Techniques of Water-Resources Investigations

of the United States Geological Survey

Chapter A8

DISCHARGE MEASUREMENTS AT GAGING STATIONS

By Thomas J. Buchanan and William P. Somers

Book 3

APPLICATIONS OF HYDRAULICS

UNITED STATES DEPARTMENT OF THE INTERIOR

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PREFACE

The series of manuals on techniques describes procedures for planning and executing specialized work in water-resources investigations. The material is grouped under major subject headings called books and further subdivided into sections and chapters; section A of book 3 is on surface-water techniques.

Provisional drafts of chapters are distributed to field offices of the U.S. Geological Survey for their use. These drafts are subject to revision because of experience in use or because of advancement in knowledge, techniques, or equipment. After the technique described in a chapter is sufficiently developed, the chapter is published and is sold by the U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202 (authorized agent of Superintendent of Documents, Government Printing Office).

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DISCHARGE MEASUREMENTS AT GAGING STATIONS

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Abstract

The techniques used in making discharge measurements at gaging stations are described in this report. Most of the report deals with the current-meter method of measuring discharge, because this is the principal method used in gaging streams. The use of portable weirs and flumes, floats, and volumetric tanks in measuring discharge are briefly described.

Introduction

The U.S. Geological Survey makes thousands of streamflow measurements each year. Discharges measured range from a trickle in a ditch to a flood on the Amazon. Several methods are used, but the Geological Survey makes most streamflow measurements by current meter. The purpose of this report is to describe in detail the procedures used by the Geological Survey for making current-meter measurements and to describe briefly several of the other methods of measuring streamflow.

Streamflow, or discharge, is defined as the volume rate of flow of the water including any sediment or other solids that may be dissolved or mixed with it. Dimensions are usually expressed in cubic feet per second. Other common units are million gallons per day and acre-feet per day.

Current-Meter Measurements

A current-meter measurement is the summation of the products of the partial areas of the stream cross section and their respective average velocities. The formula

$$Q=\Sigma(a\ v) \qquad (1)$$

represents the computation where Q is total discharge, a is an individual partial cross-section area, and v is the corresponding mean velocity of the flow normal to the partial area.

In the midsection method of making a current-meter measurement it is assumed that the velocity sample at each location represents the mean velocity in a partial rectangular area. The area extends laterally from half the distance from the preceding meter location to half the distance to the next and vertically, from the water surface to the sounded depth. (See fig. 1.)

The cross section is defined by depths at locations 1, 2, 3, 4, . . . n. At each location the velocities are sampled by current meter to obtain the mean of the vertical distribution of velocity. The partial discharge is now computed for any partial section at location x as

$$q_x=v_x\left[\frac{(b_x-b_{(x-1)})}{2}+\frac{(b_{(x+1)}-b_x)}{2}\right]d_x$$

$$=v_x\left[\frac{b_{(x+1)}-b_{(x-1)}}{2}\right]d_x, \qquad (2)$$

where

q_x=discharge through partial section x,
v_x=mean velocity at location x,
b_x=distance from initial point to location x,
$b_{(x-1)}$=distance from initial point to preceding location,
$b_{(x+1)}$=distance from initial point to next location,
d_x=depth of water at location x.

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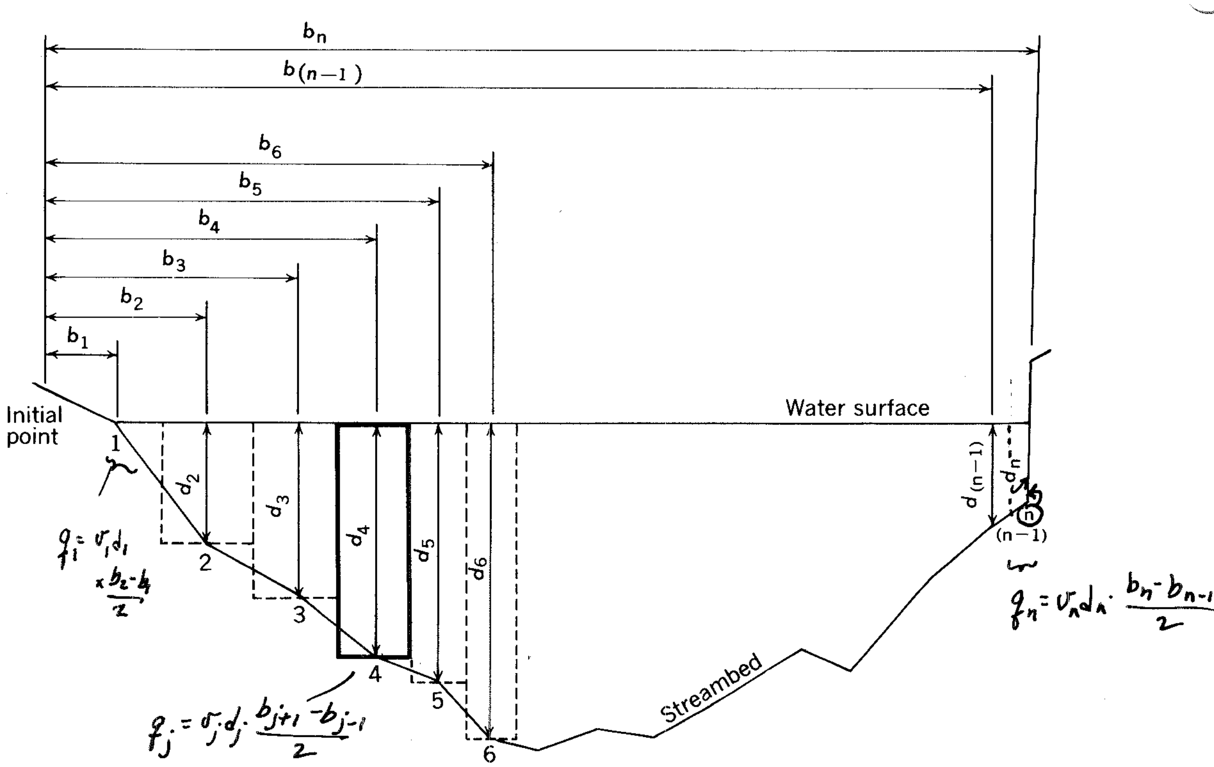


EXPLANATION

1, 2, 3, ... n	Observation points
$b_1, b_2, b_3, \ldots\ldots b_n$	Distance, in feet, from the initial point to the observation point
$d_1, d_2, d_3, \ldots\ldots d_n$	Depth of water, in feet, at the observation point
Dashed lines	Boundary of partial sections; one heavily outlined discussed in text

Figure 1.—Definition sketch of midsection method of computing cross-section area for discharge measurements.

Thus, for example, the discharge through partial section 4 (heavily outlined in fig. 1) is

$$q_4=v_4\left[\frac{b_5-b_3}{2}\right]d_4.$$

The procedure is similar when x is at an end section. The "preceding location" at the beginning of the cross section is considered coincident with location 1; the "next location" at the end of the cross section is considered coincident with location n. Thus,

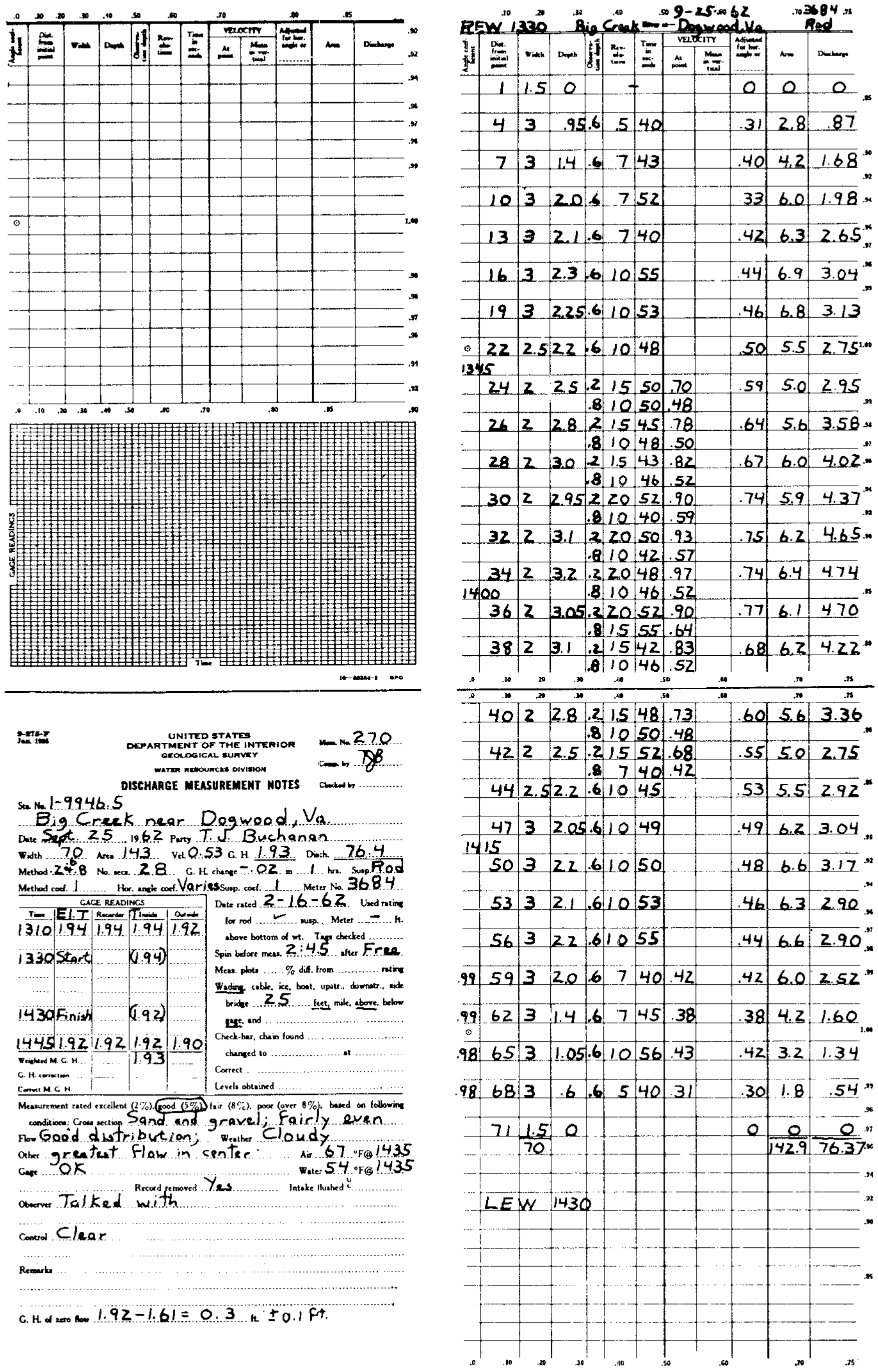
$$q_1=v_1\left[\frac{b_2-b_1}{2}\right]d_1, \text{ and}$$

$$q_n=v_n\left[\frac{b_n-b_{(n-1)}}{2}\right]d_n.$$

For the example shown in figure 1, q_1 is zero because the depth at observation point 1 is zero. However, when the cross-section boundary is a vertical line at the edge of the water as at location n, the depth is not zero and velocity at the end section may or may not be zero. The formula for q_1 or q_n is used whenever there is water only on one side of an observation point such as at piers, abutments, and islands. It usually is necessary to estimate the velocity at an end section as some percentage of the adjacent section because it normally is impossible to measure the velocity accurately with the current meter close to a boundary. There also is the possibility of damage to the equipment if the flow is turbulent.

The summation of the discharges for all the partial sections is the total discharge of the stream. An example of the measurement notes is shown in figure 2.

The mean-section method used by the Survey prior to 1950 differs from the midsection method in computation procedure. Partial discharges are computed for partial sections between successive locations. The velocities and depths at successive locations are each averaged, and



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UNITED STATES DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY WATER RESOURCES DIVISION

DISCHARGE MEASUREMENT NOTES

Meas. No. 270 Comp. by TJB Checked by

Sta. No. 1-9946.5

Big Creek near Dogwood, Va.

Date Sept. 25, 1962 Party T. J. Buchanan

Width 70 Area 143 Vel. 0.53 G. H. 1.93 Disch. 76.4

Method .2+.8 No. secs. 28 G. H. change -.02 in 1 hrs. Susp. Rod

Method coef. 1 Hor. angle coef. Varies Susp. coef. 1 Meter No. 3684

Time	E.L.T.	Recorder	Inside	Outside
1310	1.94	1.94	1.94	1.92
1330	Start		(1.94)	
1430	Finish		(1.92)	
1445	1.92	1.92	1.92	1.90
Weighted M. G. H.			1.93	
G. H. correction				
Correct M. G. H.				

Date rated 2-16-62. Used rating for rod ✓ susp. Meter — ft. above bottom of wt. Tags checked. Spin before meas. 2:45 after Free. Meas. plots ...% diff. from ... rating. Wading, cable, ice, boat, upstr., downstr., side bridge 25 feet, mile, above, below gage, and ... Check-bar, chain found ... changed to ... at ... Correct ... Levels obtained ...

Measurement rated excellent (2%), good (5%), fair (8%), poor (over 8%), based on following conditions: Cross section Sand and gravel; Fairly even. Flow Good distribution; Weather Cloudy. Other greatest flow in center. Air 67 °F @ 1435. Gage OK. Water 54 °F @ 1435. Record removed Yes. Intake flushed ✓.

Observer Talked with

Control Clear

Remarks

G. H. of zero flow 1.92 − 1.61 = 0.3 ft. ± 0.1 ft.

REW 1330 — 9-25-62 — Big Creek near Dogwood, Va. — 3684 Rod

Dist. from initial point	Width	Depth	Observation depth	Revolutions	Time in seconds	Velocity at point	Mean in vertical	Area	Discharge
1	1.5	0					0	0	0
4	3	.95	.6	5	40		.31	2.8	.87
7	3	1.4	.6	7	43		.40	4.2	1.68
10	3	2.0	.6	7	52		.33	6.0	1.98
13	3	2.1	.6	7	40		.42	6.3	2.65
16	3	2.3	.6	10	55		.44	6.9	3.04
19	3	2.25	.6	10	53		.46	6.8	3.13
22	2.5	2.2	.6	10	48		.50	5.5	2.75
1345									
24	2	2.5	.2	15	50	.70	.59	5.0	2.95
			.8	10	50	.48			
26	2	2.8	.2	15	45	.78	.64	5.6	3.58
			.8	10	48	.50			
28	2	3.0	.2	15	43	.82	.67	6.0	4.02
			.8	10	46	.52			
30	2	2.95	.2	20	52	.90	.74	5.9	4.37
			.8	10	40	.59			
32	2	3.1	.2	20	50	.93	.75	6.2	4.65
			.8	10	42	.57			
34	2	3.2	.2	20	48	.97	.74	6.4	4.74
1400			.8	10	46	.52			
36	2	3.05	.2	20	52	.90	.77	6.1	4.70
			.8	15	55	.64			
38	2	3.1	.2	15	42	.83	.68	6.2	4.22
			.8	10	46	.52			
40	2	2.8	.2	15	48	.73	.60	5.6	3.36
			.8	10	50	.48			
42	2	2.5	.2	15	52	.68	.55	5.0	2.75
			.8	7	40	.42			
44	2.5	2.2	.6	10	45		.53	5.5	2.92
47	3	2.05	.6	10	49		.49	6.2	3.04
1415									
50	3	2.2	.6	10	50		.48	6.6	3.17
53	3	2.1	.6	10	53		.46	6.3	2.90
56	3	2.2	.6	10	55		.44	6.6	2.90
.99 59	3	2.0	.6	7	40	.42	.42	6.0	2.52
.99 62	3	1.4	.6	7	45	.38	.38	4.2	1.60
.98 65	3	1.05	.6	10	56	.43	.42	3.2	1.34
.98 68	3	.6	.6	5	40	.31	.30	1.8	.54
71	1.5	0					0	0	0
	70							142.9	76.37
LEW 1430									

Figure 2.—Computation notes of a current-meter measurement by the midsection method.

the section extends laterally from one observation point to the next. Discharge is the product of the average of two mean velocities, the average of two depths, and the distance between locations. A study by Young (1950) concluded that the midsection method is simpler to compute and is a slightly more accurate procedure than the mean-section method.

Current-meter measurements usually are classified in terms of the means used to cross the stream during the measurement, such as wading, cableway, bridge, boat, or ice.

Instruments and equipment

Current meters, timers, and counting equipment are used when making conventional types of measurements. Additional equipment used depends on the type of measurements being made. Instruments and equipment used in making current-meter measurements are described in this section under the following categories: current meters, sounding equipment, width-measuring equipment, equipment assemblies, and miscellaneous equipment.

Current meters

A current meter is an instrument used to measure the velocity of flowing water. The principle of operation is based on the proportionality between the velocity of the water and the resulting angular velocity of the meter rotor. By placing a current meter at a point in a stream and counting the number of revolutions of the rotor during a measured interval of time, the velocity of water at that point is determined.

The number of revolutions of the rotor is obtained by an electrical circuit through the contact chamber. Contact points in the chamber are designed to complete an electrical circuit at selected frequencies of revolution. Contact chambers can be selected having contact points that will complete the circuit twice per revolution, once per revolution, or once per five revolutions. The electrical impulse produces an audible click in a headphone or registers a unit on a counting device.

The counting intervals are measured by a stopwatch.

Current meters generally can be classified into two main types, those meters having vertical-axis rotors and those having horizontal-axis rotors. The comparative characteristics of these two types are summarized below:

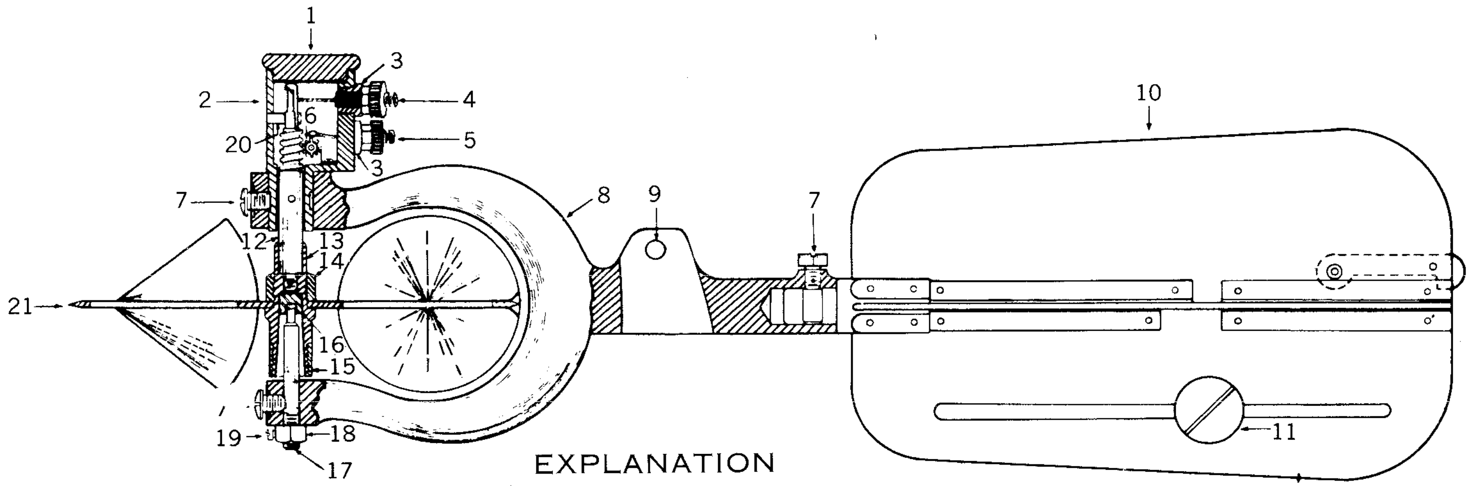
1. Vertical-axis rotor with cups or vanes.
   a. Operates in lower velocities than do horizontal-axis meters.
   b. Bearings are well-protected from silty water.
   c. Rotor is repairable in the field without adversely affecting the rating.
   d. Single rotor serves for the entire range of velocities.
2. Horizontal-axis rotor with vanes.
   a. Rotor disturbs flow less than do vertical-axis rotors because of axial symmetry with flow direction.
   b. Rotor is less likely to be entangled by debris than are vertical-axis rotors.
   c. Bearing friction is less than for vertical-axis rotors because bending moments on the rotor are eliminated.

Vertical-axis current meters

The most common type of vertical-axis current meter is the Price meter, type AA. (See fig. 3.) This meter is used extensively by the Geological Survey. The standard Price meter has a rotor 5 inches in diameter and 2 inches high with six cone-shaped cups mounted on a stainless-steel shaft. A pivot bearing supports the rotor shaft. The contact chamber houses the upper part of the shaft and an an eccentric contact that wipes a bead of solder on a slender bronze wire (cat's whisker) attached to the binding post. A separate reduction gear (pentagear), wire, and binding post provide a contact each time the rotor makes five revolutions. A tailpiece keeps the meter pointing into the current.

In addition to the standard type AA meter for general use there is a type AA meter for low velocities. No pentagear is provided. This modification reduces friction. The shaft usually has two eccentrics making two contacts per revolution. The low-velocity meter normally is rated from 0.2 to 2.5 fps (feet per second) and is recommended when the mean velocity at a cross section is less than 1 fps.

In addition to the type AA meters, the Geological Survey uses a Price pygmy meter



EXPLANATION

1 Cap for contact chamber
2 Contact chamber
3 Insulating bushing for contact binding post
4 Single-contact binding post
5 Penta-contact binding post
6 Penta gear
7 Set screws
8 Yoke
9 Hole for hanger screw
10 Tailpiece
11 Balance weight
12 Shaft
13 Bucket-wheel hub
14 Bucket-wheel hub nut
15 Raising nut
16 Pivot bearing
17 Pivot
18 Pivot adjusting nut
19 Keeper screw for pivot adjusting nut
20 Bearing lug
21 Bucket wheel

Figure 3.—Assembly drawing of small Price type AA current meter.

in shallow depths. (See fig. 4.) The pygmy meter is scaled two-fifths as large as the standard meter and has neither a tailpiece nor a pentagear. The contact chamber is an integral part of the yoke of the meter. The pygmy meter makes one contact each revolution and is used only for rod suspension.

The Geological Survey has recently developed a four-vane vertical-axis meter. (See fig. 5.) This meter is useful for measurements under ice cover because the vanes are less likely to fill with slush ice, and because it requires a much smaller hole to pass through the ice. One yoke of the vane meter is made to be suspended at the end of a rod and will fit holes made by an ice drill. Another yoke is made for regular suspensions. (See fig. 5.) The vane meter has a disadvantage of not responding as well as the Price type AA meter at velocities below 0.5 fps.

A new contact chamber has been designed by the Geological Survey to replace the wiper contact of the type AA and vane meters. The new contact chamber contains a magnetic switch, glass enclosed in a hydrogen atmosphere and hermetically sealed. The switch assembly is rigidly fixed in the top of the meter head just above the tip of the shaft. The switch is operated by a small permanent magnet rigidly fastened to the shaft. The switch quickly closes when the magnet is alined with it, and then promptly opens when the magnet moves away. The magnet is properly balanced on the shaft. Any type AA meter can have a magnetic switch added by replacing the shaft and the contact chamber. (See fig. 6.) The magnetic switch is placed in the special contact chamber through the tapped hole for the binding post. The rating of the meter is not altered by the change. An automatic counter (see p. 31) is used with the magnetic-switch contact chamber. If a headphone is used, arcing can weld the contacts.

A Price meter accessory that indicates the direction of flow is described on page 27.

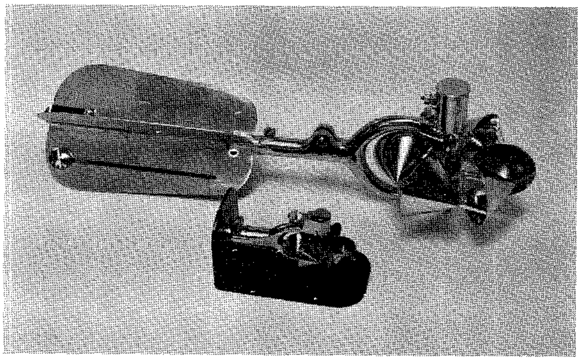


Figure 4.—Price type AA meter, top; and Price pygmy meter, bottom

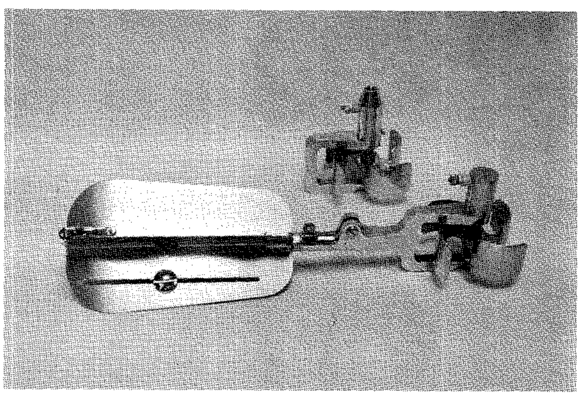


Figure 5 —Vane ice meter, top; and vane meter with cable suspension yoke, bottom.

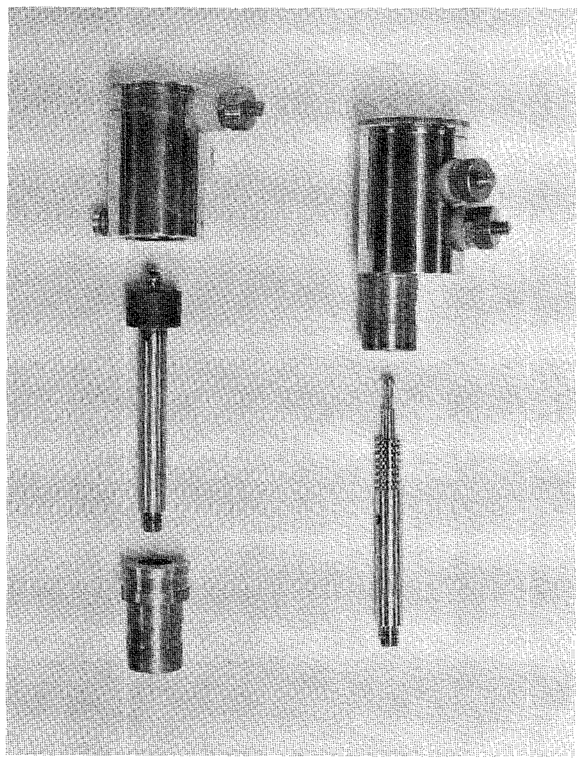


Figure 6 —Magnetic switch contact chamber, shaft, and adapter bushing, left; and cat's whisker contact chamber and shaft, right.

The care and rating of vertical-axis meters is described below and by Smoot and Novak (1968).

Horizontal-axis current meters

The types of horizontal-axis meters in use are the Ott, Neyrpic, Haskell, and Hoff. The Ott meter is made in Germany, the Neyrpic meter in France, and both are used extensively in Europe. The Haskell and Hoff meters were developed in the United States where they are used to a limited extent.

The Ott meter is a precision instrument but is not used extensively in this country because it is not as durable as the Price meter under extreme conditions. (See fig. 7.) The makers of the Ott meter have developed a component propeller which in oblique currents automatically registers the velocity projection at right angles to the measuring section for angles as much as 45° and velocities as much as 8 fps. For example, if this component propeller were held in the position *AB* in figure 8 it would register $V \cos \alpha$ rather than V, which the Price meter would register.

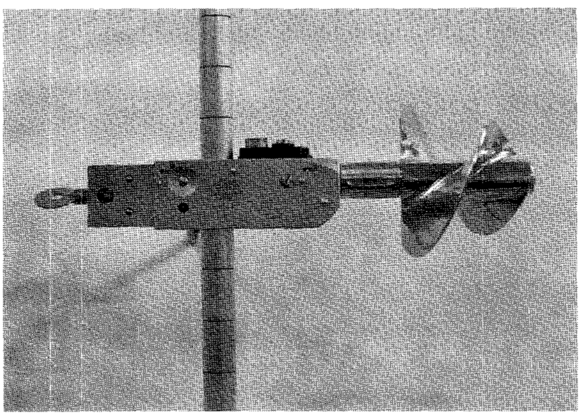


Figure 7.—Ott current meter.

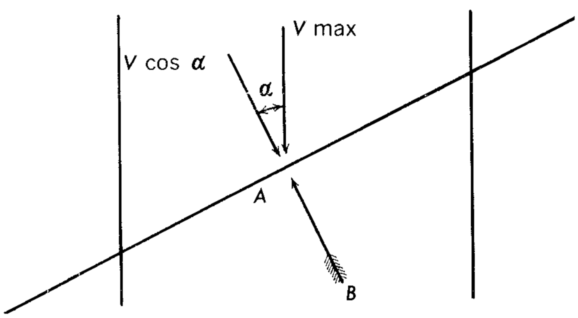


Figure 8.—Velocity components measured by Ott and Price current meters.

The Neyrpic meter is used rarely in this country because it has the same disadvantages as the Ott meter.

The Haskell meter has been used by the U.S. Lake Survey, Corps of Engineers, in streams that are deep, swift, and clear. By using propellers with a variety of screw pitches, a considerable range of velocity can be measured. The meter is durable, but has most of the other disadvantages of horizontal-axis meters.

The Hoff meter is used by the Geological Survey, the Department of Agriculture, and others, especially for measuring pipe flow. (See fig. 9.) The lightweight propeller has three or four vanes of hard rubber. The meter is suited to measurement of low velocities, but not for rugged use.

Optical current meter

The Geological Survey, in cooperation with the California Department of Water Resources, has developed an optical current meter. (See fig. 10.) This meter is a stroboscopic device designed to measure surface velocities in open channels without immersing equipment in the stream. The optical current meter will find its principal use in measurements of surface velocity during floods when it is impossible to use conventional stream-gaging equipment because of extremely high velocities and a high debris content in the stream.

Care of the vertical-axis current meter

The calibration and maintenance of vertical-axis type current meters is presented in detail

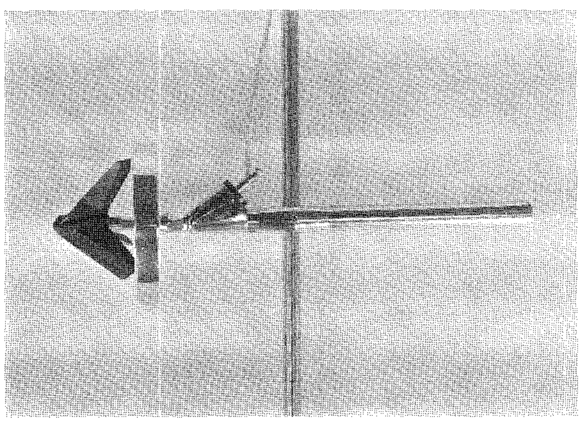


Figure 9.—Hoff current meter.