Selected Techniques in Water Resources Investigations, 1965

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1822

Selected Techniques in Water Resources Investigations, 1965

Compiled by GLENNON N. MESNIER *and* EDITH BECKER CHASE

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1822

Papers on new techniques by J. S. Bader, R. N. Cherry, O. J. Cosner, J. H. Criner, M. J. Fishman, J. R. George, H. P. Guy, N. R. Harmon, E. R. Hedman, L. S. Hughes, E. J. Kennedy, F. A. Kilpatrick, R. A. LeBlanc, E. D. Lucero, W. T. Miller, C. G. Mitchell, J. C. Mundorff, W. D. Peterson, D. Pettengill, R. J. Pickering, J. P. Richardson, W. D. Robbins, G. W. Sandberg, P. R. Seaber, R. J. Smith, L. G. Toler, J. Vecchioli, J. W. Wark, and H. B. Wilder

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1966

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

Library of Congress catalog-card No. GS 66-205

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 45 cents (paper cover)

CONTENTS

SELECTED TECHNIQUES IN WATER RESOURCES INVESTIGATIONS, 1965

COMPILED by GLENNON N. MESNIER and EDITH BECKER CHASE

INTRODUCTION

Increasing world activity in water-resources development has created an 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 on discovering 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 published accounts of this progress. In 1963 the Geological Survey published "Selected Techniques in Water Resources Investigations" (Water-Supply Paper 1669–Z) as part of the series "Contributions to the Hydrology of the United States." The report was so favorably received that successive volumes are planned, of which this is the first.

The present report contains 25 papers that represent new ideas being tested or applied in the hydrologic field program of the Geological Survey. These ideas range from a proposed system for monitoring fluvial sediment to how to construct stream-gaging wells from steel oil drums. The original papers have been revised and edited by the compilers, but the ideas presented are those of the authors. The general description of the bubble gage on page 2 has been given by the compilers as supplementary information.

THE BUBBLE GAGE—GENERAL DESCRIPTION

The bubble gage was developed by the Geological Survey for making a continuous record of the evaluation of a water surface. The bubble gage measures the elevation of a water surface by sensing pressure above an orifice submerged in the body of water of which the elevation is being determined. Pressure head of water at the orifice is transmitted by a gas-purge system, through flexible polyethylene tubing, to a servomanometer that operates a continuous water-stage recorder. Nitrogen gas from a storage cylinder in the recorder shelter feeds into the pressure system and bubbles slowly from the sensing orifice. The pressure at the orifice, and hence in any part of the system, is related to the head or depth of water over the orifice.

The bubble-gage eliminates the stilling well needed for operation of conventional float-operated water-stage recorders and substitutes the flexible pressure tubing for the more costly intake pipes. Because the gas-purge pressure system is open to the atmosphere, the problems found in many older types of closed pressure systems for measuring and transmitting water-surface elevations have been eliminated.

The gage structure for a bubble gage can be a simple shelter (to house the servomanometer, the water-stage recorder, and the nitrogen gas cylinder) placed so the flexible pressure tubing can be run to the point for which the record of water-surface elevation is needed. Elimination of a stilling well and of rigid intake pipes reduces the cost of building the gage structure, and gives a wide choice of sites at which a recording gage can be located. Because of the flexible tubing the orifice can be moved readily if the streambed or channel shift, and even the entire gage installation can be moved at nominal cost.

The bubble gage is described in more detail by E. G. Barron in U.S. Geological Survey Water-Supply Paper 1669–Z. Solutions to problems that have occurred in actual field operation of the bubble gage are given in the present report by E. J. Kennedy (p. 3) and W. D. Robbins (p. 10).

ENCLOSED BUBBLE-GAGE ORIFICE SYSTEMS

By Edward J. Kennedy

ABSTRACT

Excellent records of stage of streams whose channels are subject to severe scour and fill can be obtained by using bubble gages equipped with enclosed orifice systems. An enclosed orifice system consists of a probe which contains an orifice, a well screen, and a flushing device, and a minature stilling well above the probe. The bubble gage measures variation in hydrostatic pressure of ground water at the probe near the stream. The measured changes in ground-water head are virtually identical to variations in stream stage where geologic conditions are favorable. Where conditions are unfavorable, the orifice system can sometimes be modified to collect adequate records.

BUBBLE GAGE

A bubble gage for recording river stage uses gas forced slowly through an orifice at a fixed underwater location. Pressure necessary to bubble the gas is directly proportional to head of water over the orfice. That pressure is measured by a self-balancing mercury manometer. Manometer displacement is registered in units of gage height on a recorder. The operation of the bubble gage was described by Barron (1963, p. Z4–Z9). The unique ability of the bubble gage to measure water-surface elevation inside an extremely small well is the principal feature that permits use of the orifice system described here.

CONVENTIONAL STILLING WELLS

Most gaging wells designed for use with float-operated water-stage recorders are at least 36 inches in diameter to permit entry for maintenance. Free transfer of water between stream and well, usually by intake pipes, is vital to satisfactory gaging operation. Scour and fill of stream channels often make intakes impractical because the pipes are alternately covered with bed material or left dry above the water surface. Sometimes, under favorable circumstances, such wells can be operated satisfactorily by seepage of water through the bed material between stream and well. These wells are subject to a certain amount of lag in time before water-surface elevations inside the well and in the stream equalize. Lag may be large or small depending on such factors as rate of change of stage, surface area of well, permeability of bed material, and distance from well to stream.

MINIATURE STILLING WELLS

Surface area of a circular stilling well varies with the square of its diameter. A 1-inch well has only about $\frac{1}{1300}$ the surface area of a 36-inch well and all other factors being the same, would have only $\frac{1}{1300}$ of the lag of the larger well. Wells as small as one-half inch in diameter can be used with bubble gages.

The principal element of the enclosed bubble-gage orifice system is the probe. The probe, basically an intake for a miniature stilling well, is installed near or under an alluvial streambed. Details of a typical probe and orifice are shown in figure 1. The components are mostly $1\frac{1}{4}$-inch pipe and standard fittings.

Water enters and leaves the probe through a well screen whose mesh dimensions are not critical. Plastic or stainless-steel well screens are less prone to clog than the more common bronze screens. However, some polyethelene orifices become sealed in a few months by buildup of bacterial deposits. Copper tubing is not similarly affected. A much simpler orifice and screen than that shown in figure 1 might be satisfactory in some streams.

The part of the probe between the well screen and the pipe cap is a return pipe for flushing. (See fig. 1.) To flush the probe a pitcher pump is substituted for the pipe cap, and water is pumped slowly from the well until the discharge is clear. Flushing is rarely necessary where probes are buried deeply enough to remain covered at all times. The flushing procedures is a simple and excellent test of communication between river and probe as well as an effective way to flush both the well screen and the bed material near it.

The joints in the well pipe should be water tight to prevent entrance and circulation of unfiltered river water. The pipe must also serve as an escape patch for gas purged by the bubble gage. The gas carries away moisture that otherwise would condense inside the pipe, and might freeze and cause back pressure and faulty record. The problem is most serious in wells smaller than $\frac{3}{4}$ inch in diameter.

Antifreeze, usually kerosene, is poured into both sides of the U-shaped probe (fig. 1) for winter operation. The orifice must be below the bottom of the floating kerosene column to avoid nonlinear datum

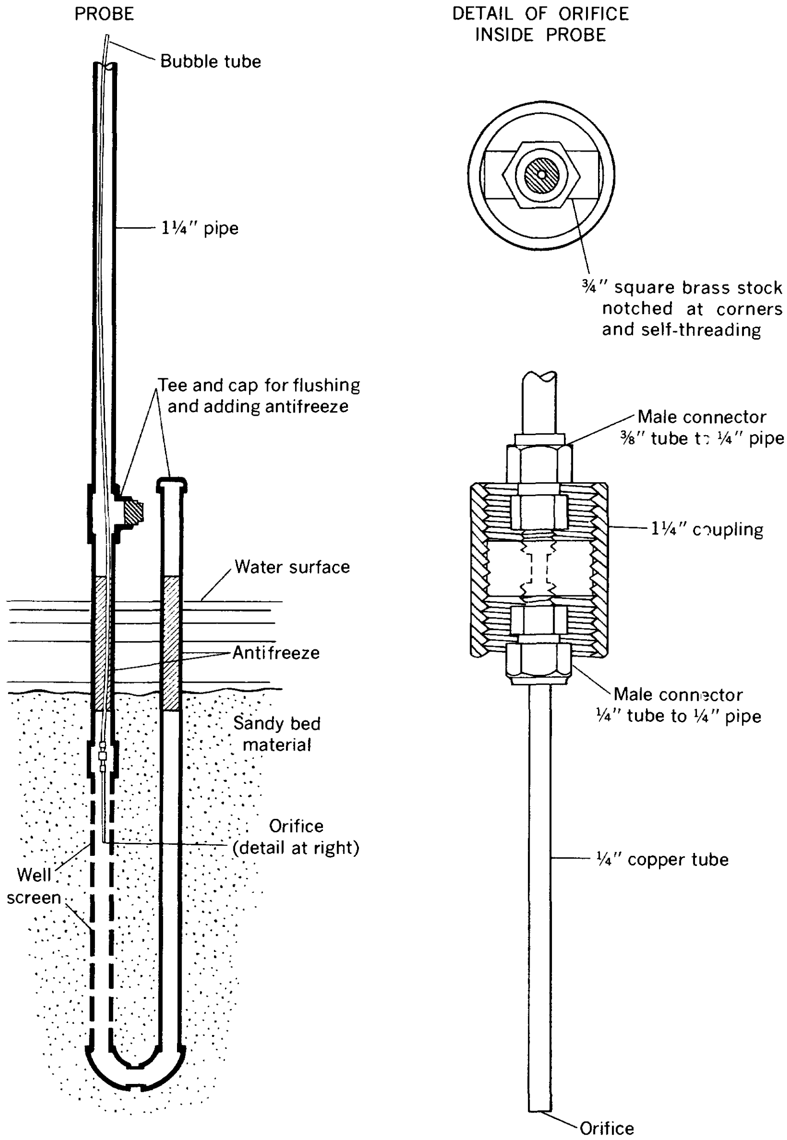


FIGURE 1.—Details of probe and enclosed bubble-gage orifie.

errors. This position is obtained by keeping the orifice below the top of the well screen openings. Excess kerosene will escape through the well screen into the bed material.

LOCATION OF PROBE

A convenient location for a probe is at the downstream side of a bridge pier. The pier makes a firm and protected support. A probe can usually be buried deeply by jetting, and it is not seriously affected by drawdown and turbulence behind a pier. Figure 2*A* illustrates such an installation in its simplest form. Deep burial (3–10 ft) is not always practical. Shallower probes are usually placed in a nearly horizontal position similar to the one in the typical bank installation shown in figure 2*B*. A pier installation requires the shortest length of watertight pipe because it need only extend to the pier top. A bank installation generally uses pipe, rather than light conduit, all the way to the shelter and consequently costs more to build. Firm anchorage of at least the lower end of the intake pipe is vital. Vertical movement of the probe causes a datum error in the stage record. Earth anchors screwed deeply and firmly into the bed material are excellent supports for probes and pipes. In rocky material, steel fence posts make satisfactory anchors. Heavy U-bolts can be used for rigid connection of pipe to anchors. Gradient of a well installed on a bank must provide for drainage of condensate and other water from the pipe so that the escape path for purged gas will not become blocked.

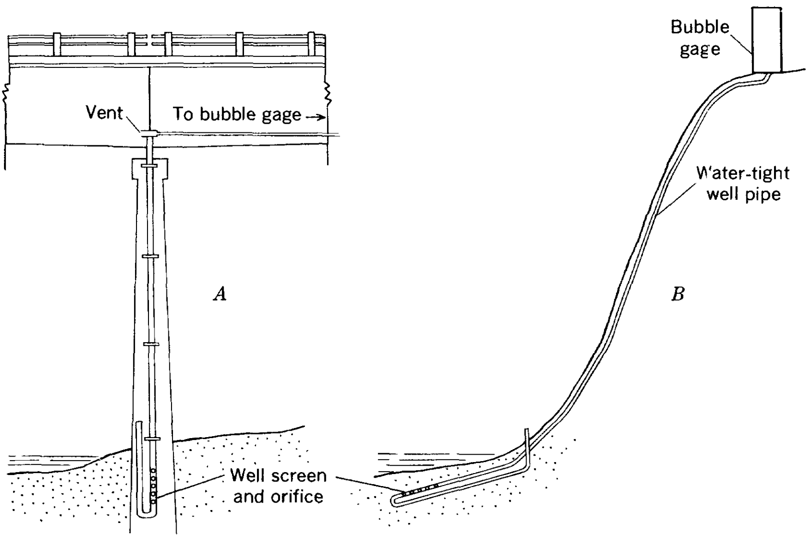


FIGURE 2.—Typical installations of an enclosed orifice bubble-gage system. *A*, Pier installation; *B* bank installation.

GEOLOGY AND GROUND-WATER CONSIDERATIONS

The gage measures ground-water head at the probe which may or may not vary directly with stream stage. If the ground water moves with appreciable velocity, a corresponding hydraulic gradient is present. If the gradient, distance from probe to streambed, and duration of water movement are large, the relation of aquifer head to surface-water head may not be equivalent for long periods of time.

The geology of the deposits underlying a gage site is the most important factor affecting accuracy of records obtained from enclosed orifice systems. Conditions are best where bank storage is least and permeability of bed material is high. A channel cut deeply in a deposit containing material of low permeability overlain by material of relatively high permeability provides ideal conditions for installation of an enclosed orifice system. Such a site is illustrated in figure 3*A*. A probe located almost any place in the sand would perform well. A similar channel in clay without the overburden of higher permeability requires some modification of the site. Material around the probe

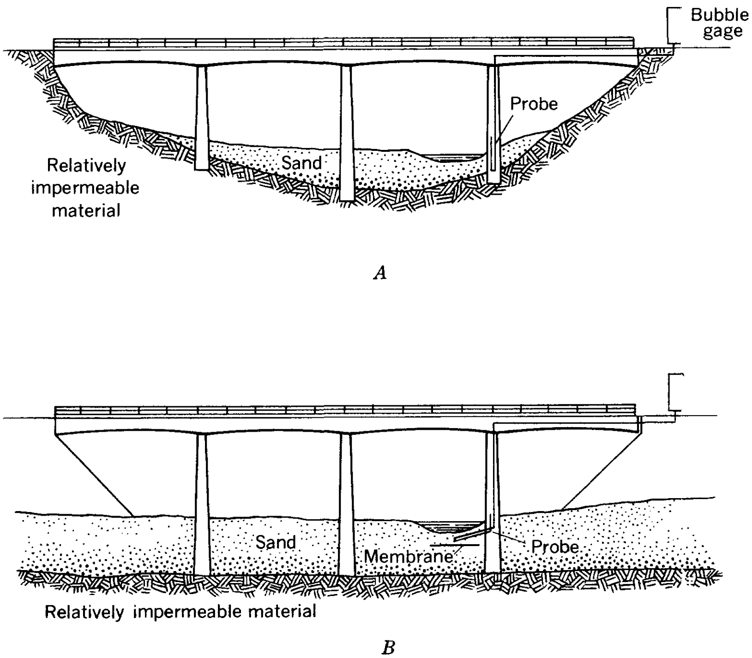


Figure 3.—Examples of (*A*) favorable and (*B*) unfavorable geologic conditions for use of enclosed orifice system.

can be excavated and replaced with sand. If the clay is extremely tight, a sand-filled trench across the stream may be necessary.

Figure 3*B* illustrates a channel in a wide sandy valley. Storage capacity is large in the wide aquifers bordering the channel. Each change in river stage is accompanied by substantial ground-water movement for long periods of time as the stream is alternately influent or effluent. Records collected using a probe of usual design and location would be dubious. At such sites, recorded graphs are usually similar in shape to those based on outside gage readings but fluctuations are seriously dampened in magnitude. A rise and fall of 3 feet in river stage may be recorded as only a 2-foot rise and fall, yet recorded time of peak will be correct. To minimize such error, several techniques may be used. The downward movement and most of the horizontal movement of ground water, with resulting head loss, may be stopped by concrete slabs, plastic membranes, or metal containers under the probe. Varying degrees of success for varying lengths of time may be expected. An extremely shallow position for the probe and frequent flushing might be considered a more practical solution to this problem by operating personnel.

Streams underlain by alternate layers of permeable and impervious material are the most difficult to gage with the enclosed orifice system. Each layer can have an artesian head substantially different from that of its neighbors. None is likely to have head variation very closely related to change in river stage. Probes used at these sites should be nearly horizontal and within inches of the streambed.

CONCLUSIONS

The enclosed bubble-gage orifice system has merit where geologic conditions are favorable. It is also worthy of consideration where open bubble-gage orifices in streams are adversely affected by high velocity or turbulence or where ice and debris damage is common.

Where geologic conditions are somewhat less favorable, other considerations are applicable. Most stage records are collected to use in computing discharge data. The stage-discharge relation for a scouring-and-filling alluvial channel is rarely stable. A stage record that contains errors no larger than the usual amount of rating shift between successive discharge measurements is adequate for computing discharge.

When geologic conditions are definitely unfavorable, the enclosed orifice system should be considered with serious reservations and in the light of possible alternatives. However, ingenuity and resourcefulness are vital ingredients in adapting new equipment to unusual conditions.

LITERATURE CITED

Barron, E. G., 1963, New instruments for surface-water investigations, *in* Mesnier, G. N., and Iseri, K. T., compilers, Selected techniques in water resources investigations: U.S. Geol. Survey Water-Supply Paper 1669–Z, p. Z1–Z12.

PURGING BUBBLE-GAGE ORIFICE LINE WITH SELF-CONTAINED AIR-PRESSURE SPRAY CAN

By Wallace D. Robbins

ABSTRACT

A satisfactory solution to the problem of removing oil, moisture, or other foreign material from bubble-gage orifice lines has been devised. The procedure makes use of an inexpensive commercial self-contained air-pressure sprayer adapted to connect directly to the orifice line. Volatile organic solvents are sprayed into the line to clean it.

INTRODUCTION

In the operation of bubble gages, oil, water, or other foreign material very often become trapped in the polyethlene tubing between the sight feed and the orifice. This material clogs the tube and causes pressure to build up in the line. When the pressure becomes great enough to move the material and unclog the line, gas will begin escaping, and as the pressure is reduced foreign material will again clog the line. This alternate clogging and unclogging of the line produces an abnormal condition at the manometer. This condition can usually be detected by examining the strip chart which will show an abnormal fluctation, or false surge caused by the manometer pressure-sensing system. One of the solutions to this problem is to purge the orifice line with volatile organic solvents such as lacquer thinner or white gasoline.

DESCRIPTION OF SPRAY CAN

An inexpensive self-contained air-pressure spray can may be used in purging the orifice lines. This can may be purchased from automotive- or janitor-supply dealers, and can easily be adapted for this purpose. Figure 1 shows the difference in the pressure spray can as purchased commercially and as altered for use on orifice lines. The can on the left (before) has a small factory-built spray nozzle

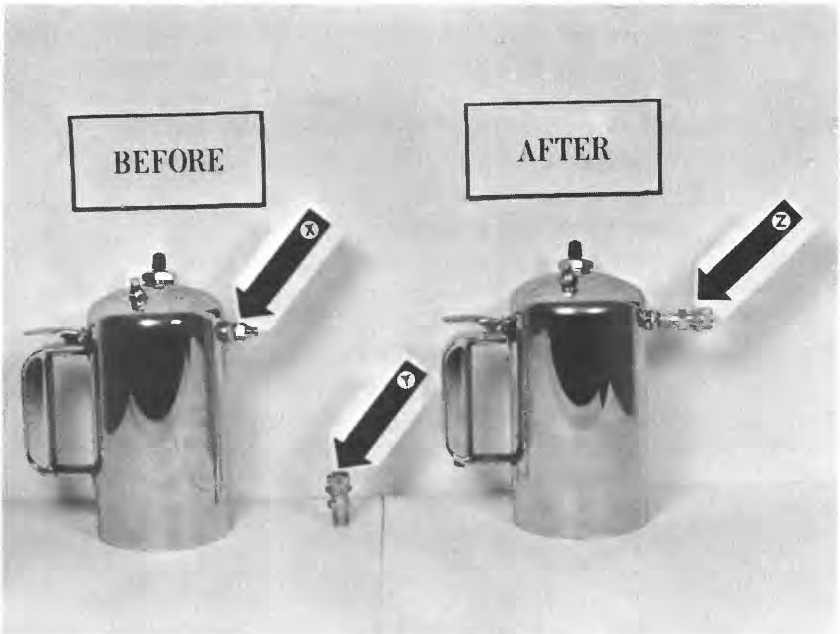


FIGURE 1.—Self-contained air-pressure spray can before and after alteration for use on orifice lines. *X*, Factory-built spray nozzle; *Z*, nozzle altered to attach directly to the orifice line; *Y*, 3/8-inch brass tube fitting.

(*X*); the can on the right (after) has been altered at point *Z* to attach directly to the orifice line. A 3/8-inch brass tube fitting (*Y*) can be tapped and threaded to screw directly to the existing fitting on the spray can after removing the spray nozzle.

PURGING PROCEDURE

Recommended field procedure when purging is necessary is as follows:

1. Pour about one-half cup of lacquer thinner or white gasoline into the spray can.
2. Fill the spray can with air from a service-station pump or with gas from the bubble-gage supply.
   - A. If service-station air supply is used, remove the valve cap from the top of the can and inject air at this point.
   - B. If service-station air supply is not available, pressure can be obtained from the bubble-gage gas supply by the following method: (a) close the sight-feed needle valve; (b) close the feed-pressure adjustment screw; (c) remove the polyethlyene brass tube connecting the regulator and sight feed,

and screw the tube directly to the spray can; (d) open feed-pressure adjustment screw to about 55 pounds, press down on spray-can trigger and allow pressure between regulator and spray to equalize; (e) release trigger, close feed-pressure adjustment screw, and remove spray can from the line.

3. When the spray can has been filled, take the following steps:
   A. Attach spray can directly to orifice line and spray contents of pressure can into orifice line.
   B. Remove spray can from orifice line, and hook orifice line directly to pressure regulator (bypass sight feed).
   C. Release gas directly into orifice line, setting pressure adjustment screw on regulator at about 55 pounds, and let it run for 2–3 minutes. This procedure will dry any remaining lacquer thinner or gasoline from orifice line.
   D. Reinstall all tubes and connections in working order. (Note: Care should be taken when opening feed-rate adjustment needle that more oil is not blown into the line.)

This procedure takes 5–10 minutes. Usually it will take another 5–10 minutes before bubbles begin to come out of the orifice.

STREAM-GAGING EQUIPMENT FOR HIGH ALTITUDES

By Wallace T. Miller and Joe P. Richardson

ABSTRACT

Reliable gage-height records and stable stage-discharge relations were obtained from stream-gaging stations at high altitudes during severe winter weather. A bubble-gage water-stage recorder driven by a negator spring was used to eliminate the problem of frozen stilling wells and intakes. The stream controls, either artificial or natural ones, were covered and heated to keep them free of ice.

INTRODUCTION

There are 90 gaging stations in Colorado above an altitude of 8,000 feet; 19 of these are above 9,000 feet and 1 is above 10,000 feet. It is practically impossible to operate many of these stations with conventional stream-gaging equipment during the severest part of the winter season because of inaccessibility or extremely low temperatures. Lack of accurate winter records at such high-altitude stations has not been considered serious because only 10–15 percent of the annual runoff occurs during this period and variation in flow is small. However, most of the storage sites at low altitudes in Colorado have been developed and additional storage reservoirs must be at high altitudes. Consequently, the need for better and more complete streamflow records at high altitudes is increasing.

During the summer of 1960 the Watershed Management Unit, Colorado State University, began a comprehensive study in the South Fork Cache la Poudre basin. Accurate streamflow records, complete for all of the year, at altitudes above 9,000 feet were desired.

SELECTION OF SITES

The Colorado Water Conservation Board cooperated in installing and operating 3 gaging stations. Two of the sites selected are on Little Beaver Creek, one at 10,000 feet (drainage area 1.8 sq mi),

796-504 O—66——2

and the other at 8,350 feet (drainage area 13 sq mi). The third station is on Fall Creek immediately below a large beaver pond at 9,770 feet (drainage area 3.7 sq mi).

PROBLEMS

The basic problems at any stream-gaging station are to be able to obtain a continuous gage-height record and to have a stable relation between stage (gage height) and discharge. At high altitudes, gage-height records are difficult to obtain because conventional stilling wells and intakes freeze. Accumulation of snow and ice on the stream controls (either natural riffles or artificial-control structures) disrupts the stage-discharge relation.

To obtain the gage-height records needed the plan finally adopted was to use bubble gages driven by negator springs. The bubble gage does not need a stilling well because it operates without a recorder float. Intake pipes are not needed because a gas-filled tube, that will not freeze, running out to the stream serves as the intake. The recorder is driven by a negator spring instead of by clock weights, which must have a well in which to travel downward; the use of the negator spring eliminates a secondary need for a stilling well.

On small streams, gaging stations are ordinarily located upstream from a well-defined riffle that will act as a stage-discharge relation control and also form a pool in which the intake can be placed. At sites where a suitable natural riffle cannot be found, an artificial control—some type of flume or low dam—is built. At two of the stations discussed here artificial controls were built, and at the third a natural riffle acts as the stage-discharge control.

The stream controls were protected from snow and ice by building roofs or covers over them, using propane heaters under the covers, and hanging curtains from the covers to keep the heat in. The heating system was adapted by the senior author from a system devised by the U.S. Forest Service for heating stilling wells in the Fraser Experimental Forest.

A secondary but important problem with stations at high altitudes is accessibility. The upper Little Beaver Creek site is 0.8 mile from the nearest road or trail. An access road suitable for jeeps or trucks was built; the road was graded with a D–4 dozer to the grade and alinement established by the Forest Service. The other two sites are accessible by improved roads.

SHELTERS FOR WATER-STAGE RECORDERS

The instrument shelter used on upper Little Beaver Creek is about 4 feet square and 8 feet high, and is made from sheet metal. This installation is shown in figures 1 and 2.

FIGURE 1.—Stream-gaging station at upper Little Beaver Creek site with winter cover removed from the artificial control. Instrument shelter is in the background. V-notch is in place in the Parshall flume.

Shelters for the water-stage recorders on lower Little Beaver Creek and Fall Creek are made from 6-foot sections of 42-inch diameter corrugated galvanized-metal culvert pipe and have conical metal roofs. The shelter on Fall Creek is shown in figure 3.

CONTROLS AND COVERS

A 4-foot Parshall flume was installed at the upper Little Beaver Creek station. A removable steel plate with a 90° V-notch was installed in the flume at the throat to increase the accuracy at low flows and to create a deeper pool over the orifice in case an ice cover should form that far upstream from the weir plate (fig. 1). The plate is $\frac{5}{16}$-inch steel, 18 inches high, and the bottom of the notch is 0.52 foot above the floor of the flume. The plate was bolted to a removable angle iron frame attached to the flume. The entire V-notch assembly can be removed easily, even during high flows. However, it is planned to remove it each year before the spring high water.

FIGURE 2.—Stream-gaging station at upper Little Beaver Creek site with V-notch plate removed from the artificial control and one panel of the cover in place over the control.

FIGURE 3.—Stream-gaging station at Fall Creek site. Cover is in place over the natural rock control.

The cover for the artificial control of the upper Little Beaver Creek station is formed of panels 32 inches wide and 5 to 7 feet long, laid side by side across the flume. Framing for each panel consists of three 2- by 6-inch planks running lengthwise on 16-inch centers with a 2- by 6-inch member spiked across each end. A layer of 65-pound roll roofing was laid on top of the framing, next 1-inch thick wooden sheathing was nailed in place, and then a layer of 65-pound roll roofing was put on top of the sheathing to complete the panel. The panels can be installed or removed readily. Heavy canvas curtains attached to the upstream and downstream ends of the cover form an enclosure for the flume. The bottom edges of the curtains are attached to a pole to hold them in place. A stock tank-type butane burner costing $17 is attached to the underside of the upstream cover panel. The burner is described in the sales catalog as a "15-inch burner with safety shut-off and shield"; it is not thermostatically controlled but is equipped with a shut-off valve that will close automatically if the flame is extinguished. The burner is supplied from a 300-gallon storage tank equipped with a gage graduated in percentage of tank capacity.

A self-cleaning concrete artificial control (fig. 4) was constructed at the lower station on Little Beaver Creek. The floor of the flume is 10 feet long and 16 feet wide. The flume is 20 feet wide at the top of the 4-foot walls. There is an ogee drop in the floor of the flume. The crest of the ogee section is a gentle V. Width of the flume at the top of the ogee crest is 17.13 feet, and elevation of the crest drops from 1.15 feet above the floor at the walls to 0.3 foot above the floor in the center of the flume, which is the bottom of the V.

The cover over this control consists of three steel ceiling joists 21 feet long set across the walls of the control on about 5-foot centers (fig. 5). These joists are the type commonly used in concrete building construction for floor or ceiling joists. Joists are available for various spans and loadings, and it is a simple matter to compute the load and select the proper joists.

Wooden panels 3 by 10 feet, similar in construction to those just described for the upper Little Beaver Creek station, were placed over the steel joists. Heavy canvas curtains were hung at the upstream and downstream ends of the cover.

The heating unit at this station is a 12,500 Btu radiant propane burner equipped with a 100-percent shutoff valve, self-generating pilot light, and an automatic temperature gage (thermostat) that ranges from 0° to 70° F. (See fig. 5.) The cost of this burner was $275. It is supplied from a 500-gallon storage tank that has the same type of meter as the one at the upper station. The burners, canvas aprons,

FIGURE 4.—Self-cleaning concrete artificial control at lower Little Beaver Creek site with cover removed.

and covers at both stations are removed before the spring runoff. High flows at this station can be measured from a footbridge temporarily constructed at the upstream edge of the apron from two of the joists braced together and two of the cover panels laid lengthwise on top for a floor.

The Fall Creek station is at an excellent natural rock control about 10 feet downstream from a Forest Service deck bridge. The control is in the shape of an irregular U and is 2½ to 3 feet high and 3 to 7 feet wide. There is a deep pool under the bridge, ideal for the bubble orifice.

Natural conditions are quite favorable at this location and it was decided not to install a heater, so comparisons could be made between the heated and unheated installations. However, a cover and canvas curtain similar to those at the other two stations were installed (fig. 3).

Because conditions at the bridge were poor for making accurate discharge measurements, a shore-operated cableway was installed at an excellent cross section a short distance downstream. With this equipment the current meter is suspended from a carrier riding on the main cable. The operator on the shore can move the carrier to any position and raise or lower the meter at will.

FIGURE 5.—Concrete flume used for the artificial control at lower Little Beaver Creek stream-gaging station. Cover is in place but roofing material and canvas curtains have not been installed. Note propane burner attached to underside of joists.

COST OF INSTALLATION AND OPERATION

Installation costs are itemized in table 1. As expected, installation costs were substantially greater than for an average gaging station on streams of this size. Annual operating costs are about $1,700 for each station.

TABLE 1.—*Installation costs*

Item	Fall Creek	Little Beaver Creek	
		Upper station	Lower station
Materials:			
Gage	$1, 380	$1, 590	$1, 370
Control	80		175
Parshall flume		265	
Cable, shore-operated	120		
Cover and heater equipment		115	505
Access road		900	
Supervision: Salary and per diem	440	635	825
Labor	295	590	880
Transportation	200	330	525
Total	2, 515	4, 425	4, 280

RESULTS

The heating equipment operated much better than we had even hoped. It took a little time to get the burners adjusted but during the winter, when they were most needed, they functioned very satisfactorily. The unregulated burner at the upper Little Beaver station burned continuously. The only adjustment made was the amount of gas to the burner. The initial gas supply lasted from November 3 to May 31.

It is very gratifying to read the hydrographer's notes which usually said, "Stream completely snow and ice covered, no ice in flume or V-notch, burner OK."

Adjustment of the heating system at the lower Little Beaver Creek station took longer. The thermostat was first set too low. The original setting, on November 4, was about 40° F, and on November 16 it was increased to 50° F. On January 16 the pool above the control and under the cover was partly ice covered, but open in the center under the burner. Ice built up below the notch, causing 0.02 foot of backwater. The chart indicated that the bubble orifice had been frozen for about 2 weeks. The thermostat was turned up to 62° F on that date (Jan. 16). Subsequently, the burner functioned satisfactorily and notes on the chart read "no ice effect" or "control clear." Mud covered the orifice several times, but otherwise an excellent record was obtained. Forty-eight percent of the gas supply of 425 gallons was used from November 4 until the flame went out, probably blown out by the wind, sometime between visits on April 17 and May 22, 1961.

On Fall Creek, the cover and curtains without a heater proved to be ineffective. Ice soon bridged over the entire stream, under the cover as well as in the open. A radiant propane burner was installed in September 1961, and winter operation since then has been satisfactory.

Perhaps such elaborate installations cannot be afforded at every ice-affected station. However, winter streamflow data were needed for this project and the results obtained justified the additional expense. These investigations demonstrated that accurate winter records can be collected at high altitudes if conventional stilling wells and intake pipes are eliminated and if the control in the stream is covered and heated.

THE ACOUSTIC SIGNALING BOX—A CURRENT-METER ACCESSORY

By Robert J. Smith

ABSTRACT

The acoustic signaling box in various forms has been used by several U.S. Geological Survey offices and other agencies for counting the revolutions of a current meter when measuring stream velocity or discharge. These boxes, particularly a new transistorized oscillator-type, offer many advantages over the conventional earphone attachment. Several models developed by a power company in California were field tested. Commercial units that can be purchased are described.

INTRODUCTION

Current meters are usually equipped with a battery-operated electrical circuit that produces a signal at each revolution or fifth revolution of the rotating cups or vanes. In the conventional meter assembly the signal is carried to a telephone receiver at the ear of the observer, and the observer determines stream velocity by counting and timing the signals or "clicks" he receives in the earphone. The acoustic signaling box described in this report is a modern device that substitutes for the earphone in the current-meter assembly. This box is essentially a transistorized audio-oscillator attached to a miniature speaker and powered by a mercury pen-light battery. Its light weight, low cost, and ease of assembly are obvious advantages. The Pacific Gas and Electric Co. Water Systems office in San Francisco, Calif., has developed two types in the past 4 years which have been tested in field use by personnel of the Geological Survey.

An acoustic signaling box does not have the undesirable features of the earphone currently used by hydrologists. Fieldmen find the discomfort of the earphone pressure on the head and ears irritating. The dangling wire from the earphone to the wading rod, or to the reel when the meter is cable-suspended, is often in the way. During a wading measurement the dangling wire interferes with field note computations, and during a bridge measurement the wire hampers the fieldman in his movements to watch for floating drift or to measure the angle of the current. The earphone is a particular annoyance when a canal measurement is made from a low footbridge with the meter attached to a pipe. At that time the observer must use a long extension wire or he must fasten the earphone to the top of the pipe, from where it is difficult to hear the meter clicks.

Throughout the years, Geological Survey fieldmen have used various approaches to improve methods of counting current-meter revolutions. These methods have included bicycle horn buzzers, telephone company testing units, and hearing-aid adapters. This article deals only with the oscillator-type acoustic receiver, commonly called a "beeper." This name refers to the peculiar beeping sound the receiver emits, one that is well known to radio "hams" when they use code to send and receive messages. The high pitched "beep" emitted by the speaker is more audible than the "click" sound of the earphone.

PACIFIC GAS AND ELECTRIC CO. ACOUSTIC SIGNALING BOX

Two types of beepers have been designed and developed since 1960 by the Pacific Gas and Electric Co. The first unit was made in 1960 from a code practice oscillator kit. The wiring was somewhat complicated for those not familiar with electronics and although the unit was reduced in size, it was still too heavy for use on a wading rod. Three flashlight batteries were used and the total weight was more than 2½ pounds. The most attractive feature of this model was a volume control which permitted the beep to be amplified so it could be heard above the sound of heavy traffic on a bridge. The original model is still being used (1964) and there have been no failures in the electronic circuitry.

Using the Pacific Gas and Electric Co. design as a guide, the author built a smaller unit in 1961 for field use by the U.S. Geological Survey. The parts were fitted into a rectangular box 6½ by 3¾ by 2¾ inches and a telephone plug was installed so the beeper could be plugged into the top of a Geological Survey top-setting wading rod. The weight was reduced to 20 ounces by eliminating some parts and using only one battery. Because the box was not watertight, a plastic bag was placed over the beeper during rainstorms to eliminate the possibility of short circuits in the wiring. There was very little muffling of the sound caused by the bag.

A new model was developed by the power company hydrologists in 1964 which appears to have additional favorable features. It is cheap, easy to put together, and has the major advantages of light weight and a lesser susceptibility to damage from shock than the two models described in the preceding paragraphs. The audio-oscillator is mounted on a 1½- by 1½-inch circuit board. The Calrad miniature 0.05-watt speaker is ¾ inch thick and 1⅝ inches square, and the battery holder for a 4.5-volt mercury battery is ¾ by ¾ by 2¼ inches. The standard female phone plug in use by the Geological Survey was assembled with the other parts on a piece of vinyl tile so that the assembled parts would fit into a plastic cigarette box. (See fig. 1.) Total cost of the beeper was only about three-fourths the present cost of an assembled earphone. The new beeper weighs only 8 ounces and is small enough to be carried in a shirt pocket.

FIGURE 1.—Acoustic signaling box, 1964 model, assembled to go into plastic box cover.

The three beeper models described above have been field tested by both power company and Geological Survey employees since 1960, and all who have used them prefer the beeper to an earphone. Figure 2 shows the 1964 model plugged into a top-setting wading rod and figure 3 illustrates how the unit may be used with a three-wheel crane and reel during bridge measurements.

COMMERCIAL SIGNALING BOXES

Signaling boxes manufactured by A. Ott Co. of Bayern, Germany, are the only ones known to be available for purchase in the United States. The Ott model F2 is both a visual and acoustic device in a box 5½ by 3¼ by 2⅛ inches. Each revolution of the current meter is announced by a buzzer signal and a small flashing light. The F2 may be used with a wading rod but was not designed for use where the box is not in close proximity to the meter. This model uses two flashlight batteries and weighs 21 ounces.

The Ott model F4 counter box is not of the acoustic type, but records

FIGURE 2.—Signaling box plugged into top-setting wading rod.

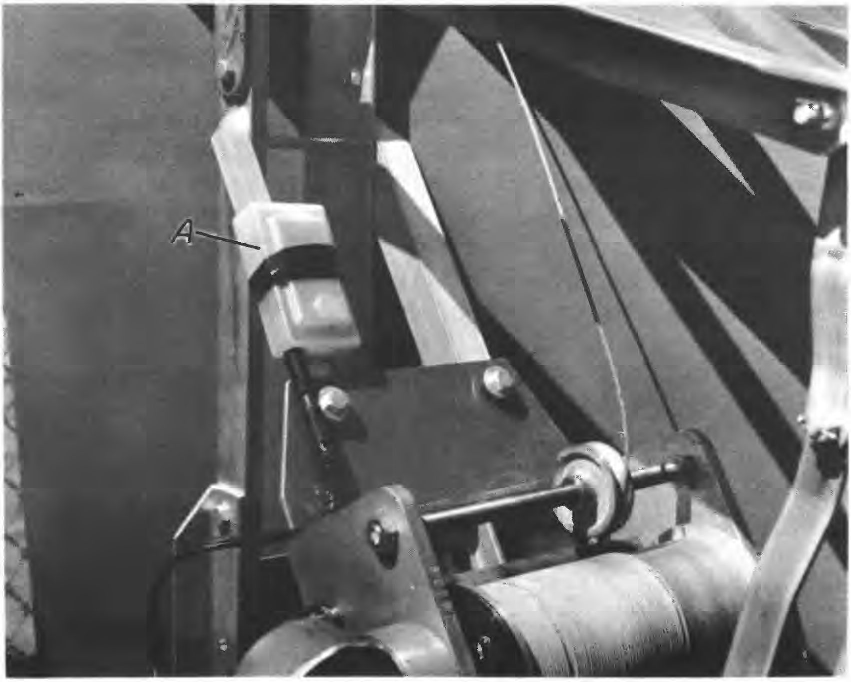


FIGURE 3.—Signaling box (*A*) attached to crane and reel used for discharge measurements from bridge.

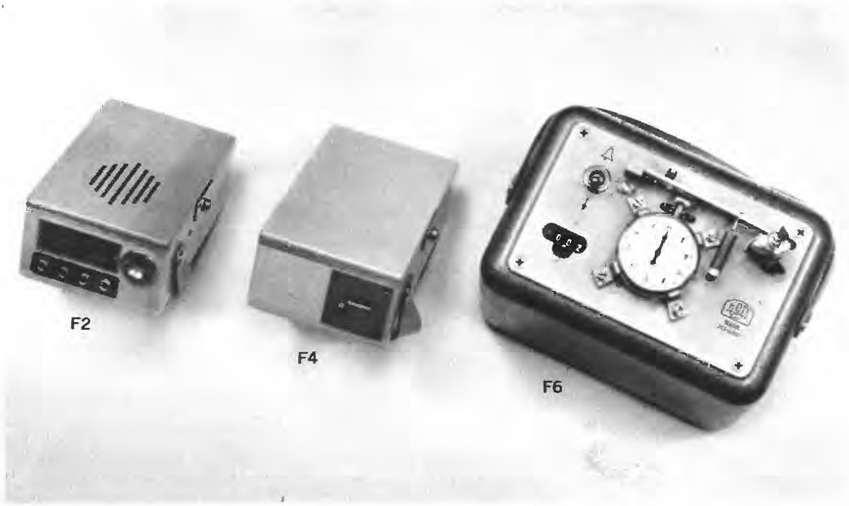


FIGURE 4.—Ott signaling boxes F2, F4, and F6.

each turn of the meter on a counter. It is housed in a 24-ounce box that is $6\frac{1}{16}$ by $3\frac{1}{4}$ by 2 inches.

The Ott model F6 is a combination acoustic and counting device. It is designed for use in measuring flow where the counter is a great distance from the current meter and would be useful in measuring some of the wide, deep rivers in the United States where a power-operated reel is used. The box is $7\frac{1}{4}$ by 5 by $5\frac{1}{8}$ inches and weighs 6 pounds.

These commercial units range in cost from eight to thirty times that of the 1964 model designed by Pacific Gas and Electric Co.

The three types of German-made signaling boxes are shown in figure 4.

SUMMARY

Transistorized oscillator-type signaling boxes offer many advantages over the conventional earphone for counting revolutions of a current meter. The signaling boxes are light weight, easily assembled, and more convenient for use than earphones. Furthermore, they can be produced for a price equivalent to or cheaper than assembled earphones. They may eventually replace earphones for general field use with current meters.

DELUXE TOP-SETTING WADING ROD

By W. DON PETERSON

ABSTRACT

The Price-type current meter is used to measure stream velocity when discharge measurements are made at the more than 8,000 stream-gaging stations operated by the Geological Survey. At low stages a wading rod is generally used to support the current meter and to measure stream depths. The standard wading rod used for many years was a ½-inch-diameter round rod made by joining 1-foot sections which were equipped with threaded ends. The round, jointed wading rod has gradually been replaced by a 4-foot hexagonal top-setting rod. By using the top-setting rod, the hydrographer can place the current meter at the proper depth for observing water velocity without touching any wet parts of the rod or meter and without removing the meter from the water. A scale on the handle of the top-setting rod indicates, for any observed depth, the correct meter setting for taking velocity readings at 0.6 of the observed depth. The author modified the top-setting rod to a deluxe model that contains penlight batteries in the handle of the rod to supply current to the electrical circuit of either the conventional headphone, a transistor-type light-weight headset, or an acoustic signaling box.

The Geological Survey, in cooperation with State and other agencies, measures streamflow at more than 8,000 stream-gaging stations in the United States. At a typical gaging station a continuous record of gage height is observed and the discharge of the stream is measured often enough during each year to determine a relation between gage height and discharge. The Price-type current meter is used to observe stream velocity as part of the procedure of making discharge measurements. On the smaller streams and also during periods of low flow on many larger streams the hydrographer takes the observations of velocity, depth, and width, which are needed to make a discharge measurement, by wading across the stream. During a wading measurement the current meter is supported on a wading rod, and the stream depths are measured by using graduations on the wading rod.

The standard wading rod used for many years is a ½-inch-diameter round rod made in sections a foot long that can be connected by threaded joints on the ends to assemble them into a unit of whatever length is needed. A base plate keeps the rod from settling into the bed of the stream. The Geological Survey has developed another type of wading rod, the top-setting rod, and is rapidly changing to the use of it. (See fig. 1.)

The top-setting rod is made of a 4-foot length of ½-inch hexagonal stainless-steel rod, graduated in feet, and tenths, that has a round base plate attached to the bottom end and an aluminum casting, 6$^{13}/_{16}$ inches long, on the top end which serves as a handle. The current meter is supported on a fitting, called a "double-end hanger," that slides freely on the hexagonal rod. A 57-inch length of ⅜-inch

FIGURE 1.—Wading rods and Price-type current meters. *A*, ½-inch-diameter round rod assembled from 1-foot lengths; *B*, top-setting wading rod. Headphone circuit with battery fastened to telephone jack is plugged into handle of the rod.

round stainless-steel rod extends upward from the hanger and passes through guide holes at the top and bottom of the aluminum handle. The $\frac{3}{8}$-inch rod is parallel to the main hexagonal rod and $\frac{7}{8}$ inch behind it. A friction catch near the top of the handle will hold the small rod and the double-end hanger and current meter at any desired depth for velocity observations. With the top-setting rod it is not necessary to remove the rod and meter from the water to make the setting for depth, or to handle any wet equipment. A grounded telephone-type male plug projects from the top of the handle. The small rod is insulated from the double-end hanger, and the main rod is insulated from the handle. A lead wire extends from the small rod to the meter contact wire, and an enclosed wire extends from the top of the main rod to the insulated element of the male plug. A female jack in a separate circuit containing a battery and an earphone is placed over the plug on the handle of the rod to complete the equipment needed to count the revolutions of the current meter.

Another feature of the top-setting wading rod is that it has graduations, on the small rod and the aluminum handle, arranged so that when the rod is raised until the graduations read the same as the total depth, the meter is positioned at 0.6 of the total depth below the water surface. For depths of less than 2 feet, a velocity reading at 0.6 depth corresponds to the mean velocity in the vertical.

The author has modified the top-setting wading rod and produced a deluxe model (fig. 2) which holds two pen-light batteries, in the hollow handle of the rod, to operate the signal circuit. Special electrodes inserted at the top have been adapted to receive either the standard telephone-type male plug or a $\frac{1}{8}$-inch-diameter transistor radio female jack.

To produce the deluxe rod, the male telephone plug was removed from the aluminum handle of the rod. The hollow part of the handle was reamed out with a $\frac{9}{16}$-inch drill bit to a depth of $5\frac{1}{2}$ inches to accommodate two pen-light batteries and a small spring. The male telephone plug was replaced with an adapter that makes contact with the upper battery. The small spring rests on the top end of the hexagonal rod and extends into the handle to make contact with the lower battery. Alkaline batteries give the best service.

The upper end of the $\frac{9}{16}$-inch hole drilled in the handle was threaded with a $\frac{5}{8}$-inch NF tap, and received an adapter machined from $\frac{7}{8}$-inch round brass stock. The adapter was the only complex piece of equipment needed and had to be produced on a lathe. The handle of the rod contains an insulated brass plug which makes contact

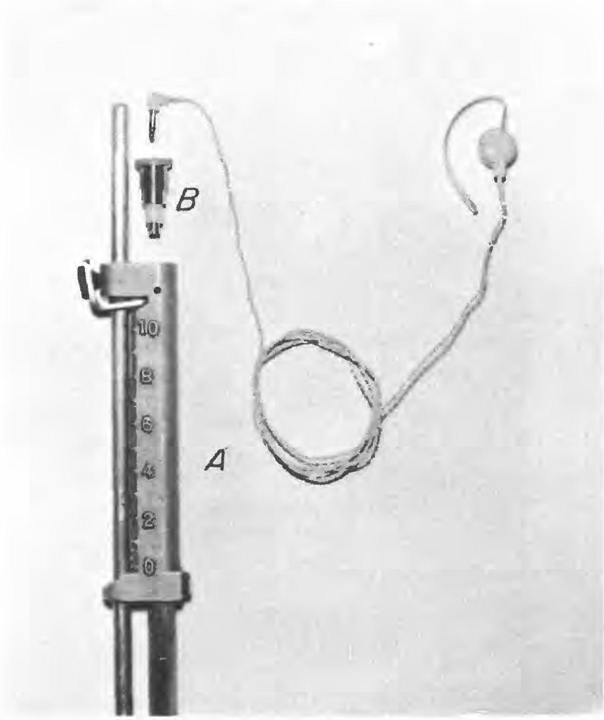


FIGURE 2.—Handle of deluxe top-setting wading rod. *A*, Handle holds two pen-light batteries; *B*, adapter screws into top of handle so male transistor plug can be used in headphone circuit.

with the center electrode of the upper battery and receives the transistor earphone plug. A slightly different adapter is needed if the telephone-type male plug is to be used on the handle of the rod. The handle of the modified top-setting wading rod having adapters for use with the two types of plugs in the headphone circuit is shown in figure 3.

This system for signaling revolutions made by the current meter is rugged and most convenient. It is exceptionally trouble free and has been giving fieldmen excellent service. The transistor earphone is not cumbersome, and gives excellent service and performance. The hydrographer is scarcely aware of the electrical equipment except for the clear signals received. Comfortable and convenient equipment to be used by the hydrographer, especially in inclement weather, will result in better quality discharge measurements.

796-504 O—66——3

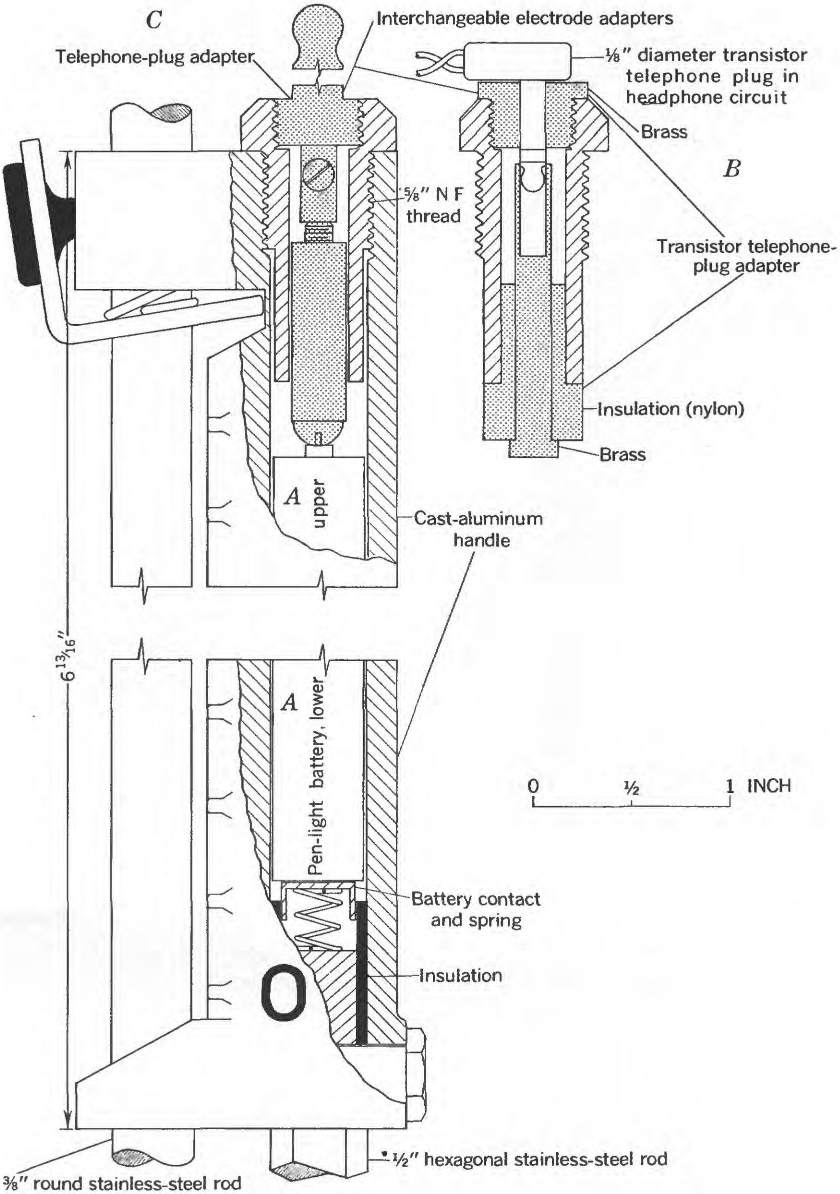


FIGURE 3.—Handle of top-setting wading rod showing changes made to convert to the deluxe model. *A*, Hollow handle was reamed enough to hold two pen-light batteries; *B*, adapter to use with headphone circuit having male transistor telephone plug; and *C*, adapter to use with headphone circuit having female telephone jack.

CONSTRUCTION OF STREAM-GAGING WELLS USING STEEL OIL DRUMS

By Elizardo D. Lucero

ABSTRACT

The problem of obtaining a practical and economical substitute for conventional materials to use in building stream-gaging wells was solved by using steel oil drums. Construction of gage wells from steel drums is especially adaptable for installations on bridge piers and for short-term and portable gaging stations.

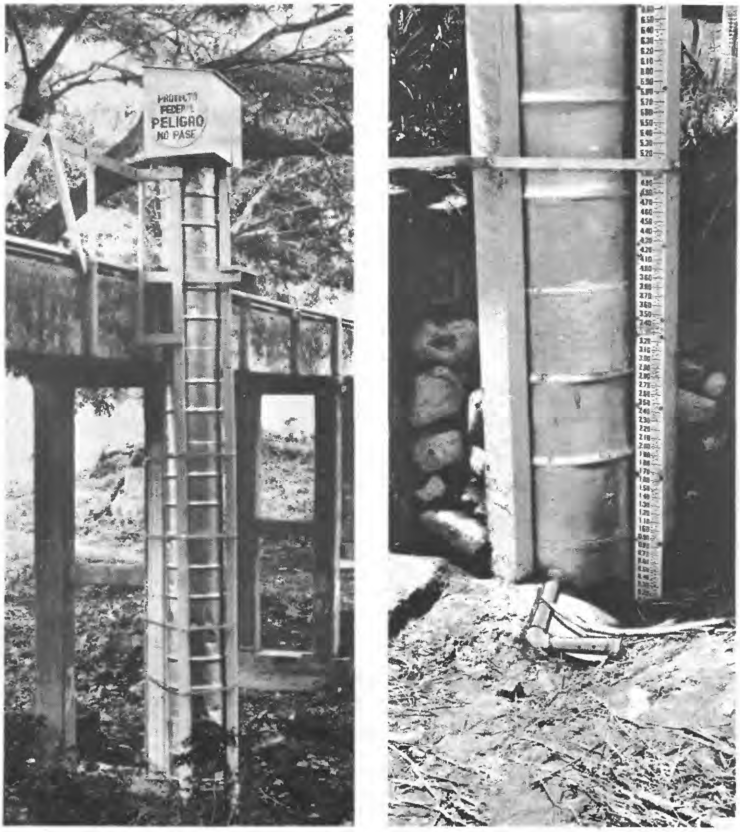
INTRODUCTION

In 1957 the U.S. Geological Survey in cooperation with the Government of Puerto Rico began an investigation of the water resources of the island. Material for gage wells for stream-gaging stations had to be imported because local distributors did not stock pipe. Nestable corrugated metal pipe was used for bank installations because it is obtainable in semicircular sections 2 feet long; in this form it is easily transported at low freight costs. However, nestable pipe is not suited for installations placed directly in the stream, such as those attached to bridge piers, because of the excessive expense involved in sealing the joints to reduce surge in the well. To avoid the expense of shipping fabricated pipe, 55-gallon oil drums, obtained locally, were used.

CONSTRUCTION

Drums in good condition were selected and the ends were burned off. Short sections were assembled in the shop by welding two drums together. Each section was painted completely with red-oxide paint and then with aluminum paint. An alternate process to inhibit corrosion is to paint the drums with zinc shield, which is best applied with a spray gun. Zinc shield contains 95 percent metallic zinc and serves as a substitute for dip galvanizing. The zinc shield is probably superior to red-oxide paint and is only slightly more expensive.

In the field the two-drum sections were assembled into a complete unit and the joints were welded. A final coat of paint was applied to cover the welds and scuffs received during transportation and erection. Vertical bracing was added for increased strength against floods and hurricanes. The two stations constructed using the oil-drum gage wells proved to be satisfactory in every respect and are shown in figure 1. The station (fig. 1*B*) on Rio Guamani near Guayama, Puerto Rico, recorded an outstanding flood having a peak flow of 20,000 cubic feet per second and survived without damage.



A B

FIGURE 1.—Stream-gaging wells in Puerto Rico constructed from oil drums. *A*, Typical installation on Quebrada (Creek) Cimarrón near Jobos; *B*, lower section of well, intake pipe with static tube to reduce drawdown, staff gage, and low-flow channel on Rio Guamani near Guayama.

Following the successful adaption of the 55-gallon oil drums to gage-well fabrication, small portable gaging stations were later installed using grease drums 14 inches in diameter. These gages were of sufficient size to accommodate a water-level recorder having an 8-inch float.

Since the experiment in Puerto Rico, oil drums have been used in construction of gaging stations in the Virgin Islands.

COST

Table 1 presents 1961 costs of comparable gaging stations constructed using nestable corrugated metal pipe and steel oil drums.

TABLE 1.—*Comparative cost of stream-gaging wells*

Material used	Size of well		Cost (dollars)				
	Diameter (in.)	Length (ft)	Pipe	Erection	Welding	Painting	Total
Nestable corrugated pipe	21	40	222	140	180	15	557
Steel drums	24	40	42	70	46	30	188

PRECAUTION

Cutting steel drums with an oxygen and acetylene torch can be hazardous if proper precautions are not observed to prevent the possibility of explosion of fumes from combustible residues in the drum. Before the drums are cut, they should be rinsed and steam cleaned and the bungs removed. A welding torch should not be used to cut any drum that has contained particularly explosive substances.

CONSTRUCTION OF LOW-COST GROUND-WATER OBSERVATION WELLS

By Oliver J. Cosner and F. A. Kilpatrick

ABSTRACT

In a study to determine the source of base flow of Piedmont streams in Georgia, 40 obervation wells 10–50 feet deep were drilled at a cost of $3.50 per foot. This cost includes $2.00 per foot for drilling and $1.50 per foot for materials and their installation by Geological Survey personnel. This low cost resulted from hiring the cable-tool drilling on an hourly basis, using Geological Survey personnel for supervision of drilling and placing of casing and screens, and using suitable low-cost materials not ordinarily used in wells.

In the fall of 1961 a study was made to determine the source of base flow of streams in the Piedmont of Georgia. Part of this investigation was the observation of ground-water levels throughout a river basin. Forty temporary observation wells ranging from 10 to 50 feet in depth were drilled to bedrock. The base-flow study was completed in 1963, but other hydrologic studies, in which the same observation wells were used, were continued in the area.

The typical cost for constructing observation wells is about $5–$6 per foot. However, for this project a cable-tool drill rig and crew drilled the wells for $2 per foot. Survey personnel supervised the drilling, logged and sampled the holes, and installed the casing. In this manner the wells were constructed at a total cost of $3.50 per foot.

Design of the wells is shown in figure 1. Twenty-six gage, 6-inch diameter galvanized crimp-joint stovepipe in 10-foot lengths ($0.40 per foot) was used for the casing, and 6-inch-diameter, 3-foot-long galvanized perforated sheet metal rolled into stovepipe ($1.00 per foot) was used for the screens. The screens fit together in the same manner as the stovepipe casing and are interchangeable with it (fig. 2).

The jig shown in figure 3 was designed to assemble the screens and pipe over the hole. The jig was necessary to aline and to hold the pipe while it was being assembled and to prevent it from falling into the hole. While the pipe was clamped in the jig, four to six ⅛-inch

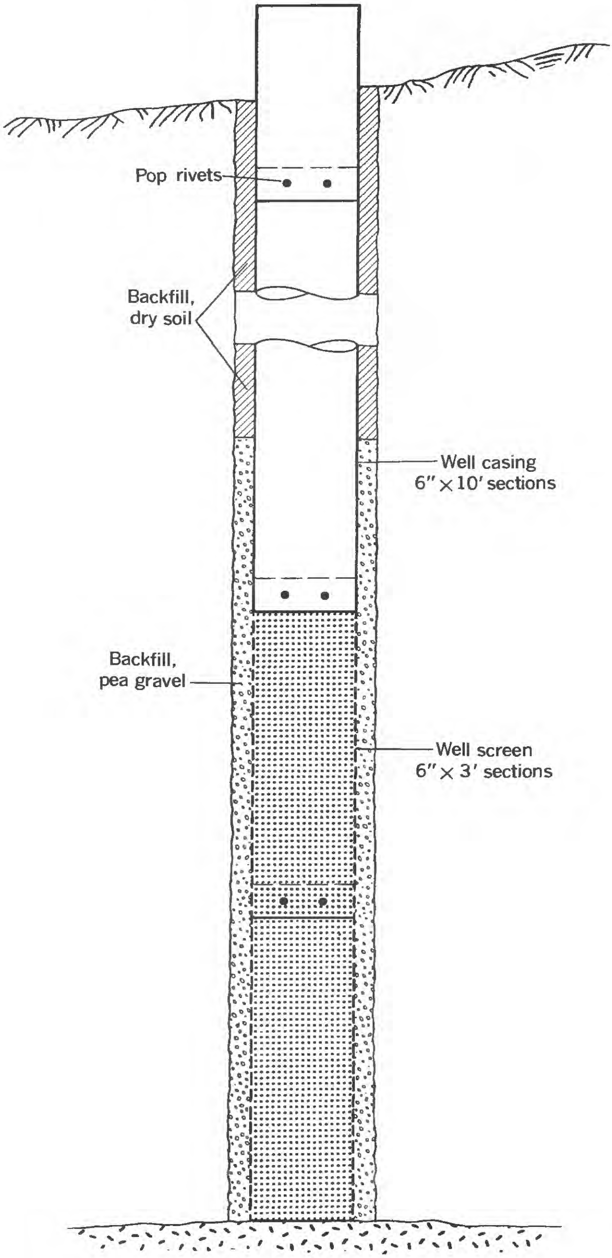


FIGURE 1.—Sketch of well construction.

holes were drilled with a hand drill around the circumference at the joint, and the two lengths of pipe or screen were secured with pop rivets.

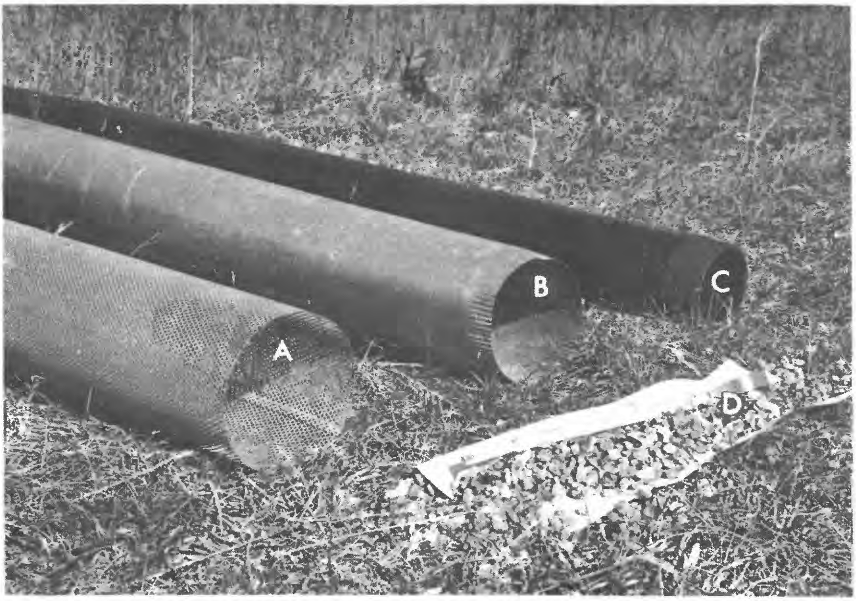


FIGURE 2.—A, Well screen (6-inch by 3-foot perforated galvanized sheet metal); *B*, 6-inch galvanized casing (6-inch by 10-foot 26-gage stovepipe); *C*, 4-inch fiber soil pipe casing; and *D*, pea gravel for packing around screens in wells.

A pop riveter is a small hand tool with a plier grip. It holds a single rivet that is inserted in the hole through the two pieces of pipe to be joined. The rivet is made fast by squeezing the grip. A pop rivet gives a strong, clean joint having no protrusion inside the casing. The rivet is secured entirely from the outside and does not require holding or backing inside the pipe. Other types of fasteners such as metal screws usually leave protrusions inside the casing which obstruct floats and other equipment lowered into the well.

When the drill crew completed the hole to the proper depth the jig was placed over the hole and the screen and casing were lowered as each joint was fastened. Pea gravel, one-half inch in diameter, was placed around the screen and the lower few feet of casing. Where runny sand and silt strata were penetrated, an 8-inch steel casing was placed as drilling progressed. The 6-inch stovepipe casing was set inside the 8-inch casing and the 8-inch casing was removed as the gravel packing was added. After placement of the gravel, the well was bailed to clean out mud and to determine well capacity. At this point the drill rig moved on to the next hole.

The annular space between the 6-inch casing and the hole, above the gravel pack, was back filled with earth. In some wells, drilling mud was used for this purpose; however, the mud built up hydrostatic

FIGURE 3.—Well casing and screen being assembled in a jig over well. Geological Survey employee is using the pop riveter.

pressure on the casing and caused complete collapse of the casing in three holes.

A more rigid type of casing is needed if drilling mud is used for back filling, or if casing is to be placed in loose wet silt or sand above the water table. Fiber soil pipe (fig. 2*C*) proved satisfactory in casing some shallow flood-plain wells. This fiber pipe is available in 2-, 4-, and 6-inch diameters ($2.90 per 4 inches by 10 feet). Also available is 4- and 6-inch diameter rigid plastic sewer pipe ($3.90 per 4 inches by 10 feet). An additional advantage of the fiber soil pipe and of the plastic sewer pipe is that they both are joined with a special friction fit and cemented coupling that is water tight.

ELECTRICAL WATER-LEVEL MEASURING REEL

By Raoul A. LeBlanc

ABSTRACT

The need to decrease maintenance of water-level-measuring equipment constructed of wood and obsolete parts was met by designing an all-metal unit. The new reel weighs less, is constructed of parts easy to obtain, and uses a smaller diameter electrode and cable than the former unit. In addition, an accessory easyover to protect the cable was improved by a grooved sheave and cable guides. The new unit is dependable and easy to operate.

INTRODUCTION

During ground-water investigations, measurements often must be made to water deeper than 500 feet below land surface, to water surfaces obscured by falling water, and to water surfaces that are changing rapidly. Steel tapes are impractical to use under these conditions; consequently, electrical equipment was developed.

One of the first electrical water-level units designed and used in the author's area was made of a wood carriage together with military-surplus parts, including a spool, bushings, a copper-tubing handle, a cable, and a separate meter. A compact 15-pound unit has been developed (fig. 1) to replace bulkier, heavier makeshift units.

DESCRIPTION OF THE UNIT

The present model consists principally of two parts, a carriage and a spool fabricated from 1/8- and 1/16-inch aluminum plate. The carriage is 12 inches high, including handle, and 18 inches long. The carriage has been equipped with self-alining bearings to assure smooth operation and ease in replacing spools of cable. The bearings allow angular movement of the 1/2-inch stainless-steel shaft when replacing a spool, and they allow the cable to pay out freely of its own weight, as the electrode is lowered into a well. The crank on the shaft is reversible for right- or left-handed operation.

FIGURE 1.—Electrical water-level measuring reel (*A*) and accessory easyover (*B*) at a well.

The spool is 9 inches in diameter, has a 4-inch core, and will hold more than 2,000 feet of $\frac{3}{32}$-inch diameter cable. Each end of the spool has a stainless-steel flange and a keyway that fits the shaft. The spool and the bearings are electrically insulated from the carriage and the ground.

The electrical components for the reel are on the spool and in the base of the carriage. The schematic wiring diagram of the reel is shown in figure 2. A 9-volt transistor radio battery and clip, a variable resistor with an on-off switch, and a 0–1 milliamp miniature edgewise panel meter (fig. 3) are installed within the carriage base. The 0–20,000 ohms resistor may be set to accommodate the electrical resistance of water at each well measured to the deflection desired on the milliamp meter indicator. A ground wire with an alligator clip and a pin jack is attached to the circuit through an insulated plug in the base at the front of the carriage.

The spool usually carries 1,000 feet of cable marked in code at 10-, 50-, and 100-foot intervals. One end of the cable is attached to the

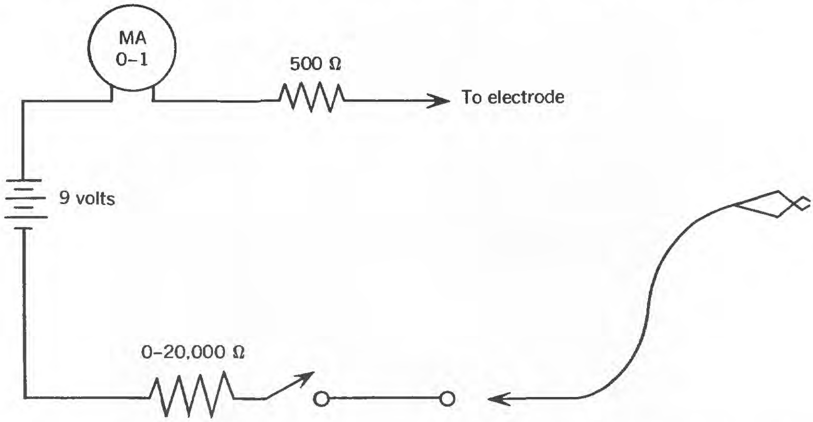


FIGURE 2.—Schematic wiring diagram for the electrical water-level measuring reel.

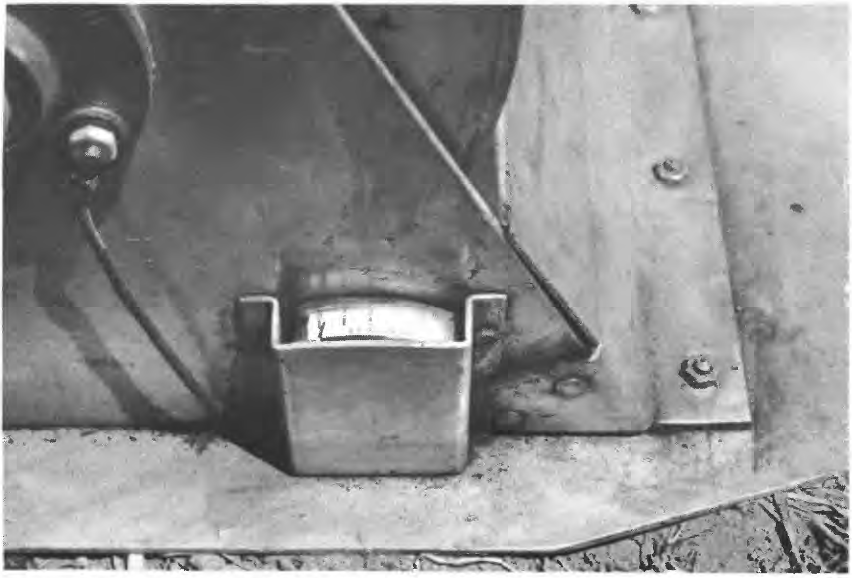


FIGURE 3.—Edgewise panel meter mounted on the carriage.

core of the spool and the other end to an electrode. The electrode is weighted with sections of lead tubing, and it has a tip protected by pliable plastic; maximum diameter of the electrode is three-eighths inch, so it can pass through small access holes. Use of a lightweight cable makes cranking 600 feet or more of cable from a well an easy task. This cable has a diameter of $\frac{3}{32}$ inch and 4 copper and 3 steel strands of wire covered with a tough but pliable plastic.

To avoid cutting the insulation or the wire on sharp edges of the pumps or well casings, an easyover is used. An easyover is a metal rod with a grooved sheave and cable guides at one end (figs. 1 and 4) and a pair of prongs at the other.

OPERATION OF THE UNIT

At a well site, place the prongs of the easyover in the ground with the sheave over the access hole to allow the cable to ride free of sharp edges. Turn on the resistor switch on the right-hand side of the carriage. Attach the ground-wire alligator clip to the casing, pump unit, or wet-ground surface for contact. Allow the cable to run freely over the easyover sheave and down the well casing while holding the unit with one knee. When the electrode contacts the water, the needle of the meter will indicate the completed circuit by a positive deflection. Slowly retract the cable from the well and watch the meter. The break in contact between the electrode and the surface of the water causes a sudden drop of the meter indicator to zero. At this point grasp the cable at the measuring point and measure the distance on the cable to the first 10-foot marker below the measuring point. Add the length of the electrode and count the 10-foot intervals from the marker mentioned above to the first identified 100-foot or 0 marker to determine the depth to water.

FIGURE 4.—Sheave and cable guides on the end of the easyover.

When making pumping tests, water levels that are rapidly changing can be measured in hundredths of a foot by attaching a steel tape, graduated in hundredths of a foot, to a marker on the cable that will remain below the measuring point during the test. The measurements can be read directly from the steel tape by raising the electrode to and above the water surface at desired time intervals.

About 10 of these electrical water-level measuring units have been in field use for 4 years. The units have required only minor repairs, including the replacement of one milliamp meter.

DEVICE FOR REMOVING DEBRIS FROM WELLS

By J. S. Bader

ABSTRACT

A grappling device, similar to a pair of ice tongs, has been designed and effectively used to remove debris from wells. Rehabilitating existing wells by using this device eliminates the cost of drilling new ones.

INTRODUCTION

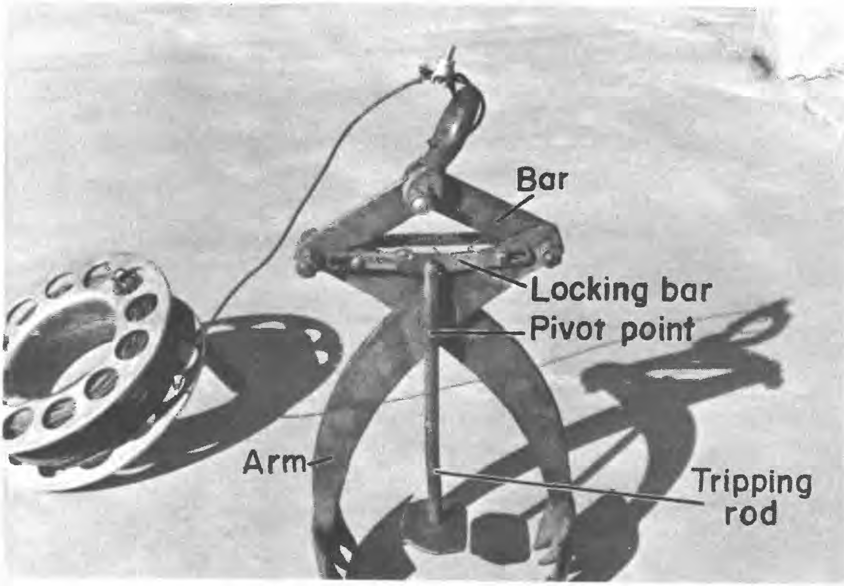
A device, referred to by the designers as the "beartrap," is useful in removing a wide variety of objects—such as blocks of wood, stones, cans, bottles, pipes, and poles—from wells. This article describes the device and how it operates. It can be constructed from a simple sketch or from a photograph by a blacksmith, and no special talent is required to operate it.

DESCRIPTION OF THE GRAPPLING DEVICE

The grappling device consists primarily of two arms and two bars fastened together to allow the arms to open and close freely about a pivot, much like a set of ice tongs (fig. 1*A*). The other parts are the locking bar, which holds the arms open, and the trigger mechanism (tripping rod), which closes the arms when the device is being used to grasp an object in a well.

The bottom ends of the arms are fitted with curved metal plates or serrated claws to grip and hold objects securely. The device is shown in the closed position in figure 1*B*.

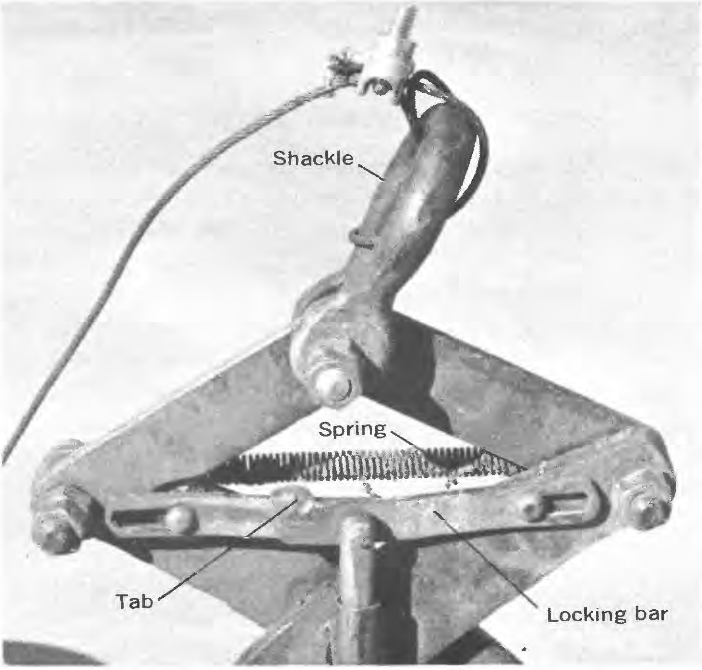
The small jointed locking bar (fig. 1*C*) holds the arms open when it is extended below center (slightly more than 180° as measured at the joint of the locking bar). The locking bar is kept from moving farther downward by a tab which bears against it when the device is in the open position (fig. 1*C*). A tripping rod extends downward between the arms from the pivot point of the locking bar.



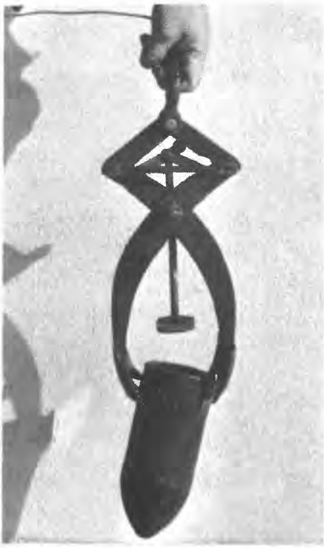
A

B

FIGURE 1 (above and facing page).—Grappling device, or "beartrap," for removing objects from wells. *A*, Device in open position; *B*, device closed;



C



D

C, detailed view of locking bar and releasing rod; *D*, "beartrap," gripping a heavy object.

796-504 O—66——4

The device may be made in any desired size. Two sizes have been built and used successfully, one fitting into an 8-inch well casing and the other into a 10-inch casing.

OPERATION OF THE DEVICE

In use, the device is cocked in the open position and lowered into the well on a suspension cable that is fastened to a ring. When the foot of the rod strikes the obstructing object in the well, the rod pushes upward on the locking bar, releasing it, and the arms are pulled together by a spring opposite the locking bar (fig. 1*C*). Once the arms grasp an object, upward pull on the suspension cable causes them to clamp even more tightly. The weight of the object being lifted holds the arms together, and the heavier the object, the tighter they grip. The arms can be closed from above if the tripping rod will not close them in an appropriate position. A line tied to the rod at the pivot point of the locking bar can be pulled when the arms are in the desired position, and thus close them around an object without the aid of the rod. Figure 1*D* shows how an object is gripped and held firmly. The projectile weighs about 15 pounds.

DEVICE FOR REMOTE RECORDING OF FLUID-LEVEL FLUCTUATIONS

By J. H. Criner

ABSTRACT

The hazard of servicing gages that record fluid level at sites where exposure to radiation or other danger exists can be avoided by using self-synchronous motors to operate recording gages at a location remote from the site of the fluid. The routine work of inspecting recorder charts, removing charts, and maintaining the recording gage can be performed at a safe distance from whatever hazard exists at the fluid for which the level is being recorded.

Disposal of liquid radioactive wastes by seepage into the ground generally requires the continuous recording of the fluid level in seepage pits and in nearby monitor wells. Information on fluid levels in the pits is needed for computations of the rate of seepage into the ground, of the volume of waste still remaining in the pits, and of the capacity of the pits to hold additional waste. Information on fluid levels in monitor wells is used in determining the configuration of the liquid surface and the rate and lateral direction of liquid movement.

Recording gages can be installed before disposal operations are begun, but the subsequent replacement of charts and servicing of the gages is hazardous if the time needed to do so results in overexposure to radiation. The remote recorder makes possible—without danger of such exposure—the recording of fluid levels at any site where radioactivity from liquid wastes poses a threat to health. It is equally suitable for installation in places not readily accessible for other reasons. Conceivably, the recording of fluid-level fluctuations at many widely scattered and remote points could be done at one convenient location.

In addition to a recording gage, each installation requires a pair of Selsyn (self-synchronous) motors, sufficient 3- or 5-wire cable to reach from the site of fluid-level measurement to the remote recording-gage site, and a source of 110-volt a-c electric power (110-volt, 60-cycle alternating electrical current). One of the motors is a master, or transmitting, unit and the other is a slave, or receiving, unit.

The master motor is mounted on a platform over the point of fluid-level measurement and, in places where radioactivity may be a hazard, is installed before any radioactive wastes are present. The pulley (removed from the recording gage) is connected to the drive shaft of the master motor, and a float and counter weight are attached to the opposite ends of a cable passing over the pully. When in operation, the upward and downward travel of the float resting on the rising or falling fluid surface will drive the master motor.

The slave motor simply repeats the turning, in either direction, of the drive shaft of the master motor, and it does so with greater force than is required to turn the shaft of the master motor. A sleeve joint is used to connect the drive shaft of the slave motor to the drive shaft of the recording gage, and both the motor and gage are mounted firmly on a single platform at a convenient and safe distance from the site where the fluid-level fluctuations are to be measured. The transmission distance may be only a few feet or as much as several miles but, if more than a few hundred feet, boosters may be required at one or more places along the line.

If a source of 110-volt a-c electricity is available at both sites and both master and slave motors are connected to it, the cable connecting the motors needs to contain only three wires. However, if a power source is available at the site of only one of the Selsyn motors, a 5-wire cable is needed to connect both motors to the electrical-power source. Where several field sites are near telephone lines, it may be possible to rent use of the lines for electrical connections of pairs of motors to centralize recording instruments in a convenient location.

At an Atomic Energy Commission installation near Oak Ridge, Tenn., fluid-level fluctuations in a "hot" waste-disposal pit were recorded on a drum-type weekly recording gage (fig. 1) situated a short but safe distance from the pit. The float was 2 inches in diameter and made of copper. The Selsyn motors were purchased at small cost from a company selling surplus military equipment and, although not needed for the 200 feet of connecting cable, boosters could have been obtained from the same outlet. Because a source of electricity was available at only the recording-gage site, 5-wire cable had to be used; it was relatively inexpensive and was installed by Survey personnel. Remote recording systems have been used for many years and at least one instruments company offers a system of the kind described here.

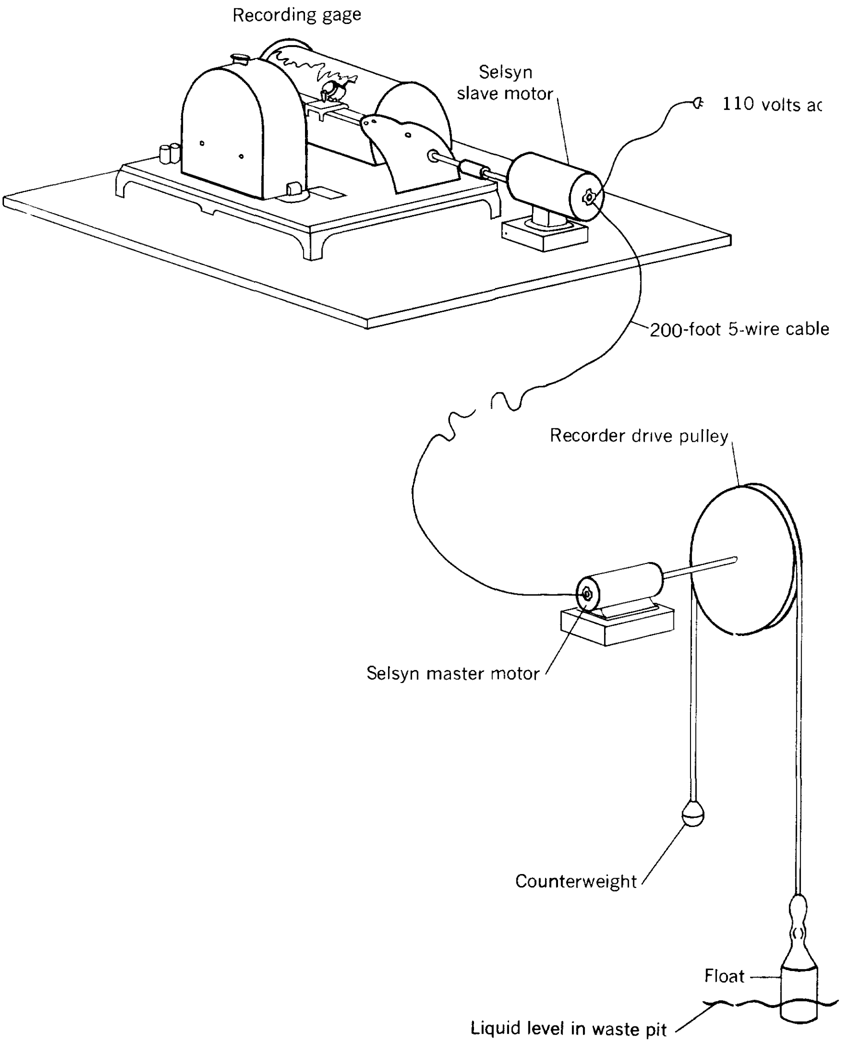


FIGURE 1.—Remote operation of fluid-level recording gage.

ICE-PREVENTION SYSTEM FOR GAGE WELLS

By DALE PETTENGILL

ABSTRACT

Bubbling a compressed gas into a gage well near the bottom will keep ice from forming around the float during subfreezing temperatures. Gas from a pressure cylinder of nitrogen, equipped with a pressure regulator and needle valve, was fed through a hose to a small pipe that released the gas near the bottom of the gage well. The bubbling creates vertical currents which carry the warmer water to the surface and prevent the formation of ice.

In localities where subfreezing temperatures occur in the winter, provisions must be made each autumn to keep the water in the gage well at a stream-gaging station from freezing. Ice can be prevented from forming by use of an insulated subfloor, by installation of oil tube for the float, or by bubbling a gas from the bottom of the well. Since the winter of 1959–60, experiments have been carried out using bubbling of a gas to keep wells free of ice.

The release of a compressed gas through a small hole in a pipe properly placed below the float near the bottom of a well creates vertical currents which bring the warmer water at the bottom of the well to the surface. This warmer water prevents freezing at the float. The water level in the well can then fluctuate to follow the water level in the stream and the float can operate the water-stage recorder. Power companies have used the method of bubbling air from an air compressor to prevent freezing of gates and equipment in the operation of hydroelectric plants. At most gaging stations, use of an air compressor is not feasible or necessary. A pressure cylinder of nitrogen can be used to supply the gas.

A standard cylinder of nitrogen (2,000 pounds per square inch pressure when full) was used for the bubbler system (fig. 1). The outlet of the pressure regulator gage at the cylinder leads into a ¼-inch air hose at the extremity of which is a short piece of ¼-inch pipe that is reduced to a ⅛-inch pipe capped at the end. A small hole was

FIGURE 1.—Cylinder of nitrogen gas, regulator, and valve used to bubble gas into well to prevent ice from forming. Instrument on the right is a continuous float-operated water-stage recorder.

drilled with a size 50 drill near the end of the ⅛-inch pipe. The setup is shown in figure 2. The ⅛-inch pipe was oriented horizontally, with the hole under the center of the float at an elevation somewhat below the expected minimum winter stage; thus a stream of bubbles was directed toward the underside of the float.

This bubbling system operates satisfactorily if the depth of water in the well is not less than 4 feet. The rate of bubbling should be increased as the temperature decreases; for example, 50 bubbles per minute was sufficient early in the winter but a maximum of 100 bubbles per minute was needed during the coldest period.

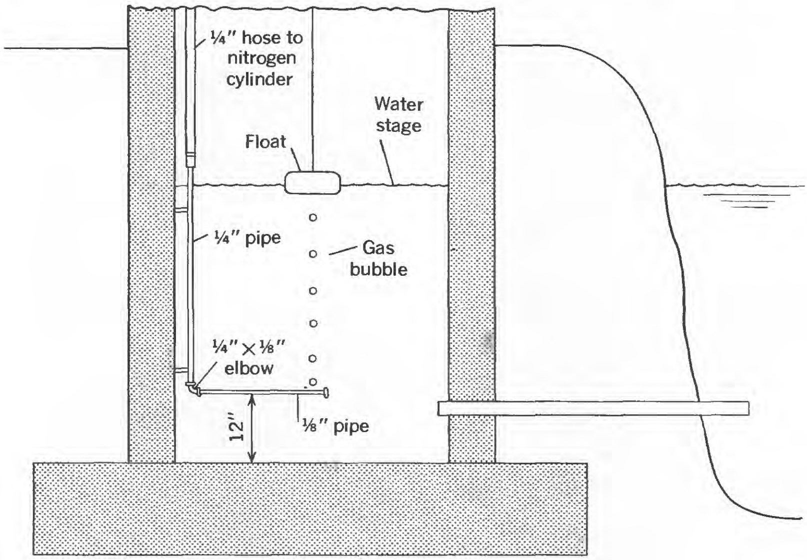


FIGURE 2.—Method of bubbling of gas in a gage well.

Some experiments have been made using compressed air (divers air) instead of nitrogen. This air is triple-filtered to remove as much moisture as possible, but the small amount of moisture that remains in the air has a tendency to freeze and clog the small hose and pipe, especially at temperatures of 0° and below. If this freezing occurs during an extended cold period, the float will freeze in the well and valuable record will be lost. Therefore, the use of nitrogen gas rather than compressed air is recommended.

ICE AUGER

By Dale Pettengill

ABSTRACT

The power-driven Swedish ice auger is an economical device for cutting holes through ice. When used with an electric drill and motor-generator set, the auger becomes an effective time-saving tool and reduces physical fatigue.

In regions of freezing temperatures, surface ice cover usually forms on streams each winter. Twenty to twenty-five holes must be cut through the ice on the streams when stream-discharge measurements are made. A simple and inexpensive device for cutting holes is the Swedish ice auger. A motor-generator set and an electric drill are needed for powered operation of the ice auger.

The cutting blade of the Swedish auger, a spadelike tool of hardened steel, is shown in figure 1. The auger is driven by a ½-inch electric drill with power source from a 1,500-watt, 2-cycle, gasoline motor-generator set weighing 110 pounds. After some experimenting with the offset on the auger shaft, the model shown in figure 2 was found most suitable. In this model, the main shaft is 2⅛ inches forward from the blade. This amount of offset effectively reduces the amount of vibration when using the auger. Cutting speed in solid ice is about 1 inch per second and the unit will satisfactorily cut through as much as 24 inches of ice.

The motor-generator set is mounted on a 4-foot toboggan to facilitate the handling of this equipment at off-road locations. The addition of the toboggan has made the equipment somewhat bulky, but has proved to be a time saver and has greatly reduced the physical exertion required to transport the equipment.

The total cost of the Swedish auger and shaft is about $7.00, $4.00 for the auger blade and the remainder for the fabrication of the auger shaft.

Modern motor-generator sets that weigh only 50 pounds can be obtained now. When more compact and lighter motor-generator sets are developed, the equipment will become easier to transport. Then it may be possible to carry the whole kit in a packsack.

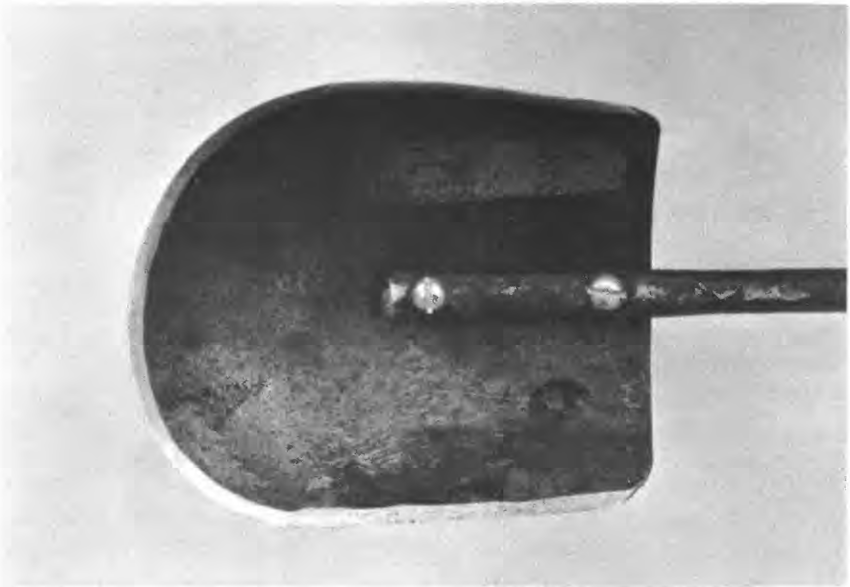


FIGURE 1.—Cutting blade of Swedish ice auger.

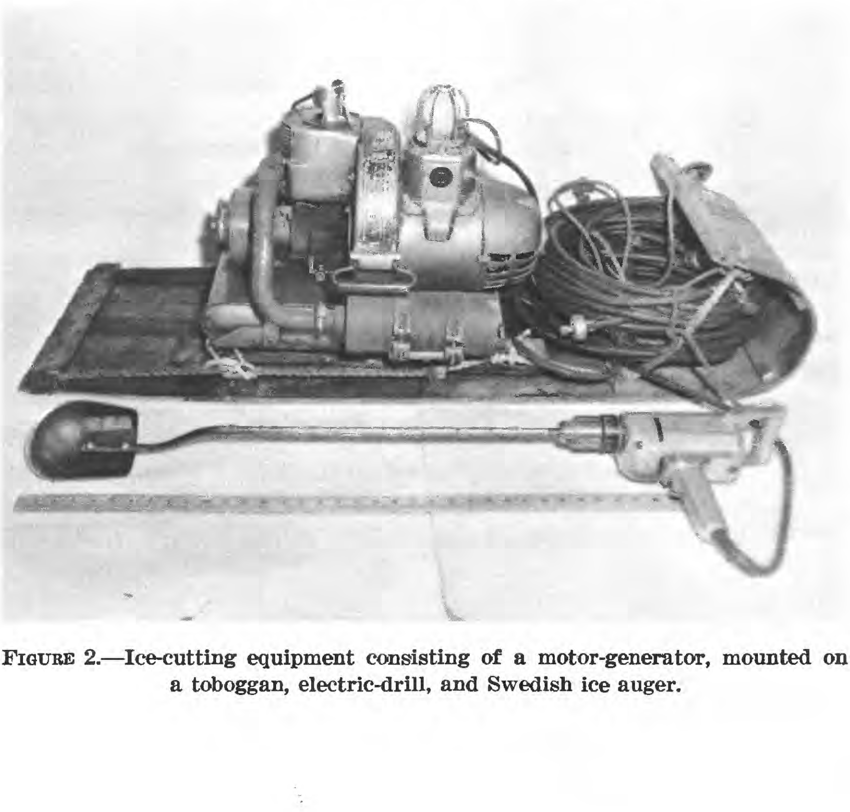


FIGURE 2.—Ice-cutting equipment consisting of a motor-generator, mounted on a toboggan, electric-drill, and Swedish ice auger.

TIPPING HANGER FOR CURRENT METER AND SOUNDING WEIGHT USED FOR DISCHARGE MEASUREMENTS UNDER ICE COVER

By E. Robert Hedman

ABSTRACT

The development of power ice drills to cut holes for making stream-discharge measurements under ice cover created a need for measuring equipment that will go through a 5- to 7-inch hole in the ice. A new Geological Survey vertical-vane current meter, without the tail assembly used on conventional meters, will pass through a 6-inch hole, but a sounding weight in a horizontal position on a regular hanger bar will not. A new tipping hanger lets the sounding weight tip into a vertical position so it can be lowered through a small hole, and then return to a horizontal position ready for taking soundings and velocity readings. To bring the equipment up through the hole in the ice the assembly is raised until a linkage on the back of the hanger touches the under surface of the ice cover and again tips the weight into a vertical position.

To make a discharge measurement when a stream is covered with ice, approximately 25 holes are chopped or drilled through the ice, and a current meter is lowered through each hole. The current meter is suspended on a wading rod if water depths are shallow and stream velocities are moderate. For greater depths and higher velocities the current meter must be suspended on a sounding cable with a sounding weight on a hanger bar below it. Chopping holes through ice cover on streams has long been a laborious and time-consuming job, but recent development of power ice drills has greatly reduced the time required to cut the holes. One of the most satisfactory ice drills presently manufactured will drill a 5- to 7-inch diameter hole, but the conventional cable-suspended discharge-measuring equipment will not pass through this size hole. Conventional equipment requires an elliptical-shaped hole about 6 inches wide and 2 feet long, because of the horizontal length of the sounding weight.

The U.S. Geological Survey has recently developed a short vertical-vane current meter without tail fins. This vane-type meter is useful for discharge measurements under ice cover because it will pass through a small drilled hole (6-inch diameter) in the ice, and the vanes

FIGURE 1.—Sounding weight tipped to a vertical position so it can be lowered through a small hole when making a discharge measurement through ice cover.

FIGURE 2.—Vertical-vane current meter with 30-pound Columbus-type sounding weight in horizontal position.

do not fill with slush ice. The tipping hanger described here was designed to use this vane-type meter suspended on a cable with a 30-pound Columbus-type sounding weight below it. With this hanger, the sounding weight can be tipped to a vertical position so the meter-weight assembly can be lowered or raised through a 6-inch hole in the ice.

The hanger was cut from 1/8-inch steel plate to a shape that fitted around the frame of the current meter, with space provided for easy removal of the meter contact chamber cap and pivot for servicing. The meter is clamped from the top and bottom to the hanger; it may be removed from the hanger by loosening the two clamps. The sounding weight is supported by two 1-inch-wide metal straps, one on each side, welded to the hanger plate and shaped into an inverted U. A 3/8-inch diameter bolt through the lower end of the straps and the hanger pin hole in the sounding weight fastens the weight to the straps. The sounding weight can be pivoted about the hanger bolt, into a vertical position, with the nose of the sounding weight fitting into the U formed by the suspension straps. In that position, it can be lowered through a 6-inch drilled hole in the ice, and will return to a horizontal position for making velocity observations after clearing the bottom of the ice. When the assembly is raised, a hinged metal frame at the back of the hanger strikes the bottom surface of the ice and forces the tail of the sounding weight down to a vertical position which enables the assembly to be easily drawn back up through the hole.

In figure 1 the sounding weight is shown tipped into the vertical position so it can be lowered through a 6-inch hole. Figure 2 shows the sounding weight returned to its horizontal position so velocity observations can be made with the current meter. The sounding cable on which the current meter and sounding weight are suspended (figs. 1 and 2) is 0.10-inch diameter reverse lay-cable that has a single insulated conductor inside; the cable is wound on a Geological Survey Type A–55 sounding reel, which accommodates 80 feet of this cable. The discharge-measuring equipment is mounted on a sled support built in the field office to fit local conditions.

FILTERING WATER SAMPLES USING VACUUM FROM AUTOMOBILE WINDSHIELD WIPER [1]

By Hugh B. Wilder

ABSTRACT

Frequently it is desirable to filter water samples in the field at the time of collection. A very satisfactory method for doing this is to utilize the vacuum system that powers the windshield wipers on many automobiles to supply suction to conventional laboratory filtering apparatus.

To obtain chemical analyses that are representative of the natural character of a water it is usually necessary to separate the solvent water from any solid material carried in it by physical suspension. Changes in chemical and physical equilibra, which may occur rapidly once a water sample has been removed from its natural environment, often require that such separation be made in the field within a few minutes after a sample is collected. This seemingly simple task frequently presents difficulties because the suspended material is too finely divided to settle out naturally, and must be removed by filtration. The filtering medium necessary to filter out the suspended matter is usually of such low porosity that gravity alone will not provide sufficient force to pull the water sample through the filter quickly, and suction is needed to increase the rate of flow.

The vacuum system used to power the windshield wiper on many automobiles and trucks can provide a very effective suction for filtering water samples in the field. Most sampling sites are accessible by automobile, and a laboratory-type filtering apparatus can quickly be set up in the vehicle in the field. No special equipment is needed to adapt the wiper mechanism for this purpose: Simply disconnect one of the rubber tubes leading from the wiper motor under the dashboard, and replace it with a piece of laboratory pressure tubing long enough to reach a suction flask.

The apparatus used by the author consists of a 500 ml suction flask

[1] An article by N. R. Harmon (p. 61) describes use of the vacuum supply directly from the intake manifold of automobiles that do not have vacuum windshield wipers.

and a No. 1 Büchner funnel fitted with a No. 7 rubber stopper. (See fig. 1.) With this arrangement, coarse suspended matter can be removed with 5.5-cm conventional filter paper, and turbidity can be removed by use of 2-inch membrane-type filters. The membrane filters are somewhat smaller than the plate of the funnel, but by careful placement, the holes in the base can be adequately covered. The flask can be set on the floor of the car or, by use of clamps and aluminum rod, attached to some part of the interior of the vehicle.

Once the connections are made, it is only necessary to start the engine and turn on the windshield wipers to obtain suction through the funnel into the flask.

The suction flask must not be allowed to fill to capacity, or water will be sucked into the wiper system. To prevent this, a catch-bottle can be installed between the filter flask and wiper motor; however, this is an inconvenience that is not necessary if reasonable care is exercised in the filtering operation.

This apparatus has proved especially valuable while collecting water samples from test wells. Frequently, time and equipment are not available to develop test holes sufficiently to obtain the perfectly clear samples necessary for a chemical analysis, and only by use of a good field filtering device is it possible to use the water samples collected under those conditions.

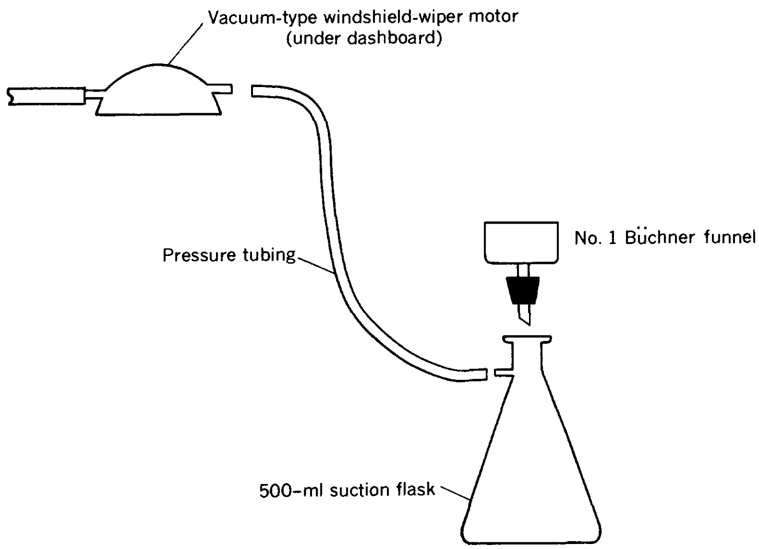


FIGURE 1.—Apparatus for filtering suspended material from water samples, in the field, by using suction from a vacuum-type automobile windshield wiper.

FILTERING WATER SAMPLES USING VACUUM FROM AUTOMOBILE INTAKE MANIFOLD[1]

By Neal R. Harmon

ABSTRACT

Frequently it is desirable to filter water samples in the field right after they are collected. Vacuum to use with the filtering equipment can be obtained by tapping into the intake manifold of an automobile motor.

The vacuum system described by Wilder (p. 59) was successful, but many late-model automobiles are not equipped with vacuum windshield wipers. The author designed an apparatus to obtain vacuum directly from the intake manifold of the engine. Compared with hand vacuum pumps, this system, tested on certain station wagons and trucks having V-8 motors, has proved very effective and has resulted in a considerable saving of time and money. Samples can be filtered while field personnel are driving from one sampling station to another, and pump breakdowns have been eliminated. Hand pumps cost $26.00 each—the average cost of parts and installation for a manifold vacuum supply is $15.00. A hand pump is portable, but this vacuum-supply apparatus has been transferred easily from one car to another at a small labor cost.

The vacuum-supply apparatus consists of copper tubing, rubber tubing, a two-way brass stopcock, a flare nut, and a brass fitting. The copper tubing is attached by the brass fitting to a threaded plug hole, available on most intake manifolds. The rubber tubing, which should be about 4 inches long, is spliced into the copper tubing at the point of contact with the firewall to prevent motor-vibration noises. One end of a 4- to 6-inch piece of copper tubing is attached to the stopcock by a flare nut, and the other end is placed where the suction tubing of the filter kit can be easily attached and removed. (See fig. 1.)

The filter kit used with the vacuum-supply apparatus is the same as that previously used with the hand pump. It consists of a Millipore

[1] The author of this article modified the system developed by H. B. Wilder (p. 59) to use the vacuum directly from the intake manifold of automobiles that do not have vacuum windshield wipers.

796-504 O—66——5

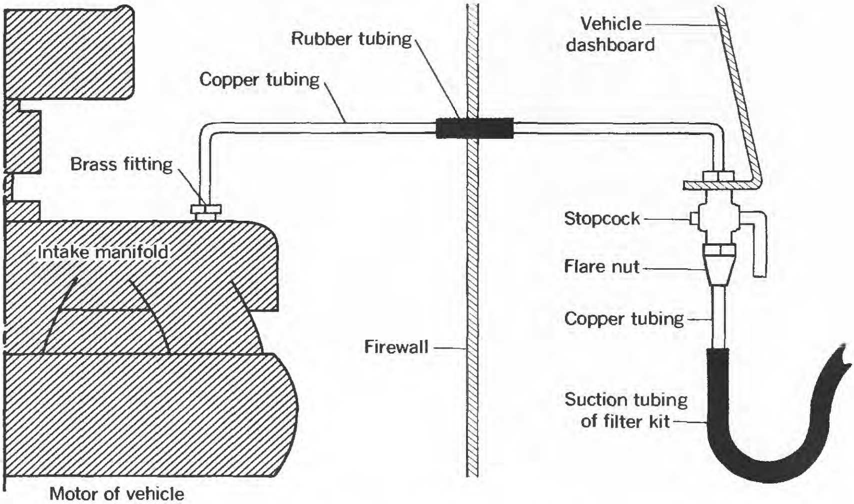


FIGURE 1.—Apparatus to connect intake manifold of automobile to filter kit.

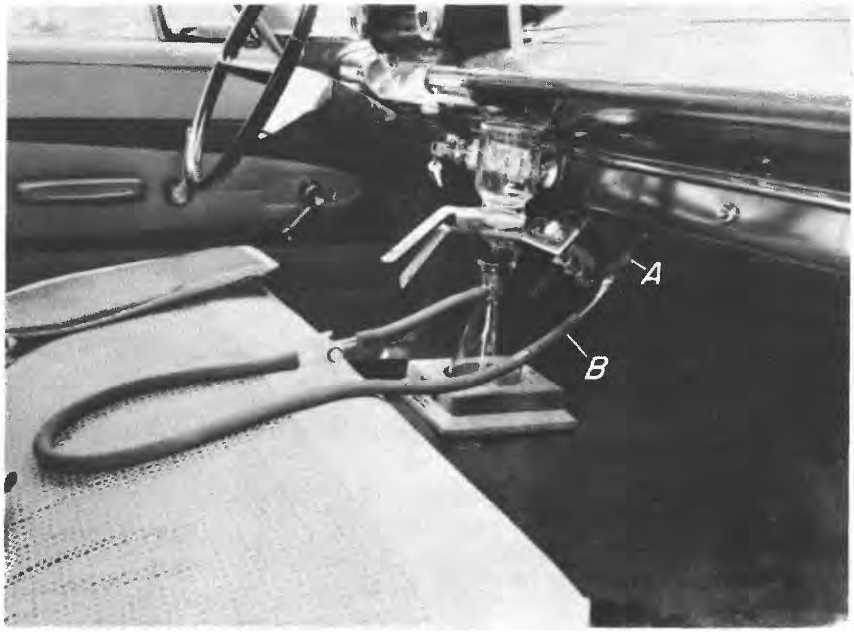


FIGURE 2.—View of filtering kit connected to vacuum line. *A*, Stopcock on vacuum line that runs through dashboard of automobile to intake manifold of motor; *B*, rubber tube from filter slips over copper tubing of the vacuum line.

filter holder, a 500-ml Pyrex flask, about 2 feet of suction tubing, a box of Millipore filters type HA, and a base to hold the flask. (See fig. 2.)

INSTALLATION ASSEMBLY FOR CONDUCTANCE CELLS

By L. G. Toler and R. N. Cherry

ABSTRACT

Electrodes for conductance recorders may require frequent removal from a stream for cleaning and replatinizing. An installation assembly that will facilitate removal of the electrodes and their return to a fixed position in the stream can be made from copper or plastic pipe, a brass rod, and two washers.

The monitoring of chemical changes in stream water is normally a part of any water-resources investigation. Records for at least 1 year are required to define seasonal variations, and continuous records are preferred. One concentration parameter of water that can be measured continuously is electrical conductance. The electrical conductance is then related to the total mineral concentration and individual constituents in the water by periodic collection and analysis of water samples.

A continuous record of electrical conductance is obtained by installing a conductance cell in the stream in a fixed position. A conductor cable connects the cell to a recorder on a bridge or platform above the stream. At many of these conductivity-recorder stations the cell must be removed frequently to clean and replatinize the electrodes. To insure uniformity in the results, the conductance cell should always be returned to the same level in the stream and oriented in the same direction. The installation assembly described here will facilitate the removal of the cell and the return to its original position.

The materials required are a 2½-inch-diameter pipe (copper or plastic pipe is best in tidal streams), a brass rod, one washer with adjusting screws—slotted on the periphery—and one fixed washer in the lower end of the housing pipe. A guide for the slotted washer must be anchored vertically against the inside of the housing pipe, above the fixed washer. The installation assembly is shown in figure 1.

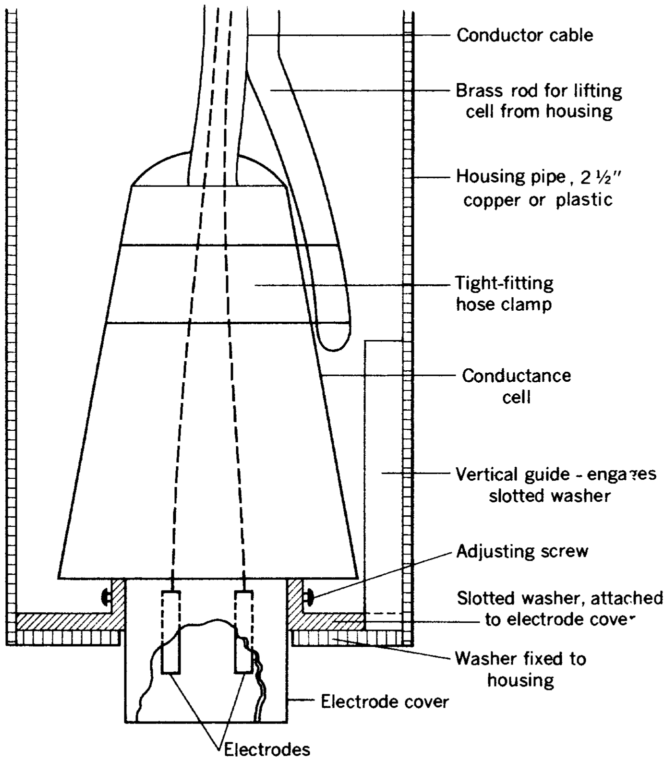


FIGURE 1.—Installation assembly for conductance cells. The housing pipe is fastened permanently to a bridge pier, or other structure. The electrode assembly can be lifted from or replaced in the housing pipe by using the brass rod as a handle. The slotted washer on the electrode cover engages the vertical guide on the pipe housing and insures that the electrodes are always returned with the same orientation.

The copper or plastic pipe houses the assembly and is installed so the top end is accessible on the mounting platform. Both washers are selected to fit over the cell cover and inside the housing pipe. The slotted washer is secured to the cell cover by means of adjusting screws. With the brass rod attached to the cell cover as shown, the cell may be rotated until the slot in the washer on the electrode cover assembly engages the vertical guide on the pipe housing. When the slot in the washer engages the vertical guide, the electrodes are returned to the same directional orientation that they were in before they were removed. The fixed washer at the bottom of the housing pipe is a stop that positions the electrodes so they can always be returned to the same elevation.

In tidal streams, a copper screen may be attached to the bottom of the pipe to enclose the conductance cell and reduce the problem of barnacles and other sessile organisms.

Cost of the assembly for mounting a conductance cell is estimated as follows:

Material	*Cost*	*Material*	*Cost*
2 washers	$0. 25	Copper screen	$2. 00
10 feet of copper tube	18. 00	Labor	25. 00
10 feet of brass rod	5. 00		

Less expensive assemblies may be fabricated by substitution of other materials for copper.

USE OF THERMISTOR-THERMOMETER IN DETERMINATION OF SPECIFIC CONDUCTANCE

By LEON S. HUGHES

ABSTRACT

Determination of the specific conductivity of water requires that the resistance of a sample of the water in a conductivity cell and the temperature of the water in the conductivity cell be observed at precisely the same time. The thermistor-thermometer described here with the probe inserted directly into the conductivity cell makes it possible to read the temperature at the same time that the resistance of the sample is observed. One step—the need to refer to a graph or table to adjust data to the standard temperature of 25° C—is eliminated by replacing the temperature scale on the thermistor-thermometer with one that reads directly in resistance of the standard calibration solution of 0.00702*N* KCl at the temperature of the water sample at the time of observation.

The specific conductance of water is a measure of the ability of the water to carry an electrical current. Chemically pure water has a very low electrical conductance but the presence of the dissociated ions increases the conductance of the solution. The specific conductance is therefore an indication of the total concentration of ionized substances in water, and the relation of dissolved solids to specific conductance can be defined for most waters (Hem, 1959, p. 37–43).

Specific conductance is easily and quickly determined and indicates the dissolved-solids content of water closely enough for many purposes. It is particularly valuable in showing the short-term changes that occur in the quality of streamflow. Conductance values are also used as a guide in selection of laboratory procedures for determining dissolved constituents and are an aid in checking the accuracy of analyses.

Specific conductance is determined by measuring the resistance of water by using a Wheatstone bridge in which a variable resistance is adjusted to equal the resistance of the unknown solution between platinized electrodes of a standardized conductivity cell. The conductance is the reciprocal of the resistance. As the temperature of a water solution of mineral matter rises, the conductance increases; therefore, to make conductance values comparable, they must all be referred to the same temperature. Conductivity data for natural water are referred to 25° Centigrade as a standard temperature. It is necessary either to have the water samples at 25° C or to determine the resistance at another temperature and compute specific conductance at 25° C. Instruments are available that provide automatic compensation for changes in temperature, and although these are excellent for fieldwork they are not sufficiently precise for laboratory use.

In Geological Survey laboratory practice each conductivity cell is calibrated by measuring, with the Wheatstone bridge, the resistance of a 0.00702*N* potassium chloride (KCl) solution throughout the range of temperatures that can be expected in the water sample to be tested. Temperature of the 0.00702*N* KCl is observed to 0.1° C, and recorded at the same time the resistance of the KCl solution is measured. A working graph of resistance of the 0.00702*N* KCl versus temperature is drawn.

Specific conductance of water samples to be tested has the same variation with temperature as the 0.00702*N* KCl solution. Resistance values observed for water samples, at temperatures other than 25° C, are converted to specific conductance at 25° C by a simple arithmetic proportion relation with data from the working graph for 0.00702*N* KCl (Rainwater and Thatcher, 1960, p. 275). The relation is:

$$\text{Specific conductance (micromhos)} = \frac{R \text{ of } 0.00702N \text{ KCl}}{R \text{ of sample}} \times 1{,}000$$

where R = resistance in ohms.

R of the sample is measured with the Wheatstone bridge and R of 0.00702*N* KCl is taken from the working graph—for the observed temperature of the sample at the time it is tested. The number 1,000 is the known specific conductance of 0.00702*N* KCl solution at 25° C.

One of the operational problems of measuring conductance of water samples is that it is difficult to obtain the sample temperature quickly and at exactly the same time that the resistance of the sample is measured. The temperature of the water sample is usually determined by inserting a thermometer directly into the sample bottle. Unless water samples are close to room temperature, the temperature of the sample may change in traveling to the conductivity cell, where resistance is measured, and be significantly different from that measured in the sample bottle. Some laboratories have the thermometer mounted in a bulb directly above the pipet conductivity cell. This latter arrangement assures that the temperature measured is the same as that of the water in the conductivity cell but may require the use of more of the sample than can be spared.

The apparatus described here uses a thermistor-thermometer available commercially, to measure the water temperature, at the same time the resistance is measured. A stainless-steel thermistor probe is inserted directly into the pipet conductivity cell. Figure 1 shows

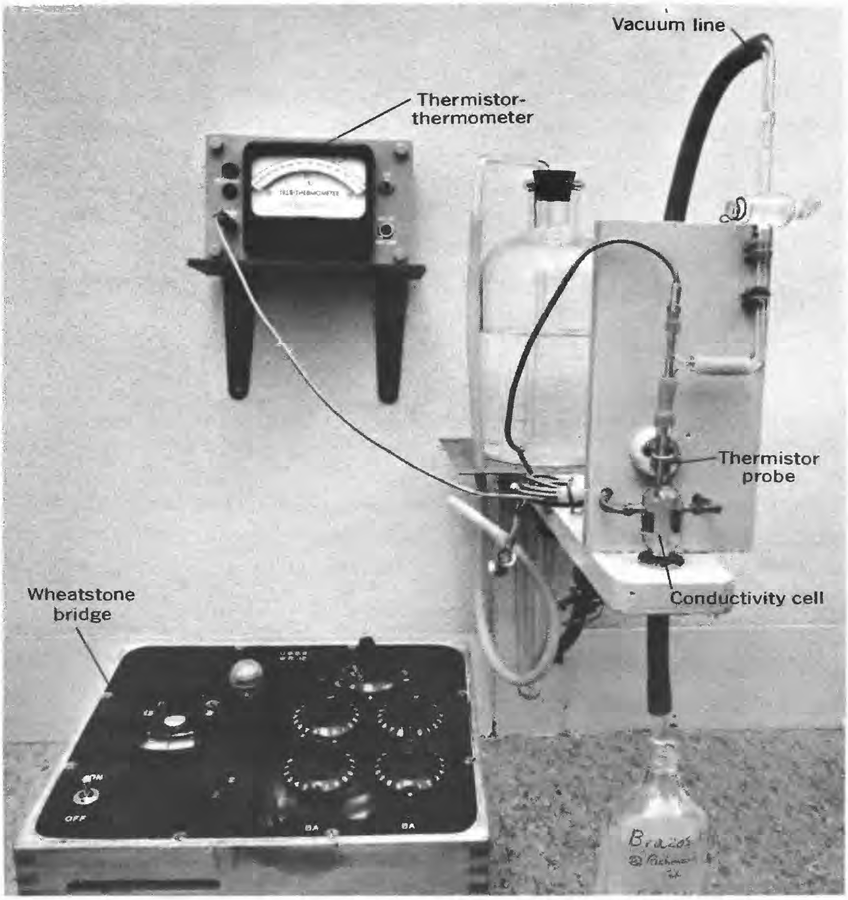


FIGURE 1.—Apparatus to measure conductivity of water. Note that thermistor probe is inserted directly into conductivity cell.

the complete conductivity apparatus. The original stopcock has been cut from the pipet cell, and a substitute stopcock has been connected by means of a glass tee and rubber-tubing joints. The thermistor probe, which is 1/8 inch in diameter and 4 1/2 inches long, passes through the tee and into the top of the cell. If the probe is kept above the level of the electrodes, the cell constant is not affected.

The temperature is read from a scale covering a temperature range from 20° to 30° C, graduated in tenths of a degree. The instrument has been checked throughout its range and it agrees with precision-grade thermometers to within 0.1° C.

Instead of the Fahrenheit scale, which originally occupied the upper part of the dial, a scale of resistance values for standard KCl has been substituted. This scale was prepared from the working graph already discussed. The thermometer, therefore, indicates directly the KCl resistance value for the sample temperature, and reference to a graph or table is not necessary.

The thermistor probe registers change in temperature very rapidly, indicating 99 percent of a full-scale change within about 4 seconds. Thus, by the time the cell is rinsed and refilled, the KCl resistance value can be read off the dial.

Determination of specific conductance by using the thermistor-thermometer requires 30–40 percent less time than by using an ordinary thermometer.

The cost of the single-channel thermistor-thermometer shown in figure 1 was $120 and the 1/8-inch diameter probe that is inserted in the conductivity cell, $25. Power supply for the thermistor-thermometer is a small 2.5-volt battery, reported to be good for 2,000 hours of operation.

LITERATURE CITED

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

Rainwater, F. H., and Thatcher, L. L., 1960, Methods for collection and analysis of water samples: U.S. Geol. Survey Water-Supply Paper 1454, 301 p.

SPECTROPHOTOMETRIC DETERMINATION OF ALUMINUM USING ERIOCHROME CYANINE RC

By Marvin J. Fishman

ABSTRACT

A spectrophotometric method for the determination of microgram quantities of aluminum in water is described. Aluminum solutions buffered to a pH of 6.0 form, with Eriochrome Cyanine RC, a red lake which exhibits maximum absorbance at 535 mμ. Aluminum concentrations as low as 0.01 mg per liter can be determined. Ascorbic acid inhibits the interference by iron. Interference by fluoride and silica are eliminated by evaporation of sample with concentrated sulfuric acid.

INTRODUCTION

Any one of several methods may be used to determine aluminum in water. Shull (1960) studied the aluminon method and modified it to improve its accuracy, sensitivity, and reproducibility. His modified method appears in "Standard Methods for the Examination of Water and Wastewater" (Am. Public Health Assoc. and others, 1960). Knight (1960) described a method using Solochrome Cyanine R as a color-forming reagent. Absorption is measured at 605 millimicrons. The method has a sensitivity of 0.004 milligrams per liter. Ascorbic acid eliminates iron interference; fluoride, orthophosphate in large amounts, pyrophosphate, and hexametaphosphate cause interference. In a review article on water analysis, Skougstad and Fishman (1961) described other colorimetric, fluorometric, and flame photometric methods for the determination of aluminum.

A sensitive method for determining aluminum in soil, ash, and plant materials is described by Jones and Thurman (1957). The results of a detailed investigation of Jones and Thurman's procedure using Eriochrome Cyanine RC and a recommended procedure for determining aluminum in water are presented in this paper.

GENERAL DISCUSSION

Principle.—Dilute aluminum solutions buffered to a pH of 6.0 form, with Eriochrome Cyanine RC, a red lake that exhibits maximum absorbance at 535 mμ. Ascorbic acid inhibits the interference of iron. Aluminum concentrations of 0.01–0.5 mg per l can be determined using 25 milliliters of the sample and higher concentrations can be determined by using less than 25 ml of the sample and diluting this to 25 ml.

Interferences.—Fluoride concentrations of more than 0.4 mg per l and silica concentrations of more than 80 mg per l cause low results. These interferences are eliminated by evaporation of sample with concentrated sulfuric acid. As much as 10 mg per l of orothophosphate does not interfere; as much as 2 mg of iron per l can be compensated for with ascorbic acid.

APPARATUS AND REAGENTS

Beckman Model B spectrophotometer (or equivalent):

Wavelength: 535 mμ.

Cells: Fisher 23-ml absorption cell, cylindrical curvettes of 50-mm path length (Coleman) or similar.

Phototube: Blue sensitive.

Initial sensitivity setting: 2.

Slit width: 23-ml cells, 0.06 mm (approximate), 50-mm cells, 0.12 mm (approximate).

The following absorbances have been observed:

Al (μg)	*Cell*	*Absorbance*
2.5	Fisher 23-ml	0.180
5.0	do	.400
7.5	do	.640
10.0	do	.910
12.5	do	1.160
2.5	Coleman 50-mm	.360
5.0	do	.800
7.5	do	1.250

Glassware: All glassware should be rinsed first with 1:1 HCl and then with metal-free water to avoid errors due to contamination.

Potassium alum, 1.00 ml=100 μg Al^{+3}: Dissolve 1.758 g of $AlK(SO_4)_2 \cdot 12H_2O$ in metal-free water. Add 0.5 ml $CHCl_3$ and dilute to 1,000 ml with metal-free water.

Potassium alum, 1.00 ml=1.0 μg Al^{+3}: Dilute 10 ml of potassium alum solution (1.00 ml=100 μg Al^{+3}) to 1,000 ml with metal-free water.

Sulfuric acid, concentrated.

Eriochrome Cyanine RC, 0.075 percent: Dissolve 0.75 g of Eriochrome Cyanine RC in about 200 ml of metal-free water. Add 25 g each of sodium chloride and ammonium nitrate; add 2 ml of concentrated nitric acid and dilute to 1,000 ml with metal-free water. (The reagent is available from Allied Chemical Corp. under the name of Alizarol Cyanine RC.)

Ammonium acetate buffer, pH 6.0: Dissolve 320 g of ammonium acetate in metal-free water; add 5 ml of glacial acetic acid and dilute to 1,000 ml with metal-free water.

Ascorbic acid, 1 percent solution: Dissolve 1 g of L-ascorbic acid in 100 ml of metal-free water. This solution should be prepared fresh each day.

PROCEDURE

1. Prepare a series of standards containing from 0.0 to 12.5 μg of Al in 50-ml volumetric flasks.
2. Pipet a volume of sample containing less than 12.5 μg of Al (25.0 ml maximum) into a platinum dish.
3. Add 1 ml of concentrated sulfuric acid to samples and evaporate to dryness on a hotplate.
4. Transfer residues with metal-free water to 50-ml volumetric flasks.
5. Add 2 ml of 1 percent ascorbic acid solution.
6. Add 5 ml of 0.075 percent Eriochrome Cyanine RC solution.
7. Add 10 ml of ammonium acetate buffer solution and dilute to 50 ml with metal-free water. Shake.
8. Read the absorbances of the sample and standards within 20 minutes.
9. Determine the μg of Al in the unknown sample from a plot of absorbances of standards containing known amounts of aluminum.

CALCULATIONS

Determine the aluminum concentration by using the equation:

$$\text{mg of Al per l} = \frac{\mu\text{g Al}}{\text{ml sample}}$$

Report aluminum concentrations below 1.0 mg per l to two decimal places and greater than 1.0 mg per l to two significant figures.

RESULTS

INTERFERENCES

Several samples of natural water were used to study the effect of interference and the accuracy and precision of the method. These samples represent a wide concentration range of dissolved materials. Known amounts of aluminum were added, and the samples were analyzed according to the described procedure except the evaporation step was omitted. The fact that aluminum recoveries were lowest in those samples known to contain appreciable amounts of fluoride indicates serious interference from fluoride.

To determine the extent of fluoride interference, varying amounts of fluoride were added to solutions containing known amounts of aluminum. The results indicated no serious error when the fluoride concentration was less than 0.4 mg per l; at concentrations of more than 0.4 mg of fluoride per l the interference from fluoride gradually increased, and aluminum recovery was low.

The extent of silica interference was determined by adding various amounts of silica of as much as 320 mg per l to solutions containing known amounts of aluminum. The results indicated that concentrations of silica of as much as 80 mg per l did not interfere; in concentrations of silica more than 80 mg per l the interference from silica increased rapidly, and aluminum recovery was low.

Both fluoride and silica interferences can be eliminated by evaporating the samples to dryness with concentrated sulfuric acid. Fluoride is removed as volatile fluosilicic acid, and almost all the silica remains insoluble when the residue is redissolved.

The minimum volume of concentrated sulfuric acid required to remove both fluoride and silica was determined. Results (table 1)

TABLE 1.—*Evaporation of samples with different volumes of concentrated* H_2SO_4 *prior to* Al *determination*

[Result as in milligrams per liter]

Sample	Al added	No evaporation; no H_2SO_4	Al found: Evaporation; H_2SO_4 as indicated— 6 drops	1 ml	2 ml
1	0.00	0.00	----	0.00	----
	.05	.05	----	.05	----
	.20	.18	----	.20	----
	[1].38	.37	----	.38	----
2	.00	.00	0.00	.00	0.00
	.05	.00	.04	.06	.07
	.20	.09	.16	.20	.20
	[1].38	.23	.34	.36	.37
3	.00	.00	.00	.01	.05
	.05	.00	.04	.05	.08
	.20	.05	.17	.20	.26
	[1].38	.18	.30	.36	.44

[1] Correct for sample dilution.

showed that the addition of 1 ml of concentrated sulfuric acid will ensure virtually complete removal of fluoride upon evaporation of the sample. Results obtained on replicate determinations made on samples containing 1.2 mg of fluoride per l and varying known amounts of aluminum are given in table 2. The standard deviation

TABLE 2.—*Replicate aluminum determination on samples containing 1.2 mg per l of fluoride*

[Results are in milligrams per liter]

Series	Al added	Fisher 23-ml cells			Coleman 50-mm cells		
		Al found	Average	Standard deviation (±)	Al found	Average	Standard deviation (±)
1	0.00	[1] 0.02 .00 .00 .00 .00 .00	0.00	0.00	[1] 0.02 .00 .01 .00 .00 .00	0.00	0.00
2	.05	.07 .07 .05 .04 .06 .05	.06	.01	.06 .06 .04 .06 .04 .04	.05	.01
3	.20	.18 .22 .22 .20 .22 .22	.21	.02	.18 .22 .22 .20 .22 .22	.21	.02
4	.40	.36 .38 .43 .43 .42 .40	.40	.03	----------	----------	----------

[1] This value not included in results.

ranges from ±0.00 mg of aluminum per l at the lowest concentration to ±0.03 mg of aluminum per l at the highest concentration. Known amounts of aluminum were added to samples of natural water containing 200 mg of silica per l, and the samples were evaporated to dryness with 1 ml of concentrated sulfuric acid. Aluminum was determined in the solution of the residues. The recovery of aluminum was in excellent agreement with the amount of aluminum added (table 3).

TABLE 3.—*Evaporation of samples with sulfuric acid to eliminate silica interference*

[SiO_2 concentration, 200 mg per l]

Sample	*Al concentration (mg per l)* Added	*Al concentration (mg per l)* Found
1	0.00	0.00
	.05	.06
	.10	.10
	.20	.18
	.40	.38
2	.00	.00
	.10	.10
	.20	.22
	.40	.42

Provision must be made to eliminate interference due to iron. Both thioglycollic acid and L-ascorbic acid have been used for this purpose. Jones and Thurman (1957) found that even with thioglycollic acid iron interfered. However, a maximum level of interference was reached at 100 μg iron. In their procedure they initially added 200 μg iron to both blank, standards and samples, and subtracted the aluminum found in the blank from the aluminum found in the standards and samples. From the recovery experiments they performed, the aluminum found agreed with the aluminum added. However, this procedure involves additional manipulations which can be eliminated by using ascorbic acid to complex the iron. The results obtained when ascorbic acid was used are included in table 4. Varying volumes of 1

TABLE 4.—*Elimination of iron interference using 1 percent ascorbic acid*

[Concentration in milligrams per liter]

Fe concentration	Al[1] found in—		
	10 ml ascorbic acid	5 ml ascorbic acid	2 ml ascorbic acid
0.00	0.10	0.10	0.10
.50	.10	.10	.10
1.0	.11	.10	.10
1.5	.11	.10	.10
2.0	.12	.10	.11
4.0	0	0	.11

[1] 0.10 mg per l aluminum was added initially.

percent ascorbic acid solution were added to solutions containing known amounts of aluminum and as much as 4 mg of iron per l. Two ml of 1 percent ascorbic acid solution is sufficient to inhibit interference of as much as 2 mg of iron per l. Four mg of iron per l results in a positive error of about 0.02 mg of aluminum per l. Because of the close agreement between the amount of aluminum added to the samples and the amount recovered, it seems unnecessary, when using ascorbic acid, to add a known amount of iron as was done for thioglycollic acid.

Phosphate interferes in some aluminum procedures. Therefore, aluminum determinations were made on samples of water containing known amounts of aluminum and as much as 10 mg of orthophosphate per l. Orthophospate did not interfere with these determinations. The effect of other phosphorus species was not studied.

COLOR DEVELOPMENT OF LAKE

The time required for the color of the aluminum-Eriochrome Cyanine RC complex to reach full intensity when ascorbic acid is added is 1–2 minutes. The complex is stable for at least 14 minutes and only a very slight decrease in intensity is observed even after 20 minutes. The stability of the colored lake was not observed for a longer time because 20 minutes is sufficient to determine the absorbences of a set of several samples. Using thioglycollic acid, the time for full color development is 8 minutes; the color remains stable for an additional 30 minutes.

PRECISION AND ACCURACY

For a 25 ml sample the standard deviation ranged from 0.00 mg per l for an aluminium concentration of 0.00 mg per 1 to 0.03 mg per l for an aluminum concentration of 0.40 mg per liter. Inasmuch as the errors were positive and negative with approximately equal frequency, it can be assumed that the accuracy of the determination is limited by the precision (that is, the inherent accuracy of the determination is better than the precision).

REFERENCES

American Public Health Association and others, 1960, Standard methods for the examination of water and wastewater: 11th ed., New York, Am. Public Health Assoc., Inc., p. 48–51.

Jones, L. H., and Thurman, D. A., 1957, The determination of aluminum in soil, ash, and plant materials using Eriochrome Cyanine RA: Plant and Soil, v. 9, no. 2, p. 131–142.

Knight, A. G., 1960, Residual aluminum; its estimation and control: Soc. Water Treatment Exam. Proc., v. 9, pt. 1, p. 72–80.

Shull, K. E., 1960, Suggested modified aluminum method for aluminum determination: Am. Water Works Assoc. Jour., v. 52, p. 779–785.

Skougstad, M. W., and Fishman, M. J., 1961, Water analysis: Anal. Chemistry, v. 33, p. 138R.

SEMIMICROANALYTICAL METHOD FOR THE DETERMINATION OF IODIDE IN WATER

By C. G. Mitchell

ABSTRACT

The semimicroanalytical method presented for determining iodide in water is based on the catalytic effect of iodide on the ceric-arsenious oxidation reaction. In the presence of a small amount of iodide, the reaction follows first-order reaction-rate kinetics. At a given temperature and for a given reaction time, the extent of reduction of ceric ion is directly proportional to iodide concentration. The reaction may be stopped at any time by the addition of silver ion. Simple photometric measurement of the absorbance of the solution permits evaluation of the extent of the reaction. Most substances normally present in natural waters do not interfere.

INTRODUCTION

Iodide is in trace amounts in both rocks and water. Iodide concentrations in fresh waters range from 0.05 to 4.5 ppb (parts per billion) (Monier-Williams, 1950). Concentrations as high as 150 ppm (parts per million) have been reported in certain thermal waters.

An accurate determination of iodide in trace amounts is useful for the study of certain water problems. This paper presents an accurate method for determining trace amounts of iodide in water. The method may be used in research or routine laboratory analysis.

The method is based on the catalytic effect of iodide on the reduction of ceric ion by arsenious ion. After a given reaction time, the amount of unreduced ceric ions is measured photometrically. Three variables—time, temperature, and amount of iodide present—determine the rate and the extent of the reaction. Thus, for a given temperature and reaction time, the extent of reduction of ceric ion is a function only of the amount of iodide present and is directly proportional to iodide concentration.

APPARATUS AND REAGENTS

Test tubes, Pyrex, 20 by 150 mm.
Glass stirring rods.
Constant-temperature water bath (30° ± 0.5° C).

Beckman Model B spectrophotometer (or equivalent):
  Wavelength: 450 mμ.
  Cells: Fisher, 23 ml.
  Phototube: Blue sensitive.
  Blank: Distilled water.
  Initial sensitivity setting: 1.
  Slit width: 0.3 mm (approximate).

Arsenious acid, 0.3*N* H_3AsO_3 (oxidation concentration): Add 14.84 g of As_2O_3 to about 500 ml of demineralized water in a 1,000-ml beaker. Next, slowly add 28 ml of concentrated (96 percent H_2SO_4 (sp gr 1.84) and warm the mixture until the As_2O_3 is dissolved. Cool and transfer to a 1-liter volumetric flask, then dilute to 1 liter with demineralized water. Add a small piece of metallic arsenic to stabilize the solution (Kydd and others, 1950).

Ceric sulfate, 0.1*N* $Ce(HSO_4)_4$ (reduction concentration): Prepare in a 1-liter volumetric flask by dissolving 52.84 g of anhydrous $Ce(HSO_4)_4$ in 5*N* H_2SO_4. Warm the mixture and stir occasionally until a clear solution is obtained (approximately 1 hour). Dilute to 1 liter with 5*N* H_2SO_4 and store away from light. The normality of this solution should be checked against the 0.3*N* H_3AsO_3 to assure that 3 volumes of 0.1*N* $Ce(HSO_4)_4$ react, in the presence of I^{-1}, with 1 volume of 0.3*N* H_3AsO_3.

Silver nitrate, 0.01 percent $AgNO_3$ by weight: Store in a dark bottle.

Sulfuric acid, 5*N* H_2SO_4: Slowly add 138.8 ml of concentrated (96 percent) H_2SO_4 (sp gr 1.84) to about 500 ml of demineralized water; mix and dilute to 1 liter.

Potassium iodide (stock solution), 1.00 ml=0.10 mg I^{-1}: Dissolve 0.131 g KI, dried overnight in a sulfuric acid desiccator, in demineralized water, and dilute to exactly 1 liter.

Potassium iodide (standard solution), 1.00 ml=0.0001 mg I^{-1}: Dilute 1.0 ml of stock KI solution to 1 liter with demineralized water.

ANALYTICAL PROCEDURE

Pipet blank and standards containing 0.00–1.2 μg I^{-1}, and samples containing less than 1.2 μg I^{-1} (20.0 ml max) into Pyrex test tubes (20×150 mm). Dilute each sample and standard to 20.0 ml. Add 1.0 ml of 0.3*N* H_3AsO_3 to each tube; stir. Place all tubes and the bottle containing $Ce(HSO_4)_4$ in a constant-temperature bath at 30° C. Allow time (30–45 minutes) for samples and $Ce(HSO_4)_4$ to reach temperature equilibrium. At zero time add 1.0 ml of 0.1*N* $Ce(HSO_4)_4$ to standards and sample, and mix thoroughly. After exactly 10 minutes add, while stirring, 1 drop (0.05 ml) of 0.01 percent $AgNO_3$.

Measure absorbance at 450mμ. The instrument is set to 0.000 absorbance with distilled water. The ratio of As (absorbance of standard) to Ab (absorbance of blank) is obtained and the iodide content of the sample is calculated from a calibration curve (fig. 1).

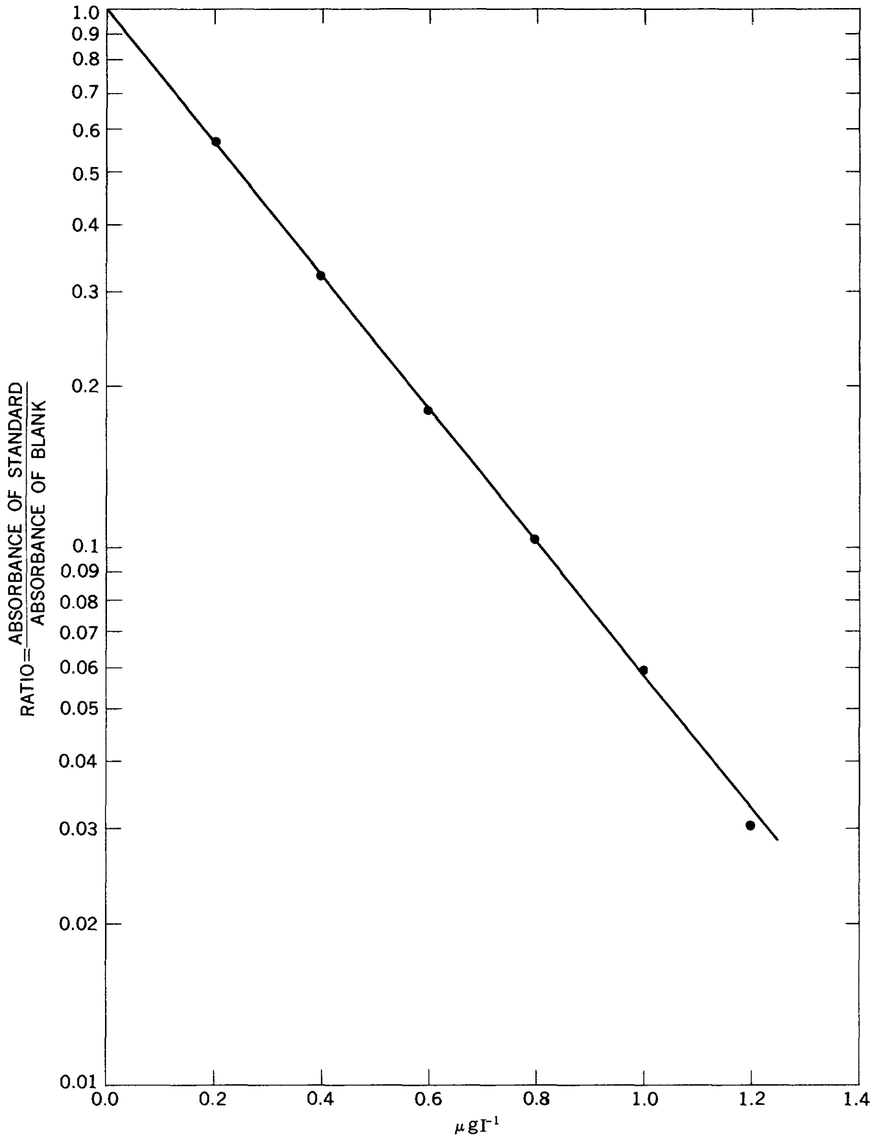


FIGURE 1.—Calibration curve (mean of six determinations) used in determination of iodide in water.

CALCULATIONS

1. Construct a calibration curve (fig. 1) by plotting the ratio As: Ab against μg of I^{-1} on semilog paper.

2. From the curve, determine μg I^{-1} corresponding to the absorbance ratio obtained for the sample.

3. $\text{ppm } I^{-1} = \frac{1}{\text{density}} \times \frac{1}{\text{ml sample}} \times \mu g \ I^{-1}$

Report I^{-1} concentrations of less than 0.1 ppm to three decimal places and those greater than 0.1 ppm to two significant figures.

DISCUSSION

In the presence of iodide, the reaction follows first-order reaction-rate kinetics (Glasstone, 1940, p. 1118; Kontaxis and Pickering, 1958). Figure 2 shows that, at a temperature of 30° C, the optimum reaction time for determining 0.0–1.2 μg of iodide is 10–12 minutes. A reaction time of 10 minutes was selected for this procedure for convenience.

The inhibitory effect of silver ion on the reaction has been previously observed (Kontaxis and Pickering, 1958). Other ions such as mercuric or hypochlorite (Rossum and Villarruz, 1960) also may be used to arrest the reaction. The effectiveness of silver ion is shown in table 1. After the addition of silver nitrate there is no change in absorbance for a period of about 30 minutes; after 30 minutes the color gradually fades and the absorbance decreases.

TABLE 1.—*Change in absorbance after addition of silver nitrate*

μg I^{-1}	Time, in hours, after addition of $AgNO_3$						
	0	0.5	1.0	2.0	3.0	4.0	5.0
	Absorbance						
0.0	0.860	0.860	0.795	0.664	0.585	0.470	0.391
.2	.506	.505	.484	.440	.410	.370	.330
.4	.306	.307	.292	.261	.252	.230	.290
.6	.158	.158	.154	.145	.140	.128	.116
.8	.094	.093	.089	.078	.080	.073	.067
1.0	.044	.045	.043	.039	.036	.031	.032
1.2	.022	.022	.022	.022	.022	.017	.016

The advantages of arresting the reaction by adding silver ion are:
1. The determination of the absorbance of the samples after an exact reaction period is possible.
2. Rigid control of temperature during spectrophotometric measurement is unnecessary.
3. The manipulation of individual samples is simplified and several samples may be analyzed conveniently at one time.

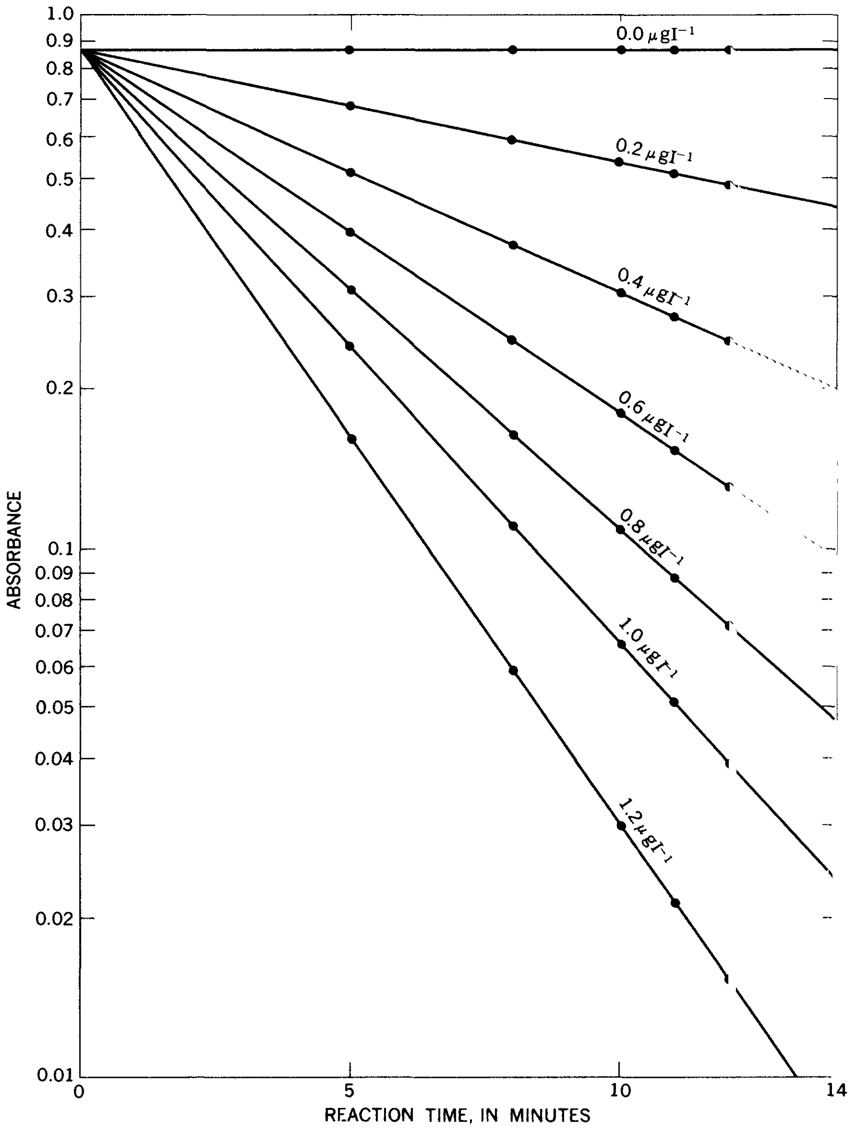


FIGURE 2.—Time relation of the ceric-arsenious reaction.

RECOVERY TEST

The iodide concentration of each of 10 natural-water samples was determined by the procedure described. The concentrations ranged from 2 to 18 ppb. Different known amounts of standard iodide solution were then added to 10-ml aliquots of each sample, and the total amount of iodide was determined. Results of this test (table 2) show

TABLE 2.—*Recovery of added iodide*

[Results in micrograms]

Sample	Iodide in 10-ml sample	Iodide added	Total iodide	Iodide recovered	Error
1	0. 08	0. 50	0. 58	0. 53	0. 05
2	. 03	. 10	. 13	. 16	. 03
3	. 04	. 20	. 24	. 29	. 05
4	. 04	. 50	. 54	. 50	. 04
5	. 02	. 60	. 62	. 64	. 02
6	. 03	. 60	. 63	. 64	. 01
7	. 10	. 50	. 60	. 60	. 00
8	. 18	. 30	. 48	. 48	. 00
9	. 14	. 20	. 34	. 35	. 01
10	. 12	. 10	. 22	. 21	. 01

Mean error .... 0.02 $\mu g\ I^{-1}$
Maximum error .... .05 $\mu g\ I^{-1}$

a maximum error of 0.05 μg of I^{-1} per 10-ml sample (0.005 ppm) and a mean error of 0.02 μg of I^{-1} (0.002 ppm).

INTERFERENCES

Low values for I^{-1} may result if the reaction test tubes are not thoroughly clean. Each sample tube should be thoroughly rinsed with HCl to remove possible contaminants.

Bromide does not interfere; any oxidizing agent that oxidizes iodide to iodine has no effect on the reaction. However, certain phosphate compounds used in water treatment (Calgon, for example) inhibit the reaction. This effect can be eliminated by adding three drops of concentrated nitric acid to the sample when placed in the test tube. The nitric acid should be aerated to remove nitrogen oxides. The effects of this treatment are shown in table 3.

TABLE 3.—*Interference of Calgon on iodide determination*

$\mu g\ I^{-1}$	Absorbance		
	Standard only	Standard containing 2 ppm Calgon	Standard containing 2 ppm Calgon and 3 drops HNO_3
0. 0	0. 860	0. 860	0. 860
. 2	. 506	. 850	. 511
. 4	. 306	. 844	. 308
. 6	. 158	. 836	. 160
. 8	. 094	. 821	. 095
1. 0	. 044	. 765	. 044
1. 2	. 022	. 740	. 023

REFERENCES CITED

Glasstone, Samuel, 1940, Textbook of physical chemistry: New York, Van Nostrand Co. 1289 p.

Kontaxis, N. E., and Pickering, D. E., 1958, A micro-method for the determination of butyl-alcohol extractable hormonal iodine in serum: Jour. Clin. Endocrinol. and Metabolism, v. 18, p. 774–786.

Kydd, D. M., Man, E. B., and Peters, J. P., 1950, Concentration of precipitable iodine (SPI) in the serum: Jour. Clin. Inv., v. 29, p. 1033–1040.

Monier-Williams, G. W., 1950, Trace elements in food: New York, John Wiley & Sons, Inc.

Rossum, J. R. and Villarruz, P. A., 1960, Suggested method for iodide determination: Am. Water Works Assoc. Jour., v. 52, no. 7, p. 919–922.

SYSTEM FOR MONITORING FLUVIAL SEDIMENT

By H. P. Guy

ABSTRACT

The determination of fluvial-sediment concentration and discharge is expensive and hence limited in proportion to needs. A complete monitoring system based on (a) a continuous recording for fine sediment, (b) the use of existing gage-height records and theoretical considerations for coarse sediment, and (c) a central computing center is suggested to lower costs and improve the published statistics. With existing sampling equipment periodic measurements would be required to adjust the fine-sediment recording and shift the rating for coarse sediment similar to rating adjustments presently applied to computations for water discharge. They new system would make available many more kinds of statistics on a more timely basis than can be obtained by present techniques.

INTRODUCTION

The processes of erosion and deposition on the landscape cause a highly variable quantity of sediment to be moved by streams. This sediment in transport poses many kinds of problems in the use of such streams. If the problems posed by sedimentation and their amelioration are to be considered in a realistic framework, it is essential that the amount of sediment in streamflow be well defined in time and space.

Methods presently used to obtain knowledge of fluvial sediments require personnel and equipment to:

1. Obtain one or more depth-integrated samples of the streamflow for each observation in time and space ([U.S.] Federal Inter-Agency Committee on Water Resource, 1963, p. 19–60).
2. Transport the samples to the laboratory.
3. Analyze the samples for concentration of sediment.
4. Interpret the sample data in the light of streamflow and other environmental data to arrive at a time distribution of sediment concentration and discharge.
5. Interpret the time distribution of sediment concentration and sediment discharge for means, variance, frequency distributions, trends, and correlation with respect to other physical data.

This chain of techniques is relatively cumbersome, time consuming, and expensive, and has caused the knowledge of stream sediment to lag seriously other related fields of hydrology.

Recent developments ([U.S.]Federal Inter-Agency Committee on Water Resources, 1963, p. 118–135) indicate that more efficient and effective methods may be used to obtain the necessary knowledge of fluvial sediment. These new methods should logically evolve from considering sediment in streamflow in the light of fine sediment (<0.062 mm) and coarse sediment (>0.062 mm); therefore, in the discussion to follow, it is convenient to consider separately the transport of fine sediment and of coarse sediment.

FINE SEDIMENT

Fine sediment is easily suspended by natural stream turbulence, and hence travels through a stream system with about the same velocity as the water. The quantity and rate of fine-sediment transport at a stream cross section are the result of erosion in the basin and the routing of the particles with the flow to the cross section in question and are consequently independent of the stream in a particular reach. The concentration of fine sediment in transport during stormflow is unpredictable with respect to time and frequently increases by a factor of 100 or 1,000 times that of "normal flow." Thus, much of the error in sediment data obtained by present measurement techniques results from a lack of sufficient observations to define this large variation in concentration.

A logical step to improve the sediment record is to develop a recording device to sense the fine sediment continuously, or at least every few minutes. Such a recording device may be developed on the basis of attenuation and scattering of light, nuclear radiation, or sound by the fine sediment. Because the fine sediment is rather uniformly distributed in the stream cross section, a representative sample can be pumped from nearly any point in the section to the sensing device. Inasmuch as the kind of fine sediment will vary somewhat from basin to basin and within a given basin, such a device must be calibrated for each stream and periodically with the seasons by means of conventional samples. Even if such a calibration has some error the continuous recording will result in a greatly improved record of fine-sediment discharge over that presently obtained with daily or even hourly depth integrated samples.

COARSE SEDIMENT

The coarse sediment, usually found in appreciable quantities on the bed of the stream, is transported at a rate that depends on the properties of the fluid, the flow, the channel geometry, and the sediment. Because the slope, width, and sediment character of most natural streams are relatively stable, the main variables affecting the transport of coarse sediment are the water discharge and the bed resistance. Colby (1961) has related the discharge of bed material (coarse sediment) to depth and velocity of flow; thus, it logically follows that water discharge can be related to coarse-sediment discharge. The water discharge is computed on the basis of stage, which is continuously recorded at gaging stations. The pen-type stage recorders are rapidly being converted to digital paper-tape recorders (Carter and others, 1963). For streams where such digital recorders are in use, the digital computer can be used to compute the coarse-sediment discharge on the basis of the streamflow records.

Colby (1964) also suggested refinements of the relation of coarse-sediment discharge to depth by consideration of the water temperature and fine-sediment concentration. Values of both of these variables would be obtained by the basic stream-measurement system and then fed into the computation for total sediment transport. Again, as with fine sediment, conventional samples will be required to "calibrate" or modify Colby's relation to compensate for irregularities or permanent changes of stream cross section and for approach conditions which affect the stream velocity and the character of the sediment in transport.

For many streams, velocity and depth will conform to a reasonably stable rating with gage height, and a stable relation of coarse-sediment discharge to stage will permit a continuous record of sediment discharge. Such an indirect method of obtaining a continuous quantitative record of coarse sediment in streamflow probably would be superior to a record computed entirely from single-vertical samples, especially if the results of periodic measurements of the coarse sediments moving in the entire stream cross section were used to adjust the computational ratings. The adjustment of coarse-sediment transport with time would be similar to adjustments presently applied to single-vertical sampling techniques and to water-discharge ratings. The periodic conventional sediment-discharge measurements also can be used to define the size gradation of the material in transport.

THE SYSTEM

The heart of the automation technique for obtaining more and better knowledge of sediment in streamflow would be a digital computer such as the one in use by the U.S. Geological Survey for obtaining water discharge data. A schematic diagram (fig. 1) illustrates the assembladge of the components required for the complete system,

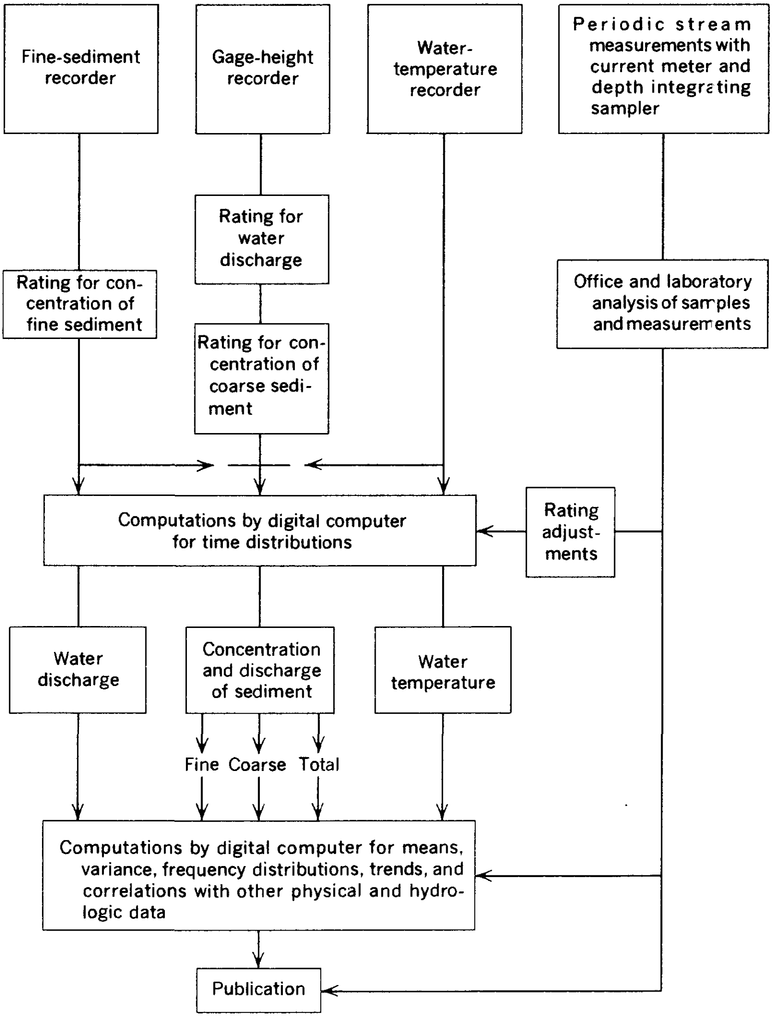


FIGURE 1.—Schematic diagram of a system for monitoring fluvial sediment.

from the recording and manual measurements at the stream to the data required for input to the computer and the final publication. Present techniques seldom go farther than publication of the time distributions (daily means) of sediment concentration and sediment discharge. In addition to much more timely publication of data, an added justification for the automation techniques is that the sediment data can be assembled into more complete and meaningful statistics than can be derived from data obtained by the present techniques.

A system for monitoring fluvial sediment cannot be completely implemented quickly or easily. Operational research and testing of several stages will require time and services of experts in many fields of endeavor. For example, several man-years of efforts are being expended by the project of the Federal Inter-Agency Committee on Water Resources on turbidimeter equipment and its accessories. Advances in technology will provide opportunities for simplified and more effective methods for many components in the system. Several methods are available for transmitting detected data from the stream to processing or computing and printing machines. For optimum benefit all components within the system must be carefully integrated with other monitoring systems for stream and environmental data such as water discharge, conductivity, dissolved oxygen, pH, water temperature, air temperature, precipitation, and sunlight intensity.

REFERENCES

Carter, R. W., Anderson, W. L., Isherwood, W. L., Rolfe, K. W., Showen, C. R., and Smith, Winchell, 1963, Automation of streamflow records: U.S. Geol. Survey Circ. 474, 18 p.

Colby, B. R., 1961, Effect of depth of flow on discharge of bed material: U.S. Geol. Survey Water-Supply Paper 1498–D, 12 p.

——— 1964, Practical computations of bed-material discharges: Am. Soc. Civil Engineers Proc., v. 90, No. HY2, p. 217–246.

[U.S.] Federal Inter-Agency Committee on Water Resources, 1963, Determination of fluvial sediment discharge, *in* A study of methods used in measurement and analysis of sediment loads in streams: Rept. 14, 151 p

SINGLE-BOTTLE SAMPLING IN OPERATION OF A SEDIMENT STATION

By J. R. George and J. W. Wark

ABSTRACT

An analysis of sediment-sample data for the Delaware River at Trenton, N.J., indicates that single-bottle sampling provides results that compare favorably with suspended-sediment concentrations determined from multiple-bottle samples. Where sediment concentration of a stream changes slowly with respect to time and concentration generally is well distributed with respect to stream depth, these data suggest that adequate definition of suspended-sediment concentration can be obtained with single-bottle samples.

Samples of the suspended-sediment concentration of a flowing stream are intended to represent conditions in the stream. Where sampling conditions are generally good and the supporting streamflow data are readily available, a properly operated sediment-sampling station should fulfill most of the specific needs for suspended-sediment data.

Fixed sediment-sampling installations similar to that shown in figure 1 are designed for ease of sample collection. Residents of the area are hired to visit the stream site frequently during periods of changing streamflow or stream-sediment conditions to collect several 1-pint bottle samples. The water samples are analyzed in the laboratory to determine the load of suspended matter that they contain. This information may be used by the engineer or scientist in a wide variety of studies.

This study is for a sediment station where water samples are taken in only one vertical in the cross section at the sediment-measuring station. A water sample is taken with the U.S. D–43 sampler by making a vertical traverse from the water surface to the stream bottom and back up to the water surface. The U.S. D–43 sampler contains a pint milk bottle. The sampler is moved at a constant vertical speed (down, then up) while making the vertical traverse, at a speed selected so the pint bottle is approximately filled when the traverse is completed. This is a depth-integrated sample. Customary water-sampling practice is to obtain one bottle of water by making the surface-to-bottom

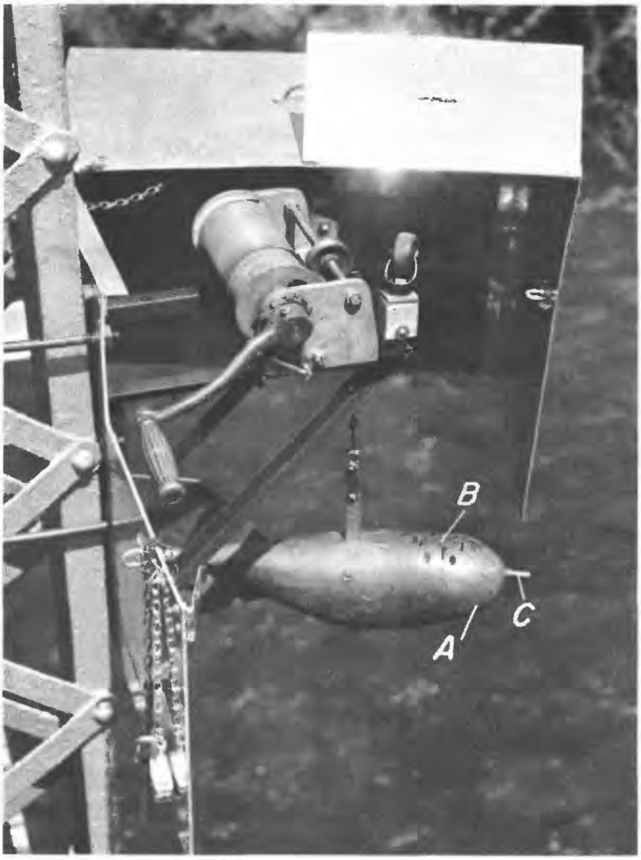


Figure 1.—Typical sediment sampling installation with U.S. D–43 suspended-sediment sampler. Sampler nose (*A*) pivots upward at hinge (*B*) so pint milk bottle can be inserted or removed from sampler; *C*, intake nozzle.

and back-to-surface traverse and then to obtain a second bottle by immediately repeating the same procedure. This is then a two-bottle sample.

Multiple-bottle sampling, the collection of two or more samples almost simultaneously, has been a normal part of sediment-station operation for some time. Several bottles collected in this manner presumably should provide a better figure of average concentration than would a single-bottle sample. However, a critical comparison of single and multiple-bottle sampling may uncover only minor differences in results. These differences in results may be neither justified by the use that will be made of the data nor worth the extra cost of the multibottle sampling. Where little variation exists, a one-bottle sample may provide adequate definition of the suspended-sediment concentration. If so, processing single-, rather than multiple-, bottle samples will produce a significant saving of time in bottle handling and laboratory analysis. This article presents a comparison of the sediment-concentrations loads obtained from one-bottle samples with those obtained from two-bottle samples, all collected on the Delaware River at Trenton, N.J.

The prerequisites for successful single-bottle sampling are: (1) an adequate depth-integrating sample technique as described by the [U.S.] Federal Inter-Agency Committee on Water Resources, Subcommittee on Sedimentation (1963), (2) generally stable distribution of suspended sediment with respect to stream depth, and (3) a relatively slow change in water discharge and sediment concentration with respect to time. Each of these conditions appears to exist at the U.S. Geological Survey sediment-measuring station on the Delaware River at Trenton, N.J.

Sediment-concentration data for Delaware River at Trenton, N.J., from 1954 to 1957 were used in this analysis. The average concentration from a two-bottle sample was compared with the concentration from the first bottle of the sample set. Concentration values were grouped into 15 classes ranging from 1 to more than 1,000 ppm (parts per million). As many as 40 observations were selected for study in each concentration class and a comparison of the results appears in table 1. The mean deviation of single-bottle concentrations from the average for concentration classes of 30 ppm and greater was only ±6 percent. Greater deviations that appear in the low-concentration

TABLE 1.—*Deviation of single-bottle sample concentration from two-bottle average, Delaware River at Trenton, N.J.*

Concentration class (ppm)	Number of samples	Mean deviation (±) from two-bottle average (percent)	Percent of time daily concentration is less than class (1950–57)
1– 4	40	35 (1 ppm)	----------
5– 9	40	23 (1–2 ppm)	30
10– 19	40	13 (1–2 ppm)	59
20– 29	40	13 (2–4 ppm)	79
30– 39	40	5.0	85
40– 49	26	5.5	88
50– 69	40	4.8	90
70– 99	38	5.3	93
100–199	40	5.2	95
200–299	31	5.5	98
300–399	16	6.7	99.0
400–499	25	4.5	99.5
500–699	14	6.7	99.7
700–999	13	4.2	99.8
≧ 1,000	19	6.3	99.9

classes (1–29 ppm) should be attributed largely to rounding procedure and weighting error. To present another perspective to these higher deviations, they also are expressed as concentration, in parts per million, in table 1. Although the concentration frequency shown in table 1 indicates that the sediment concentration of Delaware River is less than 30 ppm about 85 percent of the time, errors introduced randomly by reliance on single-bottle sample data are small in terms of actual suspended-sediment concentration. It is noteworthy that measured sediment loads produced at this concentration range usually constitute less than 10 percent of the annual sediment load.

Because average values may be misleading, a histogram of these data appears as figure 2. This figure suggests that the deviation of the one-bottle concentration from the two-bottle average is randomly distributed about zero (0) with an expected error of less than 10 percent for about two-thirds of the samples collected.

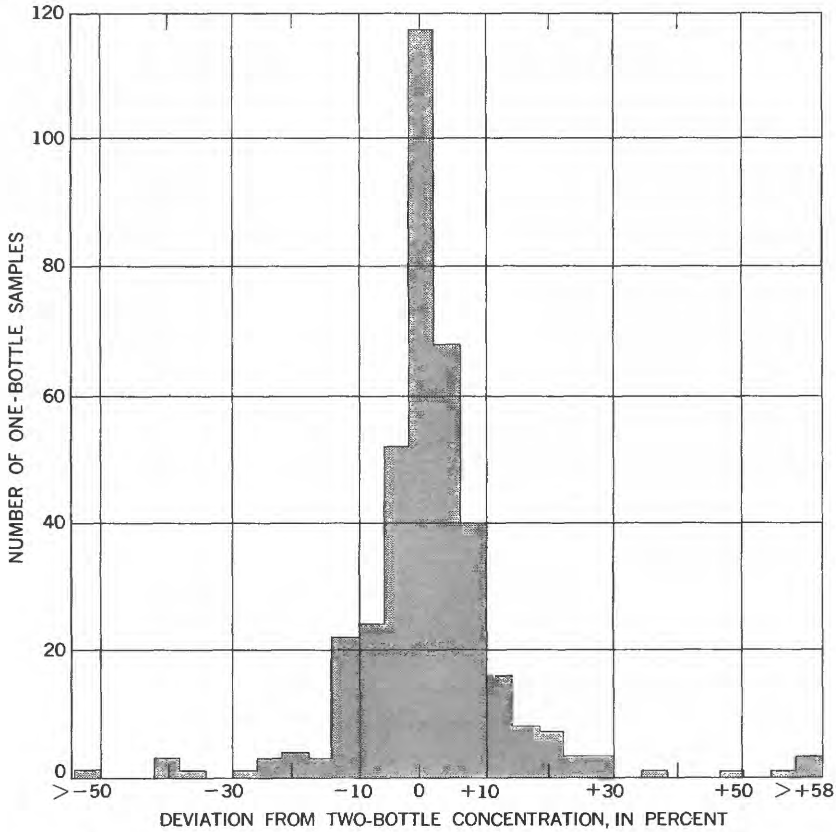


Figure 2.—Deviation of one-bottle sediment concentration from two-bottle concentration, Delaware River at Trenton, N.J.

In summary, this discussion suggests that single-bottle samples of the Delaware River at Trenton, N.J., yield reliable concentration results for defining stream-sediment characteristics. At other sampling stations, where the requisite conditions mentioned previously exist, one-bottle sampling can be expected to give results that compare equally well with multibottle sampling.

REFERENCE

[U.S.] Federal Inter-Agency Committee on Water Resources, Subcommittee on Sedimentation, 1963, Determination of fluvial sediment discharge: Minneapolis, Minn., St. Anthony Falls Hydrol. Lab., Rept. 14, 151 p.

796-504 O—66——7

RIVER-BOTTOM SEDIMENT SAMPLING WITH A SWEDISH FOIL SAMPLER

By R. J. Pickering

ABSTRACT

The collecting of undisturbed core samples of fine, somewhat fluid sediment is hampered by the tendency of the sediment to adhere to the interior of the sampling tube and thus cause compaction and preferential coring of certain sediment layers. In the Swedish Foil Sampler, this tendency is minimized by the insertion of a sheath of metal "foils" between the sediment core and the sample tube. The foils hold the sediment sample in place and let the sample tube move downward without carrying the sediment sample along with it and without compacting the sediment.

During the past 20 years the Oak Ridge National Laboratory has released very small but measurable amounts of radionuclides into the Clinch River in eastern Tennessee, and thereby created a unique opportunity for determining the distribution and behavior of fission products in a natural stream. A joint study of the fate of radionuclides released to the Clinch River has been carried on by the Water Resources Division of the U.S. Geological Survey and the Oak Ridge National Laboratory since February 1960 as part of the general program of the Clinch River Study Steering Committee. Undisturbed core samples of river-bottom sediments were required for phases of the joint study pertaining to the vertical distribution of fission products in the sediments.

Preliminary coring tests with several tools showed that the simple tube-type samplers were unsatisfactory for use in the relatively fine bottom sediment of the Clinch River. Particle-size distribution in the sediment is fairly constant throughout the part of the Clinch River that contains radioactive sediment; the sediment is composed of approximately 15–20 percent clay, 25–30 percent sand, and 50–60 percent silt. With tube-type samplers there was preferential coring of certain sediment layers and excessive compaction of the sediments in the core sample. Driving thin-walled tubes having inside diameters of 3–4 inches into the river sediments caused much less compaction of sediments than did driving tubes having diameters of 1–2 inches (P. H. Carrigan, oral commun., 1962), but still better control of compaction was necessary.

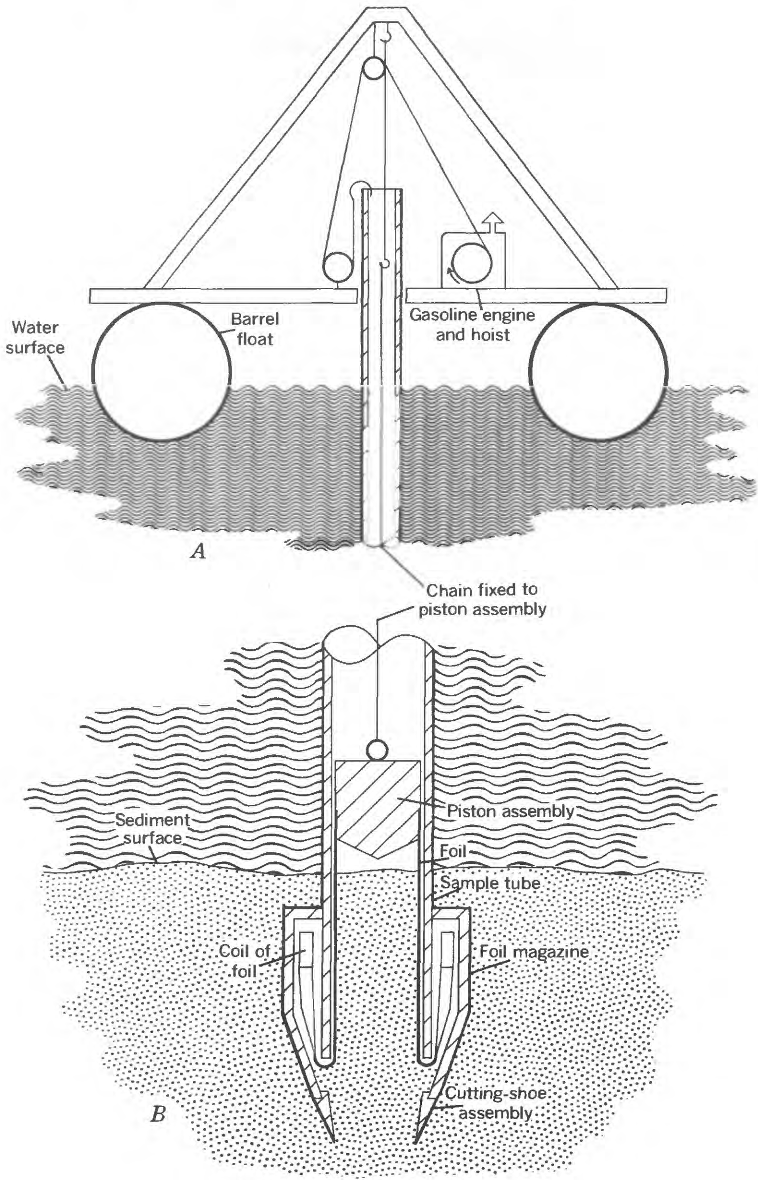


Figure 1.—Equipment for obtaining core samples of sediment from a river-bottom. *A*, Float with hoisting engine and rigging for driving and raising the sampler. *B*, Swedish Foil Sampler; piston is held in place by chain as sample tube is pushed down through the sediment; end of each foil strip is attached to piston and the strips of foil unroll from the magazine and envelope the sediment core as sampler is pushed into the sediment; the core is not compacted because the foil enveloping it does not move.

Further tests and inquiry resulted in the selection of the Swedish Foil Sampler for sampling bottom sediments in the Clinch River. The Foil Sampler, a patented device operated under exclusive license in the eastern United States, is a piston-type sampler in which thin axial metal strips (foils) are used to eliminate friction between the sediment core and the sample tube while coring is proceeding. Cores 2½ inches in diameter and as much as 14 feet in length were obtained in water as much as 45 feet deep with the Foil Sampler mounted on a barrel float equipped with a drilling tower and gasoline engine and hoist. (See fig. 1.) More than 100 undisturbed cores were collected at 14 cross sections on the Clinch River and at 4 cross sections on 2 tributary streams.

In loading the sampler, steel foils, fed from coils in the foil magazine, are attached to the piston assembly. As the piston assembly is pushed up into the sample tube a short distance, the foils are pulled down around the lip of the tube and up along its interior surface (figs. 1 and 2*A*). After the magazine shield, cutting-shoe housing, and cutting-shoe assembly (fig. 2*B*) have been attached, the Foil Sampler is ready for lowering.

The distance from the water surface to the sediment surface must be measured accurately with a weighted line before coring can proceed. The sampler is then lowered to within a few inches of the sediment surface, and the piston chain is fixed to a hook at the top of the drilling tower (fig. 1). As the sampler is pushed into the sediment, the foils unroll and form a sheath that encloses the core and prevents its contact with the interior of the sample tube. The core does not move relative to the foil strips, and the only friction in the sample tube is the metal-to-metal friction between the foils and the interior of the tube. Compaction and blocking of the core in the tube due to friction between the sediment and the tube is thus prevented. During the insertion of the sample tube into the sediment, the piston and the core of sediment do not move from their original positions.

The primary function of the piston in a piston sampler is to prevent loss of core while the sampler is being raised to the surface. Because of the rigid sample tube and the tight-fitting piston immediately above the core, the hydrostatic force due to the column of water above the base of the sample tube can act on the core only in an upward direction; thus the core is held in the tube. If the core begins to slide out of the tube, a partial vacuum is created between the top of the core and the piston, which is locked in position while the sample tube is being raised; this vacuum increases the differential upward push of hydrostatic pressure on the core and inhibits its further movement. Adhesion of the core to the metal foils of the Swedish Foil Sampler also tends to hold the core in the tube.

FIGURE 2.—Swedish Foil Sampler. *A*, Magazine in head of sampler showing coils of steel foil; ends of foil are attached to piston which has been pushed up and is now inside of sampler head; foil strips unwind from rolls in the magazine as the sampler travels down and the piston remains in place—held by a chain anchored to the drilling tower. *B*, Top to bottom, sampler head, magazine shield, cutting-shoe housing, and cutting-shoe assembly. *C*, Cutting-shoe assembly pulled apart to show basket-type core retainer used to retain cores that have a high tendency to slump. Photographs by Oak Ridge National Laboratory.

Under certain sampling conditions, satisfactory cores could not be obtained with the sampler. Recovery of river sediment was excellent at points near the bank where the river sediment overlies soil, but in the deeper parts of the river channel where soft sediment lies directly on bedrock, the lower 6–18 inches of the sample was commonly lost. To decrease core loss, a modification to the cutting-shoe assembly was made. A basket-type core retainer was designed for the sampler, and upon request, was fabricated by the drilling contractor. The basket, which consisted of curved closely spaced flexible spring steel fingers attached to a steel ring, was inserted near the base of the cutting-shoe assembly, just above the cutting-shoe (fig. 2*C*). Above the basket was fixed a thin plastic sleeve that was slit at the top so it would collapse over the basket when the sediment began to slide out of the shoe and thus partially, or at times completely, seal the opening at the base of the sample tube. Excellent sample recovery was obtained with the basket-shoe. One hundred percent recovery of a 10-inch-long core, composed entirely of sediment having a consistency of thick gravy, was obtained at one sampling site. The nearly watertight seal formed by the collapse of the plastic sleeve over the basket made such recovery possible. The basket shown in figure 2*C*, which has more widely spaced fingers made of heavier spring steel than the basket used in fine sediment, was designed for recovering sediments that have a high sand content.

Core recovery at sampling points where radioactivity was believed to be present throughout the full thickness of the river sediment generally ranged from 80 to 100 percent. Poor core recovery was accepted only where the sediment consisted of nearly pure sand or where soft mud was covered by a mat of leaves and twigs; there were few such localities.

Cores collected from the Clinch River were transferred from the metal sample tube of the Foil Sampler to a slightly larger plastic storage tube in the manner shown in figure 3. Because the plastic tube could be slipped over the sample tube, the core could be transferred, still encased in its foils, without sliding it through the entire length of plastic tube. After the cores were transferred, they were refrigerated to suppress biological and chemical action.

FIGURE 3.—Transferring sediment core to plastic tube for storage. Ends of foil strips that were cut off just below the piston are held in place by tape around the plastic tube. Sampler piston is lying on the deck. Ends of foil strips, left after core sample was cut off are seen projecting from the piston. Photograph by Oak Ridge National Laboratory.

SEDIMENT DEPOSITION FROM ATMOSPHERIC PRECIPITATION

By JAMES C. MUNDORFF

ABSTRACT

The net sediment loss from an area may be less than, equal to, or greater than the sediment yield indicated by data on fluvial suspended-sediment yield per square mile. During 1954–64, observations of sediment in atmospheric precipitation at Lincoln, Nebr., show that sediment concentrations in the rainwater were as high as 256,000 parts per million and sediment deposition of as much as 148 tons per square mile occurred as a result of precipitation in the Great Plains. For the drainage areas of some streams in the Great Plains, sediment deposition from precipitation may have exceeded sediment removal by streams in some years. The sediment budget of an area depends on the balance among the effects of wind, precipitation, and streams.

The terms "fluvial sediment," "suspended sediment," "suspended-sediment concentration," and "sediment deposition" are almost automatically associated with the work of streams; but these terms, as defined in many technical papers, also can be applied to sediment contained in or deposited from atmospheric precipitation. For example, "fluvial sediment" is "sediment that is transported by, is suspended in, or has been deposited from water" (Colby, Hembree, and Rainwater, 1956; Hubbell and Matejka, 1959).

Lincoln, Nebr., is in the glacial till and loess hills of eastern Nebraska and in the path of storms that generally move eastward across the central United States. West of Lincoln are the loess plains of central Nebraska and the loess hills of western Nebraska. To the south and southwest are loess deposits, shales (red beds) of Permian age in southern Kansas and northern Oklahoma, and rocks of Tertiary and Cretaceous age in semiarid southwestern Kansas, northern New Mexico, and southeastern Colorado. High wind velocity and wind erosion in semiarid areas to the west and southwest commonly result from pressure and wind systems that precede storms in eastern Nebraska. Large quantities of dust may be transported in an easterly direction from these areas. Some of this dust is "rinsed" from the atmosphere by precipitation. During 1954–64, some samples of precipitation were obtained at Lincoln, Nebr., when atmospheric conditions and weather forecasts indicated that appreciable sediment might be contained in the precipitation.

In eastern Nebraska, high-sediment rainfall or mudstorms are most common during the early spring months. All precipitation samples were obtained during March or April. These samples were collected in containers that were cleaned thoroughly immediately before an expected storm. The samples were placed in glass bottles immediately after each storm; the dry weight of sediment was determined in the laboratory. Sediment concentration, in parts per million (ppm), was computed for some samples. Precipitation for some storms was measured with a rain gage consisting of a glass funnel and a glass cylinder having only about one-twentieth of the cross-sectional area of the top of the funnel.

On March 11, 1954, total precipitation from a light shower was 0.03 inch, and sediment concentration of the rainwater was 256,000 ppm. This concentration greatly exceeds any suspended-sediment concentration that has been observed in streams in Nebraska during field investigations from 1946 to 1964. Sediment deposition resulting from this precipitation was computed as 72 tons per square mile. The sediment in this precipitation was a brick-red color similar to that of the surface rocks of Permian age several hundred miles to the south and southwest.

On March 18, 1954, during the first 5 minutes of a light rain, the computed sediment deposition was 14 tons per square mile; during approximately 1 hour of intermittent light rain, the total sediment deposition was 38 tons per square mile.

On April 23, 1956, precipitation was 0.08 inch. Sediment concentration was 198,000 ppm, and sediment deposition was computed as 148 tons per square mile.

Precipitation reported as a "trace" at Lincoln on April 13, 1961, contained sufficient sediment to result in sediment deposition of 100 tons per square mile.

During the period March 17–19, 1963, about 0.75 inch of precipitation resulted in sediment deposition of 36 tons per square mile. During the period March 15–18, wind velocities of as much as 80 miles per hour were reported in western Texas, northern New Mexico, and southwestern Nebraska. Sediment in this precipitation, as well as in most of the other observed precipitation that contained appreciable sediment, was light red. Significant areas of rocks of this color are not exposed within several hundred miles of the observation site.

Sediment deposition from rainfall was about 30 tons per square mile on April 2, 1963; 28 tons per square mile on April 22, 1963; 24 tons per square mile on April 1, 1964; and 54 tons per square mile on April 12, 1964.

The examples given probably represent only a minor part of the total sediment deposition by rain in Lincoln since 1954; an estimated average of 100–200 tons of sediment per square mile per year probably would be conservative for eastern Nebraska. Thus, while erosion by water is removing sediment from a given area, a combination of wind erosion in another area and of deposition by precipitation in the given area may result in net aggradation in a drainage basin. Water erosion tends to be concentrated in rills, gullies, and channels, and tends to remove sediment at a much faster rate from some parts of a drainage area than it does from other parts. Sediment deposition by precipitation tends to result in uniform deposition over the entire area on which the precipitation falls. The sediment in precipitation that falls on the drainage courses may be removed immediately by runoff through these courses, but much of the sediment in precipitation that falls on intervening areas may remain where deposited. Thus, during a period of several hundred or several thousand years, the relief would be increased not by water erosion alone but by water erosion in conjunction with sediment deposition by precipitation. Such deposition would tend to result in aggradation outside of drainage courses but would have no effect within the drainage courses.

Sediment that is originally suspended by wind and that is deposited by precipitation may be termed "fluvio-eolian." Deposition resulting from the described fluvio-eolian processes would be expected to have a different effect on relief than would deposition resulting from eolian processes only. Wind erosion and deposition, whether within a small area or over large regions, would be expected to decrease or subdue the relief. Removal of sediment by wind would be expected to be greatest from the highest and least protected topographic positions. Deposition of wind-transported sediment, in the absence of precipitation "rinse-out," would occur in wind-protected areas such as gullies, depressions, leeward slopes, and valleys. Thick loess deposits, such as those in the central United States, commonly show less relief than does the preloess surface. Thus, a tentative hypothesis is that the fluvio-eolian process results in increased relief, and eolian processes alone commonly result in decreased relief.

The effect of precipitation-deposited sediment on the characteristics of soils is not known. Such sediment undoubtedly is of colloidal or near-colloidal size and would be subject to eluviation within a soil profile. In areas where sediment deposition by precipitation is significant, this sediment may contribute significantly to the formation or accretion of claypans or of less compact textural B horizons.

Data on suspended-sediment yield per square mile are not necessarily indicative of net sediment loss from an area. Because of differences in climate and vegetation in different regions, an arid or semiarid region may supply the windblown sediment that results in a long-term net sediment gain in a humid or subhumid region. Some representative annual suspended-sediment yields for streams in the Great Plains are shown in table 1. For the drainage areas of some

TABLE 1.—*Suspended-sediment yields, in tons per square mile, by years*

Location	1952	1953	1954	1955	1956	1957	1958	1959	1960
Cheyenne River near Hot Springs, S. Dak	------	------	------	341	80	239	221	41	------
Kansas River at Wamego, Kans	------	------	------	------	------	------	314	231	------
Little Arkansas River at Valley Center, Kans	------	------	------	------	------	------	225	84	449
Little Blue River near Deweese, Nebr	------	------	------	------	------	482	261	585	------
South Fork White River below White River, S. Dak	247	303	29	------	56	78	62	------	------

of the streams, sediment deposition by precipitation may have exceeded sediment removal by streams during some years. A distant arid or semiarid area may be supporting the suspended-sediment discharge of streams from a drainage basin in a humid or subhumid area. The sediment budget of an area depends on the balance among the effects of wind, atmospheric precipitation, and streams. The sediment budget in many arid and semiarid areas would show a net sediment loss; sediment is removed in such areas both by wind and by water, and little is received from other areas. The sediment budget in transition zones (some subhumid and semiarid areas) probably would show a cyclical fluctuation of gains and losses; the rate of long-term loss would be less than from an arid region. The sediment budget in some humid and subhumid areas may show a long-term gain; sediment deposition from precipitation may exceed the combined sediment loss from both wind and water erosion.

Factors in addition to climate and suspended-sediment yield of a specific area would have to be considered for a full understanding of the sediment budget of that area. The location of the area relative to sources of wind-transported sediment and to regional and global weather patterns is of major significance. Areas having similar amounts of precipitation could have markedly different sediment budgets depending on amount and seasonal distribution of precipitation, proximity to source areas of wind-transported sediment, characteristics of the wind-transported sediment, atmospheric circulation, storm paths, and all the factors commonly described as affecting erosion by water—geology and soils, land use, vegetation, slope, maximum infiltration rate, and permeability. Further, areas having significantly different suspended-sediment yields may have similar sediment budgets if other factor affecting the sediment budget achieve a balance.

LITERATURE CITED

Colby, B. R., Hembree, C. H., and Rainwater, F. H., 1956, Sedimentation and chemical quality of surface waters in the Wind River basin, Wyoming: U.S. Geol. Survey Water-Supply Paper 1373.

Hubbell, D. W., and Matejka, D. Q., 1959, Investigations of sediment transportation, Middle Loup River at Dunning, Nebr., *with* application of data from turbulence flume: U.S. Geol. Survey Water-Supply Paper 1476.

USE OF SOIL-CONSOLIDATION TEST DATA TO DETERMINE PERMEABILITY OF CLAYS

By PAUL R. SEABER and JOHN VECCHIOLI

ABSTRACT

Laboratory tests to determine the permeability of clays are done generally with a variable-head permeameter. Permeability may also be computed from consolidation-test data based on Terzaghi's theory of consolidation. For fine-textured materials, permeability values obtained indirectly from consolidation tests commonly are smaller than those obtained from variable-head permeameter tests, and they are probably more realible. It is suggested that consolidation-test data be used to supplement available permeability data and that consolidation test are a virtually untapped source of permeability data available to hydrologists.

During many ground-water investigations, it is necessary to make quantitative determinations of vertical movement of water through confining beds. The permeability of the confining bed, most often a clay in unconsolidated deposits, is one of the factors needed in determining the amount of vertical movement or "leakage" of water. The quantity of flow may be determined directly from the following formula, which is essentially a restatement of Darcy's law:

$$Q=kIA \qquad (1)$$

in which Q = quantity of water discharged in unit time,
k = the coefficient of permeability,
I = hydraulic gradient,
and A = the cross-sectional area through which the water flows.

The "permeability" of a porous medium describes the ease with which a fluid will pass through it, and indicates its capacity for transmitting fluid under a differential head. "Permeability" is defined quantitatively as the specific property designating the rate or readiness with which a porous medium transmits fluids under standard conditions. The physical dimensions of the permeability unit will be determined by the equation used to express the flow. Permeability is expressed rationally by a coefficient that is independent of the fluid properties governing the flow. The specific permeability is commonly expressed in either centimeter-second units or Darcy units. These units are dependent upon the medium, but not upon the fluid that flows through that medium. Some equations used for expressing the flow take into account the properties of the fluid so that proper measurements on a given medium will give the same permeability value for all fluids which do not alter the medium. In ground-water studies in the United States, where only one fluid is involved and where the centimeter-gram-second (cgs) units of measurement are not commonly used, the prevailing units of permeability are defined by properties of the water as well as of the medium and are referred to as Meinzer units (Wenzel, 1942, p. 9). To convert coefficients of permeability from Darcy units (cubic centimeters per second per square centimeter at a viscosity of one centipoise) to Meinzer units (gallons per day per square foot per unit hydraulic head at 60° F) one need only multiply by a factor of 18.2. To convert coefficients of permeability from centimeter-second units (as commonly expressed in soils engineering) to Meinzer units at a temperature of 60° F, a factor of 2.1×10^4 is employed. (See Wenzel, 1942, p. 9–10 for comprehensive listing of permeability units in use and factors for conversion into Meinzer units.)

Measurements of the permeability of rocks and unconsolidated materials may be made by either field or laboratory methods as described by Wenzel (1942). Laboratory determinations of the coefficient of permeability are made by measuring the discharge or time rate of change in head for the percolation of measured quantities of water through a known area and volume of sample. Devices used for this purpose—permeameters—consist of a supply reservoir from which water is discharged through a percolation cylinder under either constant or variable head. The percolation cylinder is constructed with a fixed diameter and length, and is equipped with screens that support the sample and permit free inflow of water. Manometer tubes in the supply and receiving reservoirs are used to determine the loss of head that occurs for the vertical percolation of known quantities of water at measured rates through the sample cylinder. The variable-head permeameter is more suitable for tests on material of low permeability, such as clay, because the dimensions of the apparatus can be adjusted so that the measurements of head and time may be carried out with a high accuracy over a wide range of values.

A schematic representation of a variable-head permeameter is shown in figure 1. The coefficient of permeability (k) may be calculated from the quantities measured during the test by means of the equation

$$k = 2.3 \frac{aL}{At} \log_{10} \frac{h_0}{h_1} . \qquad (2)$$

In this equation,

a = the cross-sectional area of the manometer,
L = the length of the sample,
A = the cross-sectional-area of the sample,
t = the time,

and h_0, h_1 = the original and final hydraulic heads, respectively. Equation 2 will give the coefficient of permeability expressed as the flow of water in cubic centimeters per second through a cross-sectional area of 1 square centimeter under a hydraulic gradient of 100 percent, if L is measured in centimeters and t in seconds. A, a, h_0, and h_1 may be measured in any units, but a and A must be measured in the same units and h_1 and h_0 must be in the same units.

The results of permeability tests may be misleading because of the difficulty of obtaining representative samples of material and placing them in the permeameter without disturbance. Some permeability tests also may be subject to various types of experimental error. One of the most important of these arises from the formation of a filter

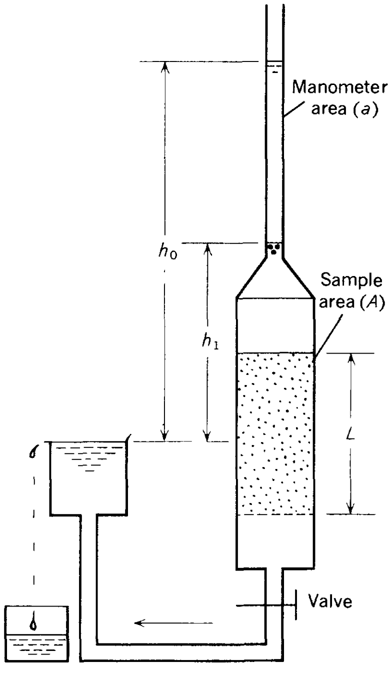


FIGURE 1.—Schematic representation of a variable-head permeameter. a, manometer area; A, sample area; h_0 and h_1, original and final hydraulic heads, respectively.

skin of fine material on the surface of the sample. In conducting permeability tests, the technician must be careful to saturate the sample completely and to make sure that no air bubbles will be released by the water during the test. The chemical character of the water used for the test should be compatible with the chemical character of the native pore water, if not, the clay-water system and the permeability values obtained will be affected. Samples obtained from depth may change in volume and structure during and subsequent to the sampling operation. In addition, for a sample of very low permeability tested under no load in a variable-head permeameter, the disturbed condition at or near the container wall creates a boundary region which may produce a zone of higher permeability than the undisturbed sample matrix.

In consolidation tests, on the other hand, lateral pressure is created against the container walls and tends to reduce the permeability of the disturbed boundary region to approximately that of the sample matrix. In fact, none of the experimental errors listed above apply to consolidation tests.

Although consolidation tests are well known to engineers, particularly those engaged in the construction industry, many hydrologists may not be aware of their uses. Consolidation tests are run mainly to obtain data used in predicting the rate and amount of settling of structures founded on clay. However, permeability of the soil may be determined also from these data. Laboratory procedures using a consolidometer for consolidation tests are described by the U.S. Bureau of Reclamation (1960, p. 492–506) in a paper on the method of computing permeability from consolidation-test data.

The theory of consolidation, generally referred to as Terzaghi's theory of consolidation (Terzaghi, 1923, 1925, 1943), and its assumptions and limitations is discussed in all modern soil mechanics textbooks. (See "References.") In brief, when a saturated soil is subjected to a load, the load is almost entirely supported initially by the water in the pores because the water is incompressible relative to the soil material. The "excess hydrostatic pressure" created causes the water to drain from the pores, and the load is shifted to the soil structure. The escape of water takes place according to Darcy's law. This transfer of load is accompanied by a change in the volume of the soil equal to the volume of the water drained. Thus, consolidation is the gradual process of volume reduction involving drainage, compression, and stress transfer. The rate at which the volume of the soil changes in relation to an applied load is directly related to the permeability of a soil because the permeability controls the rate at which the pore water can escape. Hence, a certain load increment produces a change in void ratio at a rate governed by the permeability of the soil. For sands, the permeability is so high that the time required for consolidation is considered negligible. For clays, the rate of volume change after the application of a load increment is important and consolidation laboratory studies are almost entirely limited to clays.

The coefficient of permeability of a sample for any given load increment is obtained from the equation:

$$k=\frac{c_v\gamma_w A_v}{1+e_0} \tag{3}$$

where

k=coefficient of permeability, in centimeter per second,

c_v=coefficient of consolidation, in square centimeter per second,

γ_w=unit weight of water, or 1 gram per cubic centimeter,

A_v=coefficient of compressibility, in square centimeter per gram,

and

e_0=initial void ratio.

A_v is defined by the expression:

$$A_v=\frac{e_0-e_1}{P_1-P_0} \tag{4}$$

where e_0=void ratio at pressure P_0, and e_1=void ratio at pressure P_1, pressure being in grams per square centimeter.

The coefficient of consolidation is always given in the test results and, therefore, the method of computing c_v need not be discussed.

Consolidation test results are commonly expressed graphically (fig. 2). The upper curve (*A*) in figure 2 is a plot of void ratio against pressure. The lower curve (*B*) is a plot of the coefficient of consolidation against pressure. These curves are all that are necessary to compute permeability from equation 3.

The following example illustrates the computations:

1. From figure 2, e_0=0.860 at P_0=250 g per sq cm and e_1=0.852 at P_1=500 g per sq cm.

2. Substituting in equation 4,

$$A_v=\frac{0.860-0.852}{500-250}=3.2\times10^{-5} \text{ sq cm per g.}$$

796-504 O—66——8

3. c_v for this load increment as obtained from the lower curve (*B*) of fig. 2=78×10⁻⁴ sq cm per sec.

4. Substituted in equation 3,

$$k=\frac{78\times10^{-4}\times1\times3.2\times10^{-5}}{1.860}=1.34\times10^{-7}$$ cm per sec (or, using the conversion factor of 2.1×10^{4}, the permeability may be expressed as 2.8×10^{-3} Meinzer units).

5. Therefore, 1.34×10^{-7} cm per sec is the permeability at the void ratio 0.856 (the average void ratio for this load increment).

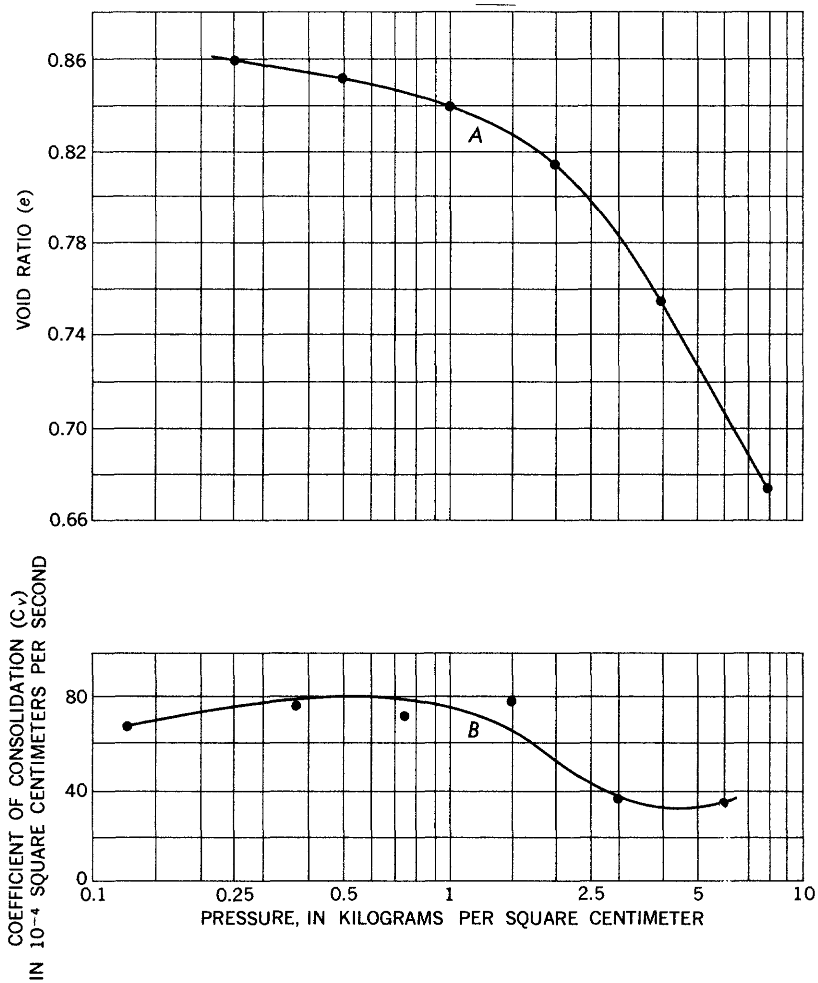


FIGURE 2.—Relation of pressure to void ratio (curve *A*) and coefficient of consolidation (curve *B*). Modified from Lambe, 1951, p. 87, fig. IX–12.

Values of permeability are then plotted against the average void ratio for each load increment (fig. 3). The plot of e against $\log_{10} k$ is a straight line, and therefore only two points should be required. However, it is advisable to use as many increments of load as were run in the consolidation test to arrive at the best fit for the line. The field permeability may then be estimated from this graph by using the field void ratio and obtaining the corresponding permeability value (point X on fig. 3). The field void ratio may be computed either from a direct determination using the sample material or from the *e*-log *p* curve if the overburden pressure is known (Peck and others, 1953, p. 18–27, 58–63, 72–86).

Foundation engineers, in dealing with small areas of clay, generally are interested only in total volumes of water, and for fine-textured materials a difference in the coefficient of permeability of as much as 1,000 times in these low ranges quite likely would not be critical. The U.S. Bureau of Reclamation (1960, p. 63) states:

> * * * Permeability in some soils is very sensitive to small changes in density, water content or gradation. In certain ranges, a few percent variation in any one of these factors may result in a few thousand percent variation in permeability. Because of the wide variation in permeability that is possible, measurement of great accuracy is not required for designs; rather the order of magnitude of the permeability is of importance.

However, in ground-water investigations dealing with movements of water between aquifers over broad areas for considerable periods of time, relatively minor differences may be quite significant. Accord-

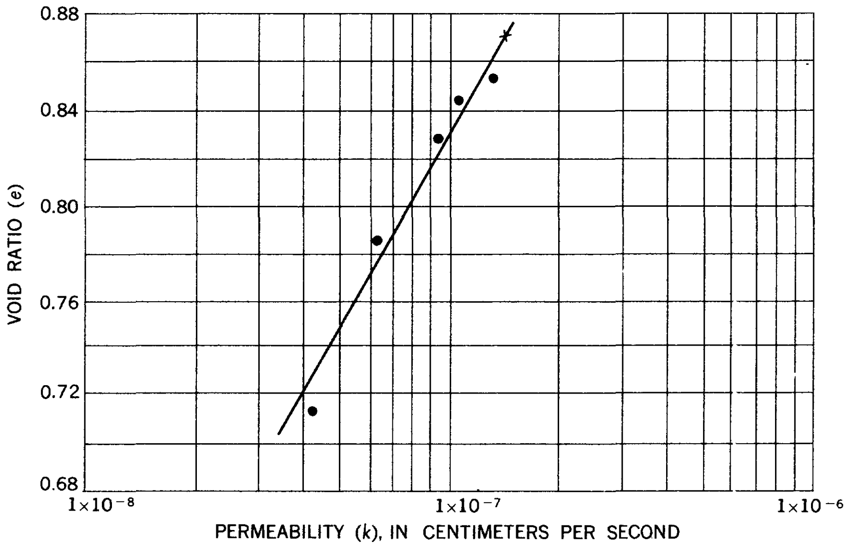


FIGURE 3.—Relation of permeability (k) to void ratio (e).

ingly, the most reliable method of determining permeability should be used for these investigations. Soil mechanics and foundation engineering textbooks (for example, Peck and others, 1953, p. 55; and Terzaghi and Peck, 1948, p. 48) state that the permeability of clay samples can be determined most accurately indirectly from data obtained from consolidation tests.

No published reference is known to the authors in which permeabilities obtained from consolidation tests and from variable-head permeameter tests on the same sample are compared, though such research is planned by the Hydrologic Laboratory, U.S. Geological Survey, Denver, Colo. Variable-head permeameter tests on many samples of fine-textured material from the Coastal Plain in New Jersey have yielded permeability values that are consistently greater than those one might expect on the basis of generally accepted permeability values for clay obtained from consolidation-test data. Meager comparative data consisting of permeability values determined by both methods on different samples of a relatively uniform lithologic unit suggest differences as great as 10,000 times. Johnson and Morris (1962, p. 48–51) found that for samples from the Los Banos–Kettleman City area in California, the coefficients of permeability for the clayey sediments of low permeabilities ($k<0.01$–0.001 in Meinzer units) tested in the variable-head permeameter in general appear to be in a considerably higher range than those computed from consolidation tests for samples of similar texture. They concluded that because of the expansion resulting from release of overburden pressure, those permeabilities obtained from consolidation tests on samples from considerable depths are more reliable than those obtained from the variable-head permeameter.

Consolidation-test data may be obtained from numerous sources, among which are large construction companies, engineering firms and consultants, State highway departments, the U.S. Bureau of Reclamation, the U.S. Bureau of Public Roads, the U.S. Corps of Engineers, and the Geological Survey's Hydrologic Laboratory. It is not suggested that computations of the permeability of clays from consolidation tests entirely replace determinations by the variable-head permeameter method. Rather, consolidation-test data can be used to supplement available data obtained by the variable-head permeameter method. It is suggested that consolidation tests are a virtually untapped source of permeability data available to hydrologists.

REFERENCES

Johnson, A. I., and Morris, D. A., 1962, Physical and hydrologic properties of water-bearing deposits from core holes in the Los Banos-Kettleman City Area, California: U.S. Geol. Survey open-file rept., 182 p.

Lambe, T. W., 1951, Soil testing for engineers: New York, John Wiley & Sons, Inc., p. 74–87.

Peck, R. B., Hanson, W. E., and Thornburn, T. H., 1953, Foundation engineering: New York, John Wiley & Sons, Inc., 410 p.

Taylor, D. W., 1948, Fundamentals of soil mechanics: New York, John Wiley & Sons, Inc., 700 p.

Terzaghi, Karl, 1923, Die Berechnung der Durchlässigkeitsziffer des Tones aus dem Verlauf der Hydrodynamischen Spannungserscheinungen: Akademie der Wissenschaften in Wien, Sitzungsberichte, Mathematishnaturwissenschaftliche Klasse, v. 132, pt. IIa, ¾, p. 125–138.

——— 1925, Principles of soil mechanics—Settlement and consolidation of clay: Engineering News-Record, November, p. 874–878.

——— 1943, Theoretical soil mechanics: New York, John Wiley & Sons, Inc., 510 p.

Terzaghi, Karl, and Peck, R. B., 1948, Soil mechanics in engineering practice: New York, John Wiley & Sons, Inc., 566 p.

U.S. Bureau of Reclamation, 1960, Earth Manual: Washington, U.S. Govt. Printing Office, 751 p.

Wenzel, L. K., 1942, Methods for determining permeability of water-bearing materials: U.S. Geol. Survey Water-Supply Paper 887, 192 p.

TWO SIMPLIFIED VARIATIONS OF A METHOD FOR COMPUTING GROUND-WATER PUMPAGE

By George W. Sandberg

ABSTRACT

Ground-water pumpage can be calculated by either of two modifications of a previously published method of computing pumpage in less time than was required by the published method. Calculated pumpages were within 2 percent of the amounts measured by totaling-type flow meters in two ground-water basins in southwestern Utah.

INTRODUCTION

This paper describes two time-saving modifications of a previously published method (Waite and others, 1954, p. 17–19) of computing total ground-water pumpage from a ground-water basin. Although the previously published method and the modifications described here are for pumps that are powered by constant-speed electric motors, they can be adapted to pumps that use other power.

VARIATION 1

The first step in planning a pumpage inventory of a ground-water basin is to assign wells into groups, according to location and the characteristics of the wells and of the hydrologic environment. These characteristics include depth of the wells, water-bearing strata tapped, faults or other hydrologic barriers within the basin, and the general magnitude of the depth to water and of the water-level fluctuations during the pumping season.

Two representative wells are chosen from each group at the beginning of the pumping season. Two wells are chosen, in case one is inoperative during part of the season. The discharge of the representative wells is measured at least five times at about equal intervals during the pumping season to determine any change. Because the other wells in each group have similar characteristics, the discharge rates of the wells in a given group should change in direct proportion to the measured change in discharge rate of the representative wells. Measurements of the other wells are made about the middle of the pumping season; the representative wells should be measured at the same time.

Power input to the pumping plant is measured each time the discharge is measured. The power input is measured by observing the time, t, in seconds, that the watt-hour meter disk requires for a given number of revolutions, n, then applying the formula

$$kwhr = \frac{3.6 \times kh \times M \times n}{t}$$

where

$kwhr$ = kilowatt-hours,
kh = disk constant on the meter nameplate or on the disk,

and

M = the product of the current transformer ratio and the potential transformer ratio (M is 1, where transformers are not used with the electric meter).

The number of kilowatt-hours required to pump an acre-foot of water (kwhr per acre-ft) is computed each time the discharge of any of the wells is measured by using the equation kwhr per acre-ft $= \frac{5{,}430\ kwhr}{Q}$, where Q is the discharge in gallons per minute. The values for at least one of the representative wells in each group of wells are plotted on rectangular coordinate paper versus date of measurement to obtain a rating curve for the group. A typical rating curve is shown in figure 1.

The next step is to determine the average number of kilowatt-hours used during the season by each pump to pump an acre-foot of water. This determination is made by relating the number of kilowatt-hours used by each pump during each month (this number can be obtained from the power company) to the rating curve for the pump, as shown in figure 1, and ascertaining the date when half the total kilowatt-hours were used (the kilowatt-hours are assumed to be used at a uniform rate throughout the month). The number of kilowatt-hours used to pump an acre-foot of water will be horizontally to the left of the point where the date intersects the curve. For a pump of a representative well, this value is the average number of kwhr per acre-ft used during the pumping season; for all other pumps, it is an index of the average number of kwhr per acre-ft. The average number of kwhr per acre-ft for the other pumps is computed by means of a proportion in which the average number of kwhr per acre-ft for a given well, in relation to the index value, is equated to the measured number of kwhr per acre-ft used by the pump in question, in relation to the measured kwhr per acre-ft used by the representative well.

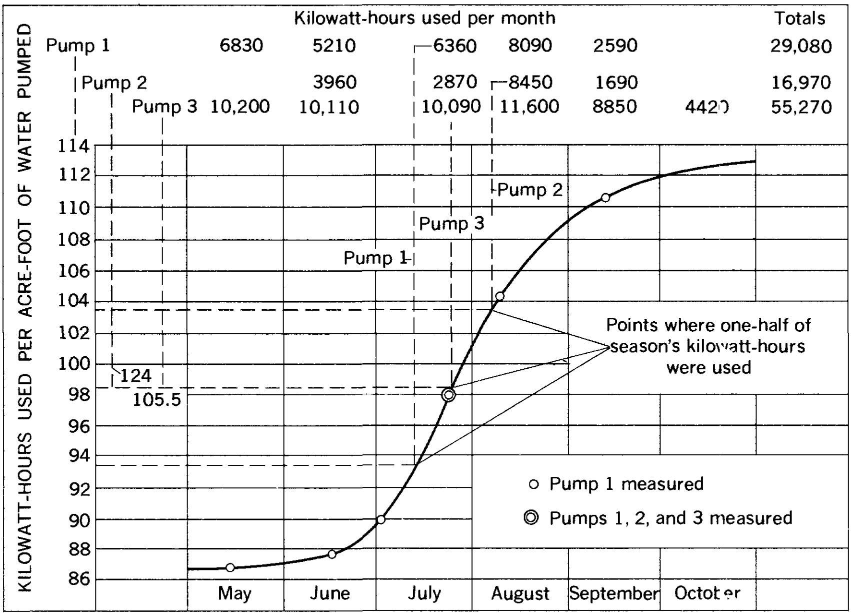


FIGURE 1.—Curve showing pumping-season change in the power consumption-discharge ratio in one well, and monthly power consumption and estimated midpoints of seasonal power consumption in this well and two related wells.

To illustrate the procedure, assume that a ground-water basin contains three wells, all having the same general characteristics, and that the field measurements and computations have been made and a rating curve drawn (fig. 1). Note that the rating curve was prepared by drawing a smooth curve through points representing the number of kwhr per acre-ft measured on six dates at intervals of 2–4 weeks. The dashed vertical lines are drawn on the dates on which half the annual power consumption was used by each pump. From the point of intersection of the dashed vertical lines with the rating curve, the dashed horizontal lines indicate the index kwhr per acre-ft of the pumps. The values obtained from figure 1 for each pump are given in the following table. The index kwhr per acre-ft is the average kwhr per acre-ft for the representative pump (No. 1). For pump 2 the average kwhr per acre-ft is a ratio of the measured kwhr per acre-ft of pump 2 to the measured kwhr per acre-ft of pump 1 on the same date, multiplied by the index kwhr per acre-ft of pump 2. For pump 2, the average kwhr per acre-ft is

$$\frac{124}{98} \times 103.5, \text{ or } 131.$$

By the same procedure, the average kwhr per acre-ft for pump 3 is

$$\frac{105.5}{98} \times 98.4, \text{ or } 105.9$$

Pump	Measured kwhr per acre-ft on July 23	Date on which half the power had been consumed	Index kwhr per acre-ft	Average annual kwhr per acre-ft	Annual pumpage (acre-ft)
1	98	July 12	93.4	93.4	311
2	124	Aug. 6	103.5	131	129
3	105.5	July 24	98.4	105.9	522

The total seasonal pumpage is obtained by dividing the seasonal power consumption in kilowatt-hours by the average seasonal kwhr per acre-ft. The seasonal pumpage from wells 1, 2, and 3 is 311, 129, and 522 acre-feet, respectively, a total of 962 acre-feet from the basin. In actual practice the accuracy of the method does not warrant reporting the pumpage figures more precisely than the nearest 10 acre-feet in the range above, but for purposes of instruction the figures have not been rounded.

VARIATION 2

The variation-1 method of computing ground-water pumpage can be simplified for use in succeeding years with only a slight diminution of accuracy. The kwhr per acre-ft is determined for each of the wells in the basin on or near the date which represents the half-way point of power consumption in the basin. This calculated value is assumed to be the average kwhr per acre-ft. The total power consumption of each pump is divided by the calculated kwhr per acre-ft of that pump to determine pumpage. The pump must be used throughout the season, however, if only one measurement is used as an average. In the above illustration, had only one measurement of kwhr per acre-ft been made for each pump, the computed total pumpage would have been 914 acre-feet for the three wells. This is within 5 percent of the total computed by using the rating curve.

The pumpage from two ground-water basins in southwestern Utah as computed by the method described herein was within 2 percent of the pumpage registered by totaling-type flow meters. The apparent excellent accuracy and the savings in time warrant the use of this method in preference to the method of Waite and others (1954, p. 17–19).

REFERENCE CITED

Waite, H. A., Nelson, W. B., Lofgren, B. F., Barnell, R. L., and Butler, R. G., 1954, Status of ground-water development in four irrigation districts in southwestern Utah: Utah State Engineer Tech. Pub. 9, p. 5–93.

U.S. GOVERNMENT PRINTING OFFICE: 1966 O—796-504