C. Richard Murray

Selected Techniques in Water Resources Investigations

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1669-Z

Selected Techniques in Water Resources Investigations

Compiled by GLENNON N. MESNIER and KATHLEEN T. ISERI

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1669-Z

Articles on new techniques by E. G. Barron, W. L. Isherwood, F. C. Craig, P. M. Frye, W. B. Mills, P. G. Drake, David McCartney, R. H. Musgrove, B. R. Colby, H. D. Brice, and Roy Newcome, Jr.

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FOREWORD

Increasing world activity in water-resources development has created an alert interest in techniques for conducting investigations in the field. In the United States, the Geological Survey has the responsibility for extensive and intensive hydrologic studies, and the Survey places considerable emphasis upon the development of better ways to carry out its responsibility. For many years, the dominant interest in field techniques has been "in house," but the emerging world interest has led to a need for a published account of this progress.

The papers contained in this report represent a sample of the new ideas being tested or applied in the hydrologic field program of the Geological Survey. Some of the techniques described, such as that for digital recording of water levels and machine processing of river records may, when perfected, influence the basic course of a major sector of water-resources investigations. Other techniques, less profound in their scope, can contribute significantly to the accuracy and ease of field operations.

Luna B. Leopold,
Chief Hydraulic Engineer,
U.S. Geological Survey

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SELECTED TECHNIQUES IN WATER RESOURCES INVESTIGATIONS

NEW INSTRUMENTS FOR SURFACE-WATER INVESTIGATIONS

By E. G. Barron

ABSTRACT

An electromagnetic velocity meter and an acoustic velocity meter have been developed for continuously recording the velocity of water at a fixed location in open channels. The electromagnetic velocity meter records the velocity of water flowing past a streamlined probe, a rodmeter, mounted at a fixed point in the water. The acoustic velocity meter records the mean velocity on a line between transducers mounted in the water near both banks of a stream. These instruments have no moving parts in the water to be fouled by debris.

A bubble gage and a surface follower have been developed also. These instruments record continuously the stage of a stream or reservoir without need of costly and troublesome stilling wells and intakes. The bubble gage utilizes the gas-purge technique to transmit the pressure of the water to a specially designed servomanometer that operates a recorder. The surface follower, which also operates a recorder, follows the water level in a 2-inch or larger pipe that is mounted vertically in a stream.

A portable sonic sounder has been combined with a Price current meter for use in measuring floodflows. In another instrument, the combination includes a remote-indicating compass for use in determining the velocity and direction of flow as well as the depth at any point in a river or a tidal estuary.

Also, a two-speed timer has been developed for use on small flashy streams, where it is desirable to automatically expand the time scale of the recording of high water to several times the low-water scale.

ELECTROMAGNETIC VELOCITY METER

The electromagnetic velocity meter measures the velocity of flowing water by a method based on Faraday's principle: an electrical conductor moving in a magnetic field generates an electrical voltage. As used in streamflow measurement, the meter continuously records the velocity of the water at a fixed point in a stream.

The instrument was originally developed by the U.S. Navy as a ship's log for indicating both the speed of the vessel and the total distance traveled. Figure 1 shows the complete instrument as modified by the Survey for use in measuring streamflow. The rodmeter (fig. 2) is about 3 feet long and consists of a fiberglass-reinforced shell with an aluminum mounting plate at the top. An electromagnet and two terminals are mounted in the plastic shell. The terminals form part of an electrical pickup loop through the water. The rodmeter exciter coil is energized by an oscillator operating at a frequency of 65 to 70 cycles to reduce the effect of 60-cycle currents that may be present in the water. The signal from the probe is amplified and recorded.

Laboratory tests indicate that the electromagnetic velocity meter is very sensitive to even slight changes in velocity and is capable of measuring velocity in either upstream or downstream directions with respect to the rodmeter. Tests also indicate freedom from long-term drift. Small percentage errors due to drift were present, however, when the velocity was changed suddenly. At all velocities, errors from drift average out in a relatively short time.

The first electromagnetic velocity meter was installed in November 1957 on the St. John's River at Jacksonville, Fla. Velocities during the tidal cycle at this site range from about 6 feet per second in a downstream direction to about 4 feet per second in an upstream direction. The meter was calibrated at the site and has performed satisfactorily. Another assembly with more simplified circuits requiring less maintenance and producing a more desirable response to the probe signal will soon be installed near Columbus, Ohio, for field trial and calibration.

ACOUSTIC VELOCITY METER

The acoustic velocity meter uses ultrasonic waves for continuous recording of velocities of flow in open channels. The technique has been used successfully to measure velocities of fluids in closed conduits, and present efforts are directed to the more complicated task of applying the method to open channels of considerable width. The phenomenon involved in measuring water velocities by ultrasonic waves is analogous to the Doppler effect of sound in air—the pitch of a constant sound source varies with both the speed and the direction of the sound source with reference to the receiver.

The principle can be illustrated by observing what happens when a stone is dropped in a quiet pool of water. The surface waves travel out from the source of the disturbance in uniformly spaced concentric circles. If the water is flowing, however, the waves moving against the direction of flow will condense—that is, the wavelengths will shorten—and those moving with the direction of flow will lengthen. Sound waves produced within the fluid behave in a similar manner.

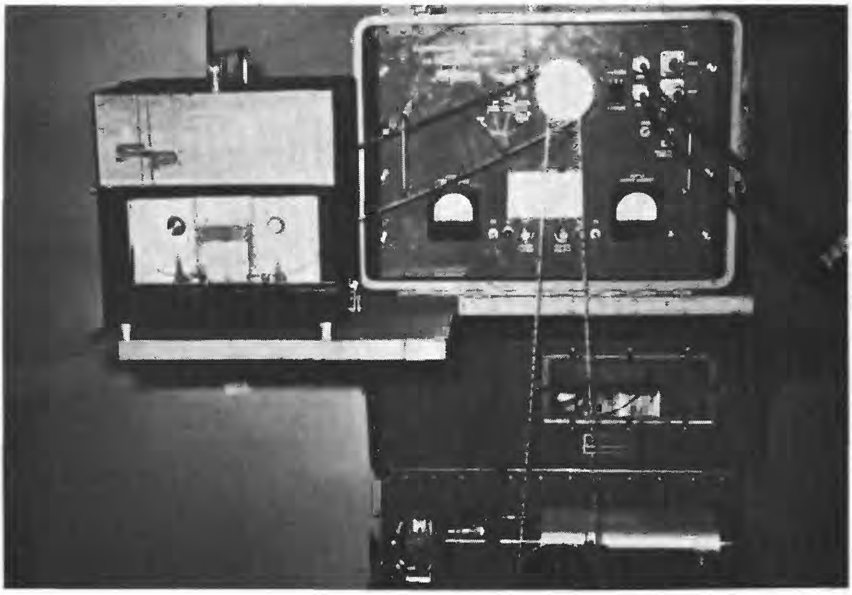

FIGURE 1.—Electromagnetic velocity meter, operating recorders.

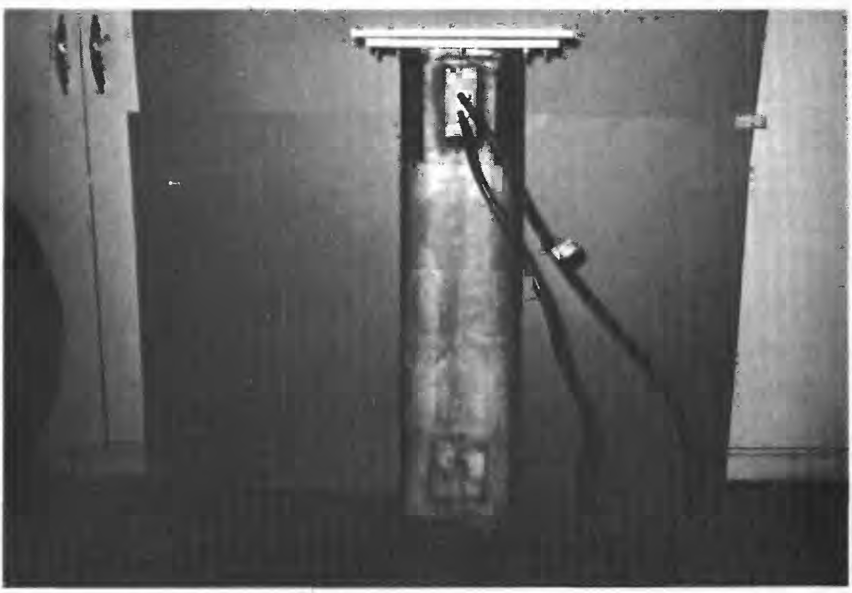

FIGURE 2.—Electromagnetic velocity meter, rodmeter.

Figure 3 illustrates a simple application of this principle to the measurement of flow velocity. If the reception is in phase without considering the velocity of flow, the reception considering the velocity of flow will be out of phase by a number of degrees proportional to the velocity of flow. However, the velocity of sound in the water varies about 6 feet per second per degree Fahrenheit change in temperature, which is more than enough to obscure the relatively small water velocities we wish to detect. It is therefore necessary to cancel the effect of sound-velocity variations by simultaneous sound transmissions, one angling upstream and one angling downstream.

The continuous-wave method was used successfully in closed conduits. However, tests in open channels indicated the presence of random deviations of the phase angle that were both meaningless and unstable. The instabilities were caused by multiple-path reception resulting from reflections of the sound waves from the water surface and refractions from thermoclines. The situation is analogous to the flutter on a television screen caused by multiple-path reception as an airplane passes overhead.

A pulse-repetition-frequency system was therefore developed as illustrated in figure 4. By this method a 135 kc (kilocycles) per second acoustic pulse is transmitted from the upstream transducer and received at the downstream transducer. The energy from this pulse activates a keying circuit, and another 135 kc pulse is transmitted. An 85 kc electroacoustic circuit operates simultaneously with, and in the same manner as, the 135 kc pulse, but in the upstream direction. The two pulse-repetition frequencies are fed into a computing circuit, the output of which is proportional to the water velocity. As installed in a river, the parallel acoustic paths are established in the water at approximately 45° to the flow so as to integrate with the width and eliminate the effect of variations in the water temperature.

A complete pulse-repetition-frequency system was installed on the Sacramento River at Sacramento, Calif., in July 1959. Performance of the meter was encouraging, but the results were not good enough for use in a standard streamflow computation, and the equipment is now undergoing modification.

BUBBLE GAGE

The bubble gage was developed to record river and reservoir levels without the use of stilling wells and intake pipes that are often expensive to construct and difficult to maintain. Installed in a prefabricated shelter at ground level at any convenient location above the reach of floodwaters, it can be used to take full advantage of existing natural or artificial controls, and the entire station can be readily dis-

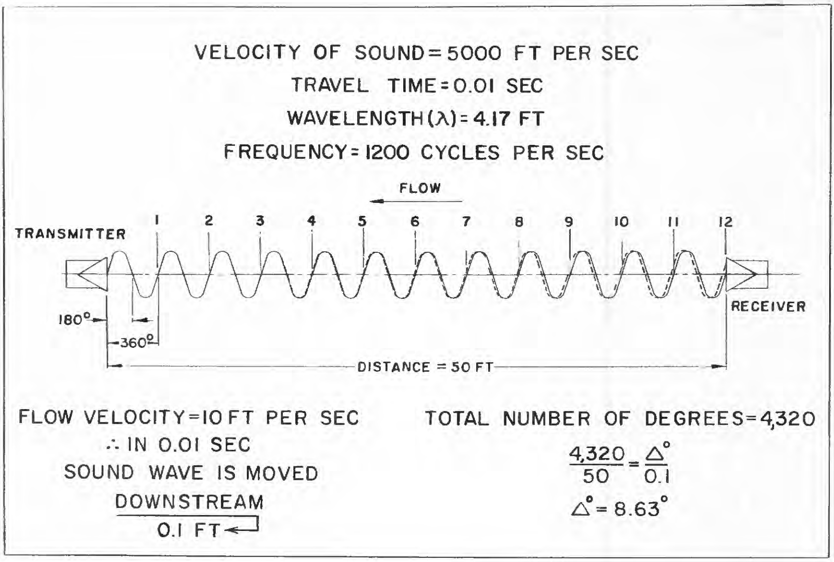

FIGURE 3.—Acoustic velocity meter, diagram of continuous-wave method of measuring velocity of water.

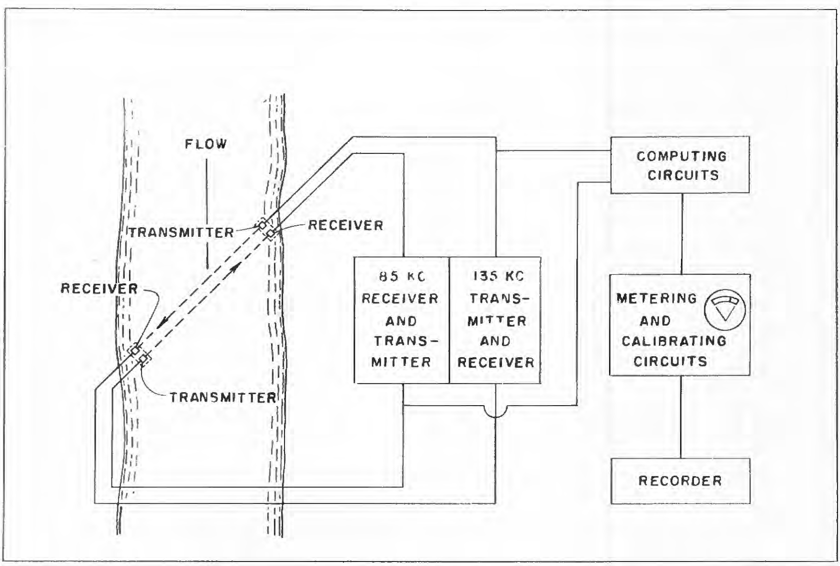

FIGURE 4.—Acoustic velocity meter, diagram of pulse-repetition-frequency method of measuring velocity of water.

mantled and relocated with practically no loss of investment. A description of the four major units that make up a bubble gage follows.

1. *Gas-purge system.*—Provides a means of transmitting the pressure head of water in the stream to the manometer location. The following principle is applied: If a gas is bubbled slowly through a small tube and discharged freely at an orifice located at a fixed elevation in the stream, the pressure at the orifice, and hence at any point in the delving tube, is related to the head or depth of water over the orifice. This system consists of a cylinder of nitrogen and the polyethylene tubing necessary to convey the gas from the instrument shelter to the orifice. For most river installations, the required gas ((nitrogen) feed rate is so low that an ordinary cylinder of gas (112 cubic feet, costing about $4 per refill) will operate the equipment for a year or longer.

2. *Servo-manometer assembly.*—Converts the pressure in the sensing element of the gas-purge system to a shaft rotation for driving a digital counter and a recording mechanism. The pressure from the gas-purge system, corresponding to the pressure in the water, is brought into the movable pressure cup through the bulkhead fitting in the manometer back plate (fig. 5). Mercury is used as the manometer liquid to keep the overall length to a minimum. The manometers have a sensitivity of ±0.005 foot and can be built to record ranges in stage in excess of 120 feet. A unique feature of the manometer is that it is designed to operate at approximately 18° with the vertical. This angle allows the use of simple standard gears and threads and also provides an

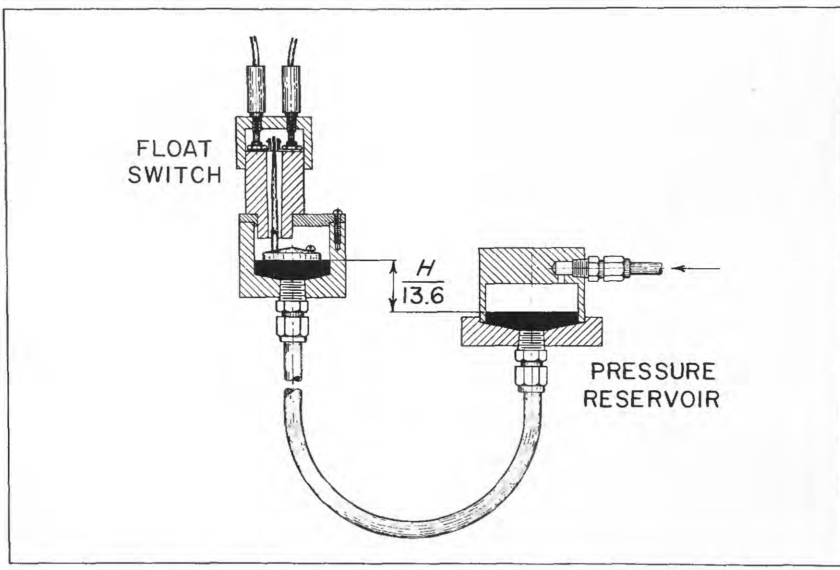

FIGURE 5.—Bubble gage, illustration of zero-displacement manometer.

exact means of adjusting for anything varying with stage (pressure) that would otherwise result in error. The river pressure in the movable cup acts on the mercury surface and causes enough movement of mercury through the flexible tube to sustain a stainless-steel float in the switch.

3. *Transistor-control unit.*—Amplifies the small electric current in the float-switching circuit sufficiently to operate the servomotor and provide an appropriate time delay between the closing of the float switch and the starting of the motor. The transistor-control unit, used with the bubble gage, contains dual amplifiers and timing networks. It is necessary to amplify the extremely small current available from the light contacts in the float switch to drive the motor. The timing networks provide a delay of about 30 seconds to eliminate or appreciably dampen the reaction of the manometer to pressure surges. Use of the delay circuit eliminates undesirable "painting" of the recorder charts, lengthens battery life, and reduces wear on the motor and other components. A pair of the 7.5-volt dry batteries will operate the manometer for about a year in most installations.

4. *Recorder.*—Converts the shaft rotation to a linear pin movement proportional to water stage and provides a continuous time scale for the recorded movements of the pen. Figure 6 shows the complete equipment for the bubble gage (35-foot range model).

The differential-type (dual pressure) manometer (fig. 7) which is similar in design to the single-pressure model, records directly the

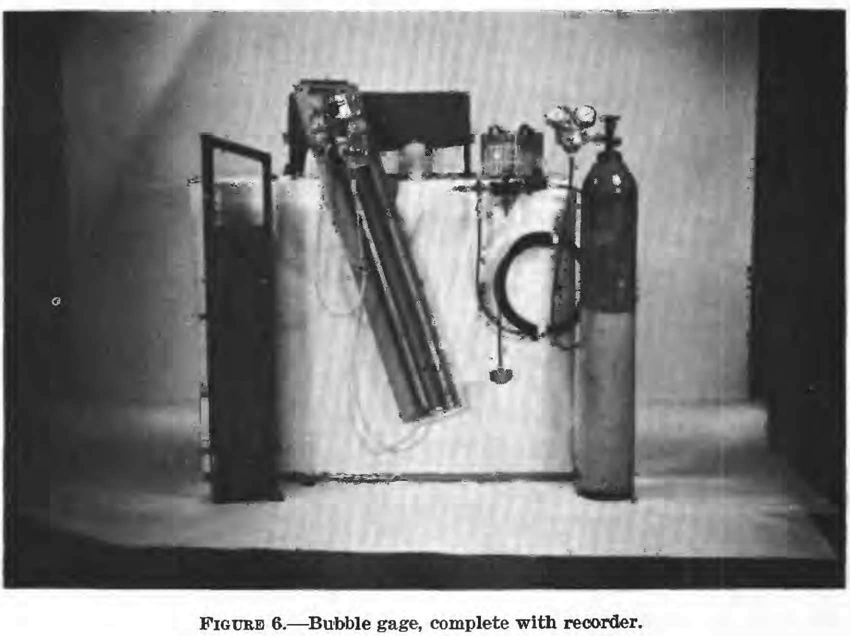

FIGURE 6.—Bubble gage, complete with recorder.

slope in a relatively short reach of river channel. The differential pressure between two orifices, each at an extremity of the reach, is recorded by connecting the lower pressure to the float-switch chamber and allowing the higher pressure to act on the liquid level in the movable reservoir.

By using a nonfreezing solution of 60 percent glycerine and 40 percent water with a specific gravity of 1.17, the accuracy of the differential-type manometer is improved to about ±0.001 foot of water.

A differential-manometer assembly is now being used at the hydraulic laboratory at Colorado State University to record the fall in a 100-foot reach of flume. A second assembly is being operated on the Olentangy River near Columbus, Ohio, in an attempt to record the fall in a 500-foot reach.

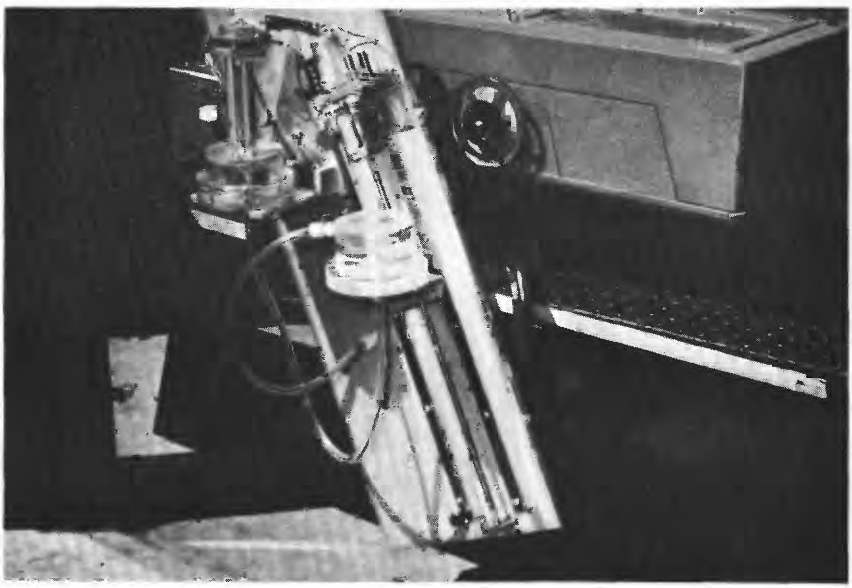

FIGURE 7.—Bubble gage, differential-type manometer-servo assembly.

SURFACE FOLLOWER

The surface follower was designed to follow the rise or fall of a liquid surface in a vertical 2-inch pipe. It is accurate to ±0.005 foot and has a maximum range of 45 feet. Two 7.5-volt dry batteries supply the necessary power for about a year to a small 6-volt reversible motor that in turn raises or lowers the float assembly in response to changes in the height of the surface of the liquid.

The instrument as designed is composed of a float assembly, a cable, a servocontrol unit, and a takeup-drum assembly. The float assembly is mounted to an electrical switch with two fixed contacts and a movable center contact attached to a lighter-than-water float; the housing for the float assembly is plastic with a perforated brass shield over the float. The shield serves two purposes: it protects the delicate float, and it provides sufficient weight to keep the cable taut. The diameter of this assembly is 1⅝ inches. A few thousandths of a foot change in the liquid level causes the float to tip until contact is made on the proper side, thus causing the cable drum to raise or lower the cable and float switch. The cable has two inner conductors and a braided outside shield that is used as a third conductor. The servocontrol unit is identical with the one used with the bubble gage and thus provides a time delay to dampen surging. The takeup-drum assembly consists of a grooved cable drum driven by a 6-volt 4.58 rpm (revolutions per minute) reversible d-c motor through a mechanical linkage. The recorder drive is accomplished through a gear on the outboard end of the cable drum that meshes with a similar gear and replaces the float wheel of a Stevens A–35 water-stage recorder. Adjustable limit switches are provided so that the unit can be used in a stream that goes dry.

Sensing at the liquid surface rather than at the recorder has considerable advantage. Because friction along the cable or float does not affect the accuracy, the pipe installation need not be exactly plumb. The instrument shelter need not be supported directly over the pipe, as special elbows with internal sheaves can be used to bring the pipe horizontally to the instrument shelter.

SONIC FLOOD-MEASURING ASSEMBLY

A combination of a depth recorder (Fathometer) and a standard Price current meter (fig. 8) permits measurement of depths and velocities in stream channels without lowering the meter and weight assembly to the stream bottom. This is extremely advantageous in floodflows where relatively great depths are encountered and debris carried by the stream is a frequent menace to the equipment.

During floodflows it might be useful to submerge the weight perhaps 3 feet below the surface, thus placing the meter only 2 feet below the surface. Velocity and depth readings would be determined, and a coefficient applied to the velocity reading would reduce it to mean velocity for the vertical section. The coefficients could be determined quite accurately under less arduous conditions. This method would eliminate the risk involved in lowering measuring equipment to considerable depths, and it would also result in a savings of valuable time, which is especially short during floods. Furthermore, under severe flood conditions, the conventional method of observing velocity

FIGURE 8.—Sonic flood-measuring equipment, complete on crane and four-wheel base.

at the 0.2 and 0.8 depths probably would be less accurate than the near-surface observation because of the inherent errors in determining depth of water and in positioning the meter at the correct depths.

The Fathometer weighs 46 pounds and is completely portable. It operates on a frequency of 200 kilocycles, which does not penetrate the streambed; therefore, the depths recorded are to the top of the bed material of the channel. The transducer has a narrow 6° beam angle that minimizes errors on inclined streambeds and permits operation close to piers or other obstructions. The Fathometer can record depths to 240 feet in four depth ranges of 60 feet each. The effects of temperature and density give a possible error range of 4 percent under field conditions in fresh water, and even this can be reduced or eliminated by adjusting the sounder for the existing conditions. A 6-volt wet-cell battery will operate the Fathometer for about 10 hours.

VELOCITY-AZIMUTH-DEPTH ASSEMBLY (VADA)

The velocity-azimuth-depth assembly is a combination of a sonic sounder with a remote-indicating compass and a Price current meter. This combined instrument records depths, indicates the direction of flow, and permits observations of velocity at any point in a stream or estuary.

Figure 9 shows the entire assembly mounted on a regular crane and four-wheel base. It shows a seven-conductor slip-ring assembly at the top of the meter hanger. This assembly, with its radial and thrust bearings, frees the meter and weight so they can rotate independently of the supporting cable and face in the direction of flow at velocities as low as a tenth of a foot per second. The line from this seven-conductor slip-ring assembly is fed into a seven-conductor jack on the top of the weight and then to the transducer and remote-compass unit in the weight. Figure 10 shows the sonic transducer and compass ready for insertion in special brass sounding weight.

The quarter-inch seven-conductor reverse-lay stainless-steel supporting cable is wound on a sounding reel that has a capacity of about 90 feet. A seven-conductor slip ring brings the circuits out of the reel.

The compass-indicating unit, shown mounted on the four-wheel base, utilizes 4 of the 7 leads and is operated by a 12-volt d-c to 400-cycle a-c inverter within the unit. Also incorporated within the remote-indicator box are the battery for the current-meter circuit, the earphone jacks, and the two-conductor jack for the sonic sounder. A switch allows the remote-indicating unit to be used separately or in conjunction with the sonic sounder.

The sonic recorder used with this assembly is the same as that described above.

FIGURE 9.—Velocity-azimuth-depth assembly (VADA), complete on crane and four-wheel base.

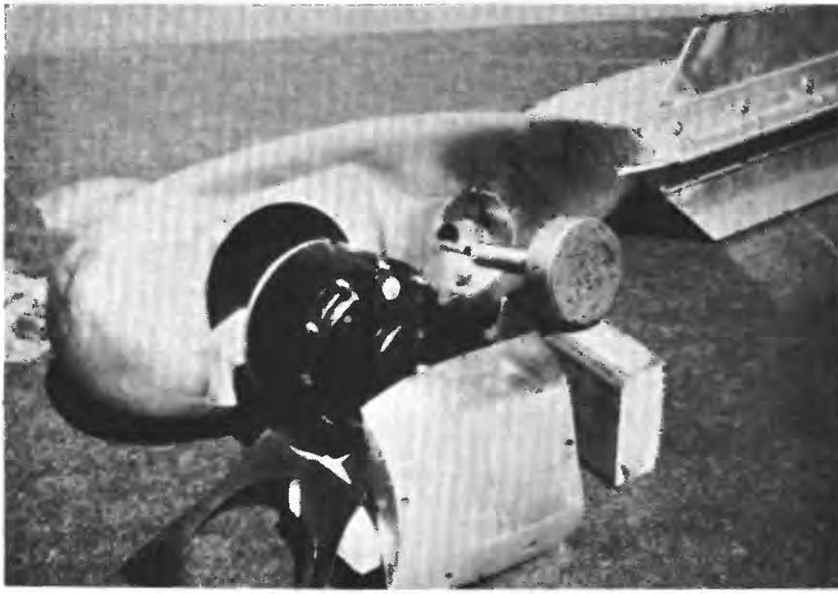

FIGURE 10.—Velocity-azimuth-depth assembly (VADA), sounding weight with sonic transducer and compass ready for insertion.

TWO-SPEED TIMER

This timer was devised for use on small flashy streams where it is desirable to automatically expand the time scale of the recording of the high-water scale to several times that at low water.

The clock of an A–35 recorder is replaced by a solenoid-ratchet device that advances the chart one-eightieth of an inch each time it is pulsed electrically. The Chelsea timer, driven by a Negator spring, rotates two timing cams at a rate of one revolution per hour. One of the cams actuates a microswitch eight times per hour to pulse the solenoid-ratchet for a low-water scale of 2.4 inches per day. The other cam closes a pair of contacts 48 times per hour to pulse the solenoid-ratchet for a high-water scale of 14.4 inches per day.

A selector-switch device is connected to the recorder float-wheel shaft by sprockets and chain. This instrument can be set to switch the recorder from low to high drive at any selected stage as the water rises and back to low drive at a slightly lower stage on the recession.

DIGITAL WATER-STAGE RECORDER

By W. L. Isherwood

ABSTRACT

The digital water-stage recorder is a slow-speed battery-operated paper-tape punch designed to record river gage heights at remote field locations unattended for periods of at least 60 days. Its shaft-rotation input is sampled at intervals of 15, 30, or 60 minutes and recorded as four binary-coded decimal digits punched in parallel mode on 16-channel paper tape. The development of this recorder is part of the Geological Survey's program to increase the speed of computing and processing stream-gaging records.

INTRODUCTION

The digital water-stage recorder shown in figure 11 was developed to register river-gage heights at remote, unattended field installations. The data are collected on a tape directly readable by automatic equipment, and this tape record enables the use of a general-purpose digital computer to process the data very rapidly with a minimum of manual handling and interpretation.

The availability of a general-purpose degital computer in the Geological Survey encouraged a search for a digital water-stage recorder. An analog computer built to scan conventional, continuous water-stage-recorder charts did not operate satisfactorily; therefore, attention was focused on use of the digital computer and the digital water-stage recorder.

DESCRIPTION OF RECORDER

Input to the digital water-stage recorder is shaft rotation. At the usual gaging station a metal tape attached to a float in a stilling well turns a pulley mounted on the input shaft of the recorder. Any other water-level sensing element that results in a shaft rotation could be substituted for the tape and float input. The input shaft turns two mechanical coding disks, one directly connected to the input shaft and the other driven by the input shaft through a 100-to-1 worm gear. The two coding disks have patterns of raised ridges along the outer 1 inch of their front faces such that each one-hundredth of a rotation of the input shaft will result in a discrete reading. With a float

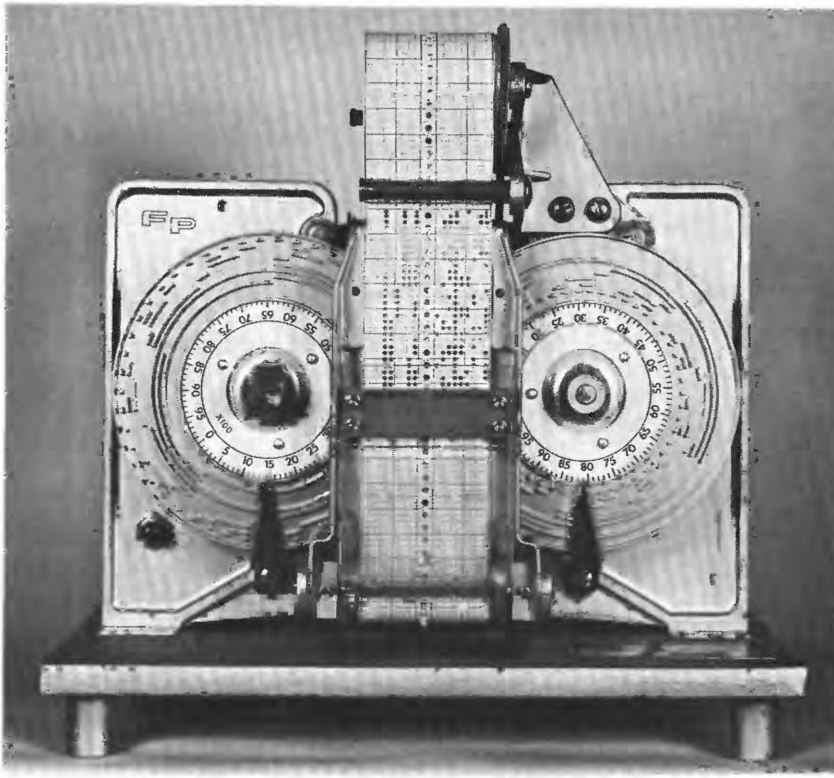

FIGURE 11.—Digital water-stage recorder.

wheel 1 foot in circumference mounted on the input shaft, the river-gage height can be recorded to the nearest 0.01 foot within the range from 0 to 99.99 feet. The position of the code disks at a particular instant is recorded by releasing a spring-loaded arm carrying a punch block threaded with paper tape against the front faces of the two code disks. Punch pins riding free in the punch block are struck against the patterns of ridges on the two code disks, so that the pins which hit the ridges are forced through the paper tape, whereas those that hit between the ridges do not go through.

The tape is punched in the binary decimal system, 4 binary bits for each of the 4 decimal digits are read, making a total of 16 information channels in parallel mode for each reading. Two fixed-position holes are also punched at each reading for later use as feed holes for the mechanical tape reader. Readings are made at regular intervals through use of a timing device. The timer consists of a clock with a cam mounted on the minute-hand shaft and a microswitch operated by an arm riding on the cam. As the cam turns one revolution an hour, a choice of cams with 1, 2, or 4 rises and dropoffs provides for readings every 15, 30, or 60 minutes, as required, to produce the refinement desired at a particular gaging station. When the switching device triggers the recorder, a small battery-driven 6-volt motor turns a programing shaft that initiates punching, advances the paper tape, compresses a spring to store power to actuate the punch on the next cycle, and turns off the motor after the reading cycle has been completed. The battery will last about a year because it operates the motor for only about 12 seconds on each punching cycle.

PROCESSING OF RECORDS

Tapes are removed from the recorder about every 6 weeks, at the regular visits of a field engineer to the gaging stations. After identification and pertinent notes are written on the tapes by the engineer, they are sent to a processing center in Washington, D.C., where the computer facilities are located. At the processing center, the parallel-coded 16-channel paper tapes are translated automatically by special equipment onto serial-coded 7-channel paper tapes readable by the computer, and the necessary fixed information identifying the stations and the starting dates are added. Shortly after this, the 7-channel tapes are read photoelectrically into the computer where the raw data are edited, arranged, and transferred onto a magnetic tape for later processing. While the transfer to the magnetic tape is being done, a simple summary of the raw data is printed out by the computer to help detect errors in any part of the data-collection system. These summary sheets are immediately sent to the field offices along with the original 16-channel tapes so that troubles with the field instruments can be detected, analyzed, and remedied at the earliest possible moment.

At the end of the period for which daily discharge records are to be computed (normally 6 months or a year), the field offices send to the processing center the supplemental data of datum corrections, shift corrections, and stage-discharge rating tables needed to complete the computations. The supplemental data are manually punched on 7-channel tape for computer input. During computation, the gage-height data are read back from prepared magnetic tape, 1 day of record at a time, while the supplemental data are read in from paper tape as needed. The main output is a list of daily mean gage heights, daily shifts, and daily mean discharges with corresponding monthly summaries, 6 months to a sheet. One supplemental computer output is a small group of standard punch cards containing lists of peak discharges above a selected base. The list of peaks is prepared later from these cards as a separate operation by different equipment. Another supplemental output is a group of punch cards containing plotting positions for automatic plotting of a hydrograph on a semilogarithmic chart. The automatic plotting is also done at a later time by equipment not attached to the computer.

The three items of output (list of mean daily gage heights with shifts and discharges, list of peak discharges, and plotted hydrograph) are sent to the field office, where they are examined for consistency, accuracy, and completeness. Any necessary corrections for special hydraulic conditions or the filling in of incomplete records are done at that time. Future plans call for corrected copies of the daily gage-height-and-discharge form to be returned to the processing center for transfer to magnetic tape and for printing the daily discharges for a year in a form suitable for direct camera copy for offset reproduction. All procedures except the latter have been put into test operation for a limited number of gaging stations, selected from a network of about 7,000 stations maintained by the Geological Survey.

VARIATION IN VELOCITY DISTRIBUTION IN A TIDE-AFFECTED STREAM

By Franklin C. Craig

ABSTRACT

A study of changes in distribution of velocity as a result of unsteady flow is of consequence in selecting the location for installing an index velocity meter. Data are presented to show the kinds of variations that occur in tide-affected streams.

INTRODUCTION

Streams subject to rapidly changing discharge usually cannot be rated by a simple stage-discharge relation. Additional parameters are required. One such parameter that can be obtained is a continuous record of the velocity at an index point.

Common types of streams whose rapidly changing discharge complicates the discharge rating are streams subject to power regulations, tidal action, and sharp peaks from storm runoff. This report is a study of flow velocities at an index point in a stream affected by tidal action. Unsteady flow causes variations in velocity which, if not taken into account, can negate the value of a record obtained from a velocity index point. The distribution of velocity in a cross section was found to vary both vertically and horizontally with the rate of flow. It is therefore necessary that a study be made of the variation in point velocities before an index point is selected for the continuous observation of velocity. A standard current meter, such as the one used in this study, is not well adapted to continuous operation for periods longer than a few days. A new instrument, the electromagnetic velocity meter, may prove to be more satisfactory.

PROCEDURE FOR DETERMINING VARIATIONS IN VELOCITY DISTRIBUTION

Variations in velocity distribution can be noted in floodtime by the changing paths of drift movement or a change in the turbulence pattern before and after the crest is reached. Data are seldom available to judge the relative significance of these changes on a given stream. To get a complete picture of changes in velocity distribution would of course require the operation of many current meters distributed vertically and horizontally throughout the cross section and operated throughout a period of changing flow. Because this is seldom practical, an attempt was made to obtain the essential information using one current meter.

A series of discharge measurements was made by conventional methods throughout a period of changing flow in one cross section at the gaging station on the Sacramento River at Sacramento, Calif. At each of approximately 25 verticals (or stations) in this cross section, velocity was measured with a current meter at 0.2 of the depth and at 0.8 of the depth—this is a standard procedure in making a discharge measurement. The time of making each velocity observation was recorded. Time-sequence graphs (not shown) were made for each observation station in the cross section to show the velocity observed while making each discharge measurement in the series and to show the recorded time of the velocity observations. The velocity at any particular time for which a study of velocity distribution was to be made was picked from this graph. This is a method of obtaining simultaneous measurements of velocities for the purpose of comparison, even though the velocities are changing rapidly with time and the discharge measurement from which they are obtained takes appreciable time to complete.

Discharge measurements were made at 2-hour intervals throughout a 14-day tidal cycle, August 13–27, 1952, and during a lunar day June 27, 28, 1957.

EXPLANATION OF RESULTS

Figure 12 shows the relation between the 0.2-depth velocity and the average velocity in a selected vertical section. It shows the magnitude of the error that would result in determining the flow through the section if a velocity index point had been located at the 0.2-depth point in that section. Greater accuracy could probably be attained by locating the index meter at or near the 0.6-depth point. Automatic depth-positioning equipment is sometimes used to maintain the meter at a 0.6-depth point. Figure 13 shows that the variations in velocity distribution are not generally of a random nature, but that they follow a pattern which is related to changes in the rate of flow that are caused by changes in the tide phase.

Shown in figure 14 are mean vertical velocities at stations spaced 25 feet apart across the stream. The observations were made throughout the lunar-day tidal cycle as shown in figure 15. During measurement 2, for example, there was far greater difference between the velocity at the center of the stream and that at the sides of the stream than during measurement 16, yet both measurements were made at nearly the same stage. Under these conditions an index meter at the center of the stream or at either bank would not yield an index parameter that varied with stage alone or that maintained a constant relation to the mean velocity of the stream. A fairly good relation could be obtained by an index meter at about station 500, where the mean velocity would tend to approach the mean velocity of the stream during all phases of the tidal cycle. Because the stream is wide and there is probably some tendency for the flow to shift laterally, espe-

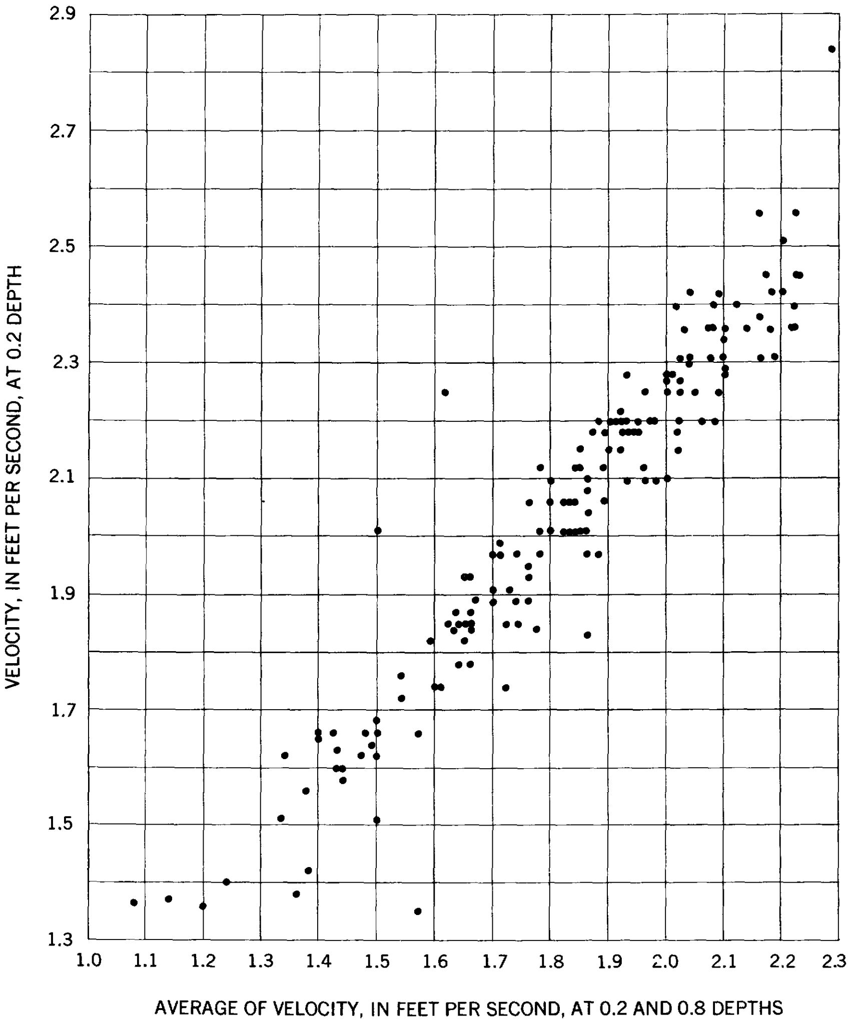

FIGURE 12.—Relation between velocity at 0.2 depth and the average at 0.2 and 0.8 depths at station 225, Sacramento River at Sacramento, Calif., August 13–27, 1952.

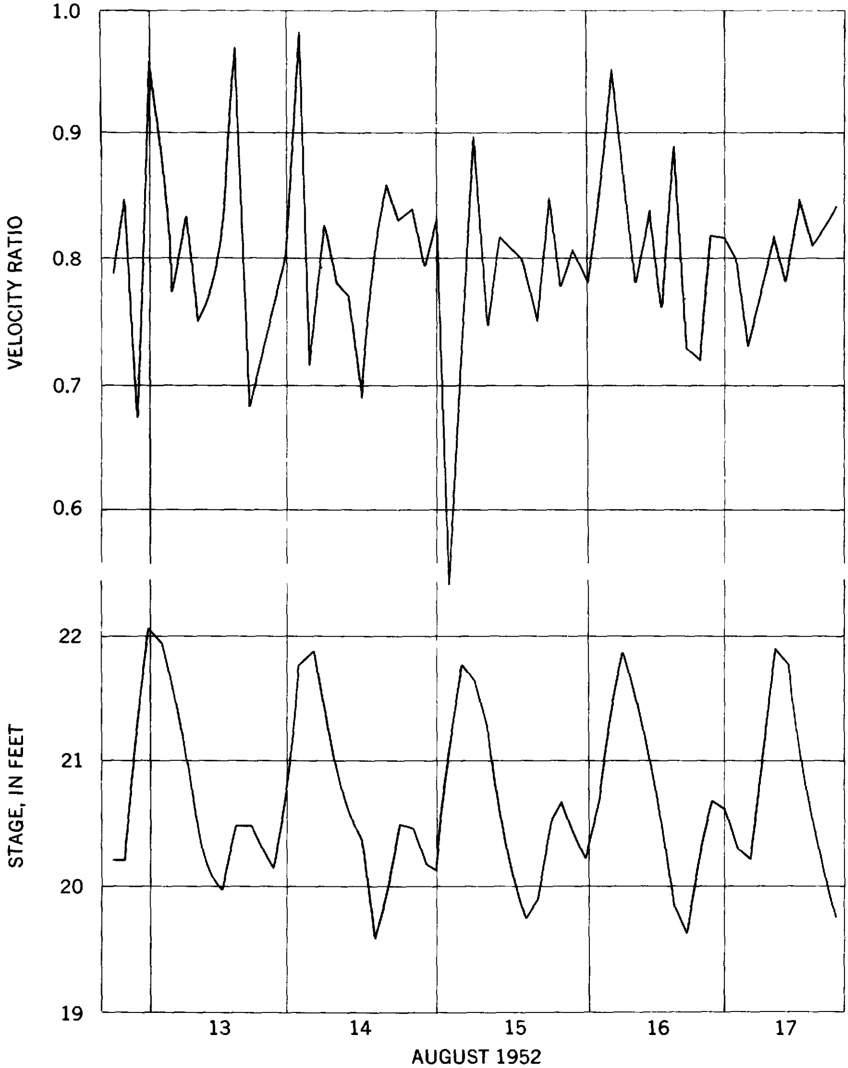

FIGURE 13.—Time variation in ratio of velocity at 0.8 depth to that at 0.2 depth, and stage hydrograph, station 225, Sacramento River at Sacramento, Calif., August 13–17, 1952.

cially when there is wind, the use of two index meters would be even better. The two index meters could be located perhaps at stations 200 and 500 and averaged. Possible relations are shown in figures 16 and 17. No attempt was made to determine the best possible index-point location or locations, but figures 15 and 16 show the improvement in relation that is possible by selecting the stationing and position in the vertical of velocity index points.

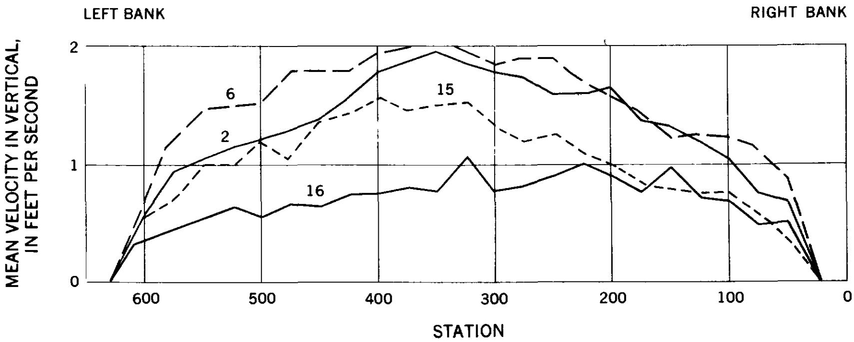

FIGURE 14.—Horizontal distribution of velocity during tidal-cycle measurement of June 27, 28, 1957, Sacramento River at Sacramento, Calif. Numerals on curves indicate measurement number.

LOCATION OF INDEX METER

The best location for a velocity index meter is that place at which the mean velocity in both the horizontal and vertical directions is approached. The location of the point or points at which the mean velocity in the horizontal direction occurs is not as well defined as it is in the vertical direction. According to data obtained by Pierce (1941), the mean velocity in a laboratory flume occurs at about two-tenths of the midstream distance from the sides. This flume presented an unnatural condition in that the walls were smooth and the bed was rough. In several large canals the mean tends to be at about four-tenths of the midstream distance from the sides. However, if there is any curvature in the channel this distance is subject to wide variation. In natural channels there are many factors that influence the location of the point of mean velocity. The point may have a tendency to move under the influence of changing flow, stage, wind, or salt or sediment loads.

It may not be possible to maintain a meter at the best possible index-point location. Errors introduced into the records as a result of unsteady flow and a meter location that is less than ideal tend to be compensating over periods of increasing and decreasing flow. Nevertheless, a study of variation in velocity distribution seems necessary in making such an installation.

REFERENCE

Pierce, C. H., 1941, Investigations of methods and equipment used in stream gaging: U.S. Geol. Survey Water-Supply Paper 868, 75 p.

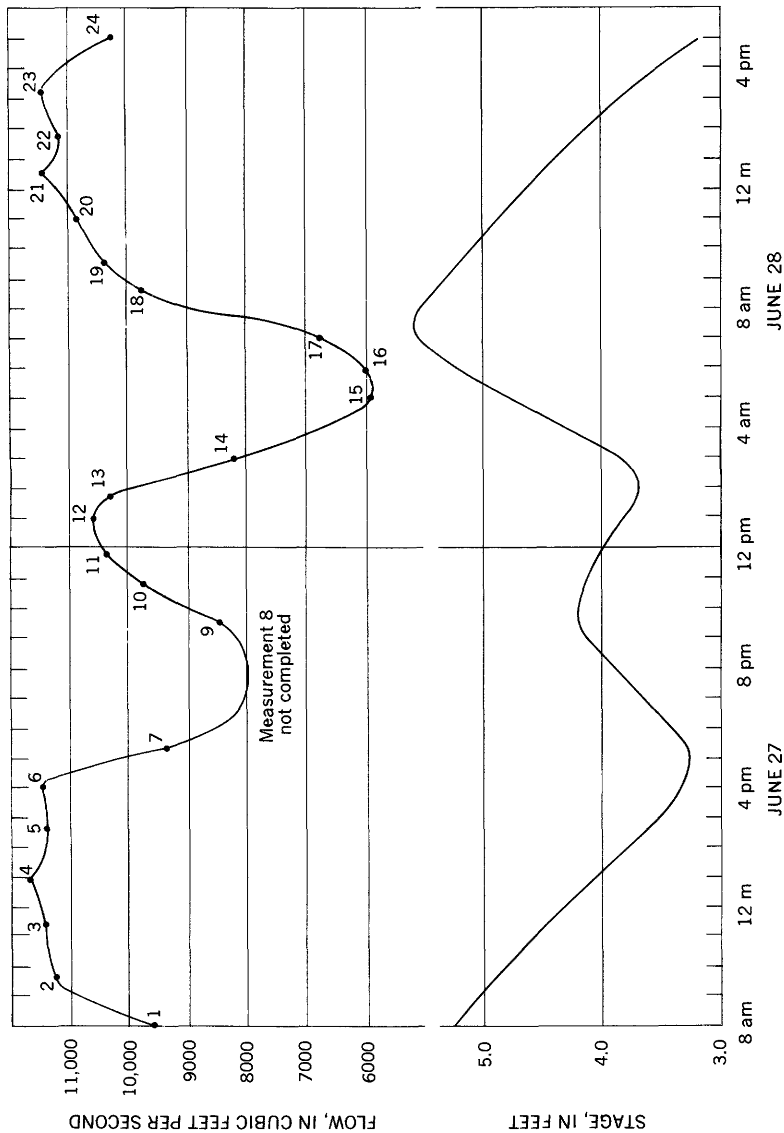

FIGURE 15.—Hydrograph of stage and flow during tidal-cycle measurement of June 27, 28, 1957, Sacramento River at Sacramento, Calif. Numerals on curves indicate measurement number.

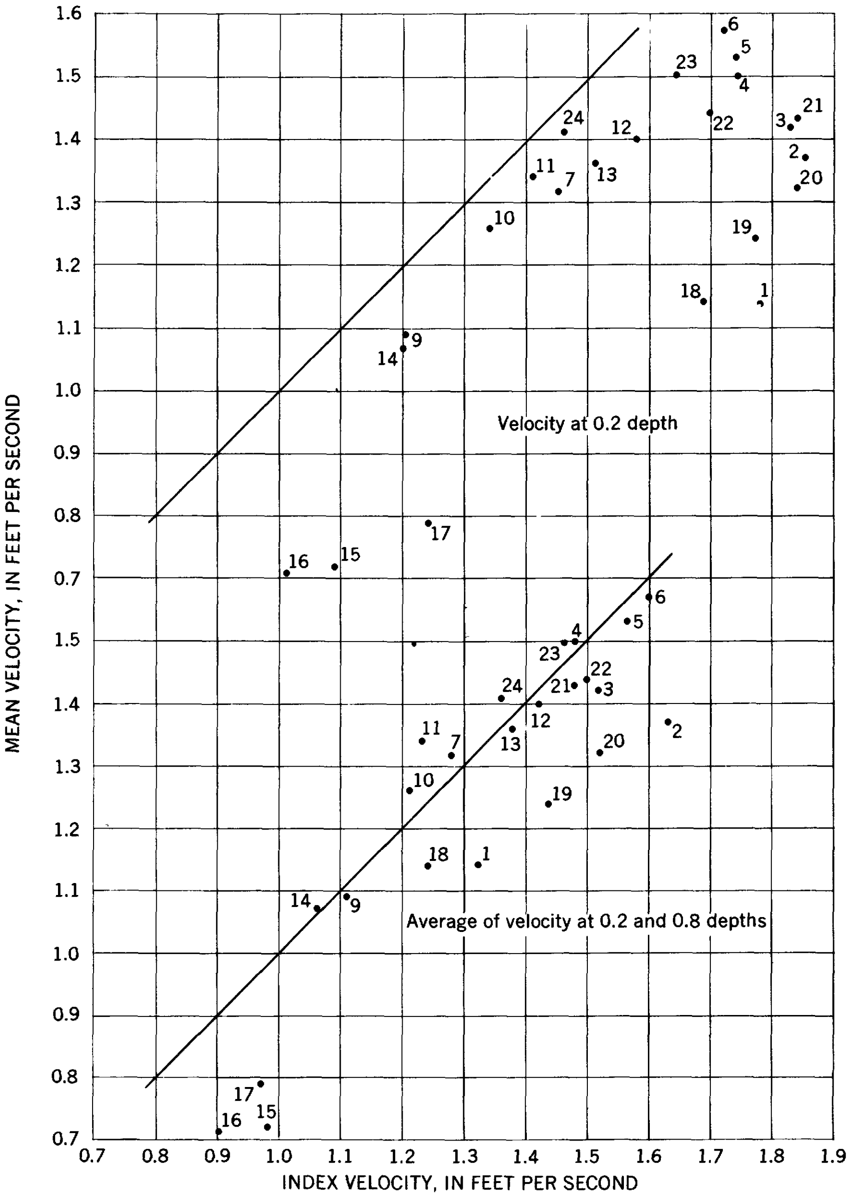

FIGURE 16.—Relations between mean velocity and index velocities at station 200 during tidal-cycle measurement of June 27, 28, 1957, Sacramento River at Sacramento, Calif. Numerals on curves indicate measurement number.

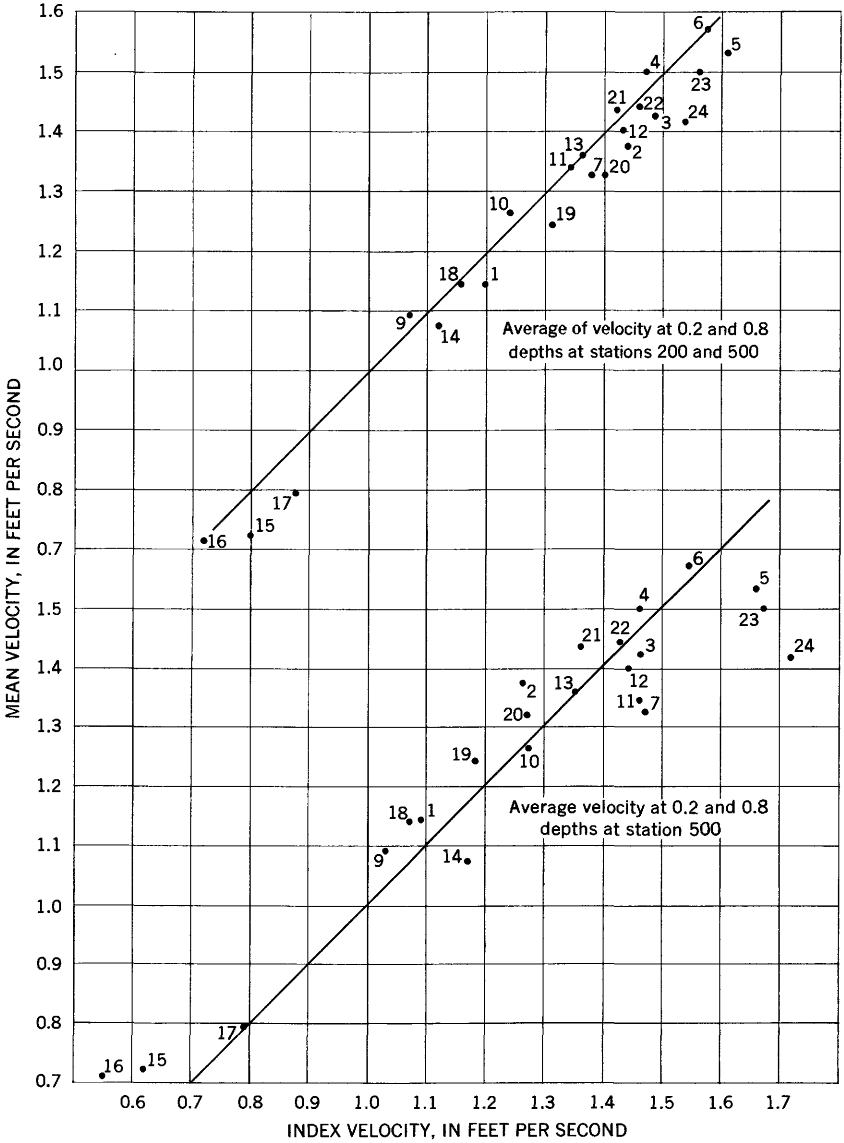

FIGURE 17.—Relations between mean velocity and selected index velocities during tidal-cycle measurement of June 27, 28, 1957, Sacramento River at Sacramento, Calif. Numerals on curves indicate measurement number.

ESTABLISHMENT OF CREST-STAGE GAGES AT DISCONTINUED GAGING STATIONS

By Prentis M. Frye

ABSTRACT

Flood-frequency studies require a definition of the mean annual flood. Peak-discharge records may not cover a sufficient period of time to be used as a basis for defining the mean annual flood, but such records can be simply and inexpensively extended by using discontinued gaging stations.

A gaging station that is discontinued or relocated should be operated as a crest-stage gage if the station does not have sufficient record to define the mean annual flood needed in regional flood-frequency studies. To obtain a reliable record of the flood history, an accurate method of collecting peak-discharge data is necessary; and because of the increasing number of relocated stations, the technique should be economical. The methods commonly used when regular gaging structures have been left in place are to install regular crest-stage gages either inside or outside the gaging structure or to dump cork dust in the well. Because installation of the regular crest gage is somewhat costly and because the dumping of cork dust in the well has not proved to be entirely satisfactory, other methods have been tried. One of these methods, an economical and effective way of obtaining water levels was used at the gaging station, Garrison Fork at Fairfield, Tenn.

A redwood stick is secured to the existing instrument shelf or floor. A small can containing cork dust is then fastened to the bottom of the stick. Small holes are punched near the bottom of the can. The typical installation, shown in figure 18, is for a corrugated-pipe well with wooden lift-top shelter. For other structures the stick may be placed near the door or hinged to ensure accessibility. The length of the stick is determined by placing the bottom of the can at the stage that is normally exceeded about three times a year.

The gage heights of peaks are determined by measuring from the top of the withdrawn stick down to the high-water mark made by cork dust. Also the inside staff gage, if still in place, should be checked for high-water marks. Gage heights can be adjusted for surge to agree with previously published data on peaks by consideration of the amount of surge shown on the recorder charts for approximately equivalent peaks.

Some of the advantages of this type installation are as follows: (1) Excellent high-water marks, (2) economical cost, (3) ease of installation, and (4) ease of servicing. The results obtained from this particular installation have been very accurate.

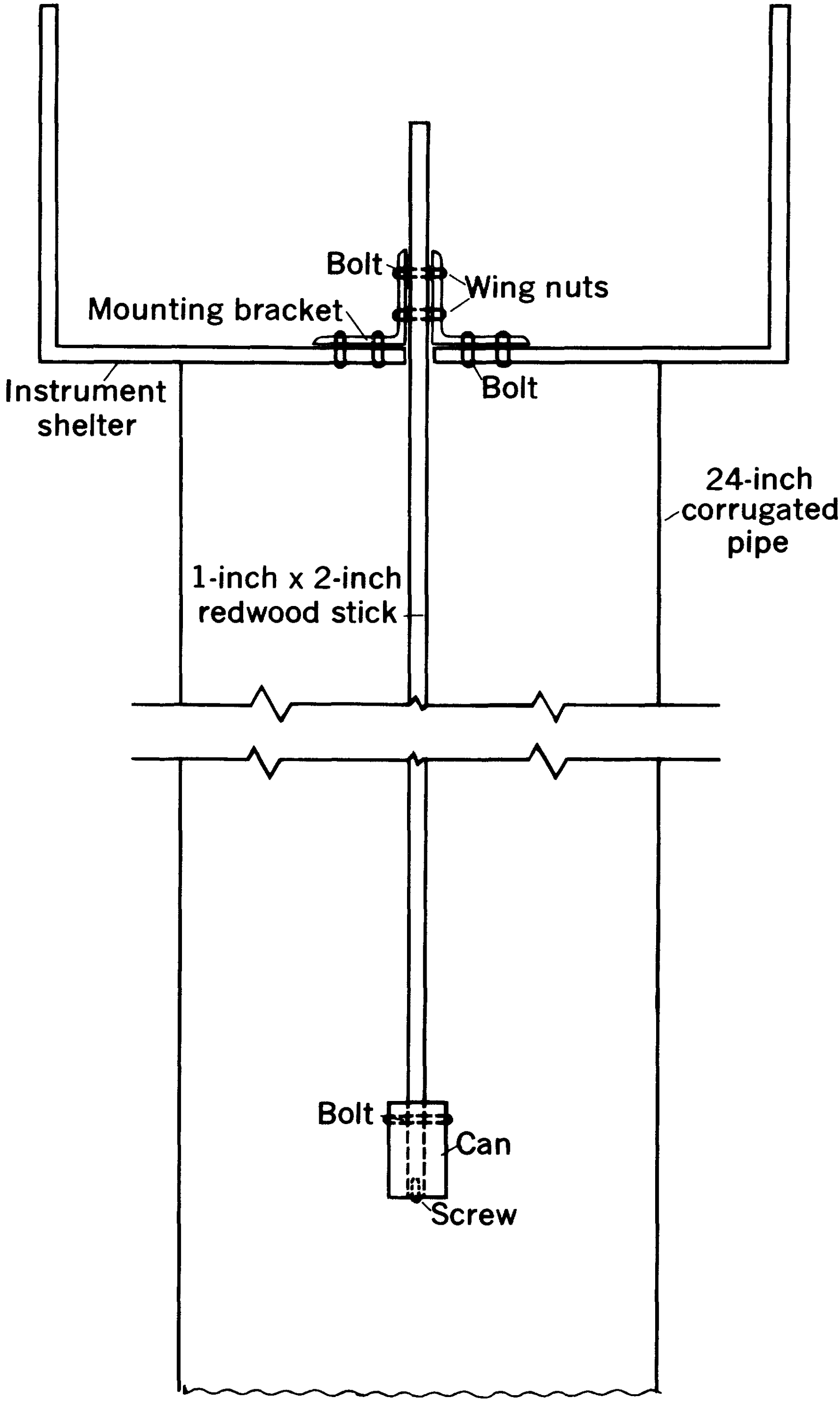

FIGURE 18.—Crest-gage mounting in stilling well, Garrison Fork at Fairfield, Tenn.

USE OF PLASTIC TUBES FOR PEAK-STAGE GAGES ON RESERVOIRS

By Willard B. Mills

ABSTRACT

A solution to the problem of obtaining peak stages at reservoirs equipped with staff gages is the use of a plastic tube. This tube, attached to an existing staff gage, provides a precise, easy-to-read, and inexpensive peak-stage indicator.

In making special studies on reservoirs it is sometimes necessary to use a minimum of equipment. For some reservoirs, nonrecording staff gages read periodically are the only means of obtaining stage data. For water-budget studies, hydrologists must have not only periodic readings of stage and content but also readings of stage and content that may occur between the periodic readings. Most reservoirs have uncontrolled outlets to bring the reservoir to a fixed level after an influx of flood runoff; thus only by chance would a periodic reading of the staff gage reflect the peak stage.

The problem was to devise a peak-stage gage that would be precise, reliable, operative throughout the range in stage, easy to read, and inexpensive.

A solution to this problem is the use of a plastic tube installed on each staff-gage post, as shown in figure 19. All that is required is a clear plastic garden hose cut to the correct length. A small amount of cork dust is poured into the hose, both ends are stoppered, and breather holes are drilled near each end. One of these devices is then clipped to each staff gage. The clips used are standard pipe clips, and these are attached to the gage by using the screws that anchor the gage plates.

This type of installation has several advantages. It is inexpensive. No levels are required, as the gage height is read from the existing staff gage plates. The cost of the material required is inconsequential. A minimum of time and tools are needed for installation; the tube can be cut with a knife and installed with a screwdriver. Peak marks on the tube can be read as precisely as the staff gage permits, yet the gage requires no special setting. Although the tube must be firmly secured, it need not be exactly vertical, as the height of the water surface is all that is required. It can be adapted to any range in stage, an important factor when each staff gage is an individual installation. Peak marks are easily removed after reading. Regardless of aging and cracking, the tube will continue to operate.

There are some disadvantages. The tube can be moved or destroyed by vandals before a peak stage can be read. This is always a threat, but most reservoirs are built on farms that are fairly well guarded against trespassers by the farmers themselves. Also, the tube is subject to becoming soft and pliable in hot weather; tight hose clamps are required or the tube will slide out. Spiders build nests in the tubes, and the webs tend to strain the cork dust and prevent a distinct peak mark.

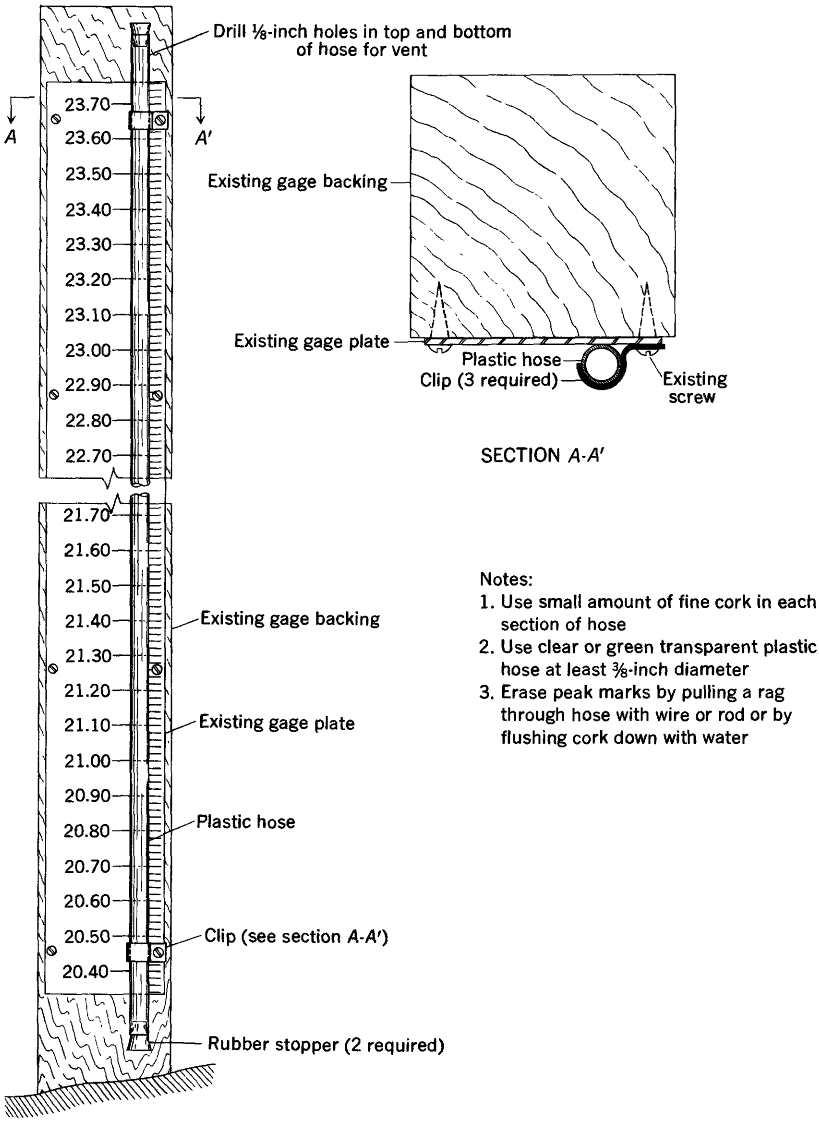

FIGURE 19.—Peak stage gage for reservoirs.

FIELD FILTERING UNIT FOR WATER SAMPLES

By PAUL G. DRAKE

ABSTRACT

Separable material can be removed from a water sample at the time of collection by a simple filtration assembly. Precipitates of heavy-metal ions, particularly iron and manganese, which may form during the storage period before analysis, can be redissolved, and the analysis will then represent the sample concentration at the time of collection.

INTRODUCTION

The validity of the chemical analysis of a natural water sample is predicated upon the assumption that equilibrium between sediment and dissolved material exists in the water at the time of collection and that with certain precautions this equilibrium is sufficiently maintained until the time of analysis.

Among the factors that may affect this equilibrium are oxidation, reduction, absorption, ion exchange, precipitation, and solution of the sediment. These reactions particularly affect many of the heavy-metal ions normally present in only trace amount to the extent that the collection of a separate sample—filtered to remove the sediment and, in some instances, chemically fixed at the time of collection—is advisable.

Iron and manganese are determined more frequently in water analysis than other heavy metals, and concentrations of iron and manganese are important parameters that affect a wide variety of municipal and industrial uses. Iron and manganese occur in water at two levels of oxidation. Iron, for example, occurs either in the bivalent ferrous or trivalent ferric state. The chemical behavior of the two forms is somewhat different, although both may be present in the same solution under certain circumstances. Under reducing conditions, iron in water will tend to be in the ferrous state. The ferrous salts, however, are unstable in the presence of oxygen or air and are changed to the ferric state through oxidation when natural water containing ferrous iron is exposed to the air.

In the pH range of 6 to 8, the solubility of feric iron in solution is limited by the solubility of ferric hydroxide, about 4×10^{-10} to 5×10^{-6} mg (milligrams) of iron per liter, which is below the limit of detection by methods ordinarily used in water analysis (Hem, 1959, p. 58–66). The precipitation of ferric hydroxide is frequently observed in stored samples that contain ferrous iron in solution.

In surface waters and in many ground waters the sediment normally present often includes some iron oxides that are formed in the process of weathering and are carried in colloidal suspension or as very small sediment particles. In water analysis, the determination of suspended iron is usually not desired; and because it is impossible to separate the soluble iron that has precipitated from the naturally occurring sediment after the sample has been collected and transported to the laboratory, the sample must be filtered at the time of collection. The filtration assembly here described is being used in the field by technical personnel engaged in water-resources investigations to obtain a sample that represents the iron or other heavy metal in solution at the time of collection. The sample can be chemically fixed after this separation process.

DESCRIPTION OF FILTERING UNIT

The filtering unit consists of a two-piece polyethylene buchner funnel and a 6-ounce polyethylene bottle that serves both as the collecting vessel and as the source of suction. The buchner funnel is modified by inserting a perforated plastic disk between the two sections. This serves as a firm base for the filter paper that is placed between the two sections of the funnel. A rubber stopper fitted on the neck of the funnel and positioned in the polyethylene bottle provides an adequate seal to maintain sufficient vacuum for the system.

The grade of filter paper used depends upon the particle size to be retained. For most waters a filter paper of medium speed and high wet strength (Whatman No. 30 or equivalent) is satisfactory. However, a more retentive paper (Whatman No. 42 or equivalent) may be used where necessary.

The parts and the unit shown in figure 20 are identified as follows:

A, Upper section of two-piece polyethylene buchner funnel, designed for 55-mm filter paper.

B, Perforated plastic disk $2\frac{5}{32}$-inch diameter, $\frac{1}{32}$-inch thick, positioned in the lower section of the buchner funnel.

C, Lower section of two-piece polyethylene buchner funnel.

D, Polyethylene bottle, 6-ounce capacity.

E, Filter paper, 90-mm diameter (oversize to form cup when placed between the two sections of the buchner funnel.)

F, Filter unit assembled.

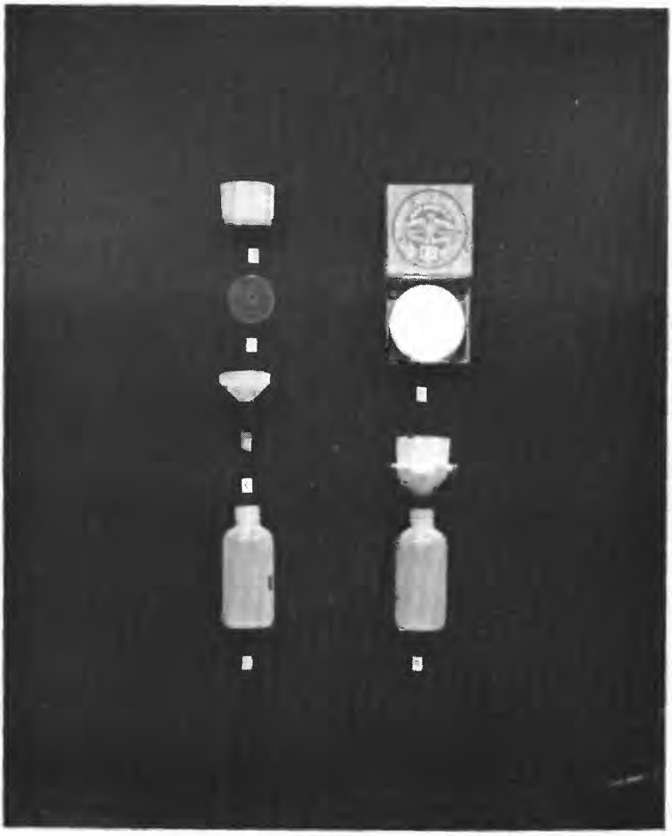

FIGURE 20.—Filtering unit for water samples.

OPERATION OF FILTERING UNIT

In operation, the filter paper is placed between the two sections of the buchner funnel, and the two sections are pressed together. The polyethylene bottle is squeezed, and the neck is connected to the rubber stopper on the funnel stem. Sample is poured into the funnel, and the bottle tension is released. The resulting vacuum is sufficient to filter the sample effectively. One operation is usually sufficient to filter the reservoir capacity of the funnel.

The filtered sample may be left in the 6-ounce polyethylene bottle and capped for transport to the laboratory; or, preferably, the sample may be transferred to a clear glass bottle, thus enhancing visual inspection.

Two-piece polyethylene buchner funnels are available in 42.5-, 55-, 70-, and 90-mm paper size. These may be combined with 6-ounce, 8-ounce, or larger polyethylene bottles to provide larger units when desirable.

REFERENCE

Hem, John D., 1959, Study and interpretation of chemical characteristics of natural water: U.S. Geol. Survey Water-Supply Paper 1473, 264 p.

TEST OF A CONTINUOUS DISSOLVED-OXYGEN RECORDER

By David McCartney

ABSTRACT

A dissolved-oxygen recorder was tested in the Delaware River near Philadelphia, Pa. The principles of operating the recorder are based on Henry's Law and the paramagnetic behavior of oxygen. The location for the test was determined by the convenience of the site and the fact that a wide variation in dissolved oxygen occurred there. Results of the test were based on 40 observations of dissolved-oxygen recorder values as compared to 40 simultaneous chemical determinations. Initially, observations were made twice daily, and finally, after reliability was established, about every 3 days. Total testing time was 59 days.

On the basis of specifications for accuracy of the dissolved-oxygen recorder and the accuracies of chemical tests, temperature, and oxygen-solubility tables, a limit of a difference of 5 percent saturation units is considered acceptable. This difference was exceeded only 5 times in 40 observations. The results of this test compare favorably with a previous test of this instrument by Macklin, Baumgartner, and Ettinger (1959).

INTRODUCTION

The absence, deficiency, or surplus of dissolved oxygen in water is closely related to management of water resources, particularly to disposal of sewage and industrial wastes. For proper classification and use of a stream it is helpful to understand the dissolved-oxygen characteristics of the water. The content of dissolved oxygen in water at equilibrium with normal atmospheric conditions is a function of the temperature and salinity of the water, because the ability of water to hold oxygen decreases with increasing temperature or dissolved solids.

The City of Philadelphia's Water Department is interested in additional information on the dissolved-oxygen content of Delaware River water. Continuous records of conductance, temperature, and dissolved oxygen are invaluable for describing the characteristics of Delaware River water and for identifying the factors that are responsible for changes in its quality.

The City of Philadelphia and the U.S. Geological Survey have been making monthly observations of the chemical quality of the Delaware River water between Trenton, N.J., and Marcus Hook, Pa., since August 1949 (Durfor and Keighton, 1954). Most of these observations have included the determinations of dissolved oxygen (D.O.) and biochemical oxygen demand (B.O.D.). Since 1955, periodic sampling has been supplemented by data from continuous conductivity and temperature recorders. The amount of dissolved solids can be estimated from the electrical conductivity of the sample; so these recorders supply a continuous estimate of the dissolved-solids concentration. In 1959 the use of a dissolved-oxygen recorder for analyzing the Delaware River water was begun, and in 1961 it was proposed to test another dissolved-oxygen recorder operating on a different principle. Such instrumentation facilitates studies of changes in dissolved-oxygen content as influenced by tidal flow, stream discharge, salinity, and other factors.

PRINCIPLES OF OPERATION

The dissolved-oxygen recorder operates on the principle of Henry's Law and the paramagnetic behavior of oxygen (oxygen is attracted by a magnetic field). As applied to water and oxygen, Henry's Law may be stated as follows: At equilibrium, the partial pressure of oxygen above a water surface is directly proportional to the concentration of dissolved oxygen in the water (fig. 21), or:

$$P = KN$$

where

P=partial pressure above the water surface,
K=proportionality constant (Henry's Law constant), and
N=concentration of dissolved oxygen in water (ppm).

The proportionality constant, K, in this equation is for a given temperature. Variation in the partial pressure at a given temperature indicates variation in dissolved oxygen. Therefore, at a given temperature, the partial pressure due to the dissolved oxygen above the water surface is proportional to the percent saturation of dissolved oxygen in the water.

Oxygen is paramagnetic because it has two unpaired electrons. Most other gases (fig. 22) such as hydrogen sulfide, nitrogen, and carbon dioxide are diamagnetic (repelled by a magnetic field). Nitric oxide and nitrogen dioxide are paramagnetic, but their concentration in surface waters is extremely small. Their effect, therefore, is negligible.

The dissolved-oxygen recorder installation consists of three major units—a pump, a contact sampler-analyzer (figs. 23, 24), and a Wheatstone Bridge recorder (fig. 25). The entire system operates from a 115-volt 60-cycle source and draws about 10 amperes. With the system in operation (fig. 26), the water sample is drawn through a 25-mesh

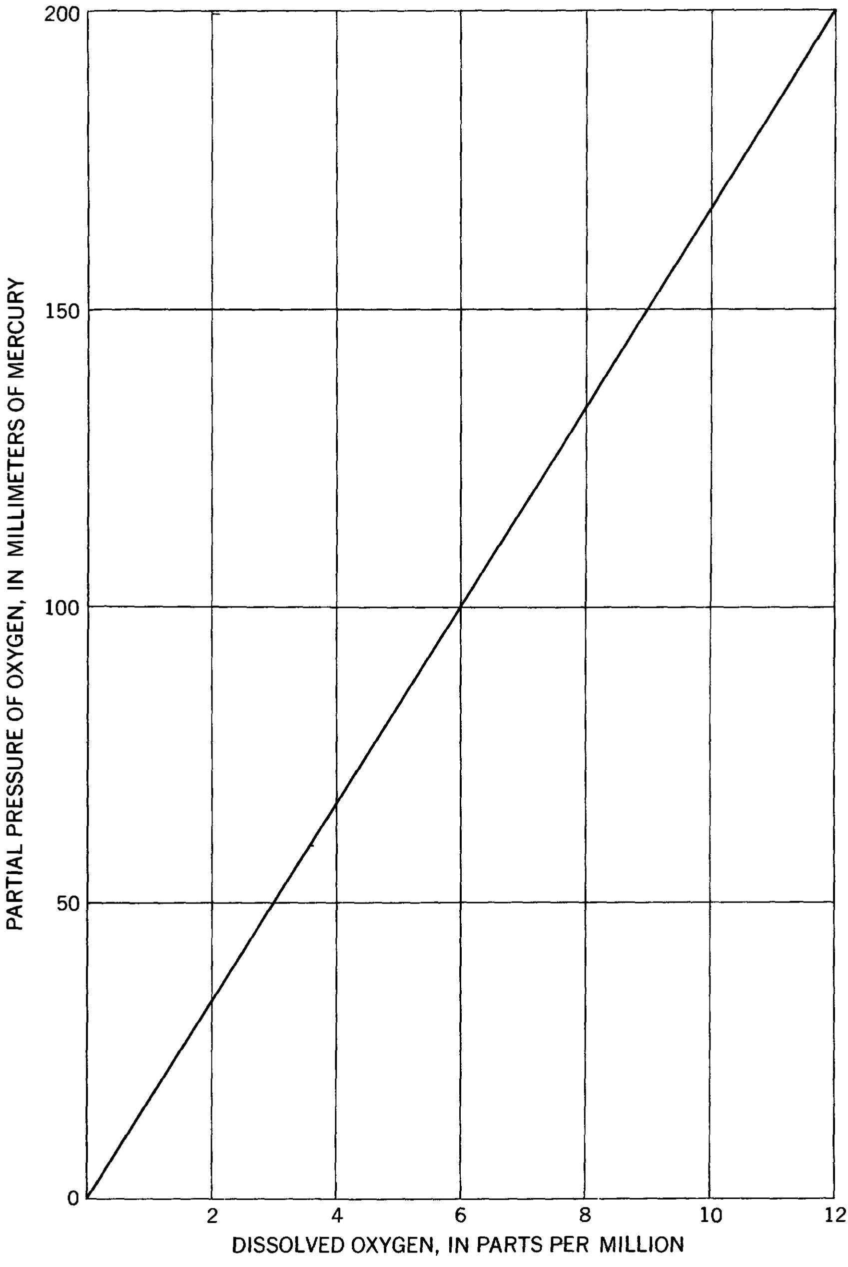

FIGURE 21.—Relation of partial pressure to dissolved oxygen at a given temperature.

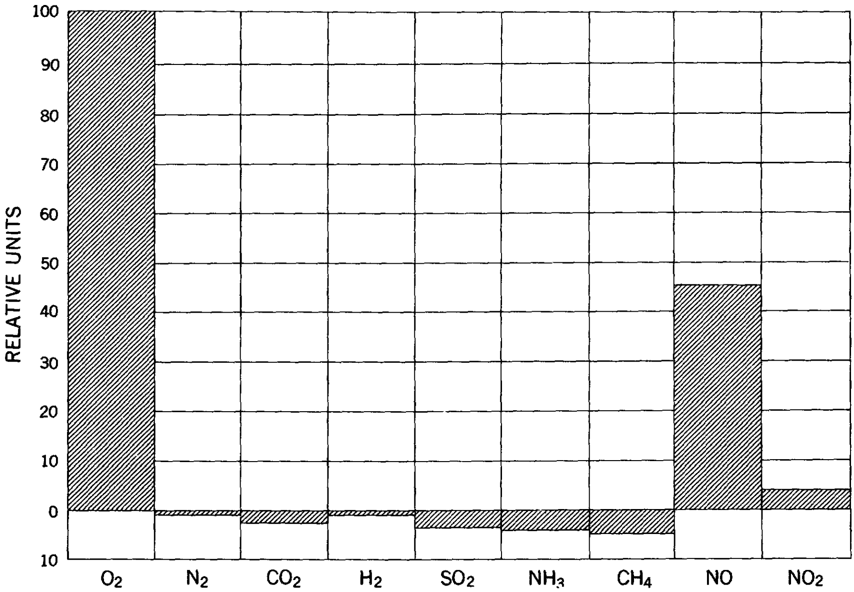

FIGURE 22.—Magnetic susceptibility of various gases relative to oxygen.

screened intake that prevents debris from fouling the system. The sample is pumped at a constant, above atmospheric, pressure (3–5 pounds-per-square-inch gage) into an aspirator where it mixes with the gases already in the system. (The exact system pressure is not important, but it must exceed the highest partial pressure exerted by the oxygen plus the nitrogen mixture. For example, at 200-percent saturation the system pressure would have to be 6 pounds-per-square-inch gage to maintain volume control.) The higher pressures of the system cause these gases to dissolve in the water.

Thorough mixing at the aspirator produces rapid equilibrium, in accordance with the principle of Henry's Law. The aspirated water sample is then forced into a water-gas separator, where the water is discharged. When the gases in the system dissolve in the water, the water level tends to rise in the water-gas separator. To prevent flooding of the system, a level-control electrode has been installed. When the water contacts this electrode a solenoid is actuated, and this allows the entry of about 1 cc of nitrogen gas, which forces the water level down. So that nitrogen may enter the system, the pressure of the gas is maintained at ½ to 1 pound per square-inch gage above the system pressure. An additional flood-prevention device has been installed in the base lines to and from the analyzing cell. Water passing these points completely shuts down the pumping unit, thus preventing damage to the analyzing cell. The undissolved gases above the water in the water-gas separator now pass on to the analyzing cell. The analyzing cell (fig. 27) consists of two similarly heated resistance elements, one of which lies in a magnetic field. The oxygen-bearing gas is drawn into the magnetic field in the measuring cell, where it cools the heated resistor. In so doing, the oxygen loses its magnetism very rapidly (in proportion to the square of its temperature rise). The heated demagnetized gas is forced out of the magnetic field and upward along the resistor by cooler and therefore more magnetic oxygen-bearing gases from below. This magnetically induced flow of gas and resultant heat extraction produces a lower temperature in the measuring cell than in the comparison cell. As a result, the resistance of the measuring cell is less than that of the comparison cell. This resultant resistance differential is measured by a Wheatstone Bridge

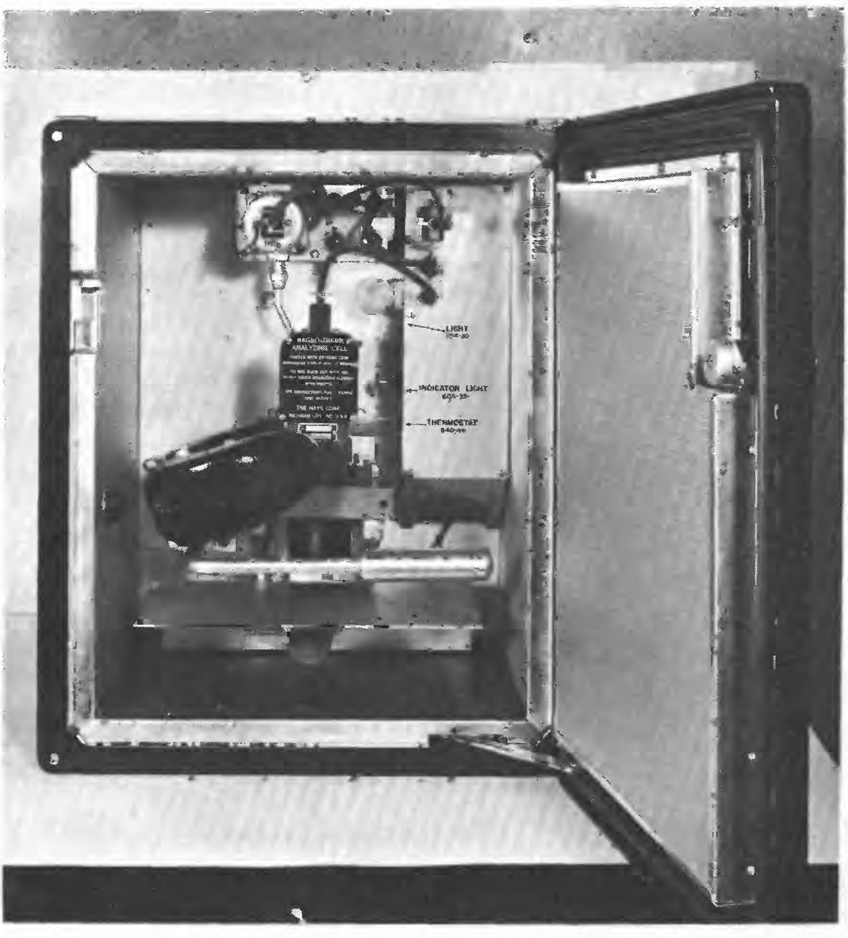

FIGURE 23.—Contact sampler-analyzer, front view.

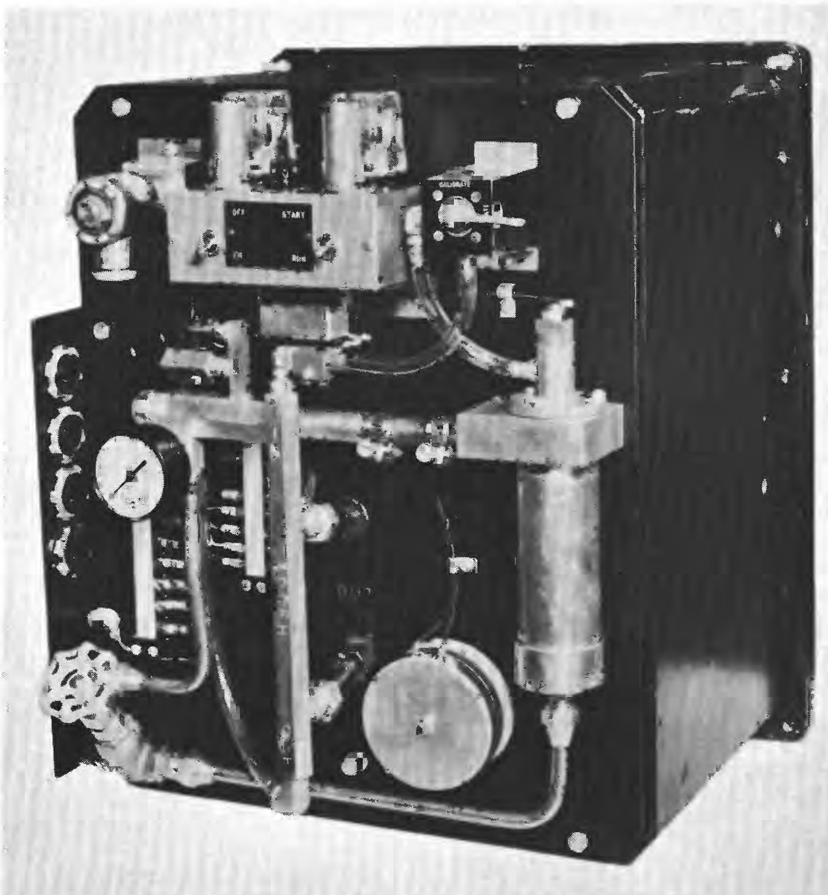

FIGURE 24.—Contact sampler-analyzer, back view.

(fig. 28) and is proportional to the percent saturation of dissolved oxygen. The hot gases in the analyzing cell are now replaced by cooler incoming gases and move into the aspirator where they are mixed with fresh incoming water. Part of this gas will dissolve in the water and be discharged, and part will recirculate through the analyzing cell. This condition and the flow of water through the system produce the response time of the system. Initial response is 15 to 30 seconds, with a 90-percent response time of about 3.5 minutes for any arbitrary change in dissolved oxygen.

Calibration of the instrument is simple and rapid. If the magnet is moved away from the analyzing cell, equal cooling will take place. Essentially, the resistance of the measuring cell equals the resistance of the comparison cell. This becomes the 0-percent saturation adjust-

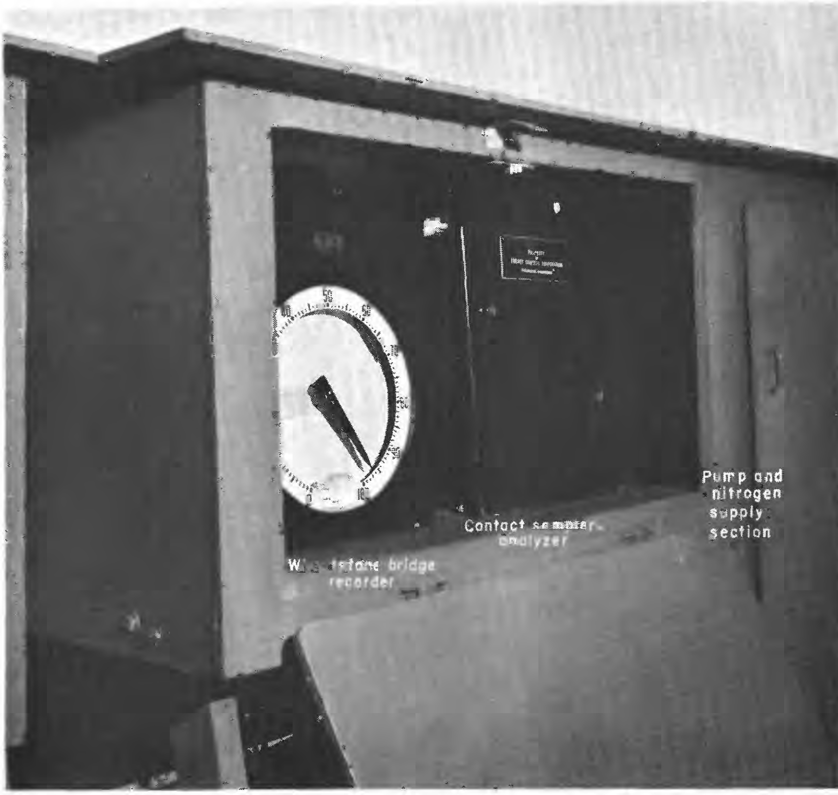

FIGURE 25.—Continuous dissolved-oxygen recorder installation.

ment for the instrument. With the magnet in place and the system exposed to the atmospheric air, the instrument is adjusted to the 100-percent saturation. (Note: A 100-percent-saturated water in the system was originally in equilibrium with the atmosphere above it.)

When calibrating the instrument at the 100-percent saturation point on the recorder, corrections must be made. The range setting, therefore, may differ from 100 percent. The correct setting is found by the following formula:

$$S = 100 \text{ percent } \frac{(P_B - H)}{P_R - W}$$

Where

S = correct range setting,
P_B = barometric pressure (in millimeters of mercury),
H = absolute humidity,
W = water vapor pressure at water temperature, and
P_R = standard barometric pressure (760 millimeters of mercury).

Example:

P_B=750 mm Hg $\qquad$ W=14 mm Hg

H=16 mm Hg $\qquad$ P_R=760 mm Hg

$$S=100 \text{ percent } \frac{(760-14)}{(750-16)}=98.4 \text{ percent}$$

The range setting in this example would be 98.4 percent. If parts per million dissolved oxygen is desired in place of percent saturation, temperature compensation can be added to the instrument.

CHOICE OF SITE

Regardless of what continuous physical or chemical measurement is made on a stream, it is important that one choose the right site. Temperature, conductivity, pH, and other factors require moving, nonsilting representative water conditions. These same requirements are especially applicable to the continuous measurement of dissolved oxygen. For example, if the intake is placed in shallow water where heavy algae growth predominates, the dissolved oxygen may be unusually high. If the intake is placed near the water surface in a turbulent area, again the results may be high and not representative. As with other continuous-recording instruments, the choice of site is based on reconnaissance.

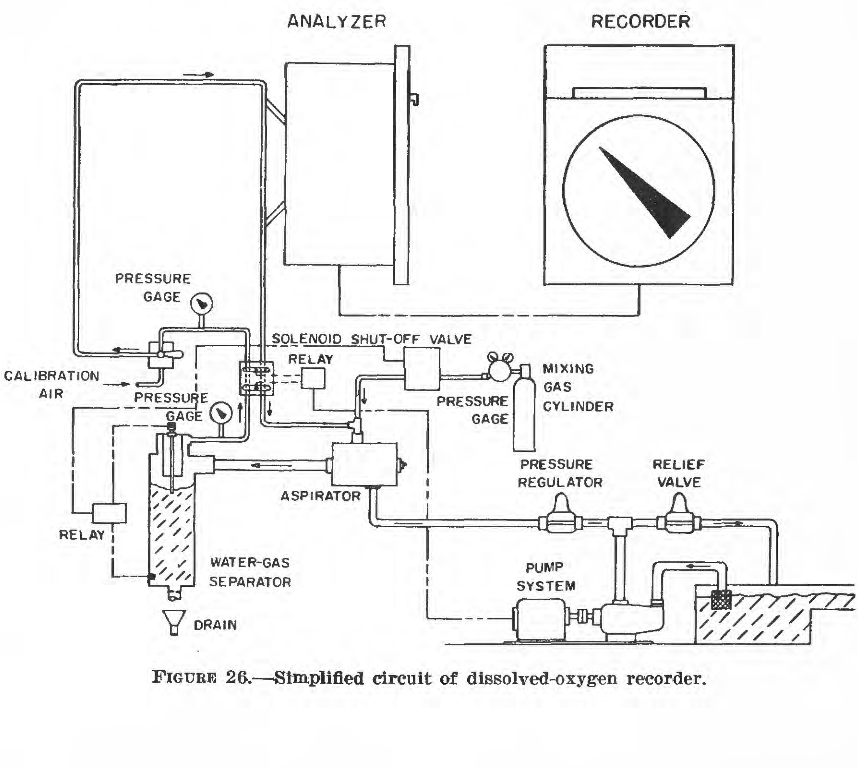

FIGURE 26.—Simplified circuit of dissolved-oxygen recorder.

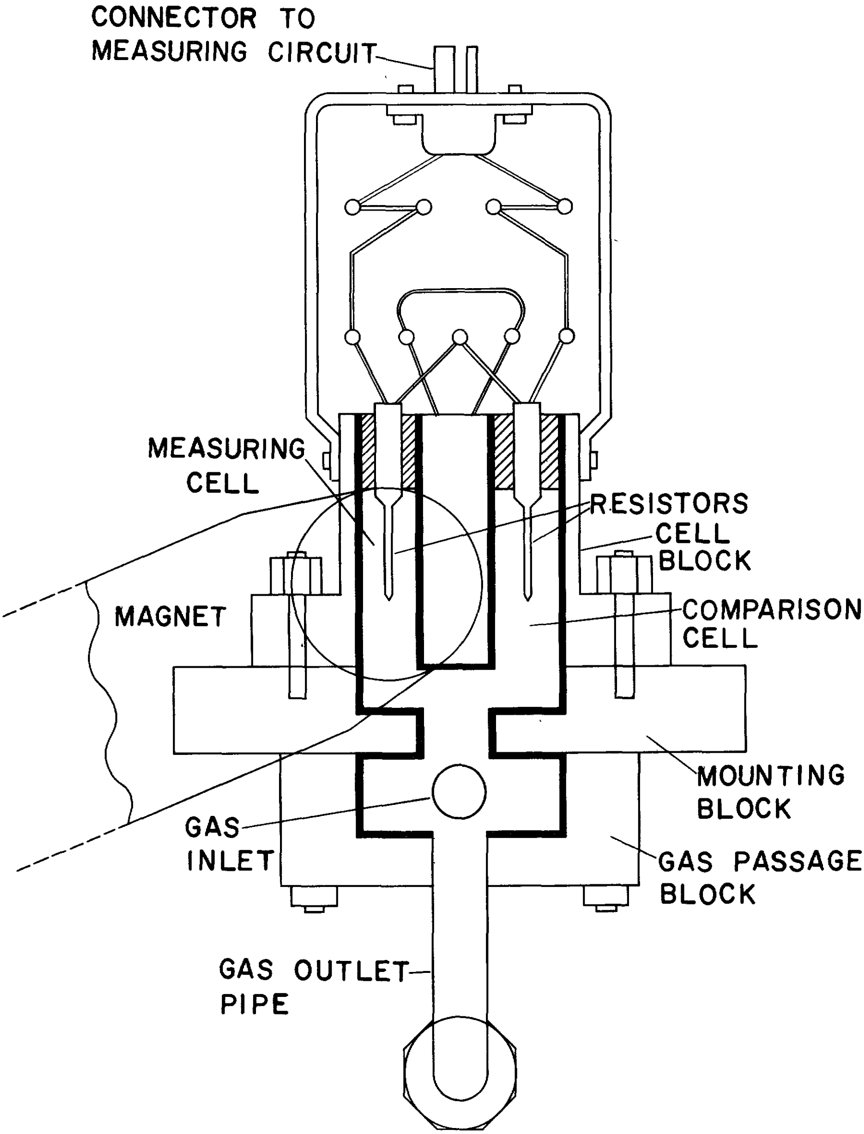

FIGURE 27.—Analyzing cell of dissolved-oxygen recorder.

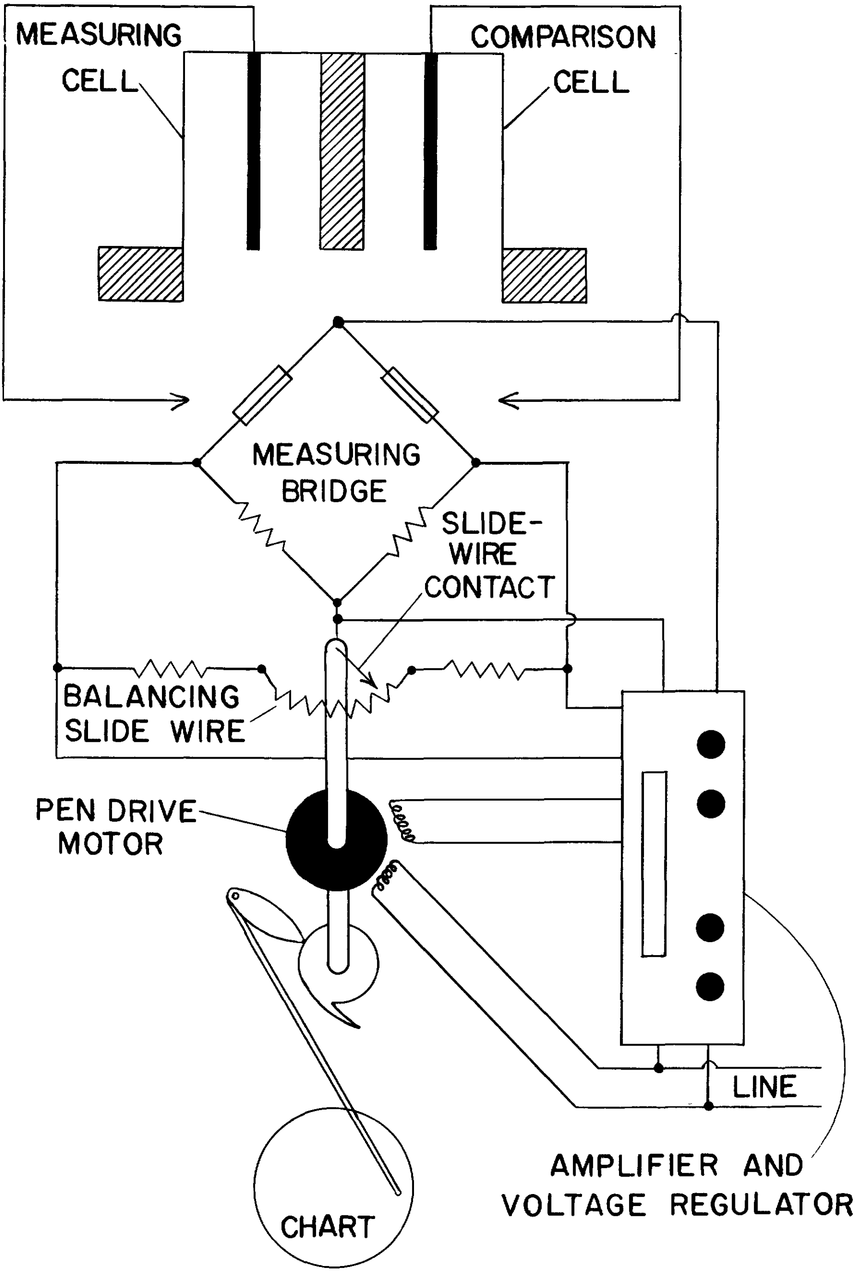

FIGURE 28.—Schematic diagram of operation of dissolved-oxygen recording system.

The site for this first dissolved-oxygen test was the Delaware River Chestnut Street pier, Philadelphia, Pa. This location was convenient for daily observations and tests, and the river at this point has a wide range of percent-saturation dissolved-oxygen values. The suspended solids of the stream did not exceed 100 parts per million during the test. Previous work has indicated that this instrument will operate in activated sludges containing as much as 4,000 parts per million solids. No tests have been made to verify this. Power requirements for the instrument are such that battery operation would be very costly, so that it is desirable to select a site where power is readily available.

RESULTS OF TEST

At the beginning of the test, water samples were collected as frequently as twice daily at the point of intake. With further testing, this time interval was extended. Collection, treatment, and determination of dissolved oxygen were carried out in accordance with recommended methods (American Public Health Assoc., 1955). The Alsterberg modification of the Winkler method (Alsterberg, 1925) was used for the laboratory dissolved-oxygen determination. The water temperature and barometric pressure were noted at the time of collection for conversion of parts per million to percent saturation of dissolved oxygen. The percent-saturation results of the chemical determinations were compared with the percent-saturation values of the recorder at the time of sampling.

During 59 days of testing, about 40 observations were made. The absolute difference between the analyzed percent saturation and the recorded percent saturation (dissolved oxygen) was noted. The average of these absolute differences was found to be 2.4-percent saturation units. These results compare favorably with the results of the initial field testing of the instrument by Macklin, Baumgartner, and Ettinger (1959). During their test, in which 21 samples of raw water from the Ohio River were analyzed, the absolute difference between recorded and analyzed values averaged 3.8-percent saturation units. It is difficult to place severe restrictions on the difference between the recorded and the analyzed oxygen concentrations because of the possible errors of both methods. However, the supplier of this test instrument has indicated an accuracy of ± 2 percent of full scale (0–100 percent saturation dissolved oxygen). On the other hand, it is not too difficult to realize ± 2-percent saturation variations in the analyzed results when considering temperature (± 1° F) or dissolved oxygen saturation tables (± 0.07 ppm) by the Alsterberg method (± 0.1 ppm). The previously mentioned investigators considered a limit of difference of 5-percent saturation as satisfactory. This figure is reasonable and has been used as the standard for this test. Of the 40 observations, only 5 exceeded this acceptable difference limit.

MAINTENANCE OF THE INSTRUMENT

All recording instruments require careful maintenance. Maintenance checks were made every 3 days. At the test site the intake screen required cleaning from algae and sediment once each week. The instrument was calibrated once each week. The system pressure and nitrogen pressure were checked daily.

Breakdowns were few and usually minor. A broken intake screen, which caused fouling of the system; a loose motor wire; and a leak in the nitrogen supply accounted for all of the downtime. Failures of this type should be considered uncommon and unavoidable as recurrence is unlikely. With experience and a proper servicing schedule, loss of record would be minimized.

REFERENCES

Alsterberg, Gustof, 1925, Methods for the determination of elementary oxygen dissolved in water in the presence of nitrites: Biochem. Zeitschr, v. 159, no. 36.

American Public Health Association, American Water Works Association, Federation of Sewage and Industrial Wastes Associations, 1955, Standard methods for the examination of water, sewage, and industrial wastes: New York, N.Y., American Public Health Assoc., 10th ed.

Durfor, C. N., and Keighton, W. B., 1954, Chemical characteristics of Delaware River water, Trenton, New Jersey, to Marcus Hook, Pennsylvania: U.S. Geol. Survey Water-Supply Paper 1262.

Macklin, M. O., Baumgartner, D. J., Ettinger, M. B., 1959, Performance test of continuous recording dissolved oxygen analyzer: Sewage and Indus. Wastes, v. 31, no. 7.

ACCURACY OF THREE NONSTANDARD RAIN GAGES

By R. H. MUSGROVE

ABSTRACT

Rainfall catches from three nonstandard gages of various sizes were compared with those from a standard U.S. Weather Bureau 8-inch gage. Results show catches in gages with thin walls or sharp-edge receiver rings are accurate regardless of the size of the gage.

Long-term rainfall records are usually the first hydrologic data to be compiled in water-resources investigations. It is often necessary to use rainfall records collected from nonstandard gages that have questionable accuracy. To make a study of the comparative accuracy of nonstandard gages, rainfall records were collected for 8 months in Ocala, Fla., from 4 nonrecording rain gages—3 were nonstandard tubes and 1 was a U.S. Weather Bureau standard 8-inch can.

The gages were installed in accordance with the U.S. Weather Bureau standards on exposure and location. The receiver rings of the gages were set at the same height and about 2 feet apart. The gages were all cylindrical and ranged from 0.65 inch to 8 inches in diameter. They are described as follows:

1. A standard U.S. Weather Bureau 8-inch can with sharp-edge receiver ring.
2. A 2.8-inch aluminum can with 0.02-inch wall thickness and square-edge receiver ring.
3. A 0.85-inch glass tube with 0.06-inch wall thickness and round-edge receiver ring.
4. A 0.65-inch plastic tube with sharp-edge receiver ring.

Rainfall catches from the three nonstandard gages were compared with those from the U.S. Weather Bureau 8-inch gage, as shown in figure 29. The results point toward certain factors that can be applied to rainfall records if the type of gage is known. The thickness and cross-sectional shape of the receiver ring and the size of the receiving area, relative to the measuring area, are important factors.

The 2.8-inch aluminum gage underregistered by an average amount of 0.07 inch compared with the U.S. Weather Bureau 8-inch gage. Rainfall catches in this gage were measured by emptying them into a graduated cylinder. Water adhered to the walls of the gage, and

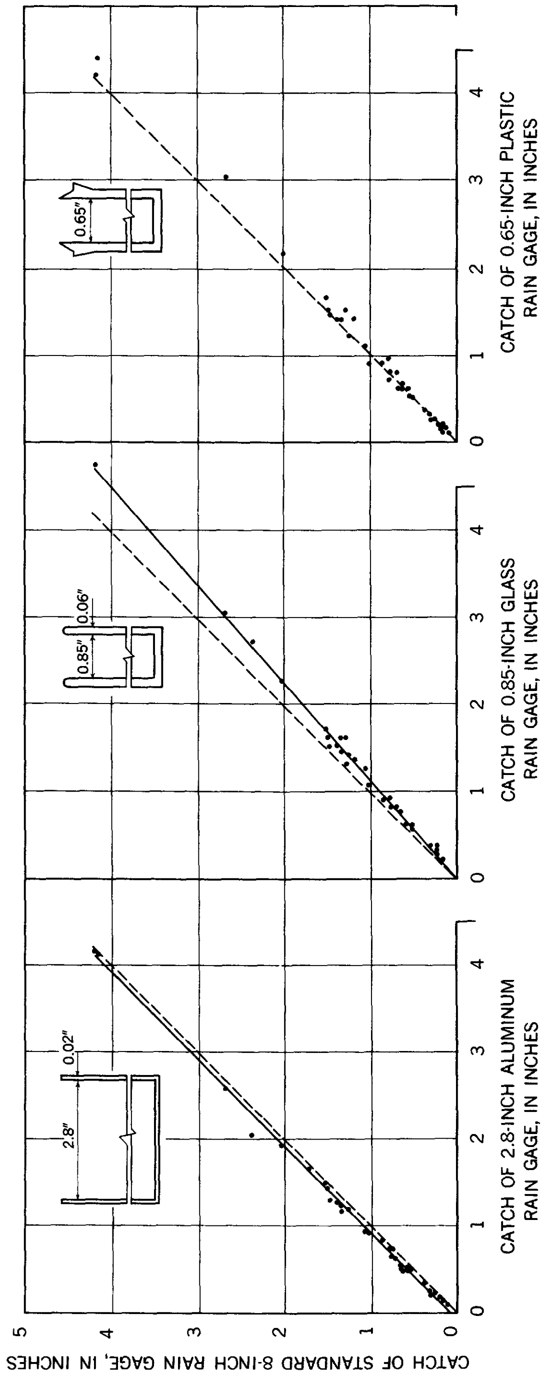

FIGURE 29.—Simultaneous rainfall catches in gages of various sizes. Broken line is line of equal catchment; solid line is average catchment.

consequently the total catch could not be measured. The 0.02-inch wall was thin enough to act as a sharp-edge receiver ring. A constant correction of +0.07 would be required when the aluminum gage is used.

The 0.85-inch glass gage overregistered all catches by an average of 11 percent. This gage was made of relatively thick glass, and the receiver ring was rounded. Much of the rain falling on the receiver ring was caught in the gage, giving a funneling effect. A coefficient of 0.89 would be required for catches from this gage.

The 0.65-inch plastic gage is the type distributed by seed companies and is used as a "backyard" rain gage. The catches from this gage showed no constant source of error except the refinement to which it could be read. The scale was on the tube mounting and was graduated to 0.1 inch. The readings scattered considerably in comparison with readings of the U.S. Weather Bureau 8-inch gage, but the average of all readings was fairly accurate.

The principal conclusion drawn from the test is that if the receiver ring of the gage is thin or has a sharp edge, the rainfall catch is accurate regardless of the size of the gage.

WORKING GRAPH FOR COMPUTING UNMEASURED SEDIMENT DISCHARGE

By Bruce R. Colby

ABSTRACT

The part of the sediment discharge that is usually not determined at a river cross section can be quickly approximated on a nomograph from the mean velocity, the depth of flow, and the concentration of bed material in depth-integrated sediment samples.

LIMITATION OF DEPTH-INTEGRATING SAMPLERS

Depth-integrating samplers such as the U.S. DH–48, U.S. D–43, and U.S. D–49 models ([U.S.] Federal Inter-Agency River Basin Committee, 1952) are widely used to sample the suspended-sediment discharge of streams. However, they have an inherent limitation in that their intake nozzles are still a few inches above the streambed when the bottom of the sampler touches the bed. Thus, neither the bedload (the sediment that moves along very near the bed and is supported mainly by the bed rather than by the turbulence of the flow) nor the suspended sediment within a few inches of the bed is usually collected in depth-integrated samples. The concentration of the unsampled suspended sediment near the bed is normally greater than the concentration of sediment higher in the flow. Hence, sediment discharges computed from the samples and from the flow through the cross section at the time of sampling are generally less than the total discharge of sediment through the section by an appreciable amount, which is commonly called unmeasured sediment discharge. This unmeasured sediment discharge consists mainly of the material that is coarse enough to be significantly more concentrated near the bed than higher in the flow. In general, it is composed mainly of particles that are coarse enough to be found in appreciable quantities in the streambed and hence to be called bed material.

FACTORS AFFECTING THE UNMEASURED SEDIMENT DISCHARGE

Several factors have major effects on the unmeasured sediment discharge per foot of stream width. The bedload discharge depends mainly on the velocity of the water near the streambed and on the particle sizes of the bed sediment. The concentration of the suspended bed material both near the bed and higher in the flow is determined by such major factors as the velocity near the bed, particle size of the bed sediment, configuration of the bed, turbulence of the flow, and water temperature. All the major factors that control the unmeasured sediment discharge can be roughly represented by mean velocity and a ratio of bed-material concentration. The mean velocity is a measure of both velocity near the bed and turbulence of the flow. For a cross section, the ratio of the concentration of bed material in the depth-integrated samples to the concentration of bed material from a set of partly empirical and partly theoretical curves (fig. 30, auxiliary diagram) is a rough measure of the availability of bed material. That is, the concentration of bed material may be higher than the standard (the auxiliary diagram of fig. 30) because of fineness of the bed material, low water temperature, or abnormally high turbulence for the particular combination of velocity and depth. If the concentration is higher than the standard, the bed material seems to be more available than usual, and the unmeasured sediment discharge probably is also higher than the standard (the main curve of fig. 30).

COMPUTATION PROCEDURES

The definition of approximately the same curves as those of figure 30 and the basic general approach to computing unmeasured sediment discharges have previously been explained in detail (Colby, 1957).

Rough approximations of the unmeasured sediment discharge per foot of width of sand-bed streams can be taken directly from the main curve of the monograph. However, more accurate unmeasured sediment discharges usually can be determined by using the auxiliary diagram to adjust for the sampled concentration of bed material if the sampled concentration and depth of flow are known.

As an example of the use of figure 30, assume a depth of 5.0 feet, a mean velocity of 4.5 feet per second, and a measured concentration of bed material of 620 parts per million. Place one leg of a pair of dividers on the intersection of the line for a depth of 5.0 feet and the vertical line for a mean velocity of 4.5 feet per second. (If the depth is between the depth lines, the interpolation is not a straight line but can be made so with a little practice.) Place the other leg of the dividers vertically below the first leg and on the line that represents 620 parts per million. From the curve of the main graph, measure this divider span downward along the line for a mean velocity of 4.5 feet per second. The indicated unmeasured sediment discharge per foot of width is 31 tons per day.

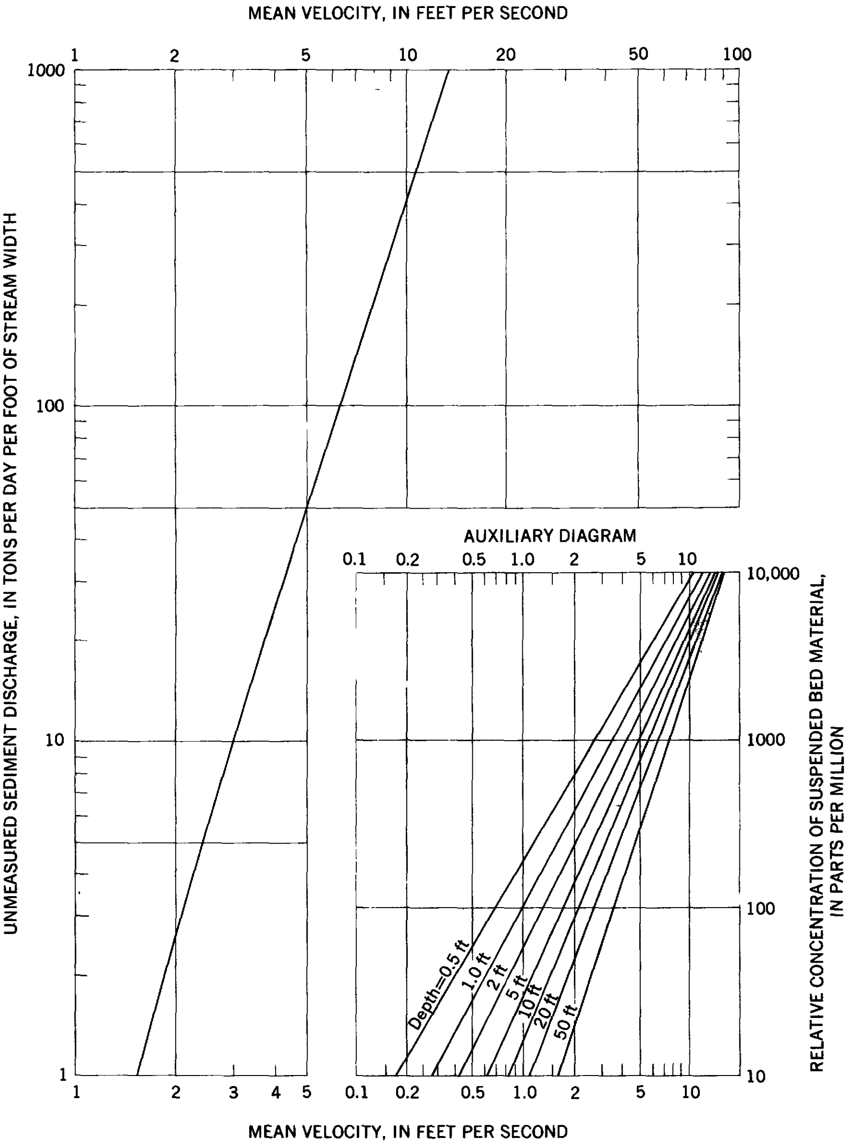

FIGURE 30.—Nomograph for computing unmeasured sediment discharge per foot of stream width.

Some hydrologists may prefer to obtain the unmeasured sediment discharge for the total width of the stream directly by "divider mathematics." Suppose the width of the stream is 67 feet. Then the divider span as determined on the auxiliary graph should be increased (the distances that represent logarithms must be added or subtracted according to algebraic sign) by the distance between the horizontal lines that are marked 6.7 and 10 tons per day on the main graph. The new span is then measured downward from the main curve along the vertical line that represents a mean velocity of 4.5 feet per second. The indicated unmeasured sediment discharge is 20.5 tons per day for a width of 0.67 foot, or about 2,000 tons per day for the width of 67 feet.

REFERENCES

Colby, B. R., 1957, Relationship of unmeasured sediment discharge to mean velocity, Am. Geophys. Union Trans., v. 38, p. 708–717.

[U.S.] Federal Inter-Agency River Basin Committee, 1952, The design of improved types of suspended sediment samplers, *in* A study of methods used in measurement and analysis of sediment loads in streams: Minneapolis, Minn., St. Anthony Falls Hydraulic Lab. Rept. 6, 103 p.

TIPPING-BUCKET RAIN-GAGE ATTACHMENT FOR A WATER-STAGE RECORDER

By H. D. Brice

ABSTRACT

The desirability of registering rainfall directly on a water-stage recorder chart prompted the development of a tipping-bucket rain gage that could be operated in conjunction with a water-stage recorder. The rain gage can be simply and satisfactorily attached to a water-stage recorder housed in a shelter made from a 48-inch corrugated metal pipe.

DEVELOPMENT OF THE RAIN-GAGE AND RECORDER ATTACHMENTS

To meet a need for synchronized records of rainfall and reservoir stage, W. B. Langbein of the U.S. Geological Survey in 1953 devised experimental models of attachments for a nonrecording rain gage and a Stevens water-stage recorder, so that rainfall and reservoir stage could be recorded on the same chart. The rain-gage attachment is a tipping-bucket unit, and the water-stage recorder attachment is a counting and marking-pen unit. Their use for concurrent recording of rainfall and reservoir stage, or of rainfall and river stage, has become widespread in this country.

DESCRIPTION OF THE ATTACHMENTS

The tipping-bucket unit shown in figure 31 was designed for attachment to the collar on the underside of the collector-ring funnel of the nonrecording rain gage. If the standard 8-inch rain-gage receiver is used, the buckets tip after each 0.1-inch increment of precipitation, but the unit can be modified to tip for amounts as low as 0.05 inch. On the other hand, the unit will tip after each 0.05 inch of precipitation without the unit being modified, if a rain gage receiver 11.3 inches in diameter is used. During rainfall of high intensity, if each tip represents only 0.05 inch, the buckets tip so frequently that the recorder should be operated at a speed of at least 4.8 inches per day.

The counter and marking-pen unit shown in figure 32 is electrically operated and not only visually counts but graphically records the number of bucket tips. The counter shows only the accumulated num-

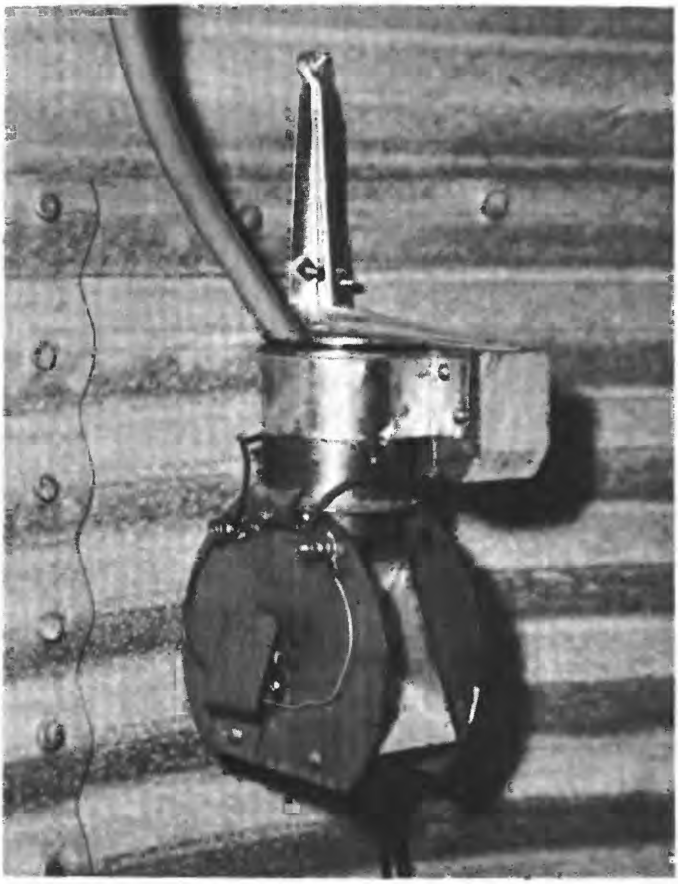

FIGURE 31.—Tipping-bucket unit attached to rain-gage collar and supported by bracket assembly bolted to wall of recorder shelter.

ber of tips, whereas the marking pen, which is simultaneously actuated, relates the tips to time and thereby provides a means for correlating rainfall and water stage.

To avoid the effects of excessive wind, rain gages ordinarily are placed on or near the ground. However, as most gaging stations are on river flood plains, a rain gage placed on the ground nearby must be securely anchored to prevent its being washed or floated away and the subsequent record for a critical event lost. Other hazards, such as damage by livestock or vandals, must be considered also.

In some locations the safest place for the tipping-bucket mechanism and the necessary wiring is inside the gaging-station shelter. In such situations the collector ring must be near enough to the tipping buckets so that not more than a negligible amount of water will adhere

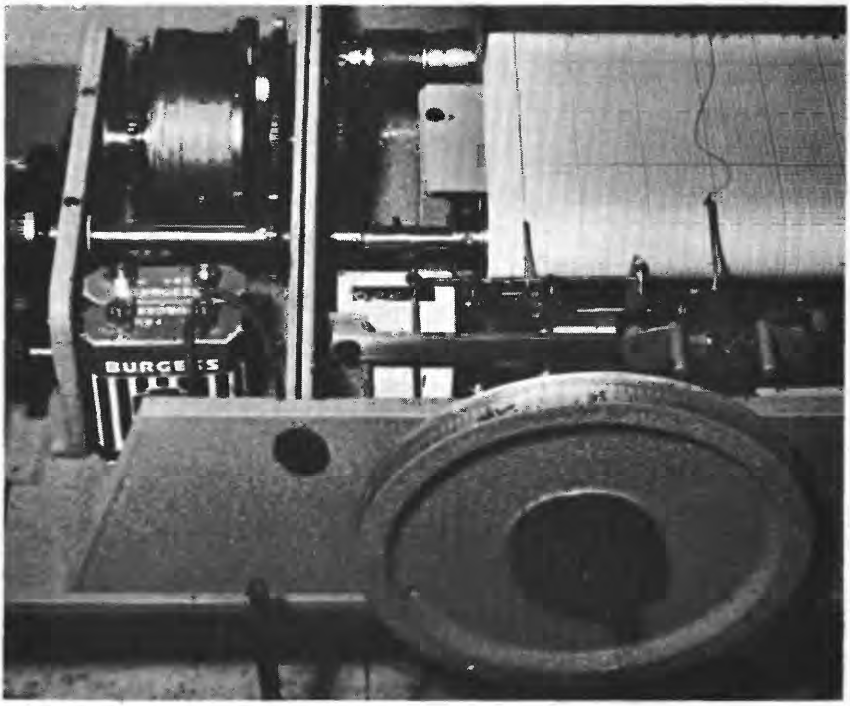

FIGURE 32.—Counter and marking-pen attachment, showing batteries, counter, and pen. Pen records rainfall along margin of chart.

to the inside of the tube that carries the water from the ring to the buckets during a period of operation. A roof installation meets this requirement adequately, provided the roof is out of the direct influence of any bridges, trees, or other large obstructions.

INSTALLATION OF THE ATTACHMENTS

Because recorder shelters built of 48-inch corrugated metal pipe (pipe commonly used for highway culverts) can be readily moved from site to site, they are especially well suited for use as gaging stations that are to be operated as secondary or short-term water-management stations. One of these installations is on Dee Creek at Greenwood, Nebr. The discharge records from this station, which represent runoff from a rural catchment area, are used in a comparative study of runoff from a nearby urban catchment area. To aid in the collection of concurrent records of rainfall and water stage at the gaging station on Dee Creek, a rain-gage attachment was installed in 1960. (See figs. 33, 34.)

An 8-inch nonrecording rain gage, a type used by the U.S. Weather Bureau, was modified for the Dee Creek recorder shelter by removing

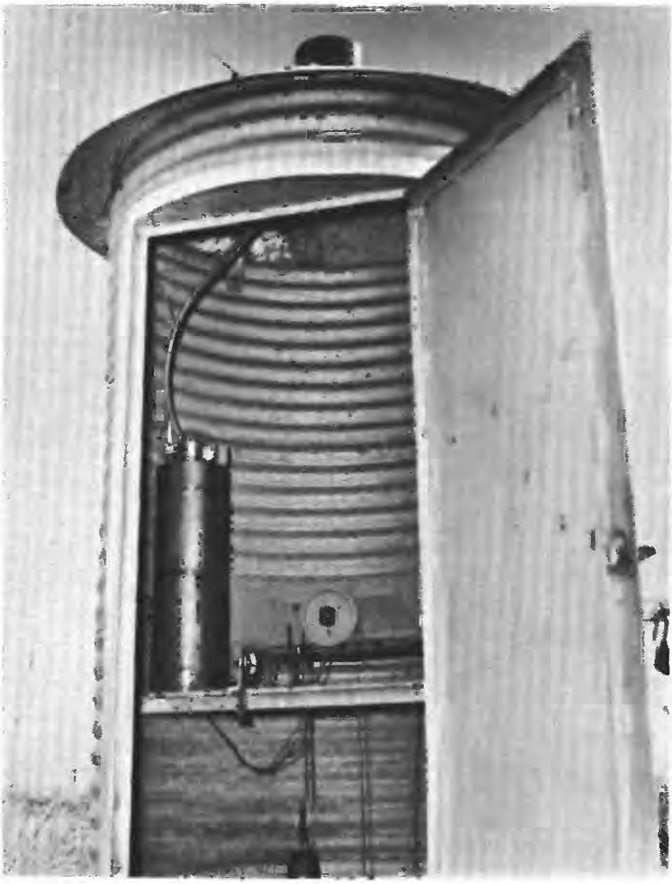

FIGURE 33.—Rain gage installed in recorder shelter.

the collar from the underside of the collector-ring funnel and soldering a ½-inch garden-hose fitting to the bottom of the funnel. This assembly was placed in a hole cut in the peak of the roof and was bolted to the roof to prevent lifting of the funnel by sudden pressure changes in the shelter.

An 8- by 10-inch shelf bracket was then bolted to the shelter wall at the left end of the instrument shelf about 2¾ inches above the top of the receiving can. A piece of wood 10 inches long, 2½ inches wide, and 1⅝ inches thick was attached to the horizontal arm of this bracket with wood screws, and the collar from the collector-ring funnel was fastened to the front face of this piece with a sheet-metal band about 2 inches wide.

The collector ring and funnel in the peak of the roof and the collar on the wall bracket then were connected by means of a short length

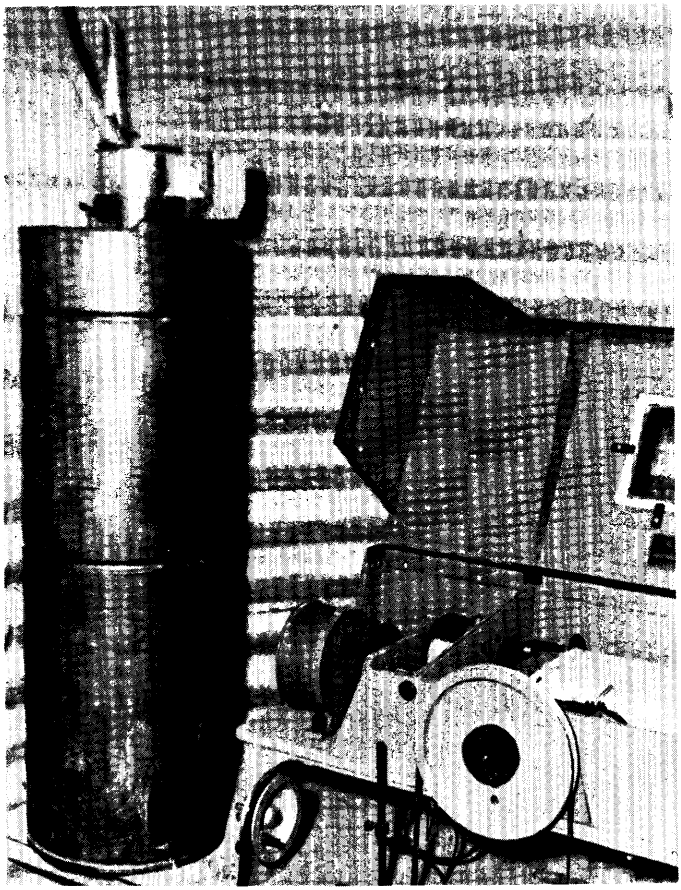

FIGURE 34.—Arrangement of instruments at left end of shelf in recorder shelter.

of transparent garden hose, and the tipping-bucket attachment was fastened to the collar. After the attachment was leveled, it was calibrated with the 8-inch receiving can in place on the instrument shelf. Then the counter and marking-pen unit was installed in the Stevens recorder, and wiring to the battery and tipping-bucket unit was completed.

SIMPLIFIED METHOD OF ALTIMETER SURVEYING

By Roy Newcome, Jr.

ABSTRACT

Altimetry is an inexpensive and time-saving substitute for spirit-level surveys that do not require extreme accuracy. A one-instrument method, in which readings at successive stations are made within small intervals of time, has been observed to provide a general accuracy within 2 or 3 feet.

INTRODUCTION

Altimetry is a useful tool for hydrologists in regions lacking adequate topographic maps. In many investigations it is not expedient, financially or timewise, to make spirit-level traverses. Also, the great accuracy obtained in spirit leveling commonly is not required.

Several methods of altimeter surveying are in use, but most of them require two or more instruments, and tedious calculations and corrections. The purpose of this discussion is to describe a method of altimeter surveying that requires only one instrument and a minimum of calculation. Altitudes determined by this method approach in accuracy those provided by the more complicated procedures. An average error of only 2 to 3 feet and a maximum error of 6 feet were noted during use of the method for 5 years in gently rolling to rough country in Tennessee.

METHOD

Following is the procedure found satisfactory by the writer. A calm clear day is chosen when possible. Gusty days or days when the sun is "in-and-out" and temperature changes are sudden should be avoided. Best results are obtained if the work is done between 9 a.m. and 4 p.m., as the effects of convection are least during that period of the day.

The altimeter is read at or near the bench mark, care being taken to place it in a level position in a shaded place. After allowing time for the altimeter to overcome any lag due to recent changes in altitude, the instrument is read 3 or 4 times at 3- or 4-minute intervals. During this period a thermometer is suspended in an open place out of the sun and some distance from the earth or any other body likely to interfere with the temperature and circulation of the air. A temperature reading is taken and recorded, along with the time of the reading. Reliable air-temperature readings can be obtained while driving by holding the thermometer outside a window on the shady side of the car.

Not more than 10 minutes should elapse between readings at successive stations. If it is not possible to go from the base bench mark to the point for which the altitude is to be determined in 10 minutes, readings should be taken at an intermediate point. This has the effect of moving the bench mark nearer the unknown point. As many intermediate points as desired may be visited, provided they are revisited on the return leg of the traverse. The traverse may be terminated at a bench mark other than the one from which the traverse started. The readings at the termination must be adjusted for the difference in altitude between the two bench marks.

When a traverse is completed, two corrections must be applied to the altimeter readings in order to obtain the correct altitude. The first correction made is the temperature correction. As most altimeters are constructed to yield accurate pressure readings only when exposed to an air temperature of 50° F, it is necessary to make corrections when the air temperature is above or below 50° F. For this purpose, a temperature-correction chart (fig. 35) constructed by Rogers (1947) is used.

Vertically, the chart is divided equally into eight sections representing 100 feet each. These are in turn divided into 10 units representing 10 feet each. The altitude of the base bench mark is set opposite the middle horizontal line. Subsequent altimeter readings are marked on the vertical scale with relation to the first reading. A sliding scale may be constructed as an aid in this step.

Horizontally, the chart is divided equally into five sections, each representing 10° F. The curved lines on the chart are obtained by use of the formula $xy=1$, $xy=3$, $xy=5$, and so on. The spaces between the curved lines on each half of the chart are numbered consecutively from 1, away from the middle horizontal line. The lines representing an altimeter reading and the temperature of the air at the time of that reading intersect at a point on the chart. The number of the section in which the point falls is the number of feet to be applied to the altimeter reading to compensate for the difference between the air temperature and 50° F. For temperatures above 50° F the corrections are positive on the upper half of the chart and negative on the lower half. If the correction is positive it is added to the observed barometric reading; if negative, it is subtracted. For temperatures below 50° F the signs of the chart are reversed. For this reason, the temperature headings at the top are 50°, 40°, 30°, 20° F, and so on.

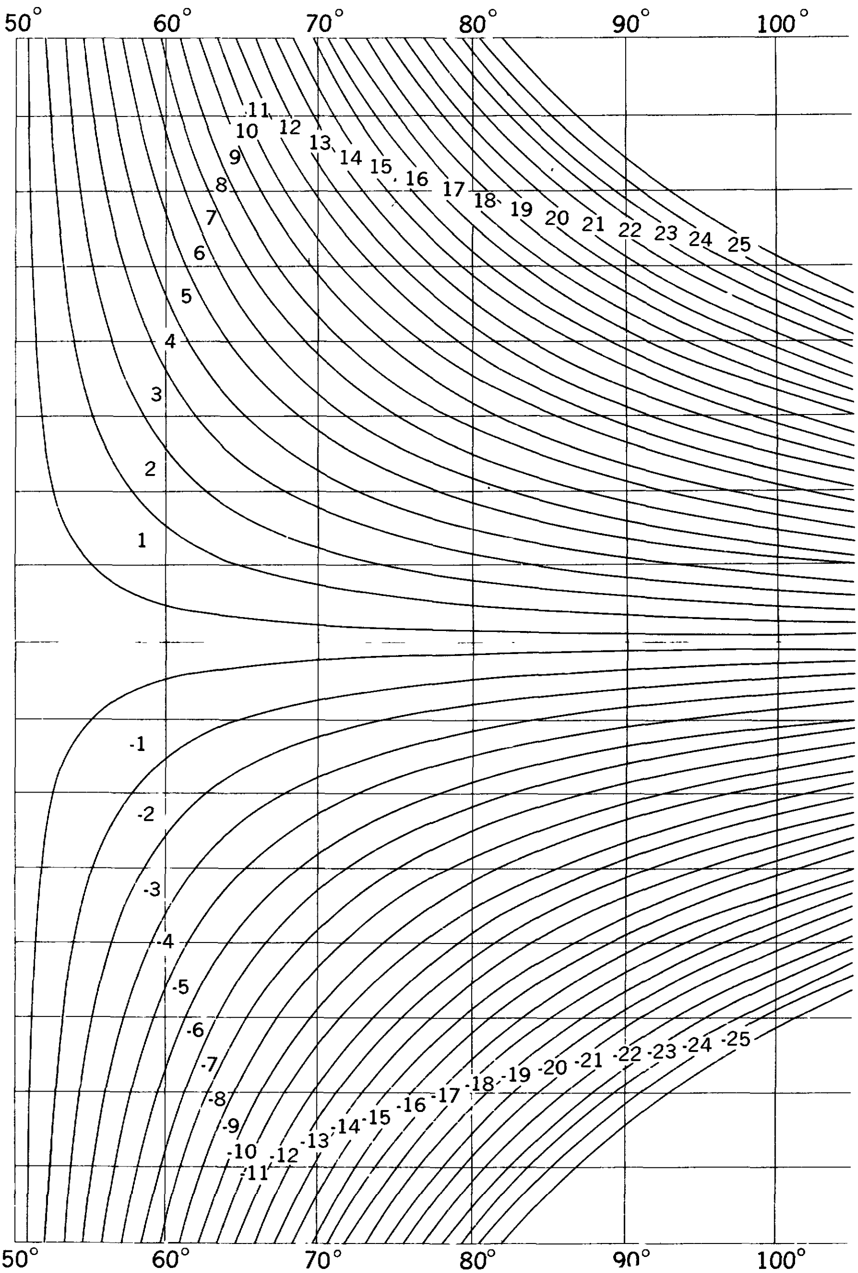

FIGURE 35.—Chart for temperature correction of altimeter readings. From Rogers (1947).

The chart in figure 35 shows that at a temperature of 50° F there is no correction regardless of differences in altitude and that for points having the same altitude as the bench mark, there is no correction regardless of the temperature.

After applying the temperature correction to the altimeter readings, the readings are plotted against time on graph paper in order to determine the barometric correction. Figure 36 is a typical traverse in which the altitude for only one well is determined.

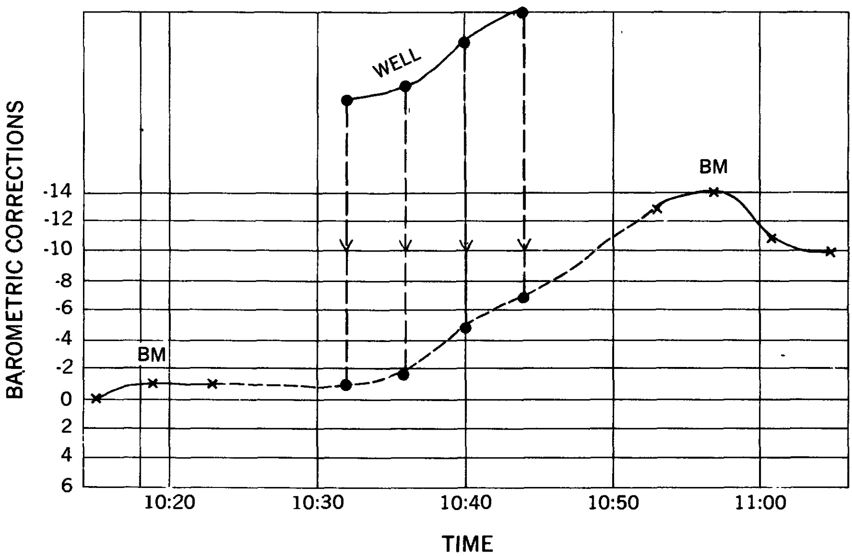

FIGURE 36.—Barometric-correction graph for one-well traverse.

In plotting the altitudes, the first reading taken at the bench mark is the datum for the other bench-mark readings. Thus it is assumed as the line of no correction and may be labeled "0." As subsequent bench-mark readings already have had temperature corrections applied to them, the amount that any reading lies above or below the "0" line is the barometric correction that must be applied to that reading to make it equal the known bench-mark altitude. The correction is negative if the reading is above the "0" line and positive if below it.

In plotting the well readings on the barometric-correction graph it is necessary only to locate the points on the proper time lines and in the correct relationship to one another, as they are moved arbitrarily up or down the time lines in order to fit into the barometric curve of the traverse. It is upon the "fit" of the well-reading curve with the barometric curve that the accuracy of the traverse depends. The first step is to draw a smooth curve that passes through the bench-mark readings. The slope of the curve between the two sets of bench-mark readings indicates the fluctuation of barometric pressure in that interval of time. It is then generally a simple matter to fit the well-reading curve into the barometric curve by sliding it up or down the time lines. At this point the barometric correction for any time on the traverse may be taken from the graph and applied to the altimeter readings already corrected for temperature deviation.

Each altimeter user will probably develop his own form of note keeping. The one shown as table 1 has proved convenient for this writer.

TABLE 1.—*Notes for graph in figure 36*

February 14, 1952
Weather clear

Bench mark: U.S. Coast and Geodetic Survey, 2327; altitude, 663.743 feet

Station	Time (a.m.)	Temperature (° F)	Altimeter reading (feet)	Temperature correction (feet)	Corrected altimeter reading (feet)	Barometric correction (feet)	Altitude (feet)
BM [1]	10:15	62	664	0	664	−0	664
BM	10:19		665	0	665	−1	664
BM	10:23		665	0	665	−1	664
Well	10:32	62	778	+3	781	−1	780
Well	10:36		779	+3	782	−2	780
Well	10:40		782	+3	785	−5	780
Well	10:44		784	+3	787	−7	780
BM	10:53	64	677	0	677	−13	664
BM	10:57		678	0	678	−14	664
BM	11:01		675	0	675	−11	664
BM	11:05		674	0	674	−10	664

[1] Bench mark.

Several altitudes can be determined in a single traverse if the points are visited in a sequence that permits for each point the drawing of a barometric curve that can be fitted logically into the curves for the other wells. This is illustrated in figure 37.

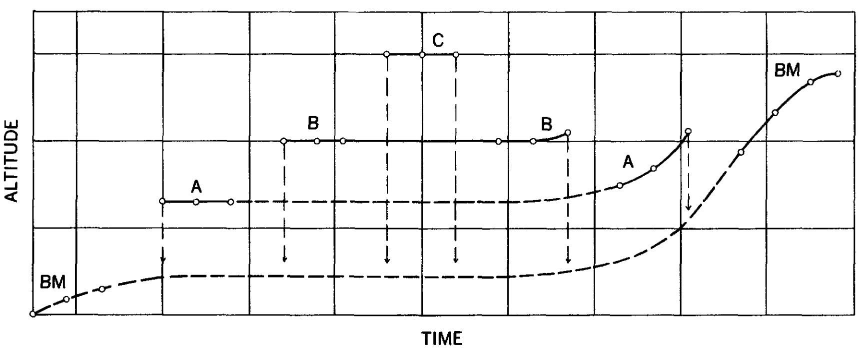

FIGURE 37.—Barometric curve for multiple-well traverse.

PRECAUTIONS TO BE OBSERVED IN MAKING ALTIMETER SURVEYS

Not all barometric curves plot as smoothly as those shown in figures 36 and 37. It is not unusual to obtain erratic or inconsistent curves for one or more of the following reasons: Unfavorable weather conditions, sticking of the altimeter needle, local warm or cold air currents, vibrations, and haste by the operator in taking readings.

The following is a list of suggestions, or precautions, that should aid in obtaining a reasonable percentage of good altitude determinations.

1. Use an altimeter that is checked frequently for instrument errors; use the same instrument for all work, if possible.
2. Run altimeter surveys only during calm weather and not during hours when the earth and air are being heated or cooled rapidly.
3. Use care in taking temperature readings; the thermometer should be in the shade and where air can circulate freely around it.
4. Allow time for altimeter to settle down after reaching a new station; be sure needle is free.
5. If readings at a station contradict one another, take a few more to define the trend.
6. The less time that elapses between visits to different stations, the more accurate the survey.
7. In plotting the barometric curve, discount points that are obviously erratic and draw a logical curve through the consistent points.

When starting an altimeter traverse, the instrument can be set to read the initial bench-mark altitude, or it can be locked in a permanent position and the difference between the first reading and the bench-mark altitude applied to all readings of that traverse. An advantage of the latter method is that it requires one less manipulation of the instrument.

SELECTED REFERENCES

Buckmaster, J. L., and Mears, A. H., 1958, Instrumental improvements in altimetry: U.S. Geol. Survey Circ. 405, 33 p.

Demler, L. E., 1950, Altimetry—its present-day techniques: Belleville, N.J., Wallace and Tiernan Products, Inc., 10 p.

Hill, R. A., 1929, Preliminary survey procedure: Los Angeles, Calif., American Paulin System, Inc.

Lahee, F. H., 1941, Field Geology: 4th ed., New York, McGraw-Hill, 853 p.

Rich, J. L., 1934, Corrections for temperature in barometric surveying: Am. Assoc. Petroleum Geologists Bull., v. 18, no. 1, p. 133–138.

Rogers, J. K., 1947, Temperature corrections in altimeter surveying: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 2, p. 370–374.

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