

CHAPTER 4.—MEASUREMENT OF STAGE

GENERAL

The stage of a stream or lake is the height of the water surface above an established datum plane. The water-surface elevation re-

ferred to some arbitrary or predetermined gage datum is called the "gage height." Gage height is often used interchangeably with the more general term "stage," although gage height is more appropriate when used to indicate a 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.

Records of gage height are used with a stage-discharge relation in computing records of stream discharge. The reliability of the discharge record is therefore dependent on the reliability of the gage-height record as well as on the accuracy of the stage-discharge relation. Records of stream stage are also useful in themselves for such purposes as the design of structures affected by stream elevation and the planning of flood-plain use. The gage-height record of a lake or reservoir provides, in addition to elevations, indexes of surface area and volume of the water body.

A record of stage may be obtained by systematic observations of a nonrecording gage or by means of a water-stage recorder. Special-purpose gages that do not give a complete record of stage are discussed on pages 74–78. The advantages of the nonrecording gage are the low initial cost and the ease of installation. The disadvantages are the need for an observer and the lack of accuracy of the estimated continuous-stage graph drawn through the plotted points of observed stage. For long-term operation the advantages of the recording gage far outweigh those of the nonrecording gage, and therefore the use of the nonrecording gage as a base gage is not recommended. However, at a recording-gage station, one or more nonrecording gages should be maintained as auxiliary gages for the operation of the station (p. 53–54). Telemetering systems are often used to transmit gage-height information to points distant from the gaging station (p. 54–59).

DATUM OF GAGE

The datum of the gage may be a recognized datum, such as mean sea level, or an arbitrary datum plane chosen for convenience. An arbitrary datum plane is selected for the convenience of using relatively low numbers for gage heights. To eliminate the possibility of minus values of gage height, the datum selected for operating purposes is below the elevation of zero flow on a natural control. Where an artificial control is used, the gage datum is usually set at the elevation of zero flow.

As a general rule a permanent datum should be maintained so that only one datum for the gage-height record is used for the life of the station. An exception occurs at gage sites where excessive streambed scour, after installation of the station, results in low-flow stages having a negative gage height. In that situation a change in gage datum

to eliminate the negative numbers is recommended, to avoid possible confusion involving the algebraic sign of the gage heights. Another exception occurs when channel changes at a station make it impractical to maintain the station at the existing site. It may then be necessary to move the station a distance, such that there is significant fall in the water-surface elevation between the old and new sites, even though discharges at the two sites are equivalent. In that situation there is generally little to be gained by establishing the datum at the new site at the same sea-level elevation as the datum at the original site. That is especially true if the station is moved downstream a distance such that negative gage heights would result from use of the original datum. When datum changes are made for whatever reason, a record of the change should be a part of the published station description.

In any event, when a station is established, it should be assumed that a permanent datum will be maintained at the site. To maintain a permanent datum, each gaging station requires at least two or three reference marks; that is, permanent points of known gage-height elevation that are independent of the gage structure. The datum at each gaging station is periodically checked by running levels from the reference marks to the gages at the station.

If an arbitrary datum plane is used, it is desirable that it be referred by levels to a bench mark of known elevation above mean sea level, so that the arbitrary datum may be recovered if the gage and reference marks are destroyed.

NONRECORDING STREAM-GAGING STATIONS

On page 23 it was mentioned that a record of stage could be obtained by systematic observation of a nonrecording gage. The advantages (low initial cost) and disadvantages (need for an observer, lack of accuracy) of a nonrecording gaging station were briefly discussed. On pages 53–54 the use of nonrecording gages as auxiliary and as reference (base) gages at recording-gaging stations will be discussed. Chapter 15 (p. 559–560) will describe the manner in which an observer's gage readings are used to compute a record of stage at a nonrecording gaging station. This section of the manual describes the various types of nonrecording gages.

Of the five types to be described, the two most generally used at nonrecording stations are either the staff or wire-weight gage. At such stations the nonrecording gage is usually read twice daily by an observer, and additional readings are made during periods of rapidly changing stage. The observer systematically records and reports his readings to headquarters. The record book and report cards shown in

figure 8 are used by the U.S. Geological Survey, the book being the permanent record of nonrecording-gage readings. The weekly report card serves as an interim report of the observations made. The weekly report cards are read promptly on their arrival at the headquarters office so that any problems or difficulties that arise can be handled without delay.

On each routine visit to a nonrecording stream-gaging station, the hydrographer also visits the observer to enter in the stage-record book the gage reading(s) that the hydrographer has made. At that time he also inspects the record book to check for discrepancies in the observer's readings. Such visits by the hydrographer are important; if they are not made the observer tends to feel that no one pays any attention to his work, and he may become less conscientious about his gage readings.

Descriptions of five types of nonrecording stage gages follow. The special-purpose crest-stage gage and its use as an adjunct to the nonrecording gaging station are described on pages 77-78.

| | | | | |
|--|--------------|---|-------------|----------|
| DI-S (Approved December 1941) | | at near | | |
| DEPARTMENT OF THE INTERIOR | | Gage heights for week ending Sat., 19... | | |
| Bureau | | | | |
| Washington District File Number OBSERVATIONS OF GAGE HEIGHT On River Creek At Near From 19 To 19 District Engineer | Day and Date | Time | Gage Height | REMARKS |
| | Sun. | a.m. | | |
| | | p.m. | | |
| | Mon. | a.m. | | |
| | | p.m. | | |
| | Tues. | a.m. | | |
| | | p.m. | | |
| | Wed. | a.m. | | |
| | | p.m. | | |
| | Thurs. | a.m. | | |
| | p.m. | | | |
| Fri. | a.m. | | | |
| | p.m. | | | |
| Sat. | a.m. | | | |
| | p.m. | | | |
| This card is an exact copy of original record in book. | | | | Observer |
| 9-176 (Rev 4-63) | | U.S. GOVERNMENT PRINTING OFFICE: 1964-O-748-675 | | |

FIGURE 8.—Cover of book and weekly report card for recording manual gage observations.

STAFF GAGE

Staff gages are either vertical or inclined. The standard Geological Survey vertical staff gage consists of porcelain-enameled iron sections, each 4 in (0.1 m) wide, 3.4 ft (1.04 m) long, and graduated every 0.02 ft (0.0067 m). (See fig. 9.) The vertical staff gage is used in stilling wells as an inside reference gage, or in the stream as an outside gage.

An inclined staff gage is usually a graduated heavy timber securely attached to permanent foundation piers. Inclined gages built flush with the streambank are less likely to be damaged by floods, floating ice, or drift than are projecting vertical staff gages. Copper barrelhoop staples and bronze numerals are generally used for the graduations. Inclined gages are used only as outside gages.

WIRE-WEIGHT GAGE

The wire-weight gage used in the U.S.A. is known as the type A wire-weight gage. It 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. (See fig. 10.) 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 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 at any desired elevation. The diameter of the drum of the reel is such that each complete turn represents a 1-ft (0.305 m) movement of the weight. A horizontal checking bar is mounted at the lower edge of the instrument so that when it is moved to the forward position the bottom of the weight will rest on it. The gage is set so that when the bottom of the weight is at the water surface, the gage height is indicated by the combined readings of the counter and the graduated disc. The type A wire-weight gage is commonly mounted on a bridge handrail, parapet wall, or pier for use as an outside gage.

FLOAT-TAPE GAGE

A float-type gage consists of float, graduated steel tape, counterweight, and pulley. (See fig. 11.) The float pulley is usually 6 in (0.152 m) in diameter, grooved on the circumference to accommodate the tape, and mounted in a standard. An arm extends from the standard 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 if the adjustments necessary are too

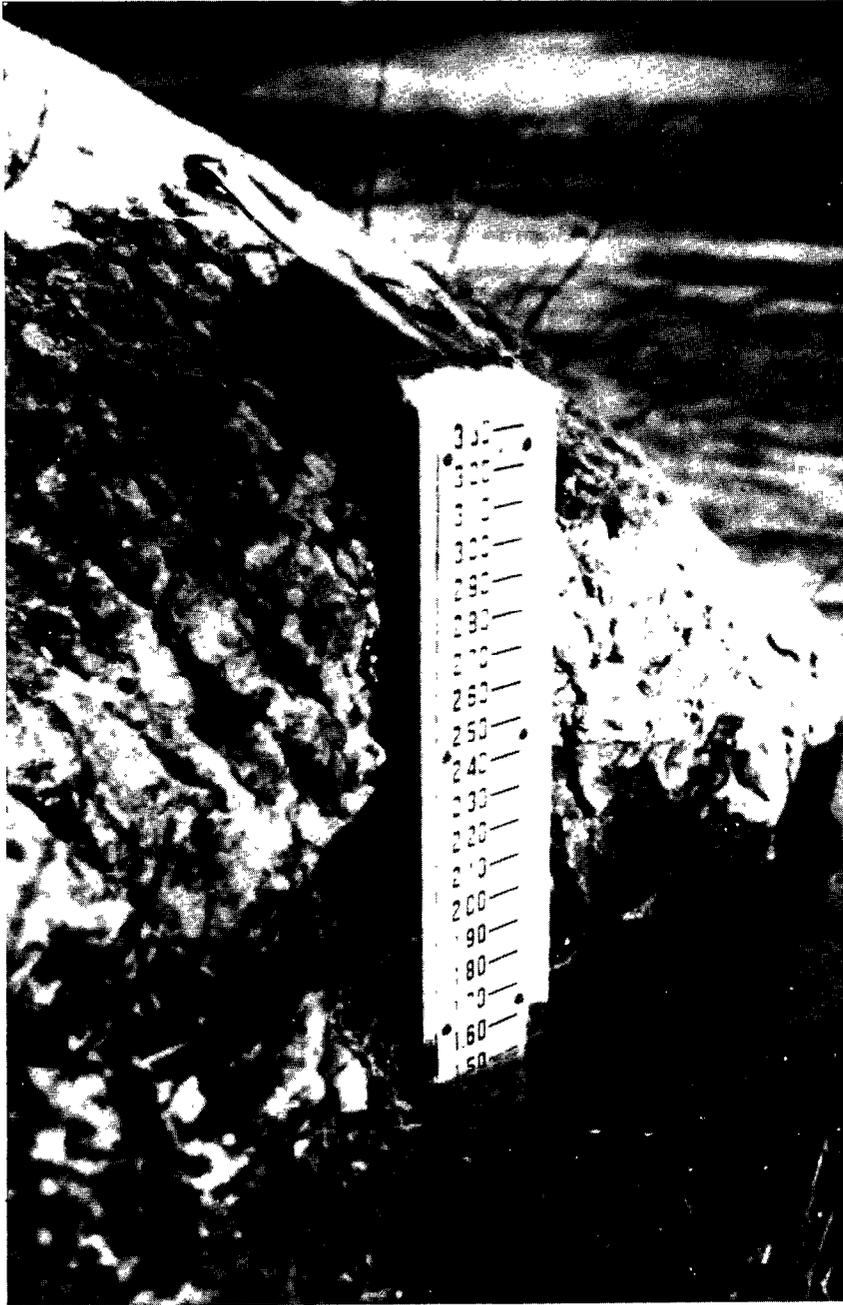


FIGURE 9.—Vertical staff gage.

large to be accommodated by the adjustable index. A 10-in (0.25 m)-diameter copper float and a 2-lb (0.9 kg) lead counterweight are normally used. The float-type gage is used chiefly in stilling wells as an inside reference or auxiliary gage.

ELECTRIC-TAPE GAGE

The electric-tape gage consists of a steel tape graduated in feet and hundredths of a foot, to which is fastened a cylindrical weight, a reel in a frame for the tape, a $4\frac{1}{2}$ -volt battery, and a voltmeter. (See fig. 12.) One terminal of the battery is attached to a ground connection, and the other to one terminal of the voltmeter. The other terminal of the voltmeter is connected through the frame, reel, and tape, to the weight. The weight is lowered until it 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, the tape reading is observed at the index provided on the reel mounting. The electric-tape gage is used as an inside reference gage and occasionally as an outside gage. If oil is floating on the water surface, the gage will give the gage height of the interface, because oil is a dielectric. In some electric-tape gages a light or audible signal is substituted for the voltmeter.

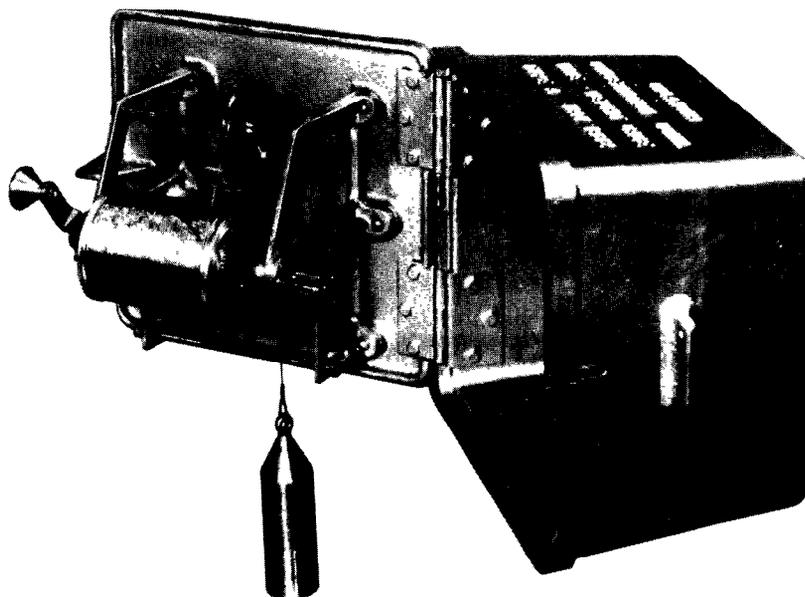


FIGURE 10.—Type A wire-weight gage.

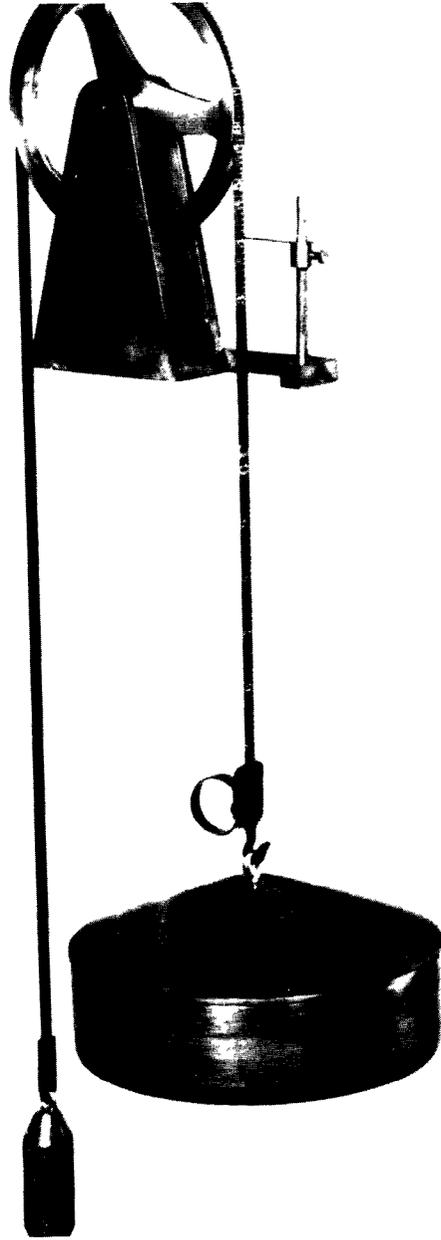


FIGURE 11.—Float-tape gage.



FIGURE 12.—Electric-tape gage.

CHAIN GAGE

A chain gage (fig. 13) is used where outside staff gages are difficult to maintain and where a bridge, dock, or other structure over the water is not available for the installation of a wire-weight gage. The chain gage can be mounted on a cantilevered arm which extends out over the stream, or which is made in such a way that it can be tilted to extend over the stream.

The chain gage consists of the cantilevered arm, one or more enamelled gage sections mounted horizontally on the cantilever, and a heavy sash chain that runs over a pulley on the streamward end of the cantilever. (See figure 13.) The chain is mounted so that it moves along the gage sections. A weight is attached to the streamward end of the chain, and an index marker (*M* in fig. 13) is attached near the other end at a distance from the weight that is appropriate for reading the gage height of low flows. Additional index markers can be attached to the chain at appropriate intervals to read gage heights greater than those directly obtainable from the mounted gage sections.

Stage is determined by lowering the weight until the bottom of the

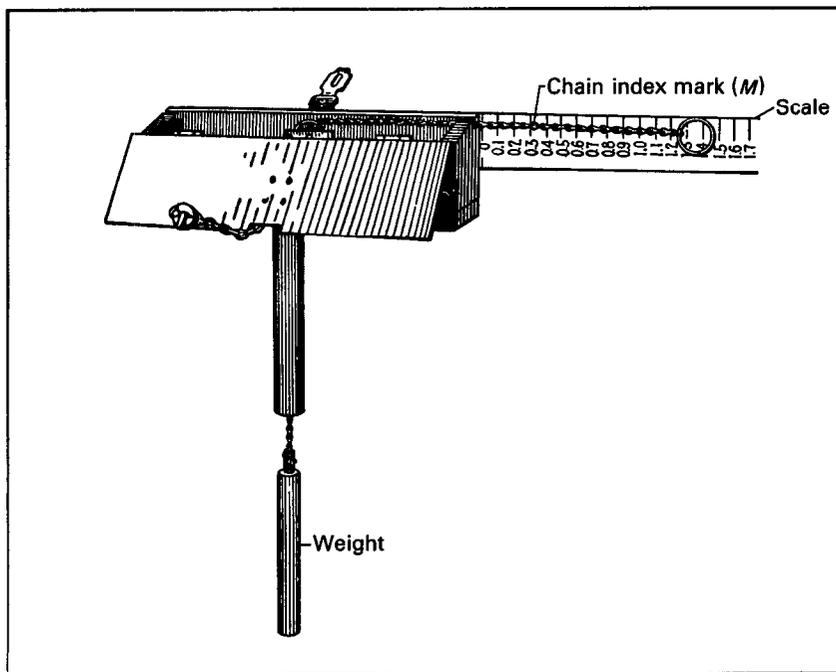


FIGURE 13.—Chain gage (cantilevered mount not shown).

weight just touches the water surface. The gage height then is read from the mounted gage plate at the location of the appropriate chain index marker.

RECORDING STREAM-GAGING STATIONS

METHODS OF SENSING STAGE FOR AUTOMATIC RECORDING

Stage is sensed for automatic recording by a float in a stilling well, or by a gas-purge system that transmits the pressure head of water in a stream to a manometer. The latter system, which does not require a stilling well, is known as a bubble gage.

FLOAT SENSOR

The float sensor consists of a tape or cable passing over a pulley, with a float in a stilling well attached to one end of the tape or cable and a counterweight attached to the other end. (See fig. 11.) The float follows the rise and fall of the water level, and the water level can be read by using an index and graduated tape, or the pulley can be attached to a water-stage recorder to transmit the water level to the recorder.

BUBBLE-GAGE SENSOR

The bubble-gage sensor (Barron, 1963) consists of a gas-purge system, a servomanometer assembly, and a servocontrol unit. (See fig. 14.) The gas-purge system transmits the pressure head of water in the stream to the manometer location. A gas, usually nitrogen, is fed through a tube and bubbled freely into the stream through an orifice at a fixed elevation in the stream. The gas pressure in the tube is equal to the piezometric head on the bubble orifice at any gage height.

The servomanometer converts the pressure in the gas-purge system to a shaft rotation for driving a water-stage recorder. Mercury is used as the manometer liquid to keep the overall manometer length to a minimum. The manometer has a sensitivity of 0.005 ft (0.0015 m) of water and can be built to record ranges in gage height in excess of 120 ft (36 m). The use of mercury in the manometer permits positioning of the pressure reservoir to maintain the float-switch contacts in null position. In this position, the vertical distance between mercury surfaces will be 1/13.6 times the head of water. A change in pressure at the reservoir displaces the mercury which in turn activates the float switch. This causes movement of the pressure reservoir until the distance of head of water divided by 13.6 is again maintained. This motion, in turn, is translated to the recorder.

The servocontrol unit provides the relay action necessary to permit the sensitive float switch to control the operation of the servomotor;

the unit also provides an appropriate time delay between the closing of the float switch and the starting of the motor.

Several bubble-gage sensors, differing in minor detail from that described above, are commercially available. Also commercially available is another type of bubble-gage sensor in which the nitrogen bubble tubing transmits the river-stage pressure to a bellows; the bellows, through a mechanical linkage, actuates a recording pen.

The proper placement of the orifice is essential for an accurate stage record. The orifice should be located where the weight of water above it represents the stage in the river. If the orifice is partly buried in sand or mud, the recorded stage will be greater than that in the river. An orifice preferably should not be installed in swift currents. If this is unavoidable, the orifice must be kept at right angles to the direction of flow. A recommended mounting for high-velocity flow is one in which the orifice is installed flush with the wall of the mounting structure. Care should also be taken to keep the orifice out of highly turbulent flow.

In unstable streambeds it is sometimes advantageous to place the bubble orifice in a vented well point driven into the unstable bottom.

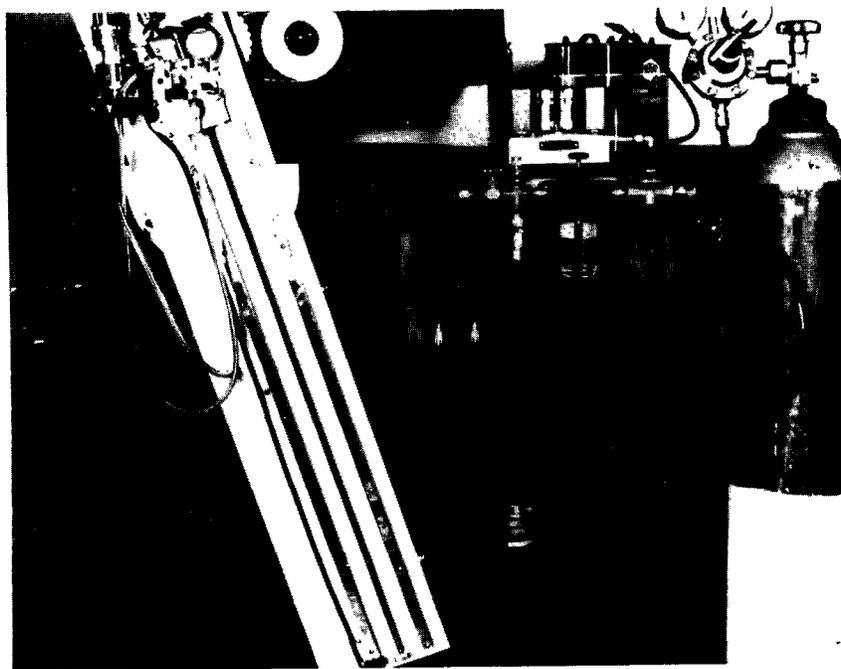


FIGURE 14.—Major units of the bubble gage.

If oil (generally kerosene) is to be added to prevent freezing in the vent pipe, the top of the well screen should be a sufficient distance below the minimum expected stream stage to retain the required depth of oil (fig. 15). To prevent variations in the depth of oil from affecting the manometer reading, the bubble orifice should be below the top of the screen so that the bubbles emerge into the water.

It is emphasized that for satisfactory operation of the well point the streambed material should not be so finely grained as to unduly impede the passage of river water to the well point and thereby cause lag in the recorded stage. To prevent clogging of the well-point screen, the screen should be made of material that will inhibit chemical reaction with substances in the water and (or) in the bed material. A stainless-steel screen set 1 to 3 ft (0.3 to 1.0 m) below the streambed is recommended.

The bubble gage is used primarily at sites where it would be expensive to install a stilling well. It is also used on sand-channel streams because the gas tends to keep the orifice from being covered with sand and the tube may be easily extended to follow a stream channel that shifts its location. However, the float stilling-well installation is cheaper to install at many sites, and its performance is usually more reliable than that of the bubble gage. The two systems have about the same accuracy— ± 0.01 ft (0.003 m). The choice of systems thus depends on the characteristics of the gage site.

WATER-STAGE RECORDERS

A water-stage recorder is an instrument for producing a graphic or punched-tape record of the rise and fall of a water surface with respect to time. It consists of a time element and a gage-height element which, when operating together, produce on a chart or on a tape a record of the fluctuations of the water surface. The time element is controlled by a clock that is driven by a spring, by a weight, or by electricity. The gage-height element is actuated by a float or a bubble gage.

If a float sensor is used, the float pulley is attached to the recorder. The float and counterweight are suspended on a perforated steel tape or on a plain or beaded cable. Cone-shaped protrusions on the circumference of the float-tape pulley match perforations in the tape. As the float rises or falls the float pulley rotates in proportion to the change in stage; the rotation of the pulley is transmitted to the recorder and the appropriate gage height is thereby recorded. A copper float 10 in (0.25 m) in diameter is normally used, but other sizes are also used depending on the type of recorder, gage-height scale, and accuracy requirements.

If a bubble-gage sensor is used, the stage is translated to the recorder by a chain and sprocket arrangement. (See fig. 14.)

Stage recorders are either digital or graphic. Both types may be

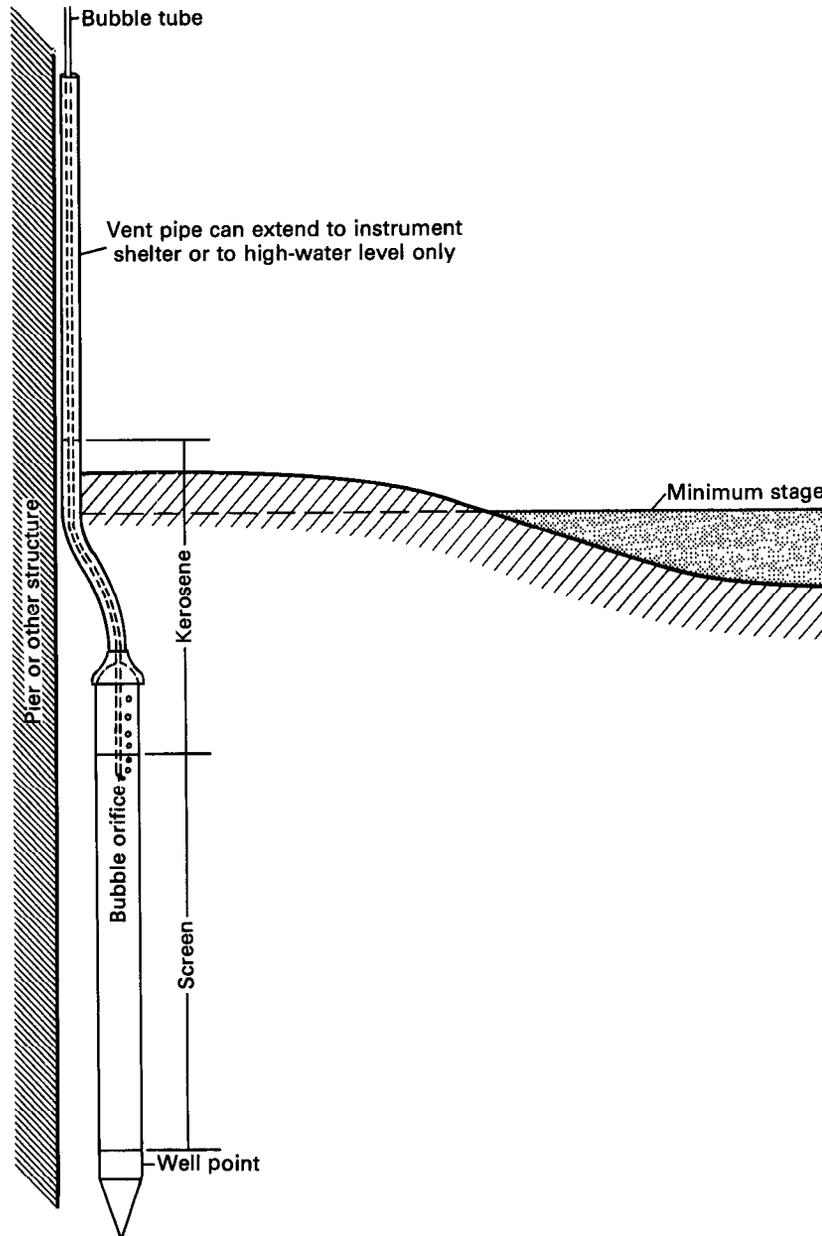


FIGURE 15.—Installation of bubble orifice in unstable streambed.

used with the float or bubble gage. Digital recorders are gradually replacing *strip-chart (graphic) recorders at gaging stations in the United States*. The two recorders are about equal in accuracy, reliability, and cost, but the digital recorder is compatible with the use of electronic computers in computing discharge records. This automated system offers greater economy and flexibility in the computation-publication process than do manual methods associated with graphic recording. However, the use of graphic recorders should be continued at those sites where a graphic record is necessary to detect ice effects, backwater, or frequent malfunctions of the recording system.

DIGITAL RECORDER

The digital recorder used by the U.S. Geological Survey (Isherwood, 1963) is a battery-operated slow-speed paper-tape punch which re-

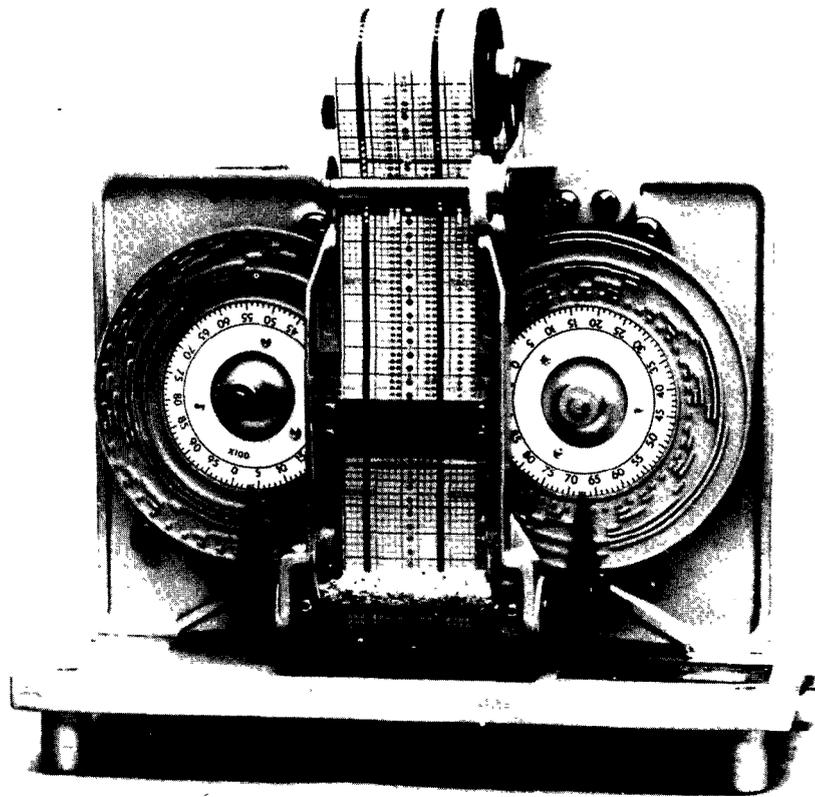


FIGURE 16.—Digital recorder.

cords a 4-digit number on a 16-channel paper tape at preselected time intervals. (See fig. 16.)

Stage is recorded by the instrument in increments of a hundredth of a foot from zero to 99.99 ft (30.5 m) and is transmitted to the instrument by rotation of the input shaft. Shaft rotation is converted by the instrument into a coded punch-tape record that is simple enough to be read directly from the tape. 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 1 to 9, with a blank space for 0, and the four groups of punches represent all numbers from 1 to 9,999. (See fig. 17.)

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 one hundred 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 which is mounted on a movable arm hinged at the base of the recorder. The punch block contains a single row of 18 pins, 16 pins for the information punches and 2 for punching feed holes.

The tape is punched when the punch block with its protruding pins is forced against the code discs by spring action. Those pins, which strike the raised ridges of the discs, punch through the paper tape and record the position of the discs at that instant. The readout cycle begins with an impulse from the timer that causes a 6-volt motor to turn a sequencing camshaft. The sequence of operations for one reading includes punching the paper, advancing the paper, and compressing the punch spring for the next readout cycle.

The timers (fig. 18) used on the digital recorders are electro-mechanical timing devices that are powered by the same 7½-volt battery that operates the 6-volt motor. The timers provide contact closure for actuating the digital recorder at preselected time intervals of 5, 15, 30, or 60 minutes by using a different cam for each different time interval.

The cam on the timer corresponds to the minute hand on a clock; that is, it makes one revolution per hour in a clockwise direction. If the cam has one dropoff point, the recorder will punch hourly; if it has two dropoff points, it will punch every 30 minutes; and if it has four dropoff points, it will punch every 15 minutes. The timer in figure 18 has four dropoff points. The arm positioned by the cam operates a single-pole double-throw switch. When the cam dropoff point passes the arm, the switch initiates the major part of the readout cycle which includes punching of the tape. A preset action returns the switch to

the initial position prior to the next readout cycle. Alternating-current timers can be used with the digital recorders at places where

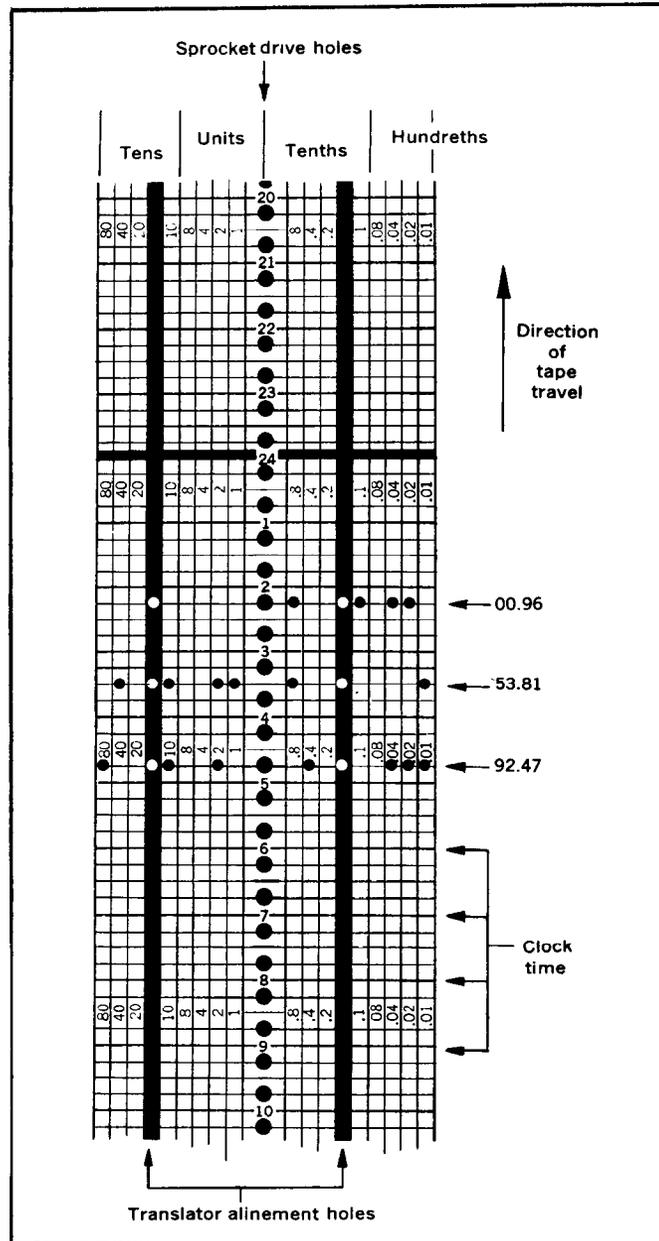


FIGURE 17.—Sample digital-recorder tape.

reliable alternating-current power is available.

Digital recorders may miss the absolute peak stage especially on flashy streams. However, a measure of the maximum peak that occurs between inspections of the recorder can be obtained by attaching a wire clip (similar to a paper clip) or small magnet to the float tape just below the instrument shelf in such a manner that it will slide along the tape as the stage rises but remain in a fixed position as the stage declines. (See p. 60-61).

Mechanically punched tape is the most practical for field use under widely varying conditions of temperature and moisture. Electronic translators are used to convert the 16-channel punch-tape records to a tape suitable for input into a digital computer for computation of a daily mean gage height and daily mean discharge.

In the metric version of the digital recorder, stage is recorded in increments of 1 millimeter from 0 to 9.999 m.

GRAPHIC RECORDER

The graphic, or analog, recorder furnishes a continuous trace of water stage, with respect to time, on a chart. Usually the gage-height element moves the pen or pencil stylus and the time element moves the chart, but in some recorders those actions are reversed. In the U.S.A. the common range of available gage-height scales is from 10 in=1 ft (10:12) to 10 in=20 ft (1:24). The width of strip charts is usually 10 in (0.25 m). The range of available time scales is from 0.3 to 9.6 in (0.0076 m to 0.244 m) per day. Normally the gage-height

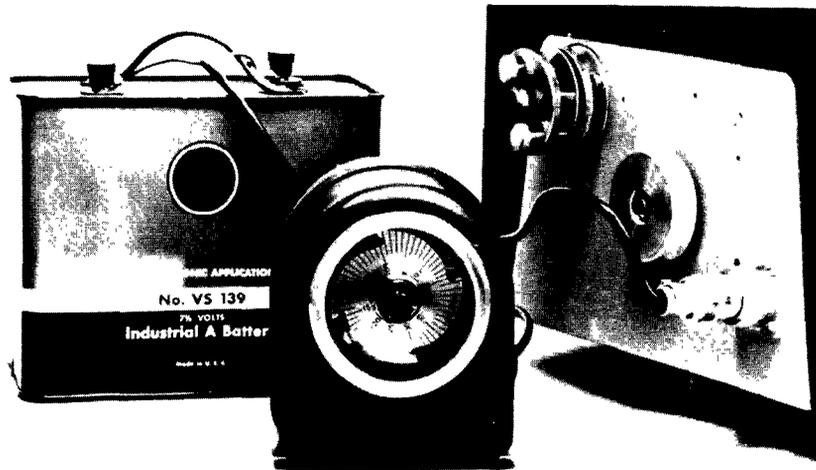


FIGURE 18.—Digital-recorder timer.

scale of 10 in=5 ft (1:6) or 10 in=10 ft (1:12) is used with a time scale of 1.2, 2.4, or 4.8 in per day.

Most graphic recorders can record an unlimited range in stage by a stylus-reversing device or by unlimited rotation of the drum.

Most strip-chart recorders will operate for several months without servicing. Drum recorders require attention at weekly intervals. Figure 19 shows a commonly used continuous strip-chart graphic recorder, and figure 20 a horizontal-drum recorder that must be serviced at weekly intervals. Attachments are available for the recorder

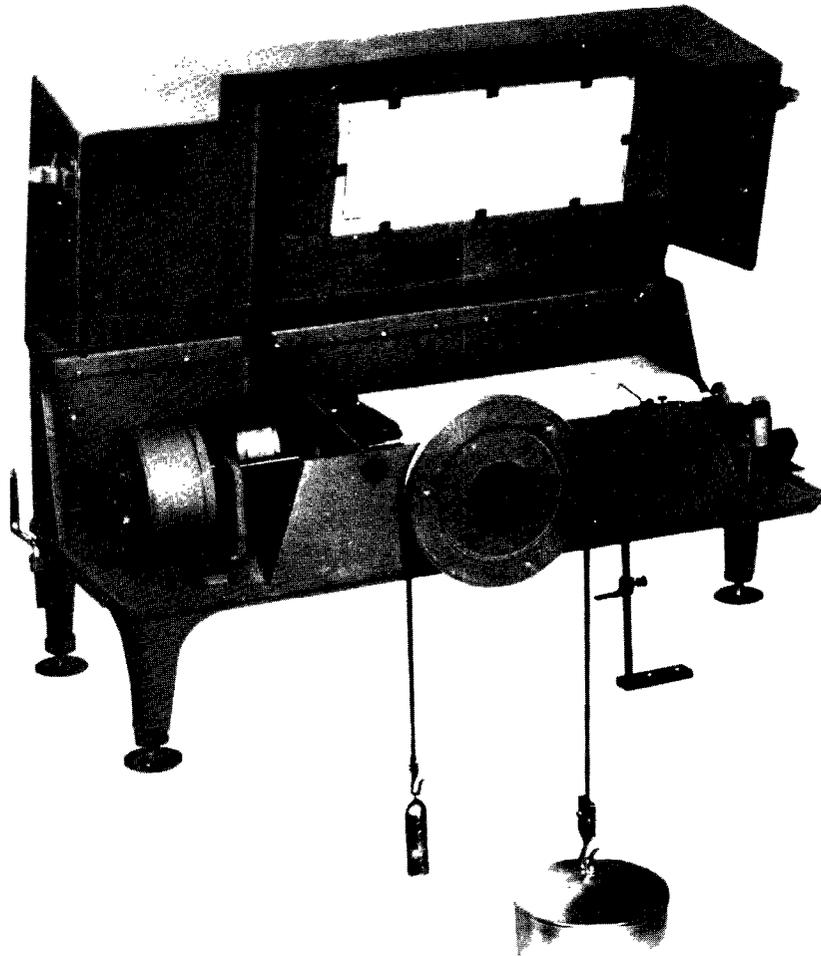


FIGURE 19.—Continuous strip-chart recorder.

shown in figure 19 to record water temperature or rainfall on the same chart with stage. Figure 21 is a section of a typical strip chart whose gage-height scale is 5:12 and whose time scale is 4.8 in per day.

STILLING WELLS

The stilling well protects the float and dampens the water-surface fluctuations in the stream caused by wind and turbulence. Stilling wells are made of concrete, reinforced concrete block, concrete pipe, steel pipe, and occasionally wood. They are usually placed in the bank of the stream (figs. 22–26), but often are placed directly in the stream and attached to bridge piers or abutments. (See figs. 27 and 28.) The

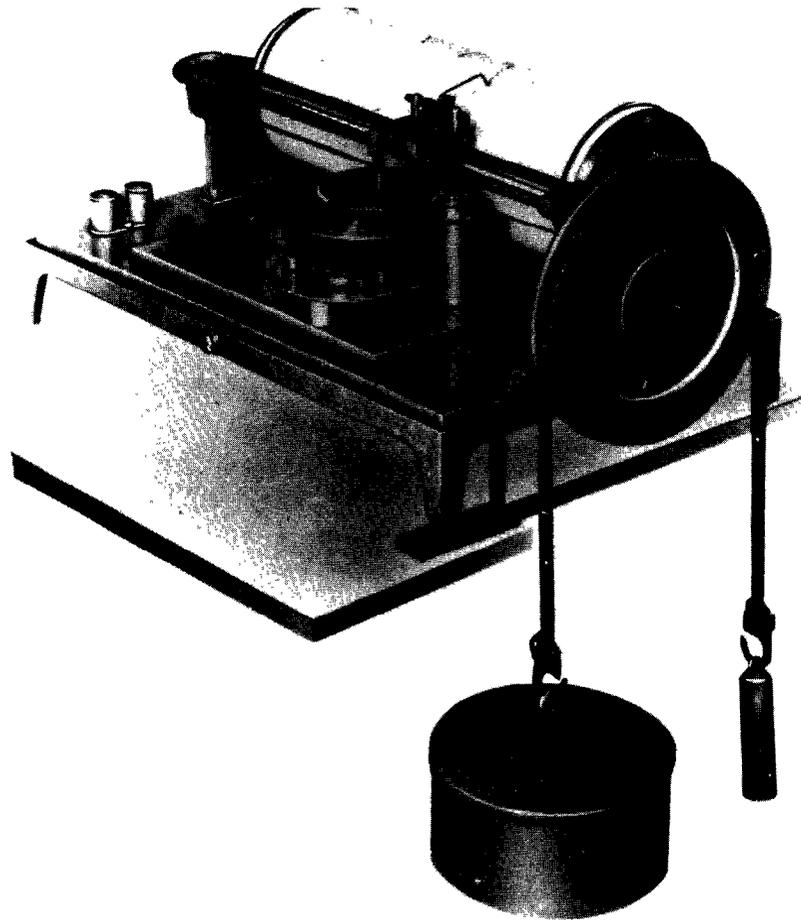


FIGURE 20.—Horizontal-drum recorder.

stilling well should be long enough for its bottom to be at least 1 ft (0.3 m) below the minimum stage anticipated, and its top preferably should be high enough so that the recording instrument will be above the level of the 100-year flood.

The inside of the well should be large enough to permit free operation of all the equipment to be installed. Usually a pipe 4 ft (1.2 m) in diameter or a well with inside dimensions 4 by 4 ft (1.2 by 1.2 m) is of satisfactory size, but pipes 1.5 ft (0.5 m) in diameter have been used for temporary installations where a conventional water-stage recorder was the only equipment to be installed. The 4 by 4 ft well provides ample space for the hydrographer to enter the well to clean it or to repair equipment. The smaller metal wells and the deep wells

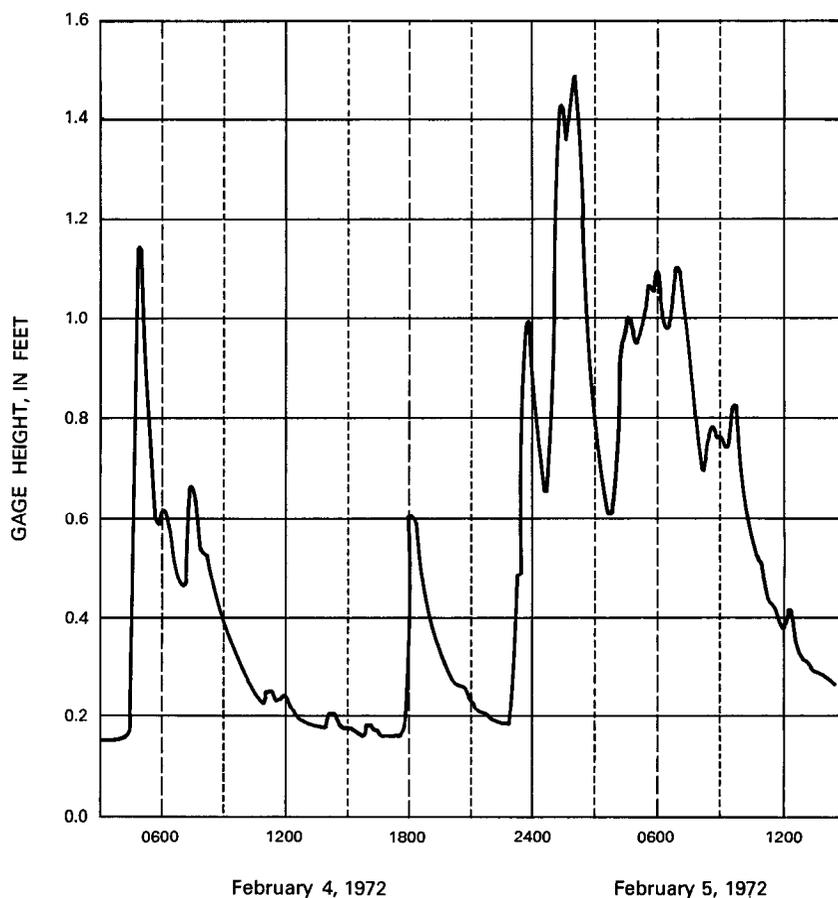


FIGURE 21.—Section of a typical strip chart.

should have doors at various elevations to facilitate cleaning and repairing. (See figs. 22 and 25.)

When placed in the bank of the stream the stilling well should have a sealed bottom so that ground water cannot seep into it nor stream water leak out.

Water from the stream enters and leaves the stilling well through the intake 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 (0.15 m) 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



FIGURE 22.—Reinforced concrete well and shelter. (Note clean-out door.)

frostline. If the well is placed in the stream, holes drilled in the stilling well may act as an intake, taking the place of a length of pipe. Some wells placed in the stream have a cone-shaped hopper bottom that serves as an intake and is self cleaning.

Two or more pipe intakes are commonly installed at vertical intervals of about 1 ft (0.3 m). During high water, silt may cover the streamward end of the lower intakes while the higher ones will continue to operate. The intakes should be properly located and sized to minimize surge.

Most stations that have intakes subject to clogging are provided with flushing systems (see fig. 29) 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 the 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.

The intakes for stations placed in the bank of the stream are usually galvanized-steel pipe. The most common size used is 2-in (0.05 m)-diameter pipe, but for some wells pipe diameters as large as 4 in (0.1 m) are used. After the size and location of the well have been decided upon, the size and number of intakes should be determined.



FIGURE 23.—Concrete well and wooden shelter with asphalt-shingle siding.

The intake pipe should be large enough for the water in the well to follow the rise and fall of stage without significant delay. The follow-

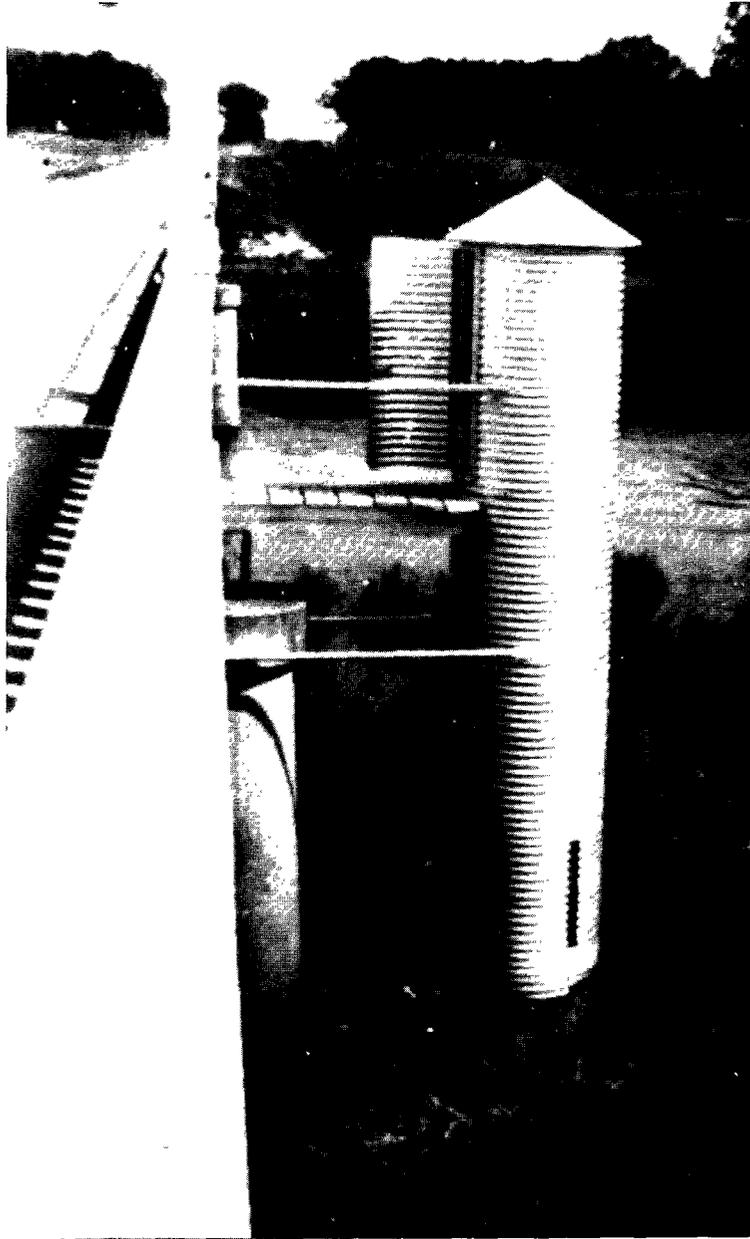


FIGURE 24.—Corrugated-galvanized-steel-pipe well and shelter.

ing relation may be used to predict the lag for an intake pipe for a given rate of change of stage:

$$\Delta h = \frac{0.01}{g} \frac{L}{D} \left(\frac{A_w}{A_p} \right)^2 \left(\frac{dh}{dt} \right)^2$$

in which

Δh = lag, in feet (or meters),

g = acceleration of gravity, in feet (or meters) per second per second,

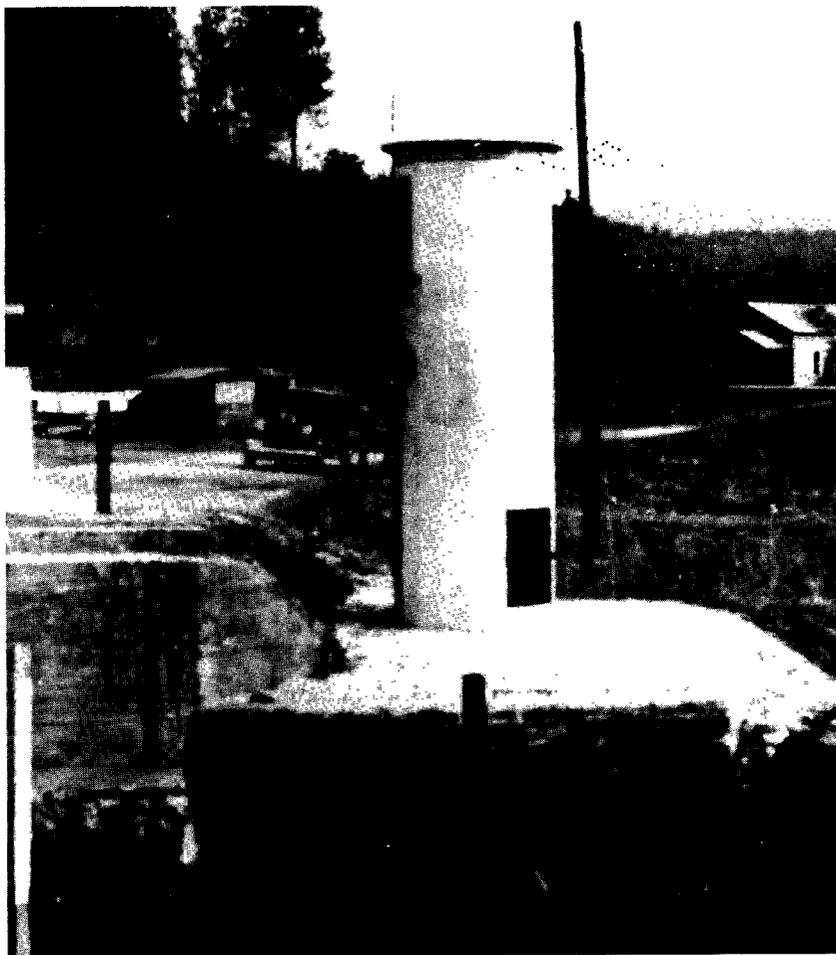


FIGURE 25.—Concrete-pipe well and shelter. (Note clean-out door, staff gage, and upper intake pipe.)

L = intake length in feet (or meters),
 D = intake diameter, in feet (or meters),
 A_w = area of stilling well, in square feet (or square meters),
 A_p = area of intake pipe, in square feet (or square meters), and
 $\frac{dh}{dt}$ = rate of change of stage, in feet (or meters) per second.

Smith, Hanson, and Cruff (1965) have studied intake lag in stilling-well systems, relating it to the rate of change of stage of the stream and to the various types and sizes of components used in the stilling-well intake system.

The intake pipe should be placed at right angles to the direction of flow, and it should be level. If the stream velocity at the end of the intake is high, either drawdown or pileup may affect the water level in the stilling well, depending on the angle of the flow at the intake opening. Drawdown causes the water level in the stilling well to be lower than that in the stream; pileup has the opposite effect. Drawdown commonly occurs at high velocities even when the intake pipe is at an angle of 90° with the flow. To reduce or possibly eliminate drawdown or pileup, a static tube should be attached to the streamward end of the intake pipe. A static tube is a short length of pipe attached to an elbow or tee on the end of the intake pipe and extending horizontally downstream. (See fig. 30.) The end of the static tube is capped, and water enters or leaves through holes drilled in the tube.

The usual means of preventing the formation of ice in the well



FIGURE 26.—Concrete-block shelter.

during cold weather are: (1) subfloors, (2) heaters, and (3) oil. Subfloors are effective if the station is placed in the bank and has plenty of fill around it. If the subfloor is built in the well below the frostline in the ground, ice will seldom 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 heat loss.

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 is used in two ways: (1) Where the well is small and leakproof, the oil may be poured into the well; and (2) where the well is large or not leakproof, the oil—usually kerosene, fuel oil, or diesel oil—is poured into an oil tube. The oil tube, which is open ended and of sufficiently large diameter to accommodate the recorder float, is supported in the well in a vertical position with its lower end just above



FIGURE 27.—Steel-pipe well and look-in shelter attached to bridge abutment.



FIGURE 28.—Corrugated-steel-pipe well and wooden shelter attached to bridge pier.

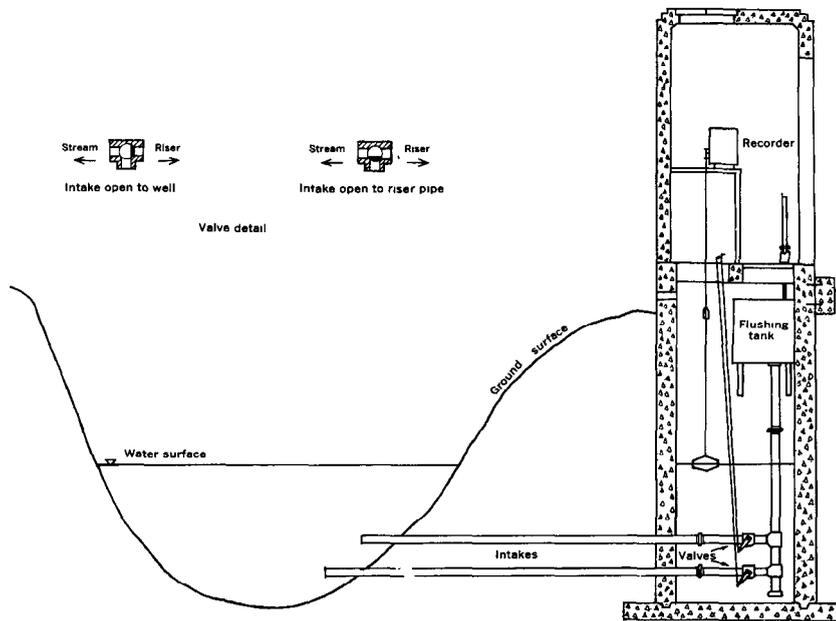


FIGURE 29.—Flushing system for intakes.



FIGURE 30.—Static tube for intakes. (Note outside reference gage.)

the floor of the well. The oil tube should be long enough to contain the oil throughout the range in stage expected during the winter. When oil is put in a well, the oil surface stands higher than the water surface in the stream. A correction must therefore be made to obtain the true river stage. The depth of oil required usually ranges from 0.5 to 2.0 ft (0.15 to 0.6 m) depending on the severity of the climate and the exposure of the well.

Stilling wells often fill with sediment, especially those located in arid or semiarid regions. If a well is located on a stream carrying heavy sediment loads, it must be cleaned often to maintain a continuous record of stage. In those locations sediment traps are helpful in reducing the frequency and labor of sediment removal. A sediment trap is a large boxlike structure that occupies a gap in the lower intake line, streamward from the stilling well. The bottom of the sediment trap is usually about 3 ft (1.0 m) below the elevation of the intake. Inside the trap are one or more baffles to cause suspended sediment to settle in the trap, rather than pass into the well. A removable top to the trap provides access to the interior of the trap for the removal of trapped sediment.

The operation of type of recording stream-gaging station requires the installation of one or more nonrecording gages for use as auxiliary or reference gages. Reference gages are discussed on pages 53–54.

INSTRUMENT SHELTERS

Shelters are made of almost every building material available and in various sizes depending on local custom and conditions. (See figs. 22–28.) The most convenient type of shelter is one that the hydrographer can enter standing. A shelter with inside dimensions 4 by 4 ft (1.2 by 1.2 m) and with ceiling height 7 ft (2.2 m) above the floor is usually of adequate size, unless the shelter is also to be used to store sediment-sampling equipment and (or) house telemetry equipment (p. 54–59). Look-in shelters (fig. 27) are also used at sites where a limited amount of equipment is to be installed and a portable and inexpensive shelter is desired.

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

The bubble gage does not require a stilling well. The instrument shelter for a bubble gage may be installed at any convenient location above the reach of floodwaters. This 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 gage is especially well suited for short-term installations because the entire station is readily dismantled and relocated with practically no loss of investment.

A shelter with inside dimensions 4 by 4 by 7 ft (1.2 by 1.2 by 2.2m) is needed to accommodate the equipment for a bubble gage. Shelters similar to those in figures 22, 23, and 26 would be adequate. The shelter can be placed on a concrete slab or other suitable foundation. The bubble orifice is placed at least 0.5 ft (0.15 m) 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. A typical bubble-gage installation is shown in figure 31. The streamward end of the metal pipe should be flush with the streamward face of the pier shown in figure 31 to prevent disturbance of the streamlines of river flow in the vicinity of the orifice. The streamward end of the orifice line should have a downward slope, as shown in the figure. It has been found that if the end of the orifice line is installed in a horizontal position, water tends to run up the bubble tube after each bubble is formed, and the induced surge is recorded by the stage recorder.

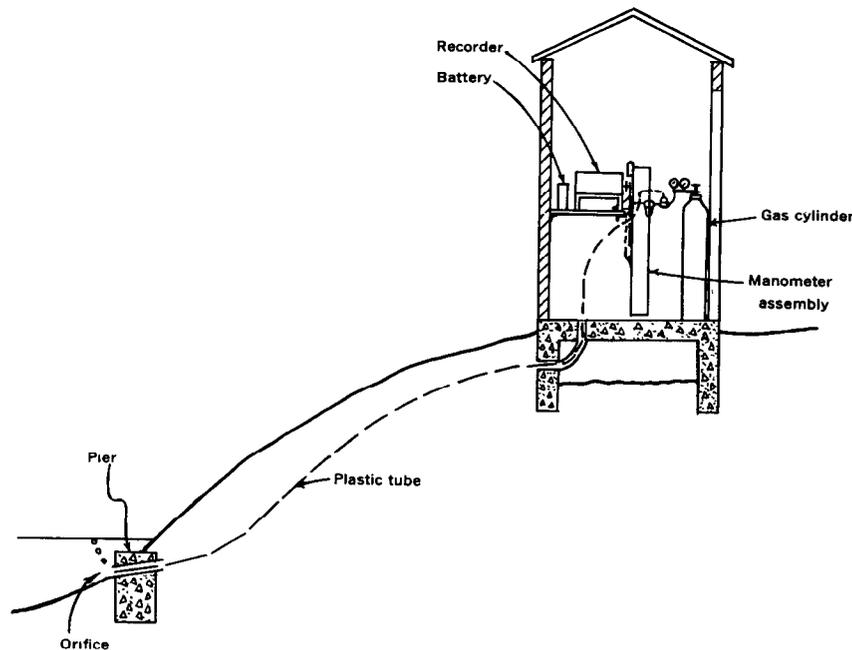


FIGURE 31.—Typical bubble-gage installation.

REFERENCE AND AUXILIARY GAGES AT RECORDING GAGING STATIONS

Nonrecording gages, which were discussed on pages 24–32, are used both as reference and auxiliary gages at recording stream-gaging stations. As used in this manual a reference gage is the gage to which the recording instrument is set; it is the base gage for the recording station. All other nonrecording gages at the recording station are considered to be auxiliary gages. A detailed discussion follows.

Outside gage—At bubble-gage stations a nonrecording gage, established in close proximity to the bubble orifice, acts as the base or reference gage for checking and resetting the gage height indicated by the water-stage recorder.

At stations equipped with a stilling well for the operation of a float-operated stage recorder, there is always the possibility that the stage in the stilling well may not be representative of the stage of the stream. For example, intakes can become plugged, floats can spring a leak, or oil can leak out of wells or oil tubes. Consequently, a nonrecording auxiliary gage is installed outside the stilling well so that the water level of the stream can be determined directly for comparison with the stage in the stilling well. It is not necessary that the two observed stages agree precisely; hydraulic conditions at the station may be such that precise agreement is not possible. If a reading of the outside auxiliary gage indicates that an unsatisfactory record is being obtained by the recording gage, the trouble is rectified immediately. If immediate repairs are not feasible, or if there has been an instrument failure, the outside auxiliary gage is used as a temporary substitute for the recording gage. The outside auxiliary gage can be read as needed by a local observer to continue the record of stage until the malfunction of the recording station is rectified.

Staff or wire-weight gages are usually used as outside auxiliary gages. Outside staff gages located in the pools near the gage structures are visible in figures 5, 6, 22, 25, and 30; a wire-weight auxiliary gage on the parapet wall of the bridge is visible in figure 1, and another is seen in figure 27.

Inside gage—At gaging stations equipped with a stilling well a nonrecording gage inside the structure is used to indicate the water-surface elevation in the stilling well. Readings on this inside gage are compared with readings on the outside auxiliary gage to assure that the stilling-well intakes are functioning properly. If the intakes are functioning properly, the inside gage is used for checking and resetting the gage height indicated by the water-stage recorder. In short, the inside gage is the base or reference gage for the station. Float- or electric-tape gages, or vertical staff gages, are the inside reference gages most commonly used in stilling wells.

On occasion a reference mark or reference point of known elevation, with respect to gage datum, is used in place of either a reference or auxiliary gage. The stage is then determined by measuring from the reference mark or point down to the water surface either in the stream or in the stilling well, as the case may be. While the practice of using a reference mark or point is acceptable, it is not nearly as convenient as the practice of using a standard nonrecording gage. (The distinction between a reference mark and reference point should be noted here: Both have elevations that are known, but a reference point is a point on the gage structure itself; a reference mark is a point that is not on the gage structure, and whose elevation is therefore unaffected by any movement of the gage structure.)

The practice described above of using the inside gage, rather than the outside gage, as the reference or base gage for a recorder equipped with a stilling well is followed in the U.S.A. and in many other countries. The reasoning behind that practice is that recorded (inside) gage heights will be used to determine discharge, and if differences exist between inside and outside stages, those differences will be known only for those times when both gages are read. If the outside gage is used as the base gage, corrections, known or assumed, must be applied to all recorded gage heights to convert them to outside stages. Furthermore, outside gages are often difficult to read with precision because of the action of wind and waves. In other countries the outside gage is used as the reference gage for the reasons that (1) river stage is often as important as discharge to the user of the record and (2) a stage-discharge relation is dependent on river stage, rather than on the stage inside a stilling well. The validity of both those reasons is recognized in the U.S.A. Therefore outside high-water marks are obtained for each flood event, and where the elevation of the marks differs significantly from the peak inside stage, both inside and outside stages are published. Also, where there is significant difference between inside and outside gage readings, the stage-discharge relation is first developed on the basis of outside-gage readings observed at the times when discharge is measured. The relation is then adjusted to correspond with inside-gage readings observed at the times of discharge measurement.

TELEMETERING SYSTEMS

Telemetering systems are used when current information on stream stage is needed at frequent intervals and it is impractical to visit the gaging station each time the current stage is needed. Current stage information is usually necessary for reservoir operation, flood forecasting, prediction of flows, and for current-data reporting. The types of telemetering systems are:

1. Those that continuously indicate or record stage at a distance from the gage site. Examples of this type are the position-motor and impulse telemetering systems.
2. Those that report instantaneous gage readings on call or at predetermined intervals. Examples of this type are the Telemark and resistance telemetering systems, and the experimental satellite data-collection systems.

POSITION-MOTOR SYSTEM

The position-motor system provides remote registering of water levels on graphic recorders or on counter or dial indicators over distances up to 15 mi (25 km). This system employs a pair of self-synchronizing motors—one on the transmitter, whose rotor is actuated by a float-tape gage or a bubble gage, and the other on the receiving unit, whose rotor follows the rotary motion of the transmitting motor to which it is electrically connected. Alternating current is used to operate the system, and a five-wire transmission line is required—two excitation wires and three line wires.

IMPULSE SYSTEM

The impulse system provides remote registering of water levels on graphic recorders or on counter and dial indicators over longer distances than does the position-motor system. This system will operate over leased telephone lines or other metallic circuits. The impulse sender at the gaging station is actuated by a float-tape gage or a bubble gage and sends electrical impulses over the line connecting it to the receiver. This system usually has a battery for the power source at the sender and alternating current at the receiver, though direct current or alternating current may be used at both ends. The advantage of this system over the position-motor system is that it will operate over long distances.

TELEMARK SYSTEM

The Telemark system codes instantaneous stage and signals this information either audibly over telephone circuits or by coded pulses for transmission by radio. The distance of transmission is unlimited because signals can be sent over long-distance telephone circuits or by radio. Telemark response to a telephone ring is automatic. When used in radio transmission, the signals are started by a timing device set for a predetermined broadcast schedule, or the Telemark may be interrogated by radio channel to start the signal.

The Telemark consists of (1) the positioning element which is actuated by a float-tape gage or a bubble gage (fig. 32) and (2) the signaling element which, when signaled, drives a contact across the

signaling drums that are positioned in correspondence with the stage. The Telemark may be operated by either alternating current or by batteries.

A Telemark that operates directly off a digital recorder is available and will probably be increasingly used. This Telemark does not need its own stage sensor; it uses that of the digital recorder. A memory system is used so that when the Telemark is signaled, the last gage height recorded on the digital recorder is transmitted.

Telemarks for radio reporting are equipped with an auxiliary switch and coding bar for transmitting identifying radio station call letters and numbers in international Morse code, in addition to transmitting the stage.

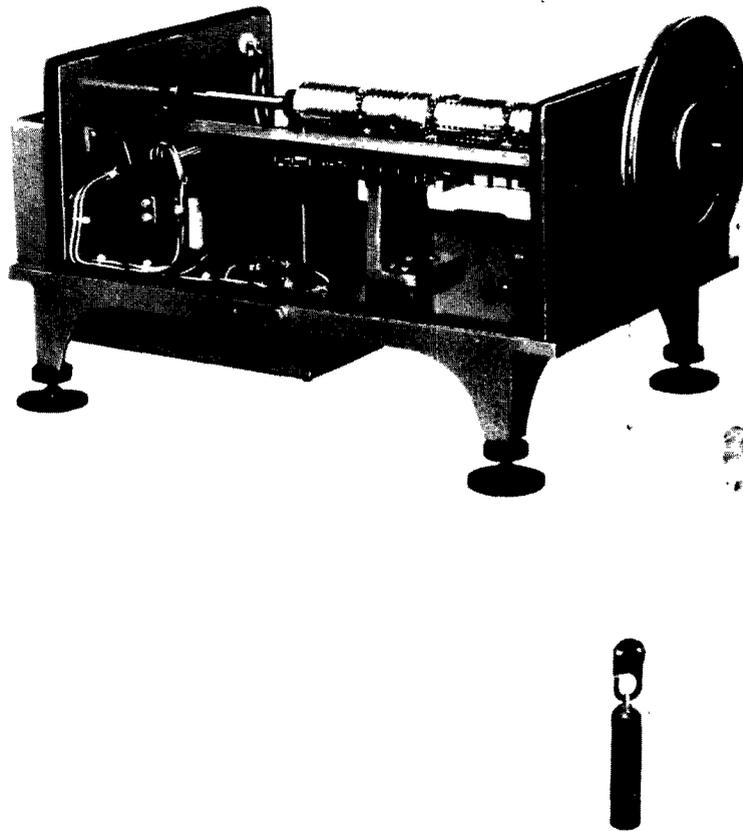


FIGURE 32.—Telemark gage.

RESISTANCE SYSTEM

The resistance system, as used in the U.S.A., was developed by the U.S. Weather Bureau. It provides remote indications of water level for distances up to about 40 mi (about 65 km). Two models are available, one for distances of about a mile (1.6 km) and the other for longer distances. The system consists of two potentiometers in a wheatstone-bridge circuit with a microammeter null indicator. One of the potentiometers is located in the gage house and is actuated by a float and pulley assembly. (See fig. 33.) The other potentiometer and the null indicator are housed at the observation site. (See fig. 34.) By adjusting this potentiometer for a null balance on the meter, the gage height can be read directly to tenths of a foot from a dial coupled to the potentiometer shaft. This system operates on batteries, and three wires connect the unit.

SATELLITE DATA-COLLECTION SYSTEM

The U.S. Geological Survey has been experimenting for several years with the collection of stream-stage data by use of an orbiting satellite which receives radio transmissions of stage and transmits

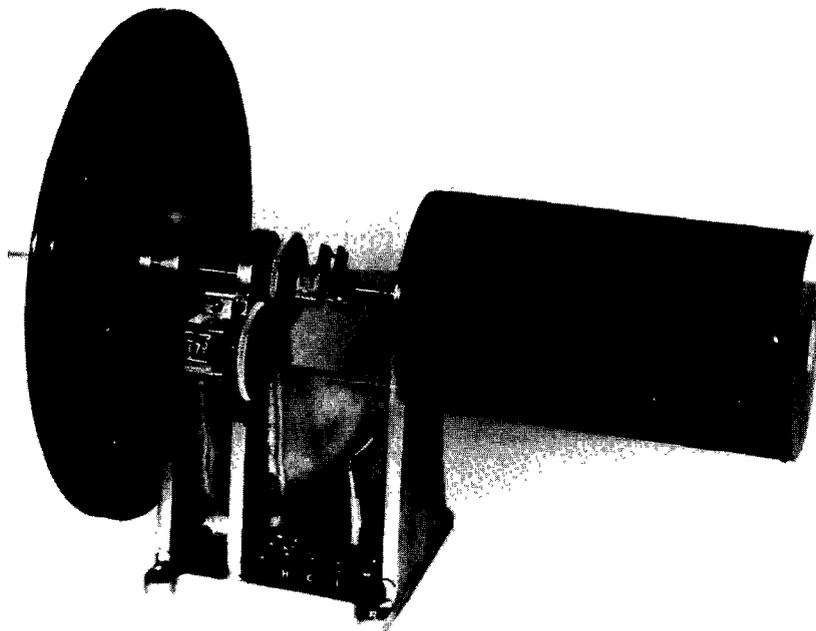


FIGURE 33.—Resistance system transmitter unit.

the data to central receiving stations. An operational system of that kind would make stage data continuously available for use by the managers of water projects who require current ("real time") information for project operation. Because the system is still in the experimental stage it will be described only briefly.

Experimental work on the system began soon after the launch of the Earth Resources Technology Satellite (ERTS) in July 1972. At numerous stream-gaging stations that are dispersed over a wide geographic area, inexpensive battery-operated radios, called data-collection platforms (DCP), are used to transmit stage data through ERTS to the National Aeronautics and Space Administration (NASA) receiving stations at Goldstone, California, and at Greenbelt, Maryland. The data are processed and distributed to experimenters from the ERTS Operations and Control Center in Greenbelt.

Data can be provided to a DCP either directly from a digital water-stage recorder or through an intermediate memory device. In the

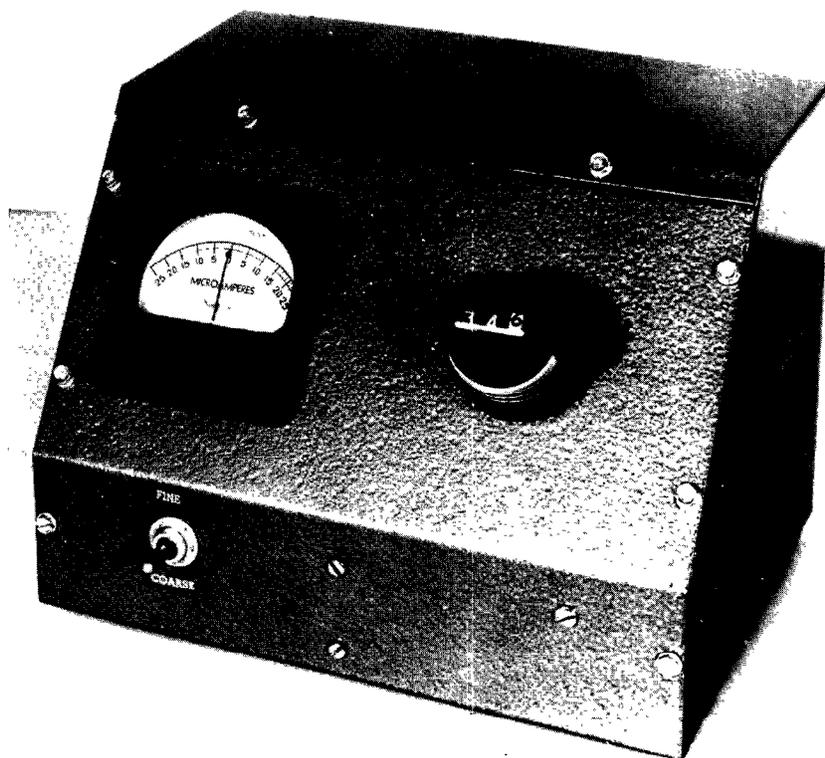


FIGURE 34.—Resistance system indicator unit.

direct communication the most recently recorded digital stream stage is continuously available to the DCP for inclusion in a 0.038-second radio message that is transmitted every 3 minutes. Several times daily the ERTS passes within 1,800 mi of the DCP, and the data are at that time relayed to the receiving stations. Where the intermediate memory device is used, the data are formatted efficiently in the device for inclusion in the periodic DCP message. By use of the memory device virtually all 24 of the hourly stream stages collected daily at North American stream-gaging stations can be accumulated and relayed, as opposed to the 5 or 6 hourly stages that are relayed daily when the DCP is directly connected to the digital-stage recorder. Tests of the satellite data-collection system have been successful to date (1980) and indicate that the satellite relay of environmental data from widely dispersed and remotely located gaging stations can be effectively and reliably performed.

OPERATION OF A RECORDING STREAM-GAGING STATION

Strip-chart or digital recorders are designed to give a continuous record of stage, but careful attention to details is necessary at each visit to the station to ensure a reliable and uninterrupted record during the period (commonly 4–6 weeks) that usually elapses between such visits. This section of the manual presents only general instructions for servicing recording stream-gaging stations. It is not practical to attempt to provide detailed instructions here for servicing stage-recorders because of the large numbers of such instruments of varying design that are available. For detailed instructions concerning any particular stage-recorder, it is necessary that the hydrographer consult the service manual prepared by the manufacturer of the instrument or prepared by the stream-gaging agencies that use the particular instrument.

The first thing done by the hydrographer on his visit to the recording station is to determine if the clock or timer is running. If it is a strip-chart recorder that is being serviced, the point at which the pen or pencil is resting is then circled; if it is a digital recorder that is being serviced, the instrument is caused to punch the digital tape and the set of punched holes is circled. The time by the hydrographer's watch is noted and the base nonrecording reference gage is read. Those observations are written on the chart or digital tape in proximity to the circled gage height. The hydrographer then reads all gages and notes the chart position or digital-tape position, with respect to time and gage height, of the circled pen mark or punched holes. All that information is also written on the chart or digital tape.

The various gage readings and the recorded gage heights are compared to determine if intakes are functioning properly or if there is a

malfunction in the gas-purge system of the bubble gage. The time indicated by the chart or digital tape is compared with the time indicated by the hydrographer's watch to determine if the instrument clock or timer is operating satisfactorily. The section of chart or digital tape bearing the gage-height record is next removed and is examined to determine if there has been any recorder malfunction since the previous servicing of the station.

The clock is then wound, or if the clock is battery driven, the battery voltage is checked and the chart or digital tape is rethreaded into the take-up roll. The pen or punch mechanism is next set to agree with the gage height indicated by the base reference gage, and the chart or digital tape is advanced to give agreement with the hydrographer's watch time. By resetting the recorder at this point, before completing his inspection of the station facilities, the hydrographer gives himself another opportunity to check the operation of the recorder after his work is completed and the instrument has been operating for a period of time.

If the station has a float-operated recorder, the hydrographer inspects the float to determine if it leaks and checks the float-clamp screw to make sure there can be no slippage of the float tape where it joins the float. He also checks the stilling well to be sure there is no unduly large accumulation of sediment in the well. If the well is equipped with an oil tube for winter operation he uses a point on the top of the tube to measure down to the oil surface within the tube and to the water surface outside the tube. The differential between the two measurements, when divided by a value equal to 1.0 minus the specific gravity of the oil, equals the depth of oil in the oil tube. The hydrographer can decide from that computation whether oil has leaked from the tube and the additional amount of oil, if any, to be added. If the stilling well is equipped with a flushing device, the intakes should be flushed as a matter of course. If no flushing device has been provided, and there are indications that the intakes are lagging, the intakes should be cleaned by forcing a plumber's snake through them.

If a high discharge has occurred since the previous visit to a stilling-well-equipped station, high-water marks should be sought both in the stilling well and outside the well, as a check on the peak stage shown by the stage recorder. After making that check, the high-water mark should be cleaned from the inside of the well to prevent confusion with high-water marks that will be left by subsequent peak discharges.

Another means of checking recorded peak stages is by having a wire clip (similar to a paper clip) or magnet attached to the float tape immediately below the shelf through which the tape passes. As the

stage rises, the wire clip or magnet, being too large to pass through the hole in the shelf, retains its position at the bottom of the shelf, and the moving float tape slides past it. When the stage recedes, the clip or magnet remains attached to the tape and moves downward as the float moves downward. Any one of several alternative methods may be used to determine the peak stage that had been attained. In one method the peak stage is obtained by subtracting a correction constant from the tape reading at the top of the wire clip. That correction constant is equal to the difference in elevation between the index pointer for the float gage and the bottom of the shelf. In a second method the visiting hydrographer computes the difference between readings on the float tape at the bottom of the shelf and at the top of the wire clip or magnet. He adds that difference to the current gage height to obtain the peak stage attained. A third method of determining the peak stage is to raise the float until the wire clip or magnet is at the bottom of the shelf; the corresponding tape-gage reading is the peak stage that had been attained. Regardless of the method used, after determining the peak stage the wire clip or magnet should be moved back to the bottom of the shelf for subsequent indication of peak stage.

If an indicator of minimum stage is desired, a similar device—wire clip or magnet—can be attached to the float tape immediately below the instrument shelf, but on the counterweight side of the float sheave. The operation of the minimum-stage indicator is similar to that described above for the peak-stage indicator.

If the station has a bubble-gage sensor, the bubble orifice should be inspected to make sure that it has not been buried by a deposit of sediment. A log of gas-feed rate, gas consumption, and gas-cylinder replacement (fig. 35) should be kept to insure a continuous supply of gas and to help in checking for leakage in the system. There can be no serious leak in the gas-purge system if (1) the manometer 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 gas leak is evident, its location can be determined by isolating various parts of the gas-purge system by the sequential closing of valves in the system. If a high discharge has occurred since a previous visit to the station, a high-water mark should be sought in the vicinity of the base reference gage, as a check on the peak stage shown by the stage recorder.

After the hydrographer has completed his inspection of the station facilities, he returns to the stage recorder and repeats the first steps he had taken in servicing the recorder. He determines that the clock or timer is running; circles the point at which the pen is resting on the

strip chart; observes his watch time; reads all gages, and writes his observations on the strip chart or digital tape. He does not leave the station without assuring himself that: the recorded gage height and time agree with the gage height of the base reference gage and his watch time; the clock is running; all necessary valves are open; the float wheel (if any) is engaged; the pen (if any) is marking.

A few generalities may be stated concerning the maintenance of recording stream-gaging stations to increase the accuracy and improve the continuity of the stage record. Malfunctions of the recorder can be reduced by the periodic cleaning and oiling of the recorder and clock or timer. Each year intakes, stilling wells, and sediment traps should be thoroughly cleaned. Excessive humidity and temperatures in the gage house should be reduced to a minimum by proper ventilation, and if feasible, extremely cold temperatures in the gage house should be modified by the use of heating units or insulation. Humidity and temperature control reduce the errors associated with paper expansion and contraction. Experience in the U.S.A. has shown that a program of careful inspection and maintenance will result in a complete gage-height record about 98 percent of the time.

FACTORS AFFECTING THE ACCURACY OF THE STAGE RECORD

Continuous records of discharge at a gaging station are computed from the record of stage and the stage-discharge relation. For that purpose stage records having an accuracy of ± 0.01 ft (± 0.003 m) are generally required. That accuracy can usually be attained by use of the continuous stage-recording systems previously described. The record obtained by sketching a continuous-stage graph through the plotted points representing periodic observations of a nonrecording gage cannot attain such accuracy, of course, but with care the individual gage observations can usually have an accuracy within ± 0.01 ft.

In the discussions that follow, nonrecording gages will be treated first and then recording gages will be discussed. A remark appropriate to a discussion of the accuracy of any gage concerns the maintenance of the gage datum to the accuracy criterion of 0.01 ft. That is achieved by running levels to reference marks for the gage (p. 24) and, if necessary, adjusting the gage to restore the original datum. Levels should be run at least once every 2–3 years, and oftener if conditions are known to be unstable. If a nonrecording gage is used only as an outside auxiliary gage for a stilling well, a larger error in gage datum may be tolerated, and adjustment to the gage need not be

made for datum discrepancies that do not exceed 0.02 ft (0.006 m). That is so because seldom will inside and outside gages agree exactly even when both are set precisely to the same datum. The inside reference gage, as explained earlier (p. 54) is the base gage for the station; the primary purpose of the outside gage at a station equipped with a stilling well is to indicate whether or not the intakes are operating properly. (As mentioned on page 54, in some countries the outside gage is used as the reference or base gage.)

NONRECORDING GAGES

STAFF GAGE

Settlement or uplift of the structure(s) supporting the staff gage may disturb the gage datum. Where levels from a reference mark show that the datum of an inclined staff gage (p. 26) has been disturbed, the gage is recalibrated by removing the staples used for the graduations and replacing them at the proper elevations. Vertical staff gages are usually made up of several porcelain-enameled iron sections, each about 3.4 ft (1.04 m) long and bearing permanent graduations. Where levels from a reference mark show disturbance of the datum of a vertical staff gage, it is necessary to reset the individual gage sections. The graduations of the manufactured gage plates often have minor discrepancies, and therefore if the gage plates must be reset, they should be reset so that a graduation near the center of each gage plate is at the proper datum.

It is often difficult to accurately detect the water line when making staff-gage observations under the conditions of poor light and (or) clear water. Under those conditions it is helpful to float a matchstick or some similar floatable material against the gage and thereby define the water line. When the water surface is surging rapidly as a result of wave action, the stage to be recorded is the mean of the elevations of the peak and trough of the waves.

WIRE-WEIGHT GAGE

Wire-weight gages (p. 26) are usually mounted on bridges, and changes in gage datum often result from the settlement of bridge abutments or piers, or from changes in the deflection of the bridges resulting either from differences in traffic loading at the times of observation or from seasonal changes in air temperature. In addition to errors attributable to datum changes, erroneous readings of the type A wire-weight gage may also be caused by slippage of the graduated disc of the gage; that slippage results from insecure tightening of the disc screws. The latter condition can be detected if a

reading of the gage height of the horizontal checking bar is always made prior to lowering the weight to the water surface.

In checking the datum of the type A wire-weight gage by levels from a reference mark, the elevation of the horizontal checking bar and that of the bottom of the weight at various heights above the water surface are compared with gage readings. When necessary, adjustment of the gage to give accurate readings is made by loosening the graduated disc, rotating the disc to the true gage height of the bottom of the weight as determined from levels, and then retightening the disc screws.

Reliable observations are difficult to obtain by wire-weight gage when the water surface is disturbed by waves; the stage sought under those circumstances is the mean of the elevations of the peak and trough of the waves. On the other hand, it is also difficult to sense the water surface from a high bridge when the water is quiescent. The ideal condition for sensing the water surface occurs when a slow-moving water current is present under the weight. When observations are made on a windy day, the wire that supports the weight will bow rather than hang vertically, thereby causing the gage to underregister. The error introduced will depend on the intensity of the wind and on the height of the gage above the water surface. The combination of a high wind and high bridge may cause appreciable underregistration of the gage.

Another source of error, and one that also increases with height above the water surface, is in the tendency of the weight to rotate about its vertical axis as the weight is being lowered. The rotation twists the wire, and sequences of untwisting and twisting of the wire follow. During each period of twisting the wire shortens and the weight ascends; during each period of untwisting the wire lengthens to its full length and the weight descends. Observation of the gage height of the water surface should not be made until the weight has ceased to rotate.

FLOAT-TAPE GAGE

Change in the datum of a float-tape gage (p. 26) may result from movement of the structure supporting the gage or from slippage of the adjustable index. A float-tape gage will also read incorrectly if the tape has slipped in the clamp connecting the tape and float (gage will overregister) or if the float has sprung a leak and has taken in water (gage will underregister). The first steps in checking a float-tape gage therefore are to make sure that the clamp screw bears tightly on the tape and to shake the float for indications of water sloshing within the float.

Where levels from a reference mark show the elevation of the adjustable index to be in error, the screw holding the index is loosened, the index is raised or lowered to its proper position, and the index screw is retightened. The elevation of the water surface in the stilling well is next obtained by measuring with a steel tape to the water surface from the index or other suitable point of known elevation. Any further adjustment that is needed to make the gage height agree with the water-surface elevation is made by adjusting the length of tape at the float clamp. After all adjustments are complete, a record should be made for future reference of the tape graduation at which the tape enters the tape clamp. If the stage of the stream is changing, the valves on the stilling-well intakes should be closed while adjustments to the float-tape gage are being made in order to maintain a constant water level in the stilling well.

ELECTRIC-TAPE GAGE

Change in the datum of an electric-tape gage (p. 28) can only result from movement of the structure supporting the gage, because the position of the index of the gage is permanent with respect to the instrument. An electric-tape gage may also read incorrectly (overregister) if the tape and weight are insecurely clamped together and slippage of the tape has occurred. Where levels from a reference mark show the gage index to be in error, nothing can be done about moving the index, but its new (and true) gage height is made a matter of record. The original datum of the gage can be maintained, however, by adjusting the effective length of the tape, that is, by changing the length of tape that is inserted and clamped in the gage weight (fig. 12). In other words, when the tape is unreeled so that the bottom of the weight is, for example, 1.00 ft (0.3 m) below the index, the tape gage should read 1.00 ft (0.3 m) less than the gage height of the index. After the adjustment is completed, a record should be made, for future reference, of the tape graduation at which the tape enters the weight. If the stage of the stream is changing rapidly at the time a reading is to be taken in the stilling well, it is helpful to close the valves on the stilling-well intakes in order to obtain a constant water level in the stilling well.

Use of the electric-tape gage as the inside reference gage is practically a necessity where a small diameter stilling well is used in a cold climate. In that situation oil must be added to prevent freezing, and because the stilling well is too small to accommodate an oil tube (p. 48), the oil must be added in the well itself. Because the oil is lighter than water, the surface of the floating oil in the stilling well will be higher than the water level at the streamward end of the stilling-well

intakes. It is the gage height of the water level (GH) that is sought, and it may be computed by either of two equations:

$$GH = [\text{gage height of oil surface}] - [(1.0 - \text{specific gravity of oil}) \times (\text{depth of oil})] \quad (1)$$

or

$$GH = [\text{gage height of interface of oil and water}] + [(\text{specific gravity of oil}) \times (\text{depth of oil})]. \quad (2)$$

Use of an electric-tape gage makes it a simple matter to measure the distances needed in equation 2. That part of the tape above the weight is rubbed with carpenter's chalk for a distance of about 1.5 ft (0.5 m) above the weight, and the weight is then lowered until a signal is received on the voltmeter. At that point the electric-tape gage reading obtained will be that of the oil-water interface (p. 28). The tape is then reeled up and the lower end inspected. The oil will have wetted the chalk on the tape leaving a sharp demarcation between the wet and dry lengths of tape. The depth of oil is equal to the distance between the demarcation line and the bottom of the weight. If the depth of the oil is less than the length of the weight, the oil will not reach the tape. In that event, the weight is lowered a known distance below the oil-water interface—say, 1.0 ft (0.3 m)—and the apparent oil depth that is determined is reduced by 1.0 ft (0.3 m), the additional distance that the weight was lowered. The computed oil depth and the observed gage height of the oil-water interface are used in equation 2 to compute the true gage height.

CHAIN GAGE

Change in the datum of a chain gage (p. 31) can result from movement of the structure on which the gage is mounted, but there are many other sources of error. They include stretching of the chain, foreign material between chain links, wear of the chain links, and wear of the pulley wheel. For that reason the chain length between the bottom of the weight and the chain index markers should be measured at each visit by the hydrographer, using a 4-lb (2-kg) pull on the chain. A small spring balance is usually used to put the proper tension on the chain when measuring its length. If the chain length differs by more than 0.02 ft (0.006 m) from the "true" value established the last time the datum was checked by levels, the length of the chain is adjusted at the point where the chain is attached to the weight. The adjustment is easily made because the chain and weight are attached by means of a cotter pin through one of a series of holes

in the neck of the weight, the spacing between holes being about 0.02 ft (0.006 m).

In checking the gage datum by levels from a reference mark, the gage height of a point of known elevation on the supporting structure (reference point) is first checked. Next, the elevation of the bottom of the weight at one or more heights above the water surface, as determined by levels from a reference mark, is compared with gage readings. When necessary, adjustment of the chain length to give accurate gage readings is made in the manner indicated above. The length of the chain is measured and recorded before and after the adjustment.

The reliability of gage readings of the water surface is affected by wind, waves, and water current, in a manner similar to that discussed for the wire-weight gage (p. 65). There is no tendency, however, for the weight to rotate when lowered, as described in the discussion of the wire-weight gage.

ACCURACY OF FLOAT-OPERATED RECORDERS

This section of the report discusses the inaccuracies inherent in any float-operated instrument; the discussion is not concerned with such sources of error as datum changes, faulty intake operation, float leakage, float-tape slippage, and paper expansion, which were discussed in the preceding sections. The principal sources of error inherent in a float-operated instrument are float lag, line shift, and submergence of the counterweight (Stevens, 1921). With regard to the algebraic sign of the errors discussed below, a positive (+) sign indicates that the instrument shows a stage higher than the true stage, and a negative (-) sign indicates that the instrument underregisters.

Float lag.—If the float-operated recorder is set to the true water level while the water level is rising, it will thereafter show the correct water level, as far as float lag is concerned, for all rising stages. For falling stages, however, the recorded stage will be above the true water level (positive error) by the amount of float lag or change in flotation depth of the float. A reverse effect occurs if the original gage setting is made when the water level is falling. Float lag varies directly with the force (F) required to move the mechanism of the recorder and inversely as the square of the float diameter (D). F commonly ranges from 1 to 5 oz (0.03 to 0.15 kg) depending on the type and condition of the instrument.

The equation for maximum float-lag error ($MFLE$) is

$$MFLE = 0.37 F/D^2 \text{ (English units),} \quad (3)$$

where $MFLE$ is expressed in feet, D is expressed in inches, and F is expressed in ounces. The equation is

$$MFLE = (0.00256) F/D^2 \text{ (metric units),} \quad (4)$$

where $MFLE$ and D are expressed in meters, and F is expressed in kilograms.

If we assume a value of 3 oz (0.08 kg) for F and a value of 8 in (0.2 m) for D , $MFLE$ equals 0.017 ft (0.005 m). If the recorder was set to the true water level while the float was rising, the record on a falling stage will be in error by +0.017 ft. If however, the index were set at the true level at a stationary stage—that is, at the peak or trough of a changing stage, or when the valves in a stilling well were closed—then the error will be halved on a changing stage. The error will be +0.0085 ft for falling stages and -0.0085 for rising stages.

Line shift.—With every change of stage a part of the float tape passes from one side of the float pulley to the other, and the change in weight changes the depth of flotation of the float. The magnitude of change depends on the change in stage (ΔH) since the last correct setting of the recorder, the unit weight (U) of the tape, and the float diameter (D). The error will be positive (+) for a rising stage and a negative (-) for a falling stage.

The equation for line-shift error (LSE) is

$$LSE = 0.37 \left(\frac{U}{D^2} \right) \Delta H \text{ (English units),} \quad (5)$$

where U is expressed in ounces per foot, D is in inches, and LSE and ΔH are in feet.

The equation is

$$LSE = (0.00256) \left(\frac{U}{D^2} \right) \Delta H \text{ (metric units),} \quad (6)$$

where U is expressed in kilograms per meter, and LSE , D , and ΔH are expressed in meters.

If we assume a value of 0.14 oz/ft (0.013 kg/m) for U , a value of 50 ft (15 m) for ΔH , and a value of 8 in (0.2 m) for D , LSE equals 0.04 ft (0.012 m).

Submergence of the counterweight.—When the counterweight and any part of the float line become submerged as the stage rises, the pull on the float is reduced and its depth of flotation is increased. The converse is true when the submerged counterweight emerges from the water on a falling stage. Thus, the error caused by submergence or emergence is opposite to that of the line-shift error and tends to

compensate for the line-shift error. The submergence error is dependent on the weight of the counterweight (c) and the float diameter (D).

The equation for submergence error (SE) is

$$SE = 0.017 \frac{c}{D^2} \text{ (English units),} \quad (7)$$

where SE is expressed in feet, c is in ounces, and D is in inches.

The equation is

$$SE = (0.000118) \frac{c}{D^2} \text{ (metric units),} \quad (8)$$

where SE and D are expressed in meters and c is expressed in kilograms.

If we assume a value of 1.25 lb (0.57 kg) for c and a value of 8 in (0.2 m) for D , $SE = 0.0053$ ft (0.0016 m).

Although not related to errors inherent in a float-operated stage recorder, it might be mentioned here that error in recorded stage may be caused by expansion or contraction of the stilling well of a tall gage structure that is exposed to large temperature changes. For example, a steel well 80 ft (24 m) high, exposed to an increase in temperature of 40°C, will have its instrument shelf raised 0.04 ft (0.012 m), assuming, of course, that the instrument shelter is attached to the well.

Summary.—The errors inherent in a float-operated stage recorder will affect computed discharges. The effect of float lag can be reduced to any desired level by the use of an appropriately large float, and that accuracy level may then be maintained by keeping the instrument cleaned and oiled to reduce friction. The recorder should be set to the gage height in the stilling well when the stage in the well is constant, because the float-lag error in subsequent recorded gage-height will then be only half as large as it would be if the recorder setting were made during a period of changing stage in the stilling well. Even if the stage of the stream is changing, the stage in the well may be kept constant by keeping the intake valves closed while the recorder is being set.

The error resulting from counterweight submergence is a constant function of stage and becomes an integral part of the stage-discharge relation. The same would be true of line-shift error if the recorder settings were made only when the stage is low, but that practice is usually impractical. Line shift can be a significant source of error only at gaging stations that experience a wide range of stage.

ACCURACY OF BUBBLE-GAGE RECORDERS

This section of the report discusses the inaccuracies inherent in any bubble-gage system for sensing stage; the discussion is not concerned with such sources of error as datum corrections, sediment deposition on the bubble orifice, and leaks in the system, which were discussed in the preceding sections. The principal sources of error inherent in a bubble-gage recorder are variation in gas friction, variation in required bubble-feed rate with rate of increase in stage, and variation in weight of gas column with stage.

Variation in gas friction.—Friction created by the flow of gas through the bubble tubing results in the pressure at the manometer being slightly higher than that at the orifice. If the bubble-feed rate could be kept constant and temperature did not vary, the friction would remain constant and the accuracy of the gage would be unaffected, because the manometer is always set to agree with the water-surface elevation. However, changes in gas-feed rates cause variation in the friction of the gas flowing through the tube, and where long bubble tubes are used, the variation in friction can produce significant error in recorded gage height.

Inaccuracies due to variation in gas friction can be eliminated by using two gas tubes—one to feed gas to the bubble orifice, the other to act as a static pressure tube to transmit pressure from a point at or near the orifice back to the manometer.

As a conservative criterion for determining when the use of dual tubing is desirable, it is suggested that variations in gas friction be limited to 0.01 ft (0.003 m). If, for a given length of orifice line, an error no greater than 0.01 ft results from a 100 percent increase in bubble rate, a single bubble tube will be satisfactory. Figure 36, based on laboratory tests using the standard U.S. Geological Survey bubble gage shows the relation between the length of bubble tubing and a 100-percent variation in bubble rate for a gas-friction error of 0.01 ft. To illustrate the use of figure 36, assume that a 100-percent variation in bubble rate represents a change from 40 bubbles per minute to 80 bubbles per minute. The corresponding length of bubble tubing indicated by the diagram is 370 ft (113 m). Thus any length of single tubing up to 370 ft could be used in this particular case without introducing a friction error in excess of 0.01 ft. If more than 370 ft of tubing is required at this particular site, and a gage-height error greater than 0.01 ft cannot be tolerated, two gas tubes should be used. When two tubes are used, they should be joined at a T-connector, from whose vertical leg a single tube extends to the orifice. The T-connector should be located above the normal high-water elevation to prevent the entry of water into both legs of the system if pressure

loss occurs. Additional valves must also be provided so that the static pressure tube can be separately purged, if necessary.

Variation in required bubble-feed rate with rate of increase in stage.—During rapid rises in stage the instrument will lag if the

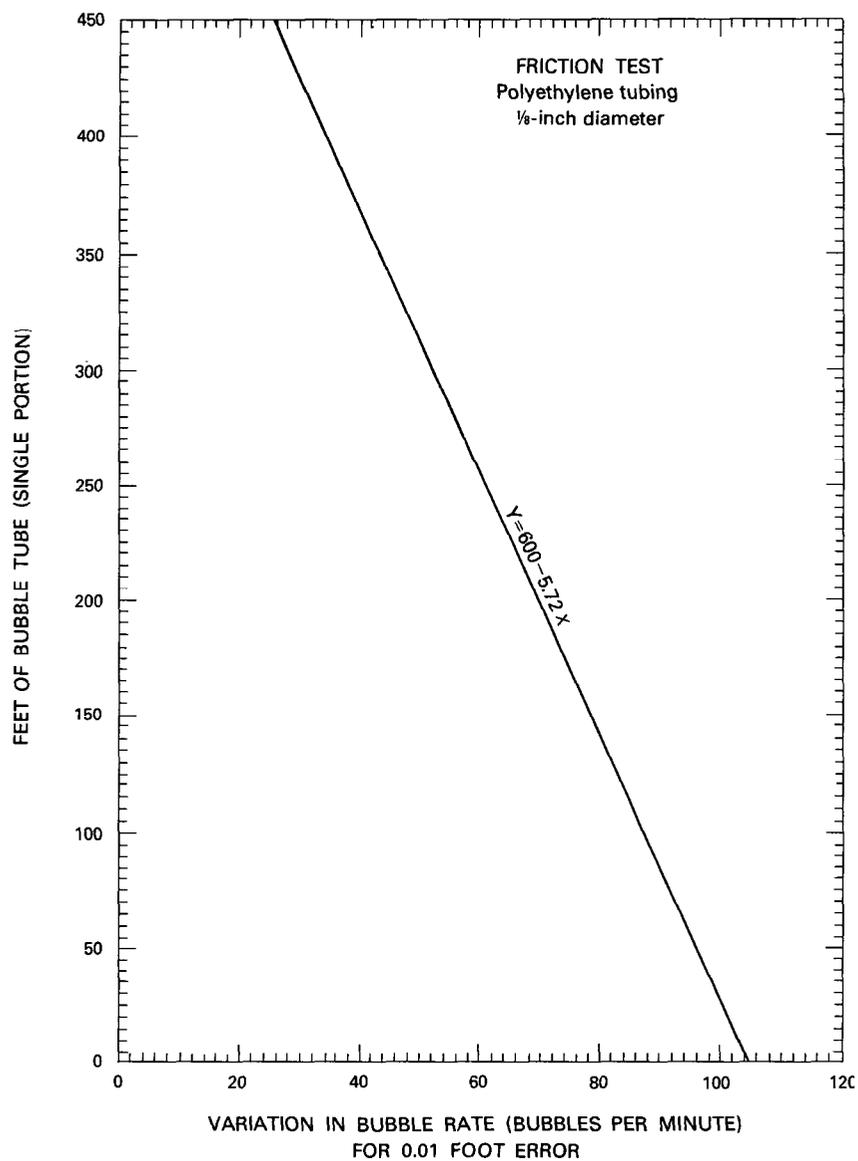


FIGURE 36.—Diagram for determining allowable length of bubble tubing for maximum friction error of 0.01 ft.

bubble-feed rate is too low. Laboratory tests on the standard U.S. Geological Survey bubble gage indicate that figure 37 may be used to

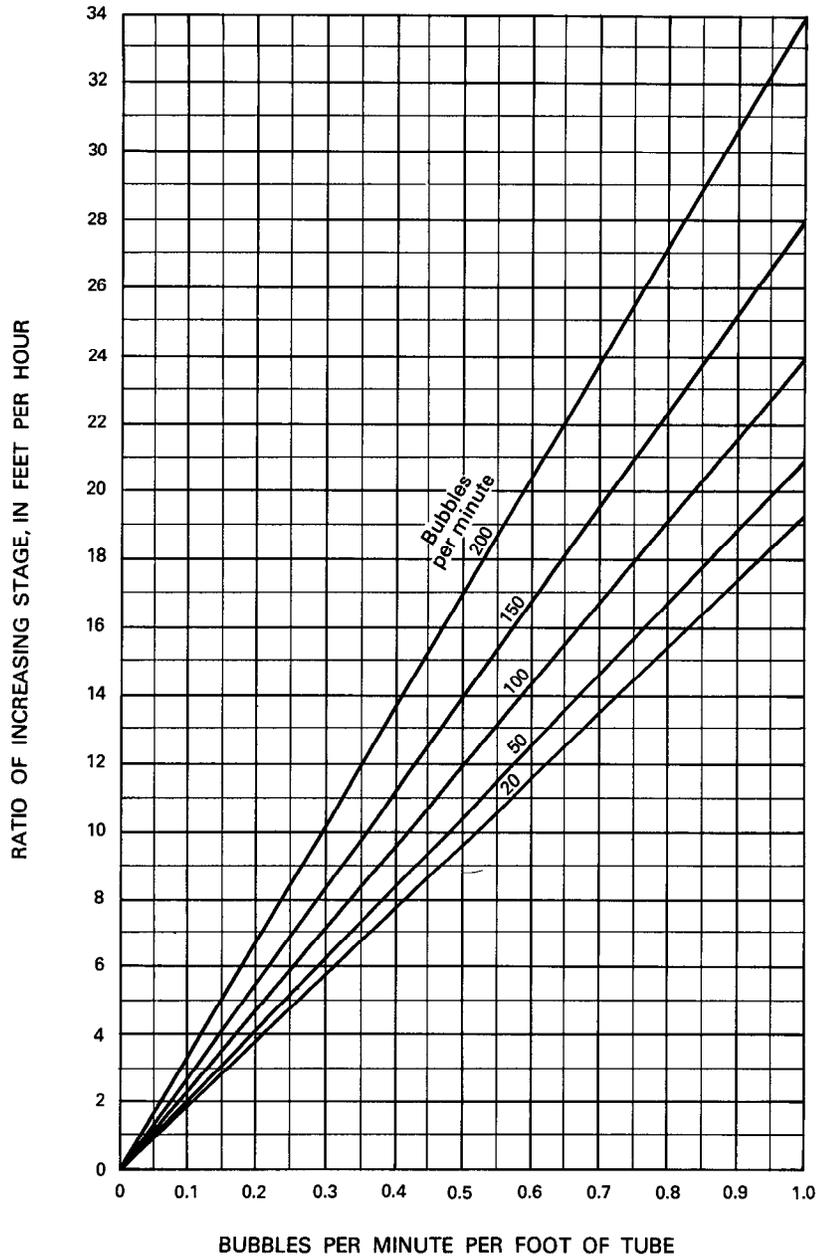


FIGURE 37.—Diagram for determining required bubble rate.

determine the bubble rate required for the maximum expected rate of increase of stage, where the minimum expected stage above the orifice will be less than 10 ft (3.0 m) for long periods of time. For periods when a minimum stage of more than 10 ft is expected to prevail, a lower bubble rate should be used to conserve gas, because the rate of increase of stage that a given bubble rate will support increases directly with stage. It was found that for installations where the minimum stage will continuously be higher than 10 ft, the maximum expected rate of increase of stage should be divided by

$\frac{H_{(\min)} + 33}{33}$ before entering figure 37. ($H_{(\min)}$ is the minimum ex-

pected stage above the orifice.) For example, for a given expected rate of increasing stage, the adequate bubble rate for a minimum stage of 100 ft (30.0m) will be one-fourth of that for a minimum stage of 10

ft—the factor $\frac{100 + 33}{33}$ equals 4.

Variation in weight of gas column with stage.—At installations where the manometer is high above the bubble orifice, and large fluctuations in stage occur, the variation in weight of the gas column with stage will cause the manometer to read low (underregister) at high stages. The error varies almost linearly with stage and for that reason the manometer readout in that situation can be corrected without too much difficulty. Depending on the type of instrument used, either the inclination of the manometer is adjusted or a change is made in the gearing between the servosystem and the recording equipment.

As a matter of fact any source of error that varies linearly with stage—for example, the density of the water may increase with stage as a result of increased sediment load—may be compensated for by the adjustments mentioned above. Changes in temperature are usually a negligible source of error, except in high-head installations having large fluctuations in stage. In that situation it is recommended that the bubble-gage system be equipped with a temperature-compensated servomanometer to minimize the error attributable to temperature changes.

SPECIAL PURPOSE GAGES

MODEL T RECORDER

The model T recorder (fig. 38) is a graphic recorder that has a 1:6 gage-height scale and a time scale of 2.4 in. per day. Use of the recorder is limited to a 3-ft (0.9 m) range in stage and it should be serviced weekly, although it will record more than one trace on the 7-day chart. The model T recorder is operated by a motor-wound spring-

driven timer, and power is supplied to the timer by a 4½-volt battery. A timer is also available that operates on a 1½-volt battery. The housing of the recorder is designed to fit on the top of a vertical 3-in (0.076 m)-diameter pipe that can be used as the stilling well. This recorder is much cheaper and more compact than the conventional graphic recorders and is well suited for temporary installations for low-flow studies, particularly those concerned with diurnal fluctuation in discharge during low-flow periods. The model T recorder is not used at continuous-record gaging stations.

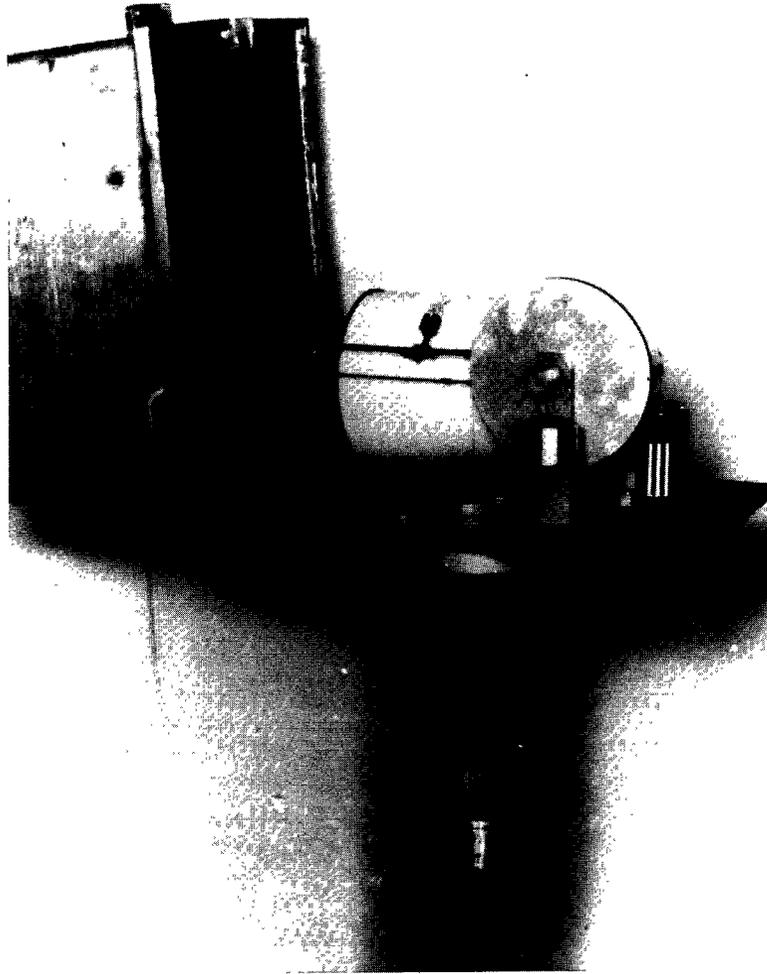


FIGURE 38.—Model T recorder.

SR RECORDER

The model SR recorder (fig. 39) is a graphic recorder that records flood stages and rainfall. A 5-in (0.127m)-diameter flat circular disc is rotated by a battery-wound clock. The power source is a 1½-volt battery. The chart is circular and turns one revolution in 24 hr. Three ranges in stage are available for the effective chart width of 2 in (0.05 m): 5, 10, or 20 ft. The recorder sits on a 2-in-diameter pipe that serves as the stilling well (similar to that for the model T). Five inches of rainfall can also be recorded on the effective width of the chart, but the rainfall reservoir can be equipped with a siphon that will allow an unlimited amount of rainfall to be recorded. The rainfall reservoir is a separate 2-in-diameter pipe that fills at the rate of 1 ft (0.3 m) for each 1 in (0.025 m) of rainfall. After the pipe has filled to a height of 5 ft (1.52 m), the siphon is tripped to empty the pipe.

The SR recorder is much cheaper and more compact than the conventional graphic recorders and is used for studying rainfall-runoff

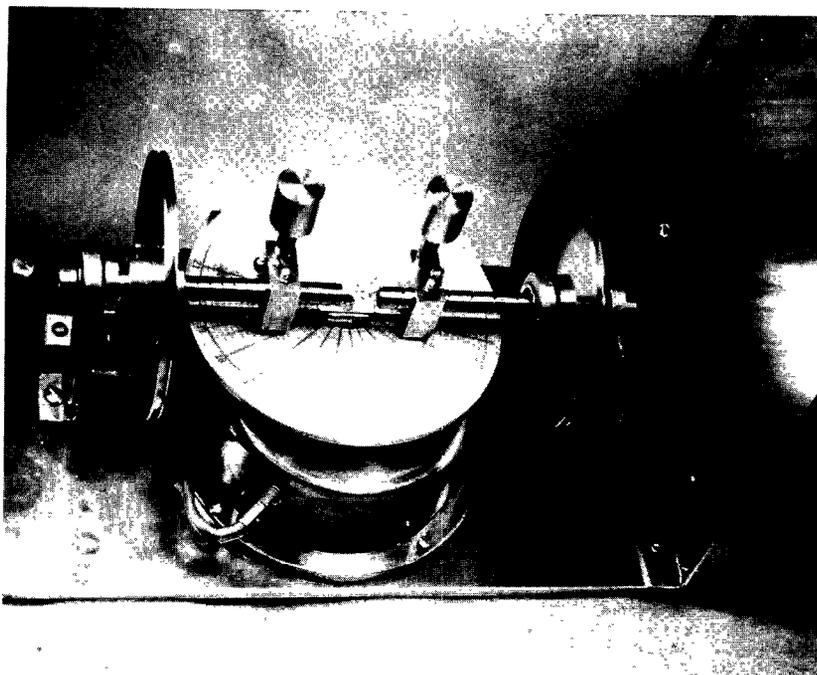


FIGURE 39.—Model SR recorder.

relations for isolated storms on small watersheds. The SR recorder is not used at continuous-record gaging stations.

A word of caution is in order at this point. The SR recorder has not proven to be an unqualified success, although it has performed satisfactorily at many installations. Its use is therefore recommended reservedly.

CREST-STAGE GAGE

The crest-stage gage is a device for obtaining the elevation of the flood crest of streams. The gage is widely used in the U.S.A. because it is simple, economical, reliable, and easily installed. Because of those attributes the crest-stage gage has become a basic instrument in regional studies of flood frequency. For such studies the network of standard gaging stations is augmented by a network of crest-stage gages, thereby providing flood-peak information at a great many sites in the region at reasonable cost.

A crest-stage gage is also a valuable adjunct to the nonrecording gage at nonrecording gaging stations. It provides a record of the peak stages of stream rises, and those stages can be used with the observer's routine readings when sketching the estimated continuous-stage graph through the plotted points of observed stage.

Many different types of crest-stage gages have been tested by the U.S. Geological Survey. (See, for example, Friday, 1965, and Carter and Gamble, 1963.) The one found most satisfactory is a vertical piece of 2-in (0.05 m) galvanized pipe containing a wood or aluminum staff held in a fixed position with relation to a datum reference. (See fig. 40.) The bottom cap has six intake holes located as shown in figure 40 to minimize nonhydrostatic drawdown or superelevation inside the pipe. Tests have shown this arrangement of intake holes to be effective with velocities up to 10 ft/s (3 m/s) and at angles up to 30 degrees with the direction of flow. The top cap contains one small vent hole.

The bottom cap, or a perforated tin cup or copper screening in cup shape attached to the lower end of the staff, contains regranulated cork. As the water rises inside the pipe the cork floats on the water 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 on the staff between the reference point and the floodmark. Scaling can be simplified by graduating the staff. The cork should be cleaned from the staff before replacing the staff in the pipe to prevent confusion with high-water marks that will be left by subsequent peak discharges.

The datum of the gage should be checked by levels run from a reference mark to the top of the staff, the graduated staff being of

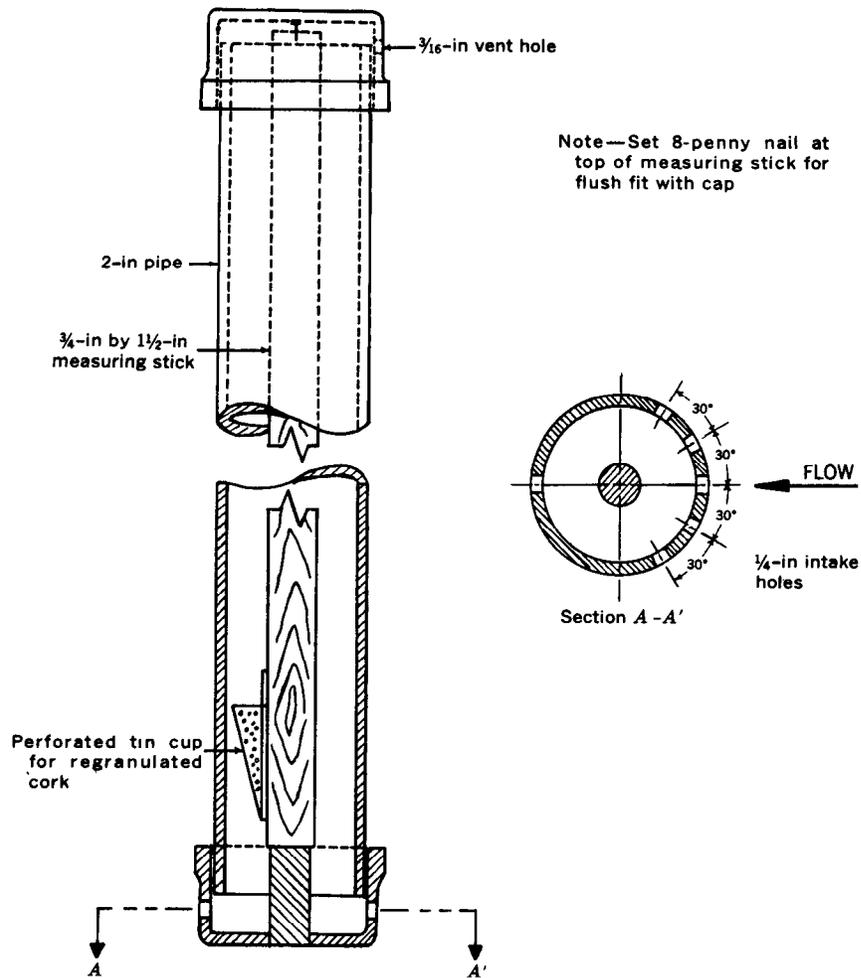


FIGURE 40.—Crest-stage gage.

known length. The gage itself should be serviced on a regular basis. However, the staff should not be removed from the pipe for any reason when the stage is high. If, after such removal, the staff is reinserted when water stands high in the pipe, the resulting surge of the water displaced by the staff will leave an artificial "high-water mark" on the staff.

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CHAPTER 5.—MEASUREMENT OF DISCHARGE BY CONVENTIONAL CURRENT-METER METHOD

INTRODUCTION

Streamflow, or discharge, is defined as the volume rate of flow of water, including any substances suspended or dissolved in the water. Discharge is usually expressed in cubic feet per second or cubic meters per second.

Discharge measurements are made at each gaging station to determine the discharge rating for the site. The discharge rating may be a simple relation between stage and discharge or a more complex relation in which discharge is a function of stage, slope, rate of change of stage, or other factors. Initially the discharge measurements are made with the frequency necessary to define the station rating, as early as possible, over a wide range of stage. Measurements are then made at periodic intervals, usually monthly, to verify the rating or to define any changes in the rating caused by changes in stream-channel conditions.

Discharge measurements may be made by any one of the methods discussed in chapters 5-8. However, the conventional current-meter method is most commonly used in gaging streams. When using this