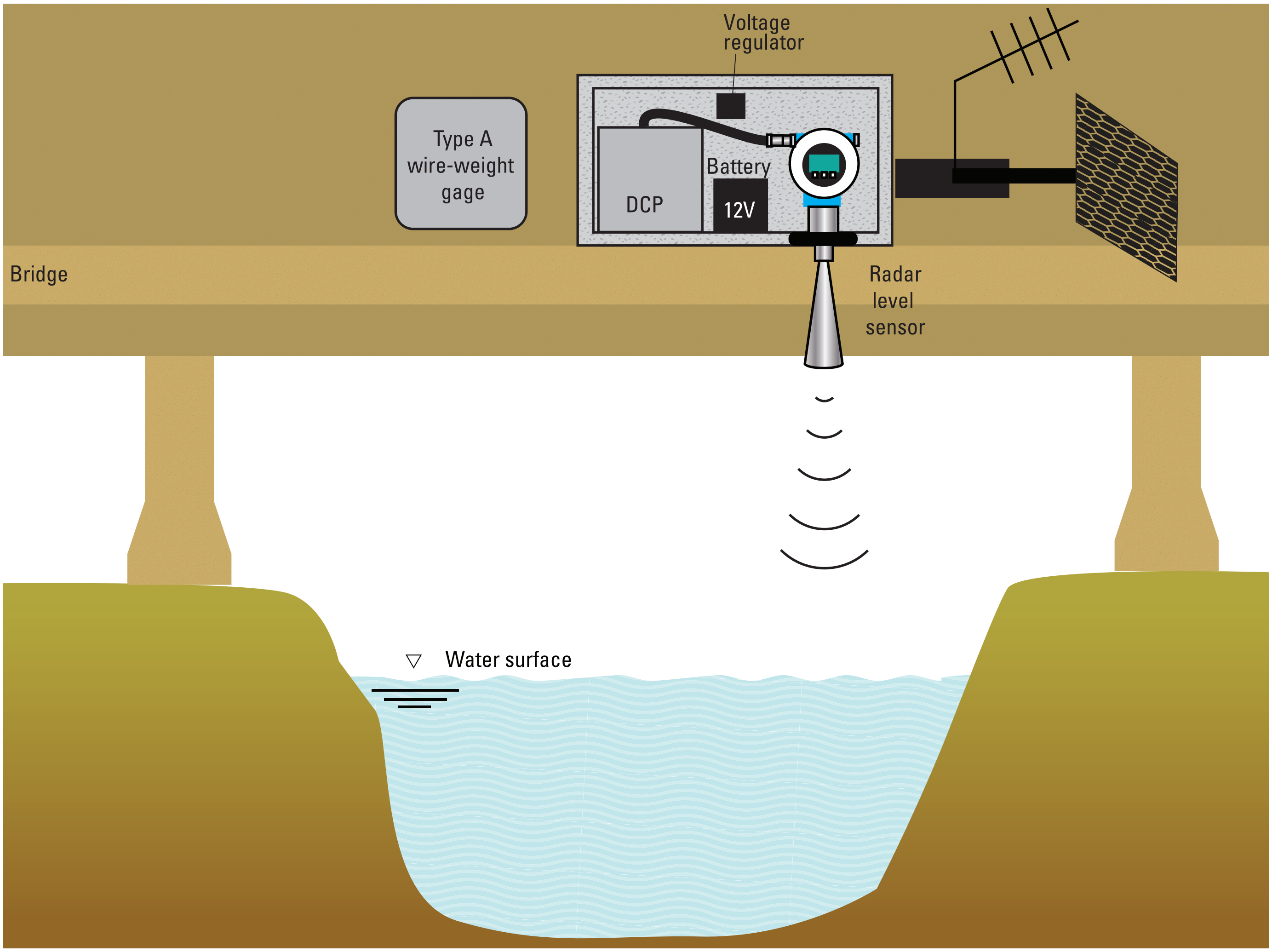

Figure 53. Schematic of a radar-level sensor used to measure stage with EDL, and (or) DCP.

Data Retrieval and Conversion

The retrieval of stage data varies according to the type of recorder used, and to the urgency of acquiring the data. The overwhelming majority of USGS stage data is transmitted, received, decoded, and entered into NWIS through the GOES system, as shown in figure 48. EDLs may require a visit to the gaging station to retrieve the data; however, if the EDL is part of a DCP configuration, the data are retrieved by radio transmission via the GOES. Data may also be retrieved from an EDL and (or) DCP by downloading to a PDA or portable field computer, or by extracting a data card from the EDL and downloading data from the card to a computer. Data may also be retrieved by transmission via telephone, radio, or one of the other telemetry methods described in previous sections of this report. Some systems may be programmed to provide an automatic alert at critical stages, such as National Weather Service (NWS) flood stage or rate of change of stage. In the USGS, data recorders that produce a paper chart or paper-punch tape are no longer used as primary record, although paper chart recorders still exist as backup recorders at some stations. In particular, verification of instantaneous peak stages is sometimes done using A–35 chart recorders.

All data retrieved by way of charts, electronic data cards, and electronic downloads are considered original stage data and should be protected against loss or damage. Data that are transmitted via DCP/GOES satellite, or other telemetry method, are considered original and must be preserved as such. Original data for automated data-collection sites are defined as unaltered (no changes in magnitude) data acquired from the primary sensor (and backup sensor, as needed) and converted to conventional (engineering) units and a standard format. USGS policy defining original data is described by Hubbard (1992).

The various DCP and EDL record data in various formats must be deciphered and converted into a standard format that can be easily used by data-processing systems, such as the USGS NWIS Automatic Data Processing System (ADAPS). The Device Conversion and Delivery System (DECODES) performs this task. To convert data from a variety of devices at many sites, DECODES also manages a database that contains configuration information about these devices and sites. DECODES can convert data recorded at either fixed or variable time intervals from most EDLs, as long as the recorder can produce appropriate data files and identify any format changes unambiguously. For example, if the data format changes, some code must be present to identify for DECODES that the format has changed. DECODES can convert data from all the DCPs in use, whether recorded in ASCII, BINARY, or the LABARGE (pseudo ASCII) format. DECODES has been designed to operate under the Unix and MS–DOS operating systems. In the USGS, DCP data are automatically processed through DECODES for input to NWIS.

New Stage-Station Design

A new gaging station is usually established for the purpose of obtaining a record of streamflow, reservoir contents, tidal fluctuation, or other purpose. Acquisition of stage data may be only one of several factors that must be considered. For purposes of this report, however, only the requirements for obtaining an accurate and representative stage record are described.

Stage data can be obtained through periodic readings of a reference gage by an observer, but this method is usually used only at sites where a short record is needed and where occasional gage readings will suffice. Although such a record may be inexpensive to obtain, its accuracy and completeness will not be as good as a stage record obtained with an automatic stage sensor and DCP or EDL. The following sections pertain primarily to sites where an automatic recording gage will be used. Table 4 summarizes some of the equipment requirements.

Table 4. Equipment requirements for a site with a stage-recording gage.

Sensor	Recorder	Stilling-well required	DC power required	Meets USGS stage accuracy requirements
Float with shaft encoder	EDL and (or) DCP	Yes	Yes	Yes
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Bubble gage with nonsubmersible pressure transducer	EDL and (or) DCP	No	Yes	Yes
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Noncontact sensor	EDL and (or) DCP	No	Yes	Yes[1]

[1] Should meet USGS stage accuracy requirements.

Site Selection

Choose the gage site for stage measurement based on the following criteria:

- If the stage record is to be used for computing streamflow, consider the requirements for controls, rating curves, backwater, and other streamflow variables in selecting the site, as well as the acquisition of stage data (see Rantz and others, 1982).
- Select the site so the intakes or orifice are in a pool, if possible, where stream velocity is low and not subject to significant turbulence. If this is not possible, place the intakes or orifice in a slack-water zone, where they are protected from high velocity.
- The gage stilling well (if used) and the instrument shelter may be located on a stream bank, bridge, dam, or other suitable structure, provided the other site selection criteria are met as closely as possible. Do not place the gage structure where it might sustain damage during floods.
- If the gage is located at or near a bridge, make sure it is on the downstream side. If this is not possible, and it must be located upstream of the bridge, then place it far enough upstream to be out of the zone of drawdown caused by the bridge during medium and high water.
- Select the site where either a stilling well with intakes can be easily installed, or where an instrument shelter can be installed for housing a bubble gage. If a bubble gage is to be used, the site must provide suitable conditions to install the necessary bubble tubing and orifice static tube. For bank installations, place the tubing underground between the gage shelter and the stream. For bridge installations, attach the tubing to the bridge members and pier or piling. Firmly anchor the orifice static tube in the stream, preferably in a zone of low velocity.
- Place the gage intakes or orifice low enough to record the lowest expected stage. In cold climates, place them below the frost line to protect them from freezing, if possible.
- The instrument shelter should be high enough to be above the 0.5 percent exceedance- (200-year) flood level, if possible.
- Minimize the distance between the stream and the stilling well and (or) instrument shelter.
- The site should have a suitable location for one or more outside auxiliary gages. These could be staff gages, wire-weight gages, or tape-down reference points. Make sure the auxiliary gages are easily accessible and located in a position so that accurate gage readings can be easily made. They should be in the same pool as the gage intakes, or orifice, and should provide readings that are indicative of the readings obtained through the intakes or orifice.
- If the gage site is for the purpose of measuring stage in a lake or reservoir and it is near the outlet structure, then make sure the gage intakes, or orifice, are located upstream of the zone of drawdown of the outlet structure.
- Make sure site conditions are such that an accurate datum can be maintained. Appropriate reference marks and reference points should be located both on and off the gaging structure to maintain accurate and timely level surveys of the gage. See Kenney (2010).

Sensor Selection

There are four basic categories of stage sensors, as described in previous sections of this report. They are (1) float-driven sensors, (2) bubble gage with nonsubmersible pressure transducer, (3) submersible pressure transducers, and (4) noncontact water-level sensors. The first two—float-driven sensors and bubble gages—can be configured with other instrumentation to provide stage data that meet the accuracy requirements for a primary stage record. The third and fourth—submersible pressure transducers and noncontact sensors—meet USGS accuracy requirements, but some manufacturers’ sensors do not, so refer to HIF testing results to make sure they do. If somewhat less-accurate stage data are acceptable, then these may be suitable sensors to use.

In some situations, it may be impossible to maintain a stilling well or bubble-gage orifice in the stream because of very high-velocity conditions or significant debris that can damage or wash out the gage. The noncontact sensor may be the best alternative for such a site, even though it does not provide the accuracy of a float gage.

Float-driven sensors require a stilling well, whereas the other sensor types do not. All, however, require some type of instrument shelter. See previous sections of this report on “Water-level sensors” for detailed descriptions.

Recorder Selection

Generally, two types of recorders are currently available for recording stage data, as described in the previous section “Water-level recorders.” These are EDLs and DCPs. Analog paper charts still exist in some parts of the country, but are typically used only for backup and verification of instantaneous peak stages during flooding events. Selection of an EDL or DCP may be dependent to some degree on the type of sensor used and the other related instrumentation as shown in table 4.

Power Requirements

Almost all of the currently used instrumentation requires 12-volt DC electrical power, as described in previous sections of this report. This may be supplied by dry or wet cell batteries, or AC power converted to DC power. Battery chargers or solar panels may be used to keep rechargeable batteries fully charged.

Operation of Stage-Measurement Station

There are numerous and varied types of stage-measuring equipment, as well as different configurations of this equipment, as described in previous sections of this report. Today's equipment options are considerably greater than in previous years when only a graphic or digital punch-tape recorder was used. It is not practical to provide detailed instructions for servicing every type of recorder, data logger, DCP, gas-purge system, and other stage-measuring device. The operation of each stage station will vary according to the type of equipment used; become familiar with each device that is serviced. Each hydrographer will generally have their own specific routine, which may be different from that of another hydrographer. Therefore, the following operational steps do not necessarily apply to all sites, nor are they in a specific order that must be followed. As closely as possible, base the operation of a stage measurement station on the steps listed below.

Clock, Timer, and Battery Check

One of the first things the hydrographer should do when arriving at a gaging station is to check the clock in the DCP or EDL. HDR DCPs come with an atomic clock, but they should also be verified as necessary. Some smart sensors also have timing associated with them. Check these to make sure they are correct. For paper strip-chart recorders, check the pen and chart to see if the recorder is running slow or fast, or if the clock may have stopped. Make sure there is a mark at the point where the pen is resting on the chart, and that the date and watch time are recorded on the chart. Adjust the clock if there is a significant time error. In some cases, it may be necessary to replace the clock.

DCPs and EDLs have internal electronic clocks that are usually very accurate. Even so, these should be compared to watch time and reset as necessary. A portable electronic clock and antenna, as described in a previous section of this report, can be used to set the time very accurately on a DCP or EDL. The more modern instrumentation, such as HDR DCPs, have internal time checks and automatic time adjustments, as described in previous sections of this report.

Most gaging stations use 12-volt batteries for clocks, timers, EDLs, and DCPs. Battery voltage should be checked each time the station is visited, and replaced if voltage is below the specified limit. If an AC electrical source or a solar-charging panel is used, it should be inspected to be sure it is operating correctly. Solar panels should be cleaned periodically to ensure optimal performance.

Gage Readings

All auxiliary gages should be read before the gage-height record is retrieved from the recorder. Record these readings, along with the time, on the appropriate form (for example, USGS inspection sheet, 9–275F, 9–275I, electronic form, and so forth). EDLs and DCPs usually have no way to input auxiliary-gage readings; therefore, the readings recorded on the gage inspection forms are used for comparison and verification that the EDL and (or) DCP are operating correctly.

Take the reference gage reading at the same time as the recorder reading and compare both to determine if there are any discrepancies. If a discrepancy is found, then determine and correct the cause, if possible.

Record Retrieval

If necessary, the gage record should be retrieved from the DCP or EDL, after the time and gage readings have been determined and recorded. Electronically recorded data may be retrieved from EDLs and (or) DCPs by removing the data card and (or) downloading the data from the card to a portable computer or PDA or by hardwiring the PDA or computer to the EDL or DCP. In all cases, it is possible to make a direct download of the data into a PDA or portable computer. The electronically recorded data should be inspected for malfunctions and unusual events, such as floods, through the use of data files and (or) graphics on the portable computer.

Float-Sensor, Gage-Well, and Intake Inspection

Float-sensor gages require that the gage well and intakes be free and clear of sediment and other obstructions that would impair their performance. Following the initial readings of time and gage readings, and the removal of the gage record, if necessary, carefully inspect the float, gage well, and intakes to be sure everything is in good working order. Inspecting the gage record in the office (if the site is transmitting in near real time) or on site, as mentioned in the preceding paragraphs, may reveal sediment and (or) intake problems that cannot be detected otherwise. Probe the bottom of the gage well for sediment deposits, and clean, if necessary. Likewise, if there is any indication of intake problems, flush the intakes. Inspect the outside end of the intakes, if possible, and clean sediment or other debris from the intakes to allow free inflow. In some cases, a problem may develop from the float itself. Inspect the float for leaks, slippage of the float-tape-clamp screw, or debris that may be lodged on top of the float.

Inspection of the gage record in the office (before visiting the gage, if possible), or on a PDA or field computer by graphing the downloaded data, can help indicate problems with the recorded stage data. When these types of problems occur, the hydrographer should try to find the cause and make appropriate corrections. For instance, it may be that the lowest intake is not low enough for the lowest stage experienced. In this case, a new (and lower) intake may need to be installed. Or it may be that the float hangs on an obstruction in the gage well at a medium or high stage. Move or remove the obstruction so that the float can freely pass.

Bubble-Gage, Gas-System, and Orifice Inspection

If the station has a bubble-gage sensor, inspect the bubble orifice to make sure it has not been buried by sediment. If the station has a nitrogen tank for pressure to the bubble gage sensor, keep a log of gas-feed rate, gas consumption, and gas-cylinder replacement to ensure a continuous supply of gas and to help spot leakage in the system. There is no serious leak in the gas-purge system if (1) the nonsubmersible pressure transducer operates to indicate stage correctly and (2) the gas consumption based on the average bubble rate over a period of time corresponds with the gas consumption computed from the decrease in cylinder pressure. If a leak is evident, its location can be determined by isolating various parts of the gas-purge system, sequentially closing of valves in the system. Gas leaks should be fixed to ensure continuous operation of the bubble gage.

Submersible Pressure Transducers

If the station has a submersible pressure transducer, query the sensor to make sure it is recording properly, and the slope and offsets are set correctly. If possible, inspect the orifice or pipe end containing the sensor to ensure it has not been buried in sediment or has another obstruction that could cause drawdown or buildup of the streamflow around the sensor, thereby causing the sensor to read low or high, respectively.

Noncontact Radar-Stage Sensors

If the station has a noncontact radar-stage sensor, query the sensor to make sure it is correctly programmed and properly recording. If the sensor has an opening to the atmosphere at the horn through which the radar is emitted, make sure it is clear of spider webs, mud daubers (dirt dobbers), wasps, and other insects and vermin. Inspect the water-surface area to make sure no obstructions, such as logs or other debris, have become lodged in the footprint of the sensor. These could create drawdown or buildup of the streamflow around the sensor footprint, causing the sensor to read low or high, respectively. As a precaution, make sure the radar signal is not impinging off a pier or other obstruction that would affect the stage measurement.

Maximum- and Minimum-Stage Determinations

If a high discharge has occurred since the previous visit to a stilling-well station, look for high-water marks both in the stilling well and outside the well. After obtaining high-water marks inside a stilling well, the marks should be cleaned and marked to prevent confusion with high-water marks that will be left by subsequent peak stages. In the case of a bubble-gage station, submersible transducer, or radar sensor, look for high-water marks along the stream bank in the vicinity of the gas orifice, location of the submersible transducer, or measurement footprint of the radar sensor. Use a crest-stage gage, as described in a previous section of this report, as the source of corroboration of high-water marks at gages that do not have a stilling well. When a low peak follows a high peak, it may be possible to find high-water marks for both peaks. Regardless of the source, high-water marks (Benson and Dalrymple, 1967) are used as an independent check on the maximum stage shown by the stage recorder, and determination of these marks should be considered a very important part of the gaging-station operation. Float-tape maximum and minimum indicators, as described in a previous section, are part of another method for determining maximum and minimum stages.

Make sure crest-stage gages are serviced on a regular basis to ensure there is always fresh cork in the cup, and to be sure the intake holes and vent hole are open. Mark and date cork lines defining high-water marks, then erase the cork lines after determining their elevations to avoid confusion with high-water marks left at a later time. Never remove the staff when water stands high in the pipe because reinserting it will result in a surge of the water in the pipe, thereby resulting in an artificial “high-water mark” on the staff.

Final Recheck

After other work is done at the gaging station, such as making a discharge measurement, painting, differential-level survey, or other maintenance, before leaving that station, return to the gage and make a final check of the DCP, EDL, and other instruments. Make another complete set of gage readings, recording all, including the watch time, on inspection sheets or other forms, as appropriate. Do not leave the station without being sure that all instruments are functioning as they should.

General Considerations

There are a few guidelines to consider concerning the maintenance of continuously recording streamgaging stations to increase the accuracy and to improve the continuity of the stage record. When needed, periodically clean and oil equipment. Keep all electronic equipment clean, free of dust, and properly ventilated. When needed, check and replace desiccant, which is kept inside of the gage house, shelter, or instrument. Intakes, stilling wells, and sediment traps should be thoroughly cleaned, at least once a year, but more often when sediment is a recurring problem. Carefully check gage-purge systems of bubble gages for leaks during each gage visit. Reduce excessive humidity and temperatures in the gage shelter to a minimum by providing proper ventilation, and in some cases, modify extreme cold temperatures using heating units and (or) insulation. Gage datum should be maintained within specified limits by periodically running a differential-level survey (Kenney, 2010); to check all gages, and by correcting gages as necessary. At new gage sites, and at sites where the datum is not stable, levels should be run at least once a year. After it is confirmed that the datum is fairly stable, levels can be run every 2 or 3 years, and in some cases, an even longer time between levels may be acceptable. Experience has shown that a program of careful inspection and maintenance will result in a complete gage-height record about 98 to 99 percent of the time.

Safety

Safety should be a primary consideration when working at gaging stations. Many times hydrographers work alone at a gaging station in a remote location, and, therefore, should always consider possible hazards in doing the work, and the fact that help may not be available if an accident occurs. Even when working with other people, one's personal safety and the safety of others should be of paramount importance.

The USGS is particularly concerned about the development of safe working habits and the observance of all safety requirements. Details of safety requirements are given in several official USGS WRD memoranda, the latest being WRD memorandum No. 99.32 (U.S. Geological Survey, 1999). This memorandum also directs the hydrographer to other safety-related memoranda that specifically deal with safety guidelines for working in and around gaging stations. Each field hydrographer should obtain a copy of these memoranda, and carefully study them to become familiar with all safety requirements. USGS Water Science Centers should provide training in safety to each employee. Documents such as job hazards analyses and traffic closure plans should be an integral part of station folders in the office, the field vehicle, and the gage shelter. Keep these documents current by reviewing and updating them as necessary and follow the documented procedures outlined in these safety guides.

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