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

INTRODUCTION

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

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

Discharge measurements may be made by any one of the methods discussed in chapters 5–8. However, the conventional current-meter method is most commonly used in gaging streams. When using this method, observations of width, depth, and velocity are taken at intervals in a cross section of the stream, while the hydrographer is wading or supported by a cableway, bridge, ice cover, or boat. A current meter is used to measure velocity. This chapter describes the conventional current-meter method.

GENERAL DESCRIPTION OF A CONVENTIONAL CURRENT-METER MEASUREMENT OF DISCHARGE

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

$$Q = \Sigma(a\ v) \tag{9}$$

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

In the midsection method of computing a current-meter measurement, it is assumed that the velocity sample at each vertical represents the mean velocity in a rectangular subsection. The subsection area extends laterally from half the distance from the preceding observation vertical to half the distance to the next, and vertically from the water surface to the sounded depth. (See fig. 41.)

The cross section is defined by depths at verticals 1, 2, 3, 4, . . . n. At each vertical the velocities are sampled by current meter to obtain the mean velocity for each subsection. The subsection discharge is then computed for any subsection at vertical x by use of the equation,

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

$$= v_x \left[\frac{b_{(x+1)} - b_{(x-1)}}{2}\right] d_x \tag{10}$$

where

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

Thus, for example, the discharge through subsection 4 (heavily outlined in fig. 41) 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 vertical" at the beginning of the cross section is considered coincident with vertical 1; the "next vertical" at the end of the cross section is considered coincident with vertical n. Thus,

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

and

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

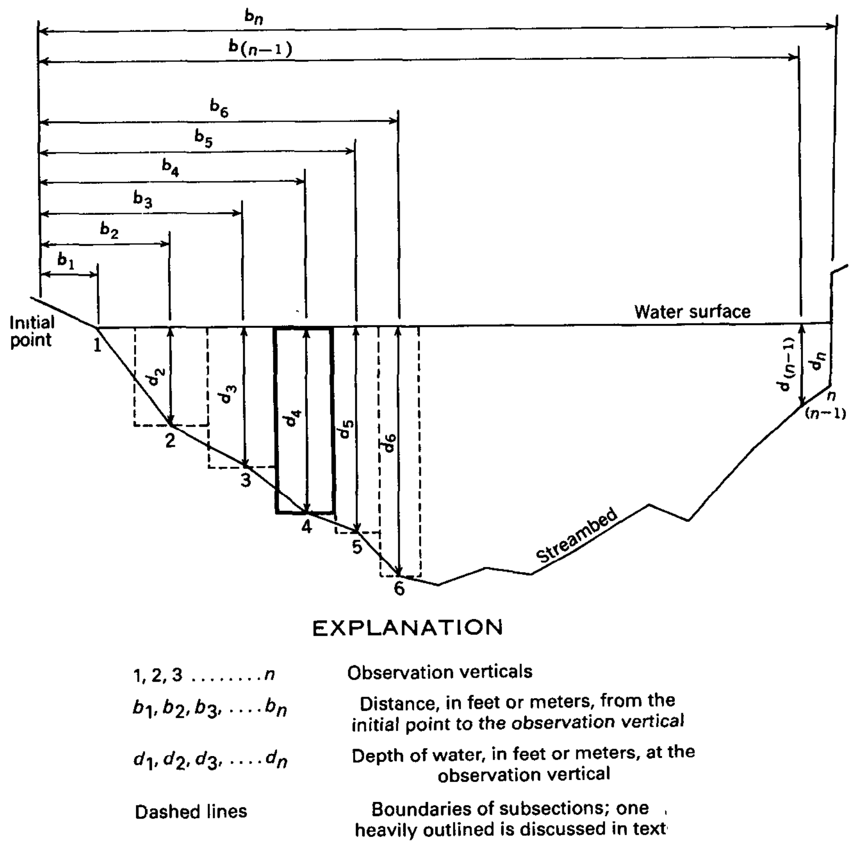


FIGURE 41.—Definition sketch of midsection method of computing cross-section area for discharge measurements.

For the example shown in figure 41, 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 vertical n, the depth is not zero and velocity at the end vertical 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 vertical such as at piers, abutments, and islands. It is necessary to estimate the velocity at an end vertical, usually as some percentage of the adjacent vertical, because it is impossible to measure the velocity accurately with the current meter close to a boundary. There is also the possibility of damage to the equipment if the flow is turbulent. Laboratory data suggest that the mean vertical velocity in the vicinity of a smooth sidewall of a rectangular channel can be related to the mean vertical velocity at a distance from the wall equal to the depth. The tabulation below gives values that define the relation.

Distance from wall, as a ratio of the depth	*Mean vertical velocity, as related to V_D*
0.00	$0.65V_D$
.25	$.90V_D$
.50	$.95V_D$
1.00	$1.00V_D$

NOTE—V_D is the mean vertical velocity at a distance from the vertical wall equal to the depth.

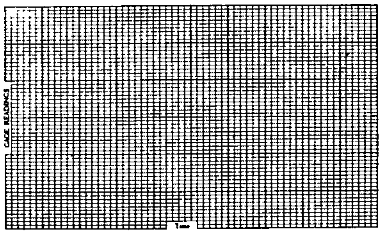
The summation of the discharges for all the subsections—usually 25 to 30 in number—is the total discharge of the stream. An example of the measurement notes used by the U.S. Geological Survey is shown in figure 42.

The mean-section method, used by the U.S. Geological Survey prior to 1950, differs from the midsection method, described above, in computation procedure. In the older method discharges are computed for subsections between successive observation verticals. The velocities and depths at successive verticals are each averaged, and each subsection extends laterally from one observation vertical to the next. Subsection discharge is the product of the average of two mean velocities, the average of two depths, and the distance between observation verticals. In both methods total discharge is the sum of the subsection discharges. 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 meaurements are usually classified in terms of the means used to cross the stream during the measurement, such as wading, cableway, bridge, boat, or ice cover.

INSTRUMENTS AND EQUIPMENT

Current meters, timers, and a means of counting meter revolutions are needed for the measurement of discharge, along with additional



9-204-F
Jan. 1956

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

GAGE READINGS				
Time	EIT	Recorder	T Inside	Outside
1310	194	194	194	192
1330	Start		(194)	
1430	Finish		(192)	
1445	192	192	192	190
Weighted M. G. H.			193	
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.

RFW 1330 Big Creek near Dogwood, Va. 9-25-62 Meter No. 3684 Rod

Angle coef.	Dist. from initial point	Width	Depth	Observation depth	Revolutions	Time in seconds	Velocity At point	Velocity Mean in vertical	Adjusted for hor. angle or	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 42.—Computation notes of a current-meter measurement by the midsection method.

equipment that depends on the manner in which the measurement is to be made—that is, whether by wading, cableway, bridge, boat, or from ice cover. Instruments and equipment used in making the current-meter measurements are described in this section of the manual 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 intervals during which meter revolutions are counted are timed with a stopwatch. A discussion of the required time interval follows.

Turbulent flow, which is ordinarily found in natural streams and in artificial channels, is always accompanied by local eddying, which results in pulsations in the velocity at any point. Figure 43, taken from a study by Pierce (1941), shows the pulsations observed in a laboratory flume for two different mean velocities. The greater magnitude of the pulsations, relative to the mean, at the lower velocity explains why current-meter observations at a point should cover a longer period when low velocities are being measured than when higher velocities are being measured. At high velocities, pulsations have only minor effect on the current-meter observations. In the U.S.A. it is customary to observe velocity at a point by current meter for a period that ranges from 40 to 70 s. It is recognized that the use of a period of from 40 to 70 s is not long enough to insure the accuracy of a single point-observation of velocity. However, because the pulsations are random and because velocity observations during a discharge measurement are made at 25 to 30 verticals, usually with two observations being made in each vertical, there is little likelihood that the pulsations will bias the total measured discharge of a stream. (See p. 181–182.) Longer periods of current-meter observation at a point are not used, because it is desirable to complete a discharge measurement before the stage changes significantly and because the use of longer observation periods may add significantly to the operating cost of a large number of gaging stations.

Current meters generally can be classified with respect to 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

A common type of vertical-axis current meter is the Price meter, type AA. (See fig. 44.) This meter is used extensively by the U.S. Geological Survey. The standard Price meter has a rotor 5 in (0.127

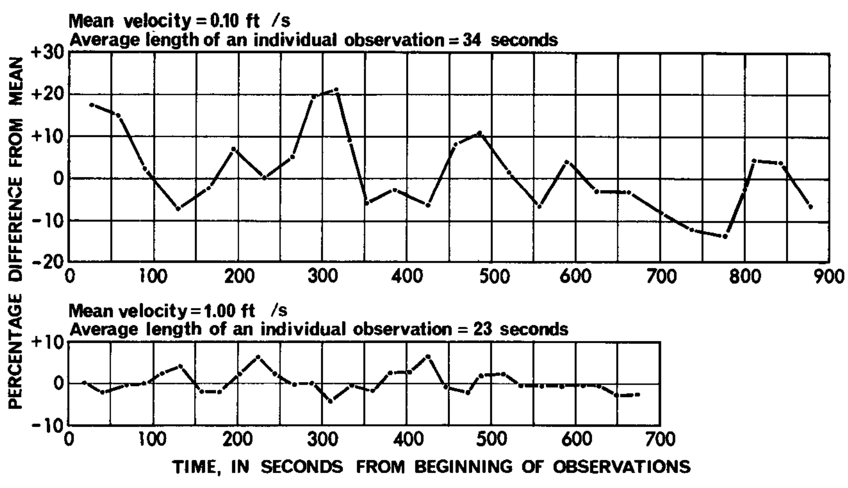


FIGURE 43.—Comparison of pulsations for two different mean velocities measured in a laboratory flume, 12 ft wide.

m) in diameter and 2 in (0.05 m) high with six cone-shaped cups mounted on a stainless-steel shaft. A pivot bearing supports the rotor shaft. The contact chamber houses both the upper part of the shaft and a slender bronze wire (cat's whisker) attached to a binding post. With each revolution an eccentric contact on the shaft makes contact with a bead of solder at the end of the cat's whisker. 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 ft/s (0.06 to 0.76 m/s) and is recommended for use when the mean velocity at a cross section is less than 1 ft/s (0.3 m/s).

In addition to the type AA meters, the U.S. Geological Survey uses a Price pygmy meter in shallow depths. (See fig. 44.) 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 per revolution and is used only with rod suspension.

The U.S. Geological Survey has recently developed a four-vane vertical-axis meter. (See fig. 45.) 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 for passage 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

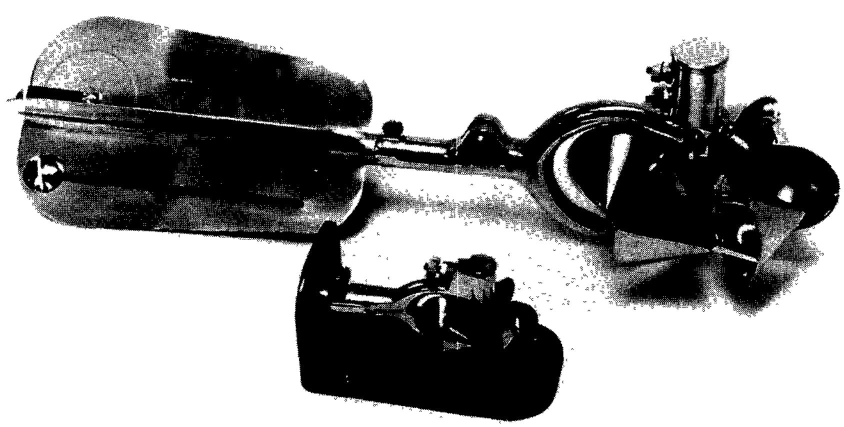


FIGURE 44.—Price type AA meter, top; Price pygmy meter, bottom.

is made for regular cable or rod suspension. (See fig. 45.) The vane meter has the disadvantage of not responding as well as the Price type AA meter at velocities less than 0.5 ft/s (0.15 m/s).

A new contact chamber has been designed by the U.S. 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. 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 (p. 130) is used with the magnetic-switch contact chamber. If a headphone is used, arcing may weld the contacts.

A Price meter accessory that indicates the direction of flow is described on page 129.

Vertical-axis current meters do not register velocities accurately when placed close to a vertical wall. A Price meter held close to a right-bank vertical wall will underregister because the slower water velocities near the wall strike the effective (concave) face of the cups. The converse is true at a left-bank vertical wall. (The terms "left bank" and "right bank" designate direction from the center of a stream for an observer facing downstream.) The Price meter also

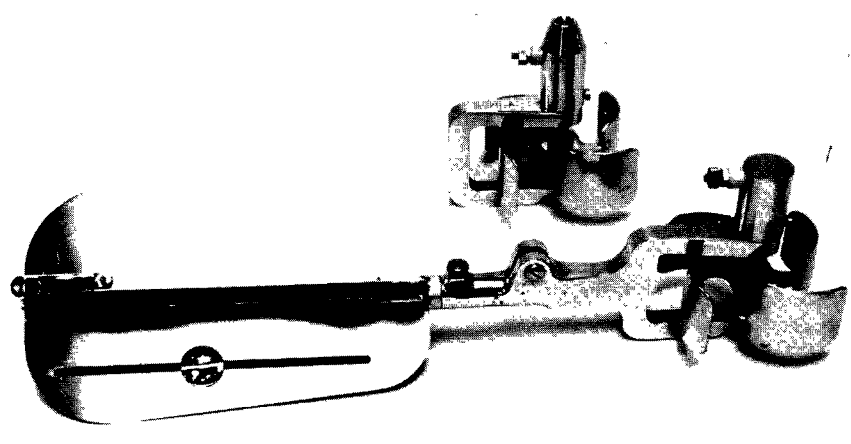


FIGURE 45.—Vane ice meter, top; vane meter with cable suspension yoke, bottom.

underregisters when positioned close to the water surface or close to the streambed.

HORIZONTAL-AXIS CURRENT METERS

The types of horizontal-axis meters most commonly used are the Ott, Neyrpic, Haskell, Hoff, and Braystoke. 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 Braystoke meter is used extensively in the United Kingdom. The Ott meter (fig. 46) is a precision instrument but is not widely used in the U.S.A. because it is not as durable as the Price meter under extreme conditions. The makers of the Ott meter have developed a component propeller that in oblique currents automatically registers the velocity component at right angles to the measuring section for angles as great as 45° and

FIGURE 46.—Ott current meter.

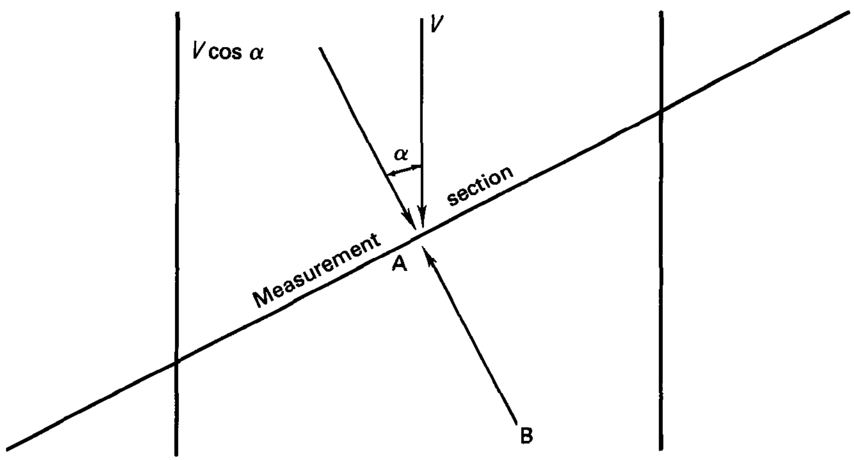


FIGURE 47.—Velocity components measured by Ott and Price current meters.

for velocities as great as 8 ft/s (2.4 m/s). For example, if this component propeller were held in the position *AB* in figure 47 it would register $V \cos \alpha$ rather than V, which the Price meter would register.

The Neyrpic meter is used rarely in the U.S.A. for the same reason that the Ott meter is rarely used there.

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 Haskell meter is more durable than most other horizontal-axis current meters.

The Hoff meter (fig. 48) is another current meter used in the U.S.A. The lightweight propeller has three or four vanes of hard rubber. The meter is suited for the measurement of low velocities but is not suited for rugged use.

COMPARISON OF PERFORMANCE OF VERTICAL-AXIS AND HORIZONTAL-AXIS CURRENT METERS

Comparative tests of the performance of vertical-axis and horizontal-axis current meters, under favorable measuring conditions, indicate virtually identical results from use of the two types of meter. That was the conclusion reached in 1958 by the U.S. Lake Survey, Corps of Engineers, after tests made with the Price, Ott, and Neyrpic current meters (Townsend and Blust, 1960). The results of one of their tests is shown in figure 49.

Between the years 1958 and 1960, the U.S. Geological Survey made 19 simultaneous discharge measurements on the Mississippi River using Price and Ott meters. The average difference in discharge between results from the two meters was −0.15 percent, using the measurements made with the Price meter as the standard for comparison. The maximum differences in discharge measured by the two meters was −2.76 and +1.53 percent.

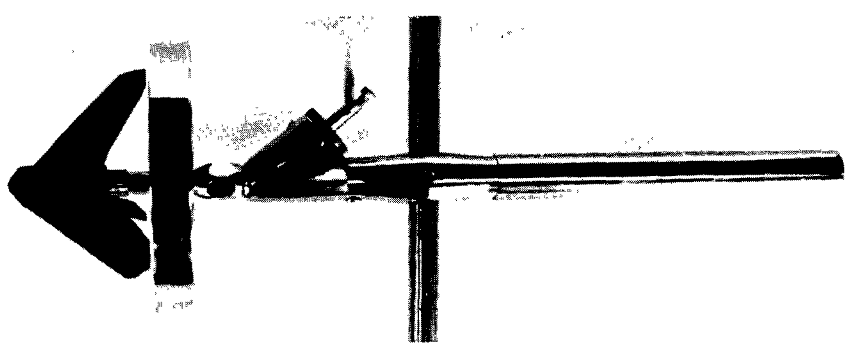


FIGURE 48.—Hoff current meter.

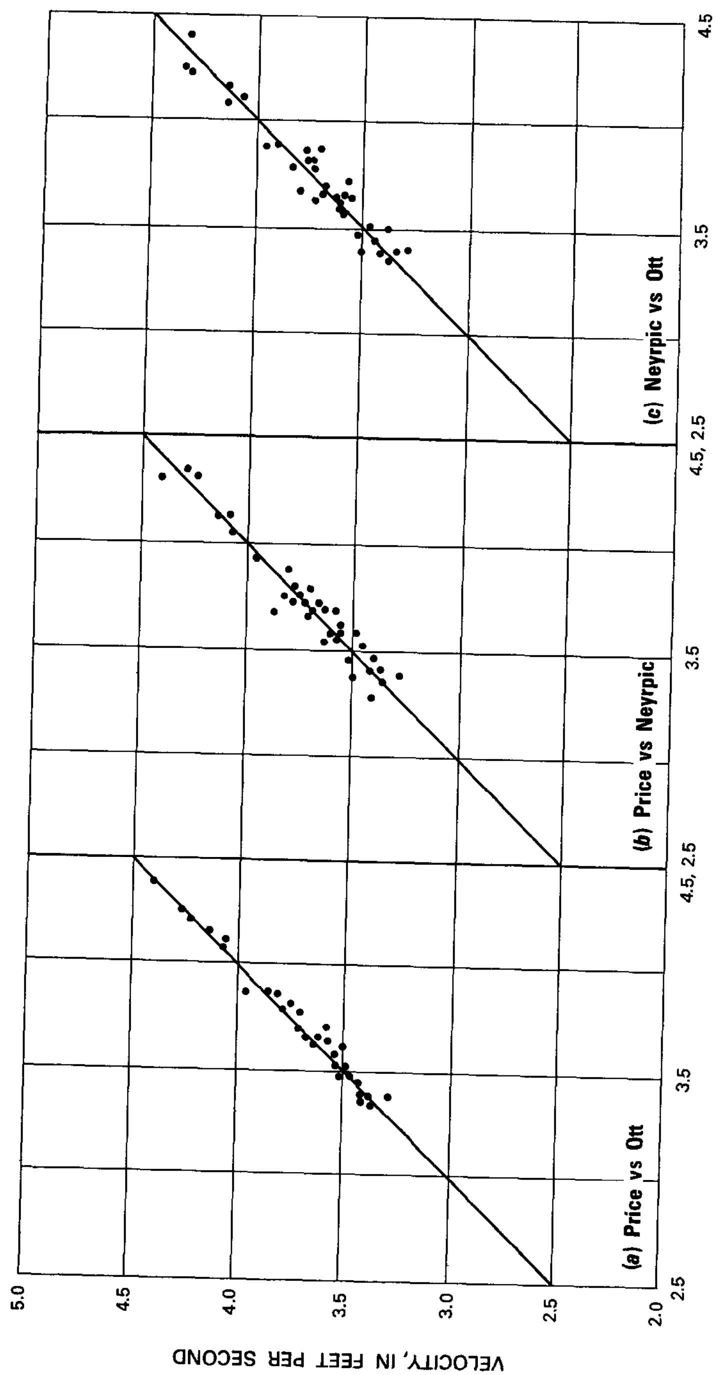


FIGURE 49.—Comparison of mean *velocities* measured simultaneously by various current meters during 2-min periods, Stella Niagara section, Panel point 5. (After Townsend and Blust, 1960.)

OPTICAL CURRENT METER

In recent years the U.S. Geological Survey has developed an optical current meter (fig. 50). The meter and its use have been described by Chandler and Smith (1971). The optical current meter is designed to measure surface velocities in open channels without immersing equipment in the stream. However, because it measures only surface velocity, the optical meter is not considered a substitute for conventional equipment in those situations where good measurements can be made by standard techniques. It is a device that has extended the capability of making discharge measurements to a range of situations under which standard current-meter techniques cannot be used. Those situations include flood velocities that are too high to be measured by conventional meter—for example, supercritical velocities in floodways—or the presence of a debris load during flood periods that makes it hazardous to immerse a current meter.

Basically, the meter is a stroboscopic device consisting of a low-power telescope, a single oscillating mirror driven by a cam, a variable-speed battery-operated motor, and a tachometer. The water surface is viewed from above through the meter, while gradually changing the speed of the motor to bring about synchronization of the

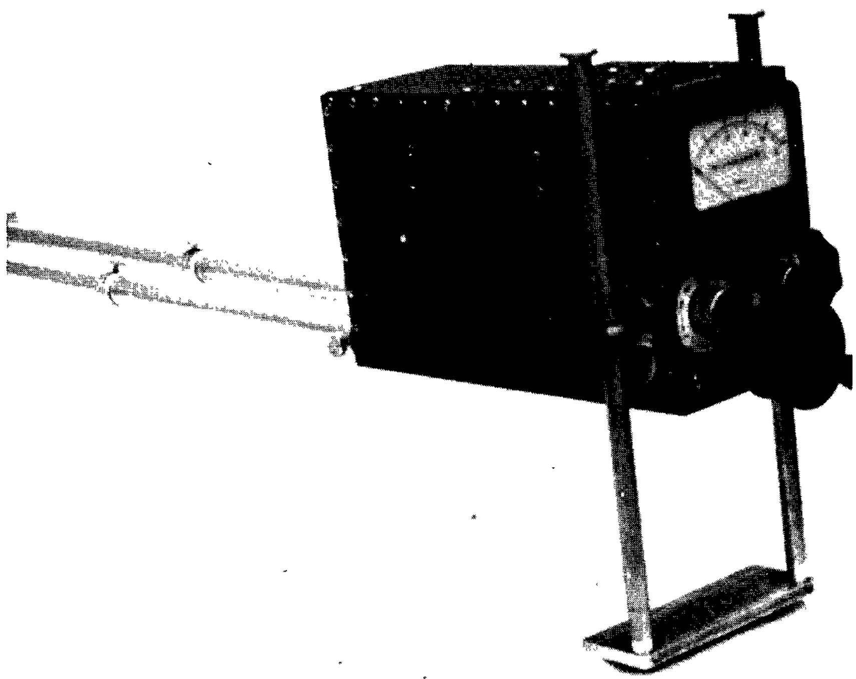


FIGURE 50.—Optical current meter.

angular velocity of the mirror and the surface velocity of the water. Synchronization is achieved when the motion of drift or disturbances on the water surface, as viewed through the meter, is stopped. A reading of the tachometer and height of the meter above the water surface are the only elements needed to compute the surface velocity.

The velocity measurement may be made from any bridge, walkway, or other structure that will support the optical meter. The vertical axis of the meter must be perpendicular to the water surface. Surface velocity (V_s) is computed from the equation

$$V_s = KRD,$$

where K is the constant for the meter, R is the readout from the tachometer, and D is the distance to the water surface in feet. The tachometer is scaled to produce a value of K equal to 1.00. The surface velocity computed from the above equation must be corrected by an appropriate coefficient to obtain the mean velocity in the vertical. The precise coefficient applicable is, of course, unique to the particular stream and to the location of the vertical in the stream cross section. However, data abstracted from conventional current-meter measurements show that application of a coefficient of 0.90 will not introduce errors of more than ±5 percent in concrete-lined channels. For natural channels a coefficient of 0.85 has been used.

A unique feature of the optical current meter is the automatic correction that is made for variations in the direction of the streamlines of flow. If the flow approaches the cross section at an angle other than the perpendicular, and if the axis of the oscillating mirror in the meter is parallel to the cross section, then at the null point of observation, the water will appear to move laterally across the field of view. The meter measures only the velocity vector normal to the cross section, and there is no need to apply horizontal angle corrections.

The range of velocities that can be measured with the optical current meter is limited at the lower end by the accuracy of the tachometer and at the upper end by the physical limitations of the human eye. Table 1 shows the range of velocities that can be meas-

TABLE 1.—*Range of velocities that can be measured with optical current meter*

Observation height (D)		Maximum velocity		Minimum velocity for ±5 percent resolution	
(ft)	(m)	(ft/s)	(m/s)	(ft/s)	(m/s)
5	1.52	25	7.62	1.6	0.49
10	3.05	50	15.2	3.2	.98
15	4.57	75	22.9	4.8	1.46
20	6.10	100	30.5	6.4	1.95

ured from various heights above the water surface with the U.S. Geological Survey model of the meter. The minimum velocities shown in column 3 of the table can be measured with an error of ±5 percent; the higher velocities at the various observation heights will be measured with lesser error.

CARE OF THE CURRENT METER

To insure reliable observations of velocity it is necessary that the current meter be kept in good condition. The care of conventional meters will be discussed first.

Before and after each discharge measurement the meter cups or vanes, pivot and bearing, and shaft should be examined for damage, wear, or faulty alinement. Before using the meter its balance on the cable-suspension hanger should be checked, the alinement of the rotor when the meter is on the hanger or wading rod should also be checked, and the conductor wire should be adjusted to prevent interference with meter balance and rotor spin. During measurements, the meter should periodically be observed when it is out of the water to be sure that the rotor spins freely.

Meters should be cleaned and oiled daily when in use. If measurements are made in sediment-laden water, the meter should be cleaned immediately after each measurement. For vertical-axis meters the surfaces to be cleaned and oiled are the pivot bearing, pentagear teeth and shaft, cylindrical shaft bearing, and thrust bearing at the cap.

After oiling, the rotor should be spun to make sure that it operates freely. If the rotor stops abruptly, the cause of the trouble should be sought and corrected before using the meter. The duration of spin should be recorded on the field notes for the discharge measurement. A significant decrease in the duration of spin indicates that the bearings require attention. In vertical-axis current meters the pivot requires replacement more often than other meter parts, and it therefore should be examined after each measurement. The pivot and pivot bearing should be kept separated, except during measurements, by use of the raising nut provided in the Price meter or by replacing the pivot with a brass plug in the pygmy meter. Fractured, worn, or rough pivots should be replaced.

Meter repairs by the hydrographer should be limited to minor damage only. That is particularly true of the rotor, where small changes in shape can significantly affect the meter rating. In vertical-axis meters, minor dents in the cups can often be straightened to restore the original shape of the cups, but in case of doubt, the entire rotor should be replaced with a new one. Badly sprung yokes, bent yoke stems, misalined bearings and tailpieces should be reconditioned in shops equipped with the specialized facilities needed.

There are only few details connected with care of the optical current meter. The meter should be transported in a shock-proof carrying case and the battery should be checked periodically. Field performance of the tachometer should also be checked periodically. Three steps are involved in the checking process. First, a cam speed is measured by counting and timing mirror oscillations with a stopwatch, and the corresponding dial reading of the tachometer is observed. Next, a tachometer dial readout is computed from the measured cam speed and the known scale factor of the tachometer dial. In the final step the observed dial reading and the computed dial readout are compared.

RATING OF CURRENT METERS

To determine the velocity of the water from the revolutions of the rotor of a conventional current meter, a relation must be established between the angular velocity of the rotor and the velocity of the water that spins the rotor. That relation is known as the rating of the current meter. The rating is established by first towing the meter at a constant velocity through a long water-filled trough, and then relating the linear and rotational velocities of the current meter. The following paragraphs describe the rating of meters by the U.S. Geological Survey at the Hydrologic Instrumentation Facility in Mississippi.

The rating trough used is a sheltered concrete tank 450 ft (137 m) long, 12 ft (3.7 m) wide, and 12 ft (3.7 m) deep. An electrically driven car rides on rails extending the length of the tank. The car carries the current meter at a constant rate through the still water in the basin. Although the rate of travel can be accurately adjusted by means of an electronic regulating gear, the average velocity of the moving car is determined for each run by making an independent measurement of the distance it travels during the time that the revolutions of the rotor are electrically counted. Eight pairs of runs are usually made for each current meter. A pair of runs consists of two traverses of the basin, one in each direction, at the same speed. Practical considerations usually limit the ratings to velocities ranging from 0.1 to about 15 ft/s (0.03 to about 4.6 m/s), although the car can be operated at lower speeds. Unless a special request is made for a more extensive rating, the lowest velocity used in the rating is about 0.2 ft/s (0.06 m/s), and the highest is about 8.0 ft/s (2.5 m/s).

For convenience in field use, the data from the current-meter ratings are reproduced in tables, a sample of which is shown in figure 51.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

RATING TABLE FOR TYPE AA CURRENT METER

EQUATIONS V=2 180R + 020 (2 200) 2 170R + 030 Std Rating No 1

Time in Seconds	VELOCITY IN FEET PER SECOND									Time in Seconds
	Revolutions									
	3	5	7	10	15	20	25	30	40	
40	183	292	401	565	.837	1.11	1 38	1 65	2 20	40
41	180	286	392	552	818	1 08	1.35	1 62	2 15	41
42	176	280	383	539	799	1 06	1 32	1 58	2 10	42
43	172	273	375	527	780	1 03	1 29	1 54	2 05	43
44	.169	268	367	515	.763	1 01	1 26	1 51	2 00	44
45	165	262	359	504	747	989	1.23	1 47	1 96	45
46	162	257	352	494	.731	968	1 20	1 44	1 92	46
47	159	252	345	484	716	948	1.18	1 41	1 88	47
48	156	247	338	474	701	928	1 16	1 38	1 84	48
49	153	242	331	.465	687	910	1 13	1 35	1 80	49
50	.151	238	325	.456	.674	892	1.11	1 33	1 76	50
51	148	234	319	447	661	875	1 09	1 30	1 73	51
52	146	230	313	.439	649	858	1 07	1 28	1 70	52
53	143	226	308	431	637	843	1 05	1 25	1 67	53
54	141	222	303	424	626	827	1 03	1 23	1 63	54
55	139	218	297	416	615	813	1 01	1 21	1 61	55
56	.137	215	292	409	604	.799	.993	1 19	1 58	56
57	135	211	288	402	594	785	976	1 17	1 55	57
58	133	208	283	396	584	.772	960	1 15	1 52	58
59	131	205	279	389	574	759	944	1 13	1 50	59
60	129	202	274	383	565	747	928	1 11	1 47	60
61	127	199	270	377	556	735	913	1 09	1 45	61
62	125	196	266	.372	547	723	899	1.07	1 43	62
63	.124	193	.262	366	539	712	885	1 06	1 40	63
64	122	190	258	.361	531	.701	.872	1 04	1 38	64
65	121	188	255	355	523	691	858	1 03	1 36	65
66	119	185	251	350	515	681	846	1 01	1 34	66
67	118	.183	248	345	508	.671	.833	996	1 32	67
68	116	180	.244	341	501	661	821	982	1 30	68
69	115	178	241	336	494	652	810	968	1 28	69
70	113	176	238	331	487	643	799	954	1 27	70
	3	5	7	10	15	20	25	30	40	

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

RATING TABLE FOR TYPE AA CURRENT METER

Actual Rating Limits 0 25 to 8 0 feet per second Date 03-05-70

Time in Seconds	VELOCITY IN FEET PER SECOND									Time in Seconds
	Revolutions									
	50	60	80	100	150	200	250	300	350	
40	2 74	3 28	4 37	5 45	8.17	10 88	13 59	16 30	19 02	40
41	2 68	3 21	4 26	5 32	7 97	10 62	13 26	15 91	18 55	41
42	2 61	3 13	4 16	5 20	7 78	10 36	12 95	15 53	18 11	42
43	2 55	3 06	4 07	5 08	7 60	10 12	12 65	15.17	17 69	43
44	2 50	2 99	3 98	4 96	7 43	9 89	12 36	14 83	17 29	44
45	2 44	2 92	3 89	4 85	7 26	9.67	12 09	14 50	16 91	45
46	2 39	2 86	3 80	4 75	7 11	9 46	11 82	14 18	16 54	46
47	2 34	2 80	3 72	4 65	6 96	9 26	11 57	13 88	16 19	47
48	2 29	2 74	3 65	4 55	6 81	9 07	11 33	13 59	15 85	48
49	2 24	2 69	3 57	4 46	6 67	8 89	11 10	13 32	15 53	49
50	2 20	2 63	3 50	4 37	6 54	8 71	10 88	13 05	15 22	50
51	2 16	2 58	3 43	4 28	6 41	8 54	10 67	12 79.	14 92	51
52	2 12	2 53	3 37	4 20	6 29	8 38	10 46	12 55	14 64	52
53	2 08	2 49	3 31	4 12	6 17	8 22	10 27	12 31	14 36	53
54	2 04	2 44	3 24	4 05	6 06	8 07	10 08	12 09	14 09	54
55	2 00	2 40	3 19	3 98	5 95	7 92	9 89	11 87	13 84	55
56	1 97	2 35	3 13	3 90	5 84	7 78	9 72	11 65	13 59	56
57	1 93	2 31	3 08	3 84	5 74	7 64	9 55	11 45	13 35	57
58	1 90	2 27	3 02	3 77	5 64	7 51	9 38	11 25	13 12	58
59	1 87	2 24	2 97	3 71	5 55	7 39	9 22	11 06	12 90	59
60	1 84	2 20	2 92	3 65	5 45	7 26	9 07	10 88	12 69	60
61	1 81	2 16	2 88	3 59	5 37	7 14	8 92	10 70	12 48	61
62	1 78	2 13	2 83	3 53	5 28	7 03	8 78	10 53	12 28	62
63	1 75	2 10	2 79	3 47	5 20	6 92	8 64	10 36	12 09	63
64	1 72	2 06	2 74	3 42	5 12	6 81	8 51	10 20	11 90	64
65	1 70	2 03	2 70	3 37	5 04	6 71	8 38	10 05	11 71	65
66	1 67	2 00	2 66	3 32	4 96	6 61	8 25	9 89	11 54	66
67	1 65	1 97	2 62	3 27	4 89	6 51	8 13	9 75	11 37	67
68	1 62	1 94	2 58	3 22	4 82	6 41	8 01	9 60	11 20	68
69	1 60	1 92	2 55	3 17	4 75	6 32	7 89	9 46	11 04	69
70	1 58	1 89	2 51	3 13	4 68	6 23	7 78	9 33	10 88	70
	50	60	80	100	150	200	250	300	350	

FIGURE 51.—Current-meter rating table.

The velocities corresponding to a range of 3 to 350 revolutions of the rotor within a period of 40 to 70 s are listed in the tables. This range in revolution and time has been found to cover general field requirements. To provide the necessary information for extending a table for the few instances where extensions are required, the equations of the rating table are shown in the spaces provided in the heading. The term, R, in the equations refers to revolutions of the rotor per second. The equation to the left of the figure in parentheses (2.20 in fig. 51) is the equation for velocities less than 2.20 ft/s (0.67 m/s), and the equation to the right is for velocities greater than 2.20 ft/s. The velocity 2.20 ft/s is common to both equations.

It should be noted that the equations given are those of the rating table and not necessarily those of the actual rating. If a rating table already on file matches a rating within close tolerances, that table is selected in preference to preparing a new one. The tolerances are listed below:

Revolutions of rotor per second (R)	*Tolerance, in percent*
Less than 1.0	1.0
1.0 and greater	.5

Because of the rigid control in the manufacture of the Price meter, virtually identical meters are now being produced, and their rating equations tend to be identical. Therefore, the U.S. Geological Survey now feels no need to calibrate the meters individually. Instead, an average standard rating is established by calibrating a large number of meters that have been constructed to U.S. Geological Survey specifications, and that rating is then supplied with each meter. To insure that all meters are virtually identical, the dies and fixtures for the construction of Price meters are supplied to the manufacturer.

Price meters that have been first rated using a wading-rod suspension, and then rated using a cable suspension with U.S. Geological Survey Columbus-type weights and hangers, have not shown significant differences in rating. Therefore, no suspension coefficients are needed, and none should be used, if Columbus-type weights and hangers are properly used. Tests that compared meters were discussed on pages 89–90. In those tests Columbus-type weights were used with all meters. The close agreement of results for all meters indicate that no suspension coefficients are required when horizontal-axis current meters are used with Columbus-type weights.

The rating of the optical current meter is relatively simple. Its operation is based on precise mathematical principles, and, given an accurate tachometer, meter accuracy is dependent only on the configuration of the cam that oscillates the mirror. A master cam is used in the manufacture of the individual meter cams. The meter is rated by observation of a long endless belt driven at constant speed. That known belt speed is checked against the speed computed by multiplying the height of the meter above the belt by the tachometer reading. If the comparison of known and computed speeds shows a lack of agreement, the tachometer scaling is changed to bring about agreement.

SOUNDING EQUIPMENT

Sounding (determination of depth) is usually done mechanically, the equipment used being dependent on the type of measurement being made. Depth and position in the vertical are measured by a rigid rod or by use of a sounding weight suspended from a cable. The cable length is controlled either by a reel or by a handline. A sonic sounder is also available, but it is usually used in conjunction with a reel and a sounding weight.

Sounding equipment used by the U.S. Geological Survey is described in the following categories: wading rods, sounding weights, sounding reels, handlines, and sonic sounder.

WADING RODS

The two types of wading rods commonly used are the top-setting rod and the round rod. The top-setting rod is preferred because of the convenience in setting the meter at the proper depth and because the hydrographer can keep his hands dry in the process. The round rod can be used in making ice measurements as well as wading measurements and has the advantage that it can be disassembled to 1-ft (0.3-m) lengths for storing and transporting.

The top-setting wading rod has a 1/2-in (12.7-mm) hexagonal main rod for measuring depth and a 3/8-in (9.5-mm) diameter round rod for setting the position of the current meter (fig. 52).

The rod is placed in the stream so the base plate rests on the streambed, and the depth of water is read on the graduated main rod. When the setting rod is adjusted to read the depth of water, the meter is positioned automatically for the 0.6-depth method. (See p. 134.)The 0.6-depth setting might also be described as the 0.4-depth position measured up from the streambed. When the depth of water is divided by 2 and this new value is set, the meter will be at the 0.2 depth position measured up from the streambed. When the depth of water is multiplied by 2 and this value is set, the meter will be at the 0.8-depth position measured up from the streambed. These two positions represent the conventional 0.2- and 0.8-depth positions. (See p. 134.)

The round wading rod consists of a base plate, lower section, three or four intermediate sections, sliding support, and a rod end (not essential). The parts are assembled as shown in figure 53. The meter

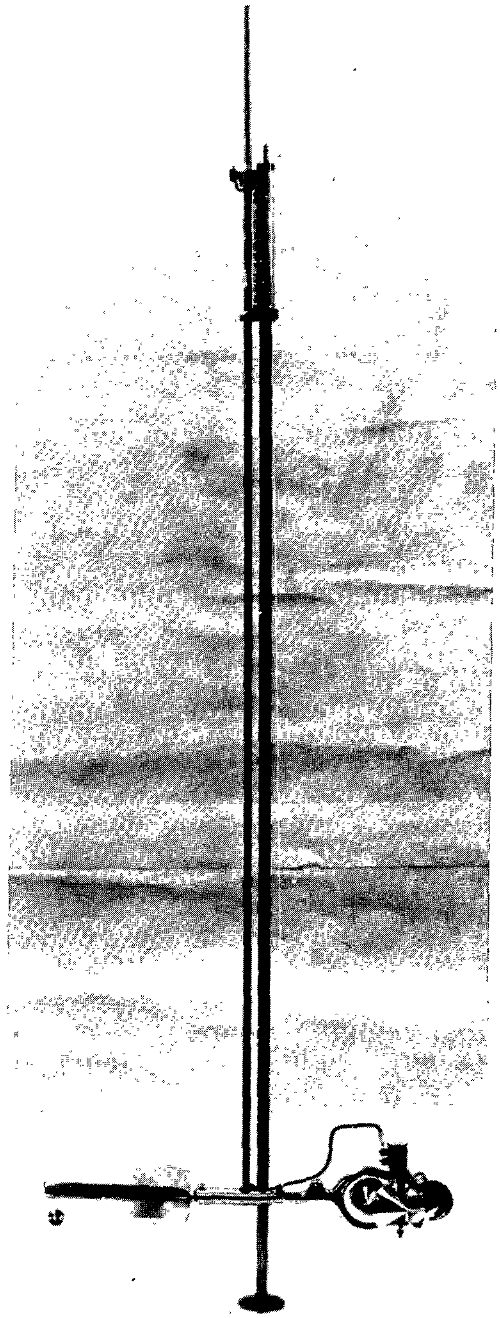


FIGURE 52.—Top-setting wading rod with meter attached.

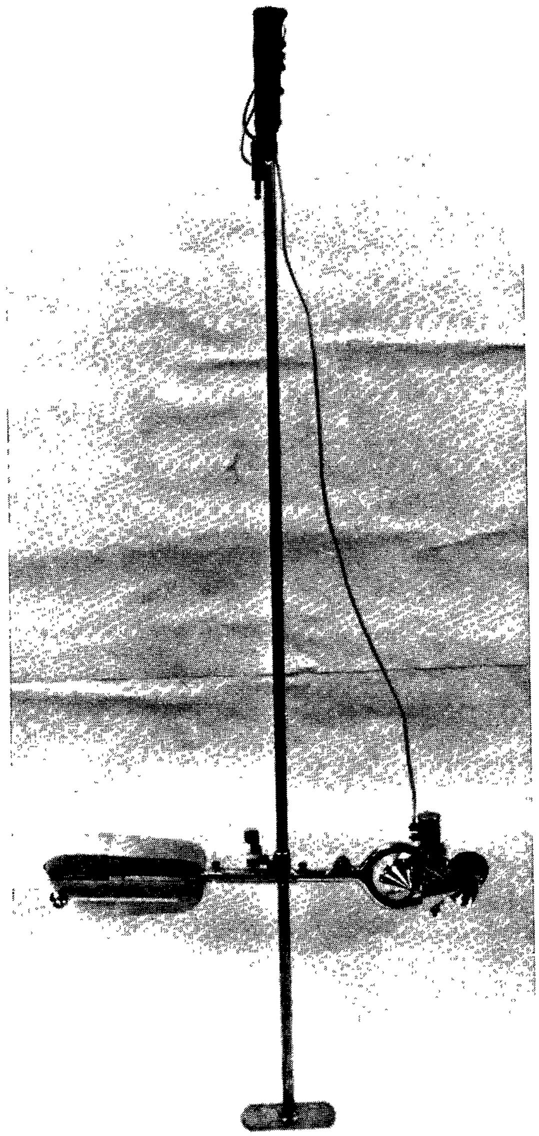


FIGURE 53.—Round wading rod with meter attached.

is mounted on the sliding support and is set at the desired position on the rod by sliding the support.

The round rod is also used in making ice measurements. Intermediate sections of the round rod are screwed together to make an ice

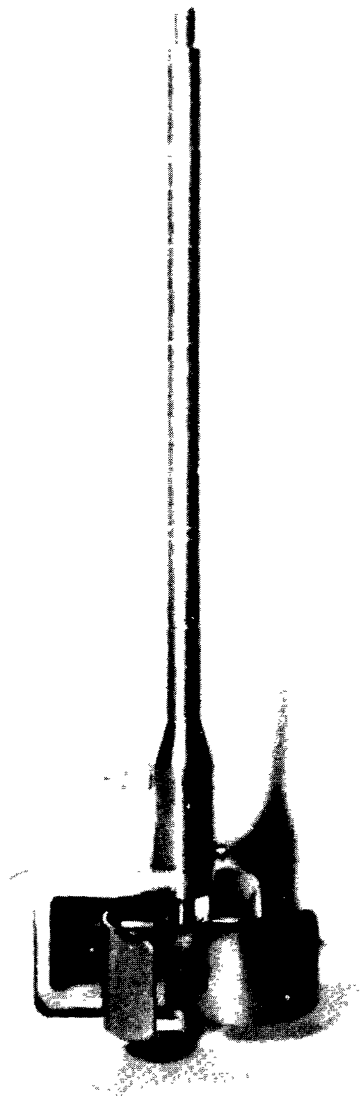


FIGURE 54.—Lower section of ice rod for use with vane ice meter.

rod of desired length (fig. 54). The most convenient length for an ice rod is about 3 ft (1 m) longer than the maximum depth of water to be found in a cross section. About 12 ft (4 m) is the maximum practical length for an ice rod; depths greater than 10 ft (3 m) are usually measured with a sounding weight and reel. The base plate, sliding support, and lower section are not used on an ice rod. Instead, a special lower section is screwed directly into the top of the contact chamber of the vane ice meter. (See fig. 54.) If a Price meter is used under ice cover, another special lower section is used to hold the meter by means of the hanger screw. (See fig. 55.) All lower sections for ice rods are now made so that the center of the vanes or cups is at the 0-ft point on the rod.

SOUNDING WEIGHTS AND ACCESSORIES

If a stream is too deep or too swift to wade, the current meter is suspended in the water by cable from a boat, bridge, or cableway. A sounding weight is suspended below the current meter to keep it

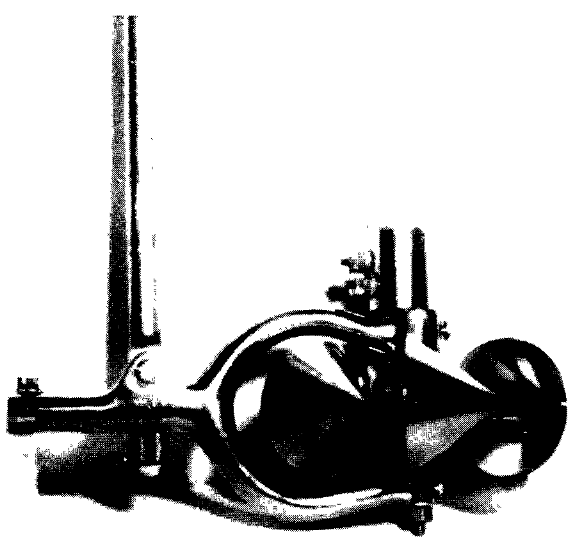


FIGURE 55.—Lower section of ice rod for use with Price meter.

stationary in the water. The weight also prevents damage to the meter when the assembly is lowered to the streambed.

The sounding weights now used in the U.S.A. are the Columbus weights, commonly called the C type. (See fig. 56.) The weights are streamlined to offer minimum resistance to flowing water. Each weight has a vertical slot and a drilled horizontal hole to accommodate a weight hanger and securing pin.

The weight hanger (fig. 57) is attached to the end of the sounding line by a connector. The current meter is attached beneath the connector, and the sounding weight is attached to the lower end of the hanger by means of the hanger pin.

In addition to the weights shown in figure 56, weights of 150, 200 and 300 lb (68, 91, and 136 kg) are used for measuring the discharge of deep, swift rivers. The sounding-weight hangers shown in figure 57 are designed to accommodate the weights of the various sizes. The height of the meter rotor above the bottom of the sounding weight must be considered in calculations to position the meter for velocity observations at various percentages of the stream depth.

SOUNDING REELS

A sounding reel has a drum for winding the sounding cable, a crank and ratchet assembly for raising and lowering the weight or holding it in any desired position, and a depth indicator. The U.S. Geological Survey has five types or sizes of sounding reel in common use, the choice of reel being dependent on the depth of water to be measured and on the weight required for sounding. The lightest of the reels, known as the Canfield reel (fig. 58), can be used with either single- or two-conductor cable; the other four reels use two-conductor cable, whose diameter ranges from 0.084 in to 0.125 in (2.13 to 3.18 mm),

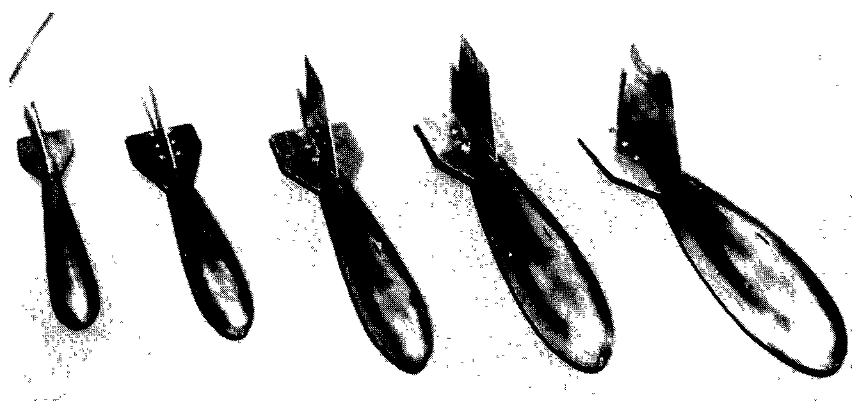


FIGURE 56.—Columbus 15-, 30-, 50-, 75-, and 100-lb sounding weights.

depending on the weight to be handled. The three smaller reels have a hand crank for raising and lowering the meter and weight (fig. 58);

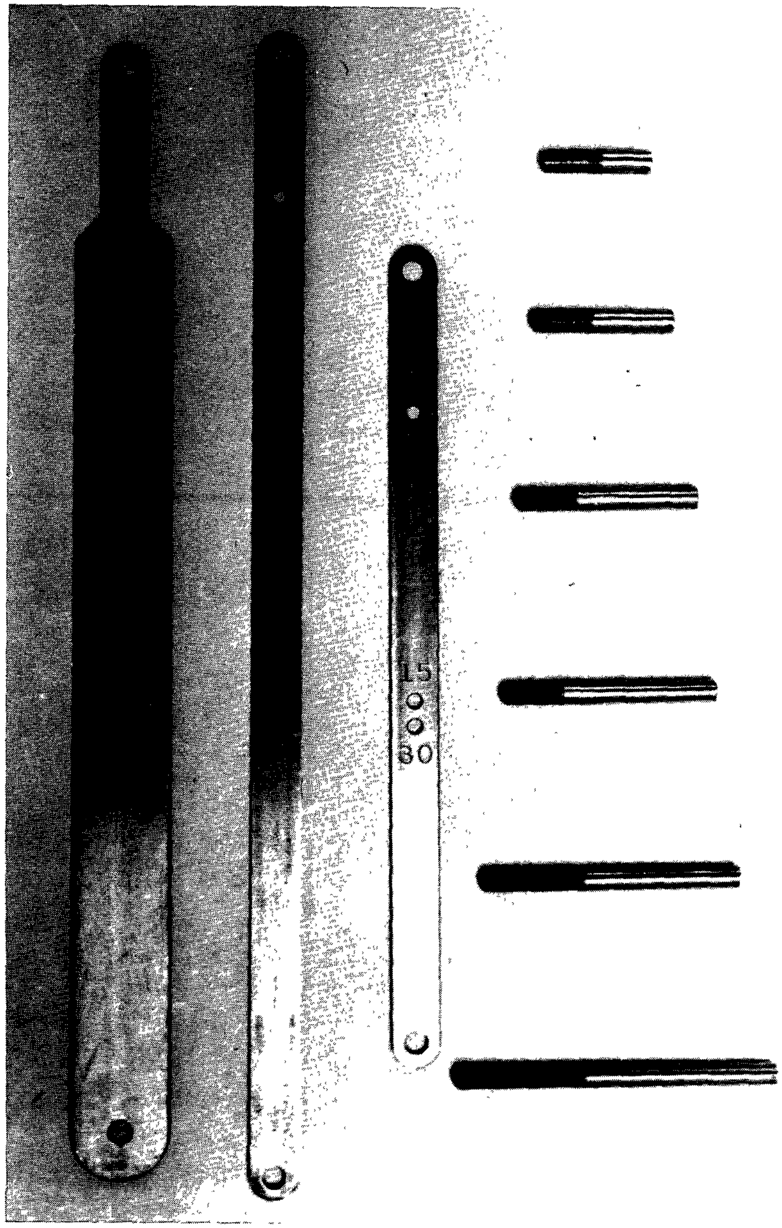


FIGURE 57.—Sounding-weight hangers and hanger pins.

the largest of the five reels is operated by a battery-powered unit but has a handcrank for emergency use; the second largest reel (fig. 59) may be operated either by a hand crank or a power unit. Specially designed connectors are used to join the end of the reel cable to the sounding-weight hanger.

The two smaller reels (Canfield and A-pack reels) are equipped with counters for indicating depth (fig. 58); the three larger reels are equipped with computing depth indicators (figs. 59 and 60). On the computing depth indicator, depth is indicated by a pointer. Tens of feet are read on a numbered dial through an aperture near the top of the main dial. The main dial also has a graduated spiral to indicate directly the 0.8-depth position (p. 134) for depths up to 30 ft (9.15 m).

HANDLINES

When discharge measurements that are to be made from a bridge require light sounding weights—15 or 30 lb (6.8 or 13.6 kg)—the weight and meter are often suspended on a handline (figs. 61 and 62). Handlines can also be used from cable cars, but they seldom are because a sounding reel mounted on the cable car is much more convenient to use.

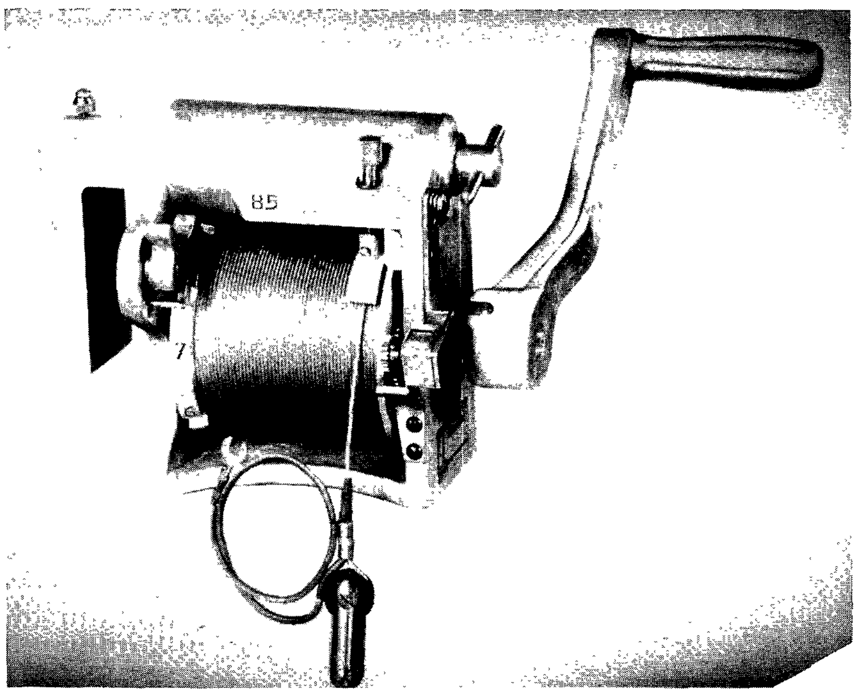


FIGURE 58.—Canfield reel.

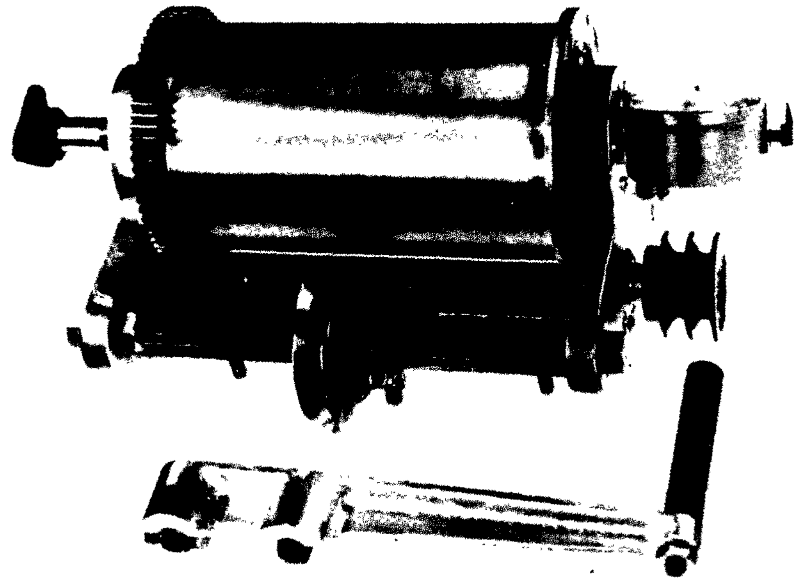


FIGURE 59.—B–56 reel.

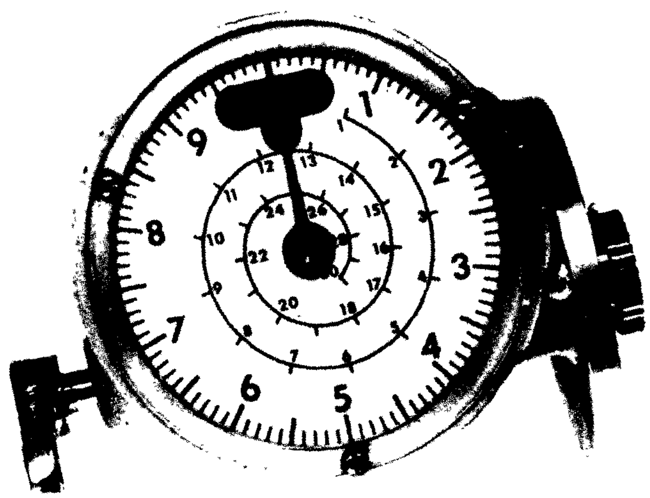


FIGURE 60.—Computing depth indicator.

The handline is made up of two separate cables that are electrically connected at a reel (fig. 63). The upper or hand cable is that part of the handline that is used above the water surface. It is a heavy-duty two-conductor electric cable, whose thick rubber protective covering makes the cable comfortable to handle. At its upper end is a connection for the headphone. The lower or sounding cable is a light reverse-lay steel cable with an insulated core. A connector joins the lower end of the sounding cable to the hanger that is used as a mount for the current meter and sounding weight. Sounding cable in excess of the length needed to sound the stream being measured is wound on

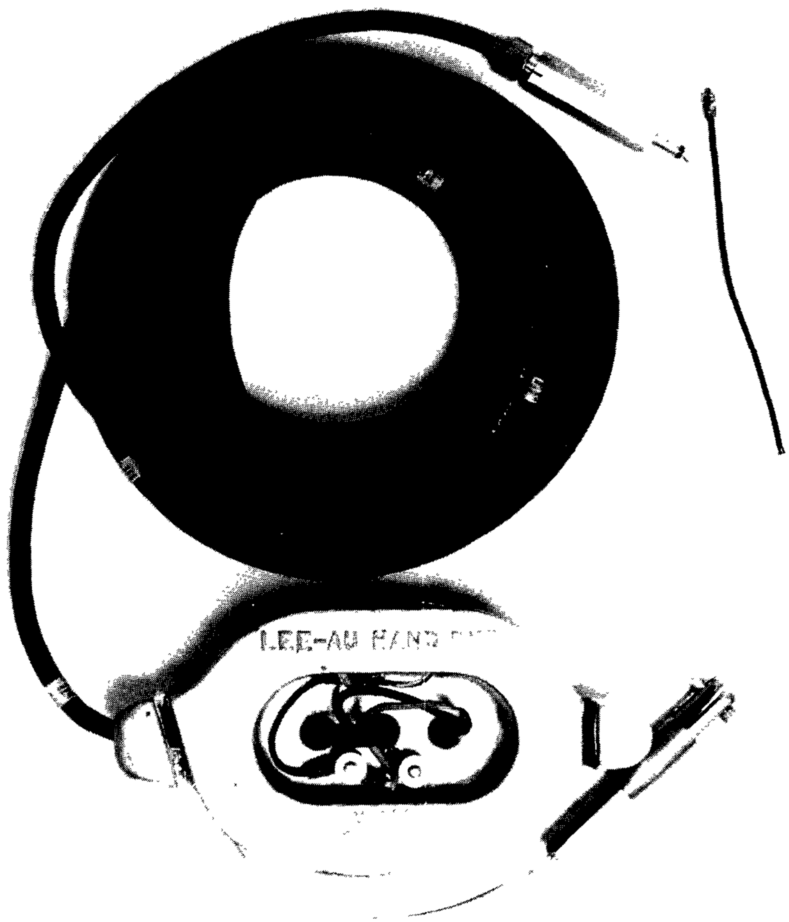


FIGURE 61.—Handline.

the reel. The sounding cable is tagged at convenient intervals with streamers of different colored binding tapes, each colored streamer being a known distance above the current-meter rotor. The use of these tags in determining depth is described on page 150.

The advantages of the handline are ease in assembling the equipment for a discharge measurement and relative ease in making discharge measurements from certain types of bridges, particularly truss bridges that do not have cantilevered sidewalks. The disadvantages of the handline are a lesser degree of accuracy in depth determination than that obtained with a sounding reel, more physical exertion is required in making the discharge measurement, and the handline can seldom be used for high-water measurements of large

FIGURE 62.—Handline in use from a bridge.

streams because of the heavy sounding weights needed for such measurements.

SONIC SOUNDER

A commercial, compact, portable sonic sounder has been adopted by the U.S. Geological Survey to measure stream depth. (See figs. 64 and 65.)

The sounder is powered by either a 6- or 12-volt storage battery and will operate continuously for 10 hr on a single battery charge. Three recording speeds are available, 36, 90, or 180 in (0.91, 2.29,4.57 m) per hr. Four operating ranges, 0–60, 60–120, 120–180, and 180–240 ft (0–18.3, 18.3–36.6, 36.6–54.9, and 54.9–73.2 m) allow intervals of 60 ft (18.3 m) of depth to be recorded. The sounder is portable, weighing only 46 lb (20.9 kg). The transducer has a narrow beam angle of 6° which minimizes errors on inclined streambeds and allows the hydrographer to work close to piers or other obstructions.

In swift debris-laden streams measurements can be made with this equipment without lowering the meter and weight to the streambed. As soon as the weight is in the water, the depth will be recorded. The meter can then be set at the 0.2 depth or just below the water surface for a velocity observation. The observed velocity can be converted to mean velocity in the vertical by applying an appropriate coefficient. (See p. 135–137.)

FIGURE 63.—Handline reels; Lee-Au (top) and Morgan (bottom).

Temperature change affects the sound-propagation velocity, but error from that source is limited to about ±2 percent in fresh water. That error can be eliminated completely by adjusting the sounder to

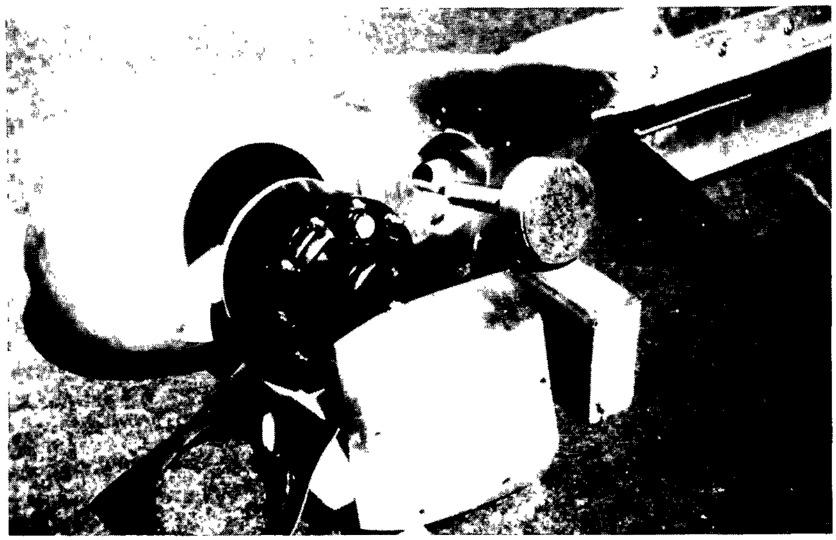


FIGURE 64.—Sounding weight with compass and sonic transducer ready for assembly.

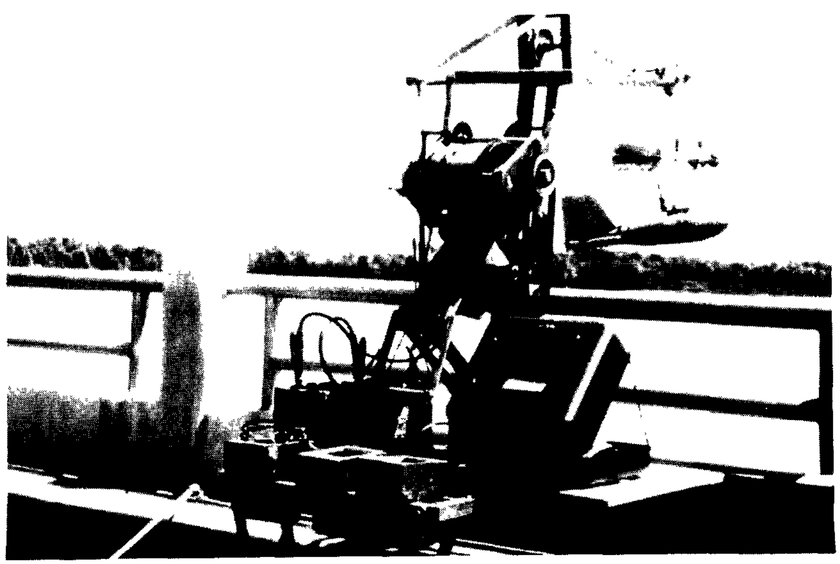


FIGURE 65.—Sonic measuring assembly.

read correctly at an appropriate average depth determined by other means.

WIDTH-MEASURING EQUIPMENT

The distance to any point in a cross section is measured from an initial point on the bank. Cableways and bridges used regularly for making discharge measurements are commonly marked at 2-, 5-, 10-, or 20-ft (0.61-, 1.52-, 3.05-, or 6.10-m) intervals by paint marks. Distance between markings is estimated, or measured with a rule or pocket tape.

For measurements made by wading, from boats, or from unmarked bridges, steel or metallic tapes or tag lines are used. Tag lines are made of 1/32-, 1/16-, 3/32-, or 1/8-in (0.79-, 1.59-, 2.38-, or 3.18-mm)-diameter galvanized steel aircraft cord having solder beads at measured intervals to indicate distances. The standard arrangement of solder beads or tags used by the U.S. Geological Survey is as follows:

- one tag every 2 ft for the first 50 ft of tag line;
- one tag every 5 ft for stations between 50 and 150 ft on the tag line;
- one tag every 10 ft for stations between 150 ft and the end of the tag line.

For identifying the stationing of the tags, an additional tag (total of two tags) is used at stations 0, 10, 20, 30, 40, 50, 150, 250, 350, and 450 ft. Two additional tags (total of three tags) are used at stations 100, 200, 300, 400, and 500 ft.

The standard lengths of tag line are 300, 400 and 500 ft (91.4, 122, and 152m), but other sizes are available.

Three types of tag-line reels in use are Lee-Au, Pakron, and Columbus type A (fig. 66). Larger reels designed particularly for use with boats are described on page 120. It is practically impossible to string a tag line for discharge measurements from a boat when the width of the stream is greater than 2,500 ft (750 m). The methods used to determine width at such sites are described on pages 156–157.

EQUIPMENT ASSEMBLIES

Special equipment is necessary for each type of current-meter measurement. The meters, weights, and reels used have already been described. The additional equipment needed is described in this section.

The special equipment assemblies have been divided into five basic groups: cableway, bridge, boat, ice, and velocity-azimuth-depth assembly (VADA) equipment.

CABLEWAY EQUIPMENT

The cableway provides a track for the operation of a cable car from which the hydrographer makes a current-meter measurement. Cable cars also support the sounding reel and other necessary equipment. Both sitdown and standup types of cable cars are used in stream gaging. (See figs. 67 and 68). Pierce (1947) describes plans for both types. Normally, sitdown cars are used for cableway spans less than 400 ft (122 m) and for those spans where the lighter sounding weights are used. The standup car is used on the longer spans and where heavy sounding weights are needed.

The cars are moved from one point to another on the cableway by means of cable-car pullers. (See fig. 69.) The standard car puller is a cast aluminum piece with a snub attached to act as a brake. The snub, usually four-ply belting, is placed between one of the car sheaves and the cable to prevent movement of the car along the cable. A second-type puller is used when a car is equipped with a follower brake (fig. 69). A third type, the Colorado River cable-car puller, is the same in principle as the puller used on cars equipped with a follower brake.

Power-operated cable cars are available for extremely long spans or other special situations. (See fig. 70.)

Sitdown cable cars have a variety of means of supporting the sounding reel. A-pack and Canfield reels are designed to clamp on the side of the car (fig. 71). Permanent or portable reel seats are attached to the cable cars for larger reels. (See figs. 67 and 72.)

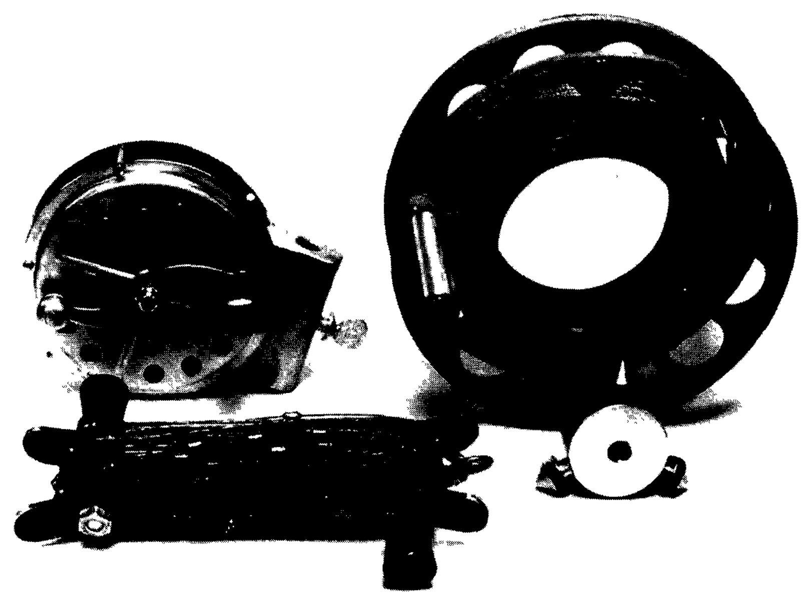


FIGURE 66 —Tag-line reels: top left, Pakron; top right, Lee-Au with removable hub in front; bottom, Columbus type A.

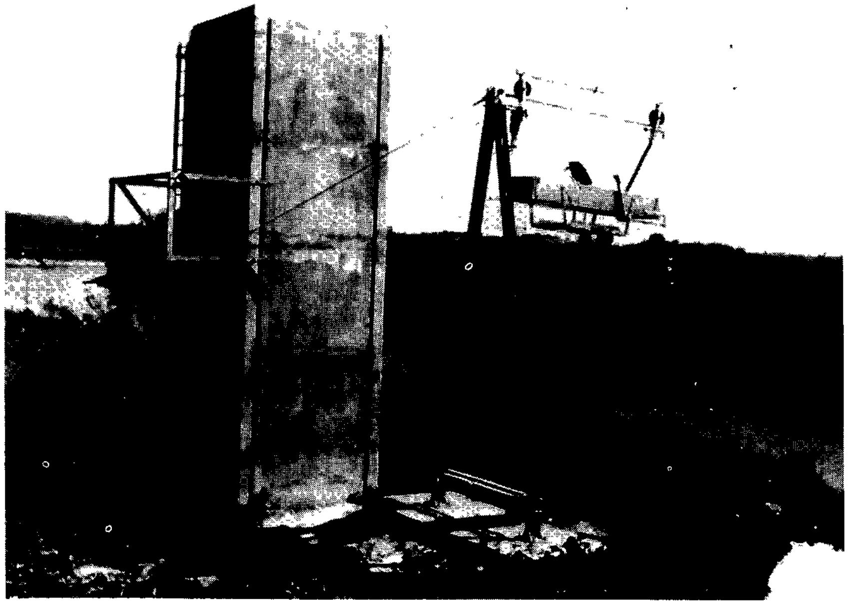


FIGURE 67.—Sitdown cable car.

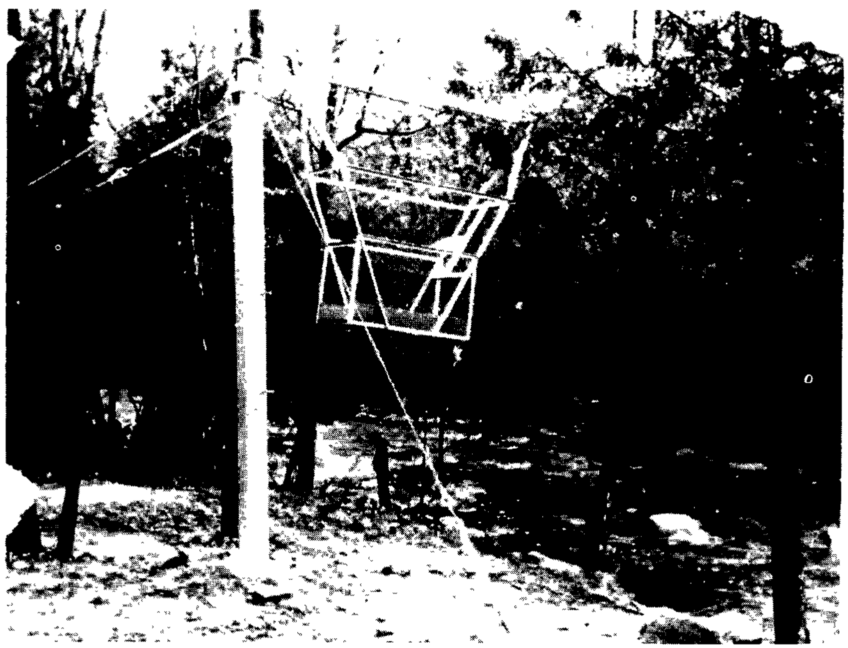


FIGURE 68.—Standup cable car.

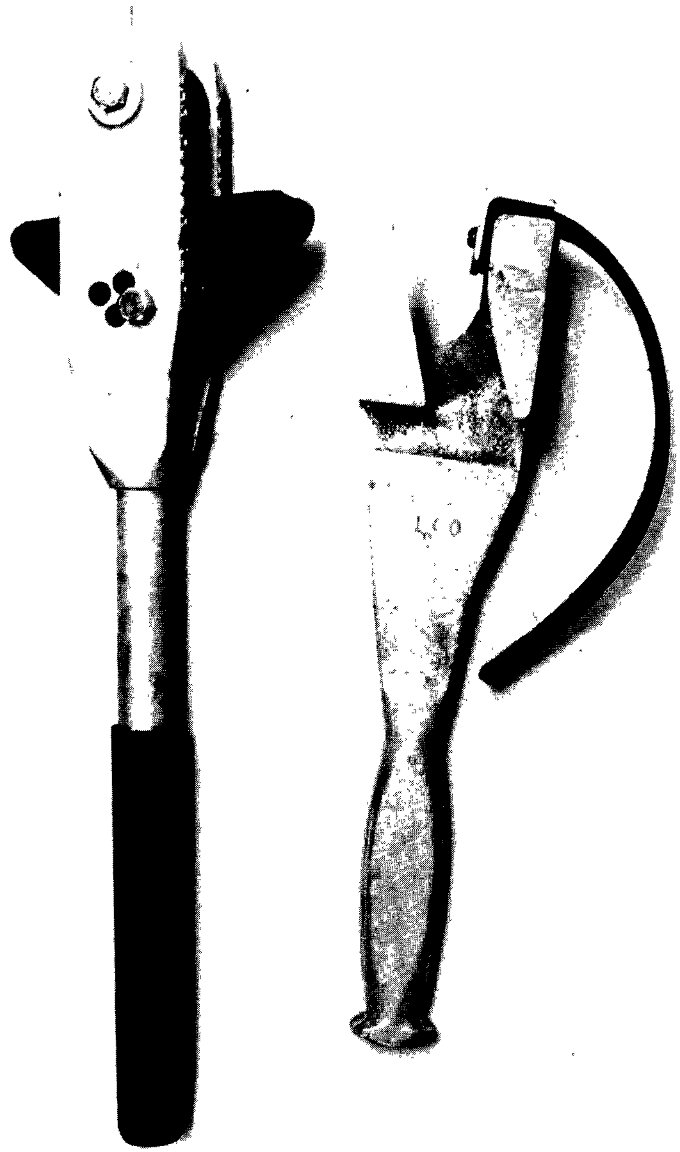


FIGURE 69.—Cable-car puller for follower-brake cable cars, left; for standard cars, right.

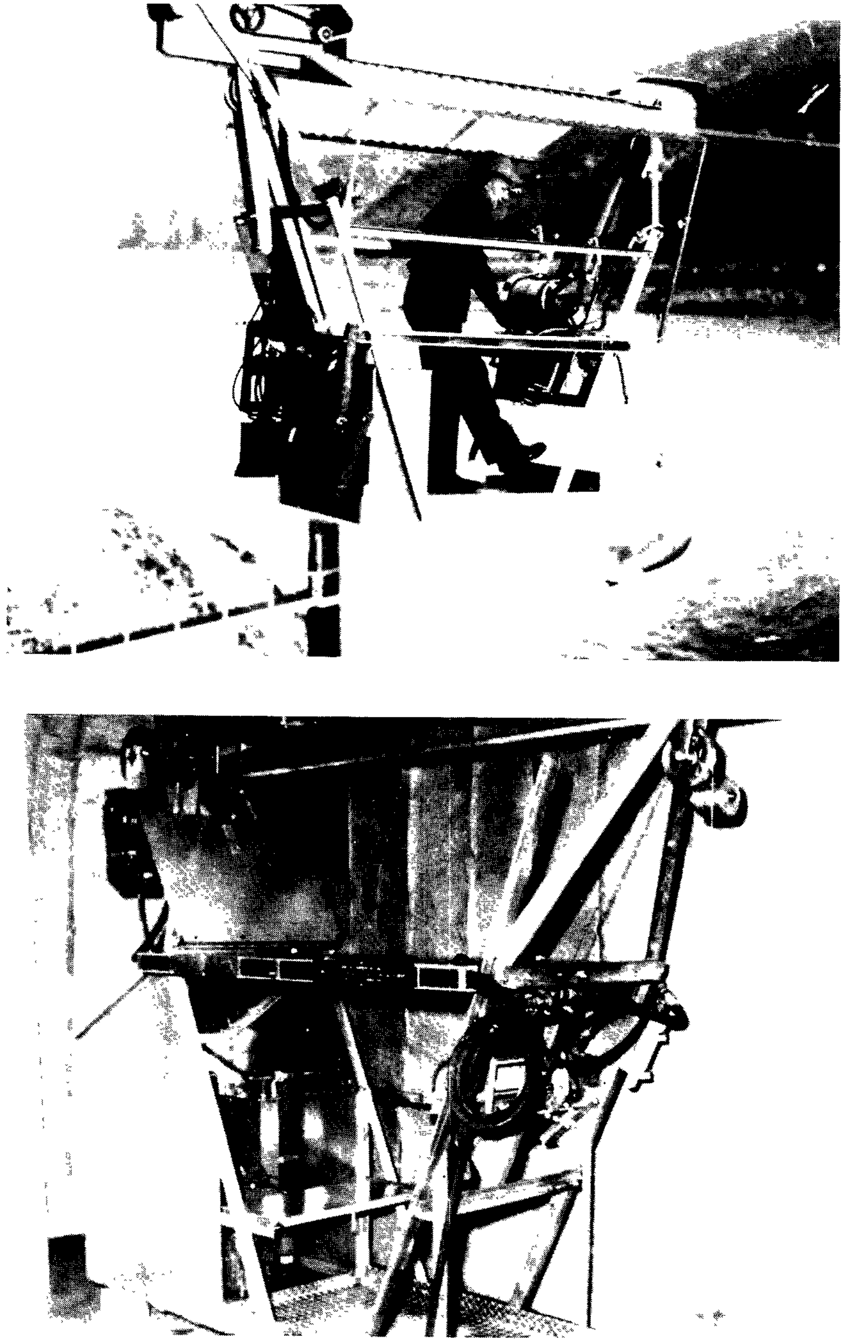


FIGURE 70.—Power-operated cable cars. (*A*) battery-powered car; (*B*) gasoline-powered car.

Standup cable cars have reel seats attached to the structural members of the car (fig. 68). A sheave attached to the structural members carries the sounding line so that the sounding weight and current meter will clear the bottom of the car. Power reels can also be used on standup cable cars.

Carrier cableways are sometimes used on the smaller streams for measuring discharge as well as for sediment sampling. They are used in areas where it is impossible to wade, where no bridges are avail-

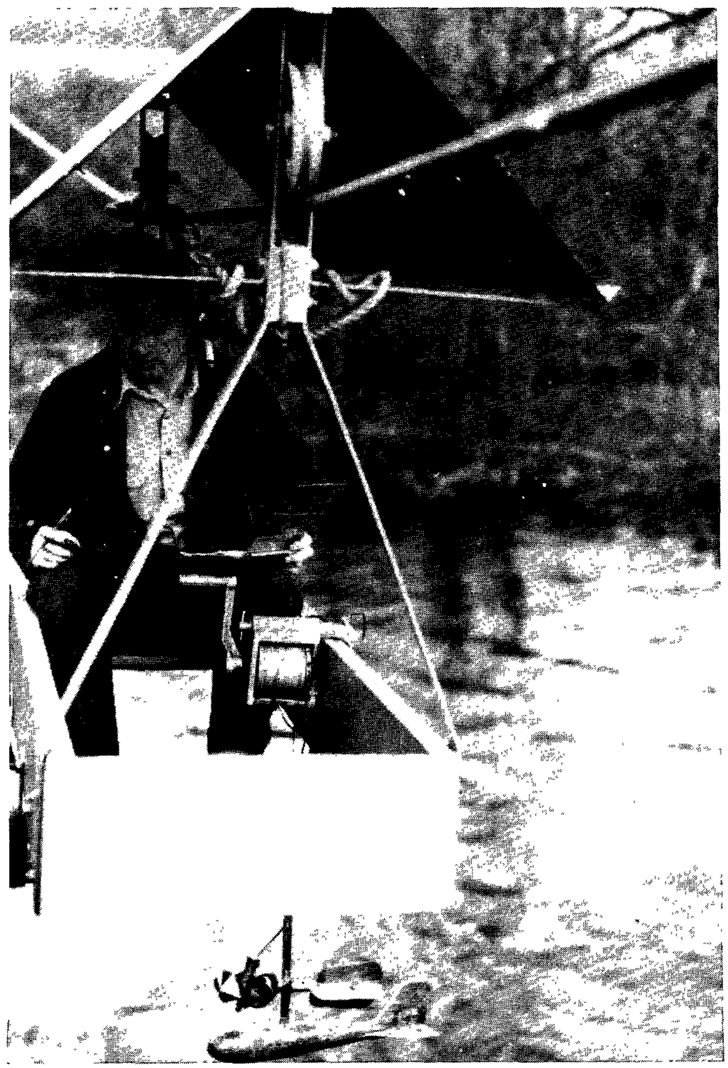


FIGURE 71.—Sitdown cable car with Canfield reel clamped to side of car.

able, and where it has been impractical to build a complete cableway. The assembly is operated from the shore (fig. 73). Carrier cables are

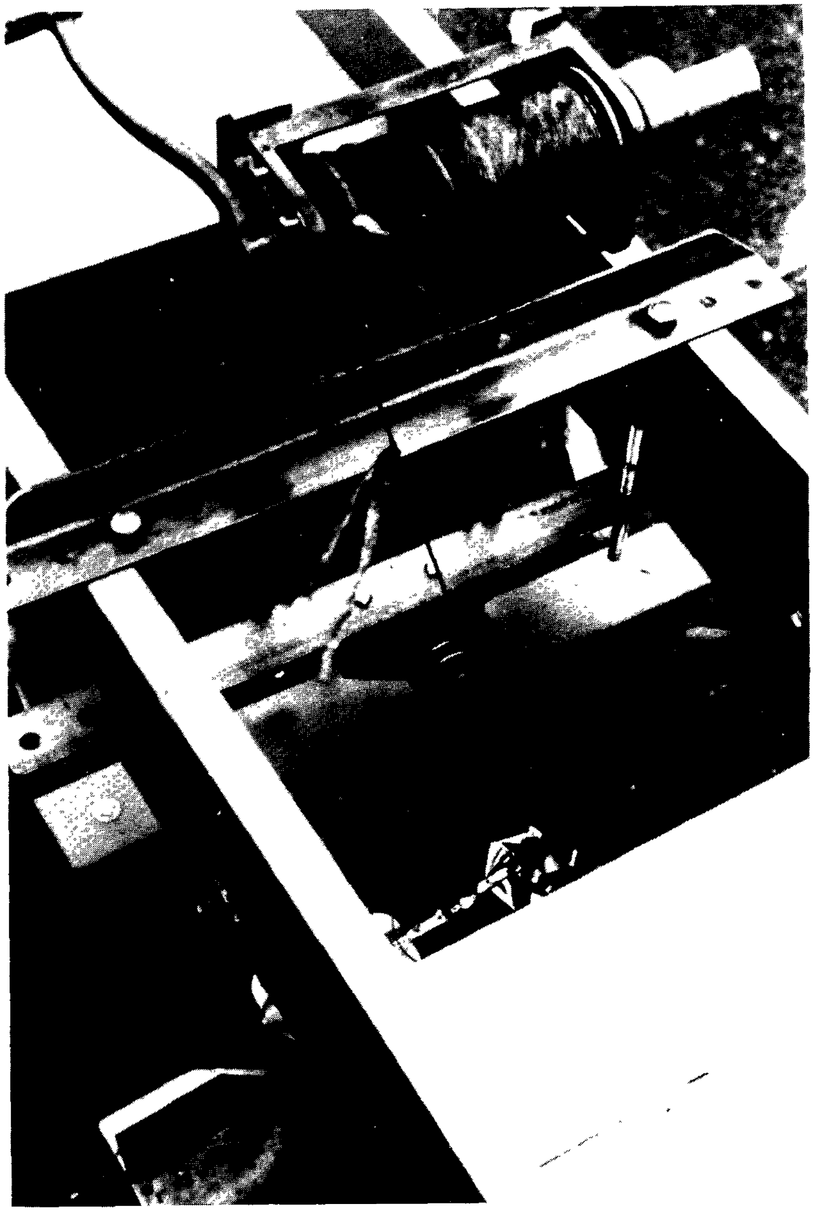


FIGURE 72.—Portable reel seat on sitdown-type cable car. (Note tags on sounding cable.)

more widely used in Europe, particularly in the United Kingdom, than they are in the U.S.A.

BRIDGE EQUIPMENT

When one measures from a bridge, the meter and sounding weight can be supported by a handline, or by a sounding reel mounted on a crane, or by a bridge board. The handline has been described on pages 104–108.

Two types of hand-operated portable cranes are the type A (figs. 74 and 75) for use with weights up to 100 lb (45.4 kg) and the type E for heavier weights.

All cranes are designed so that the superstructure can be tilted

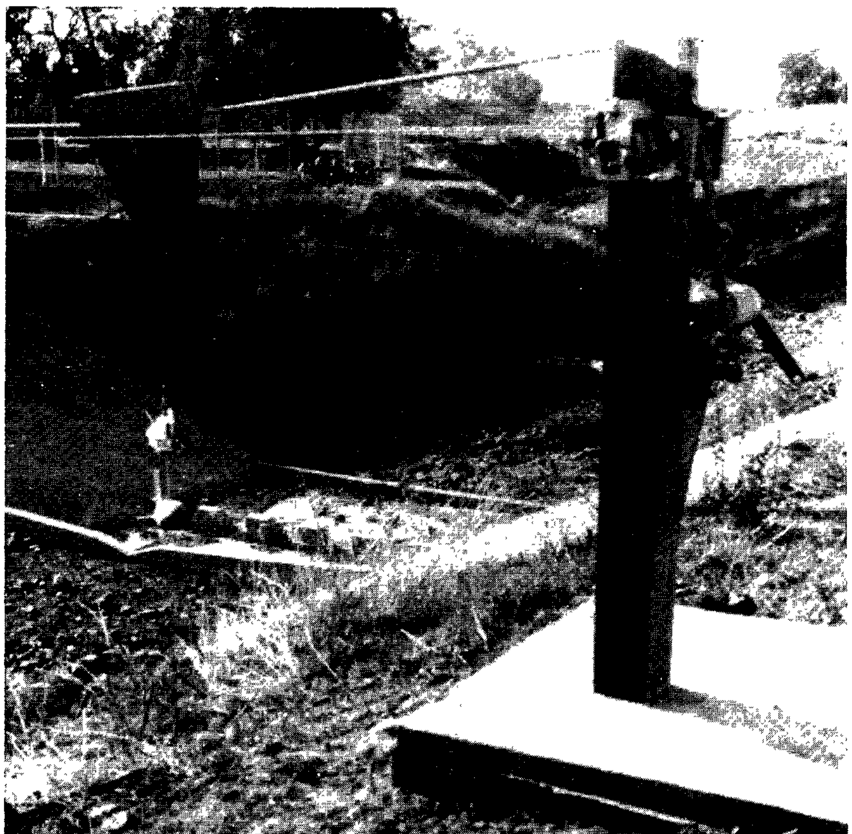


FIGURE 73.—Carrier (bank-operated) cableway. Two reels are used; one moves the meter assembly laterally, and the other moves the current meter vertically.

forward over the bridge rail far enough for the meter and weight to clear most rails. Where bridge members obstruct the movement of the crane from one vertical to the next, the weight and meter can be brought up, and the superstructure can be tilted back to pass by the obstruction. (See figs. 74 and 75.)

Cast-iron counterweights weighing 60 lb (27.2 kg) each are used with four-wheel-base cranes. (See fig. 75.) The number of such weights needed depends upon the size of the sounding weight being supported, the depth and velocity of the stream, and the amount of debris being carried by the stream.

A protractor is used on cranes to measure the angle the sounding line makes with the vertical when the weight and meter are dragged downstream by the water. The protractor is a graduated circle clamped to an aluminum plate. A plastic tube, partly filled with colored antifreeze, fitted in a groove between the graduated circle and

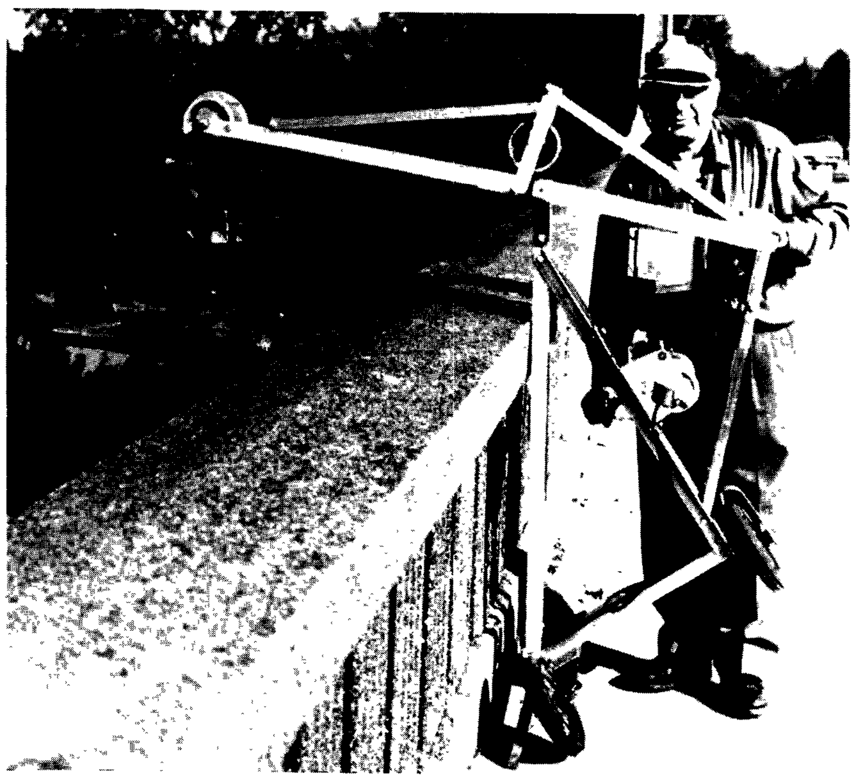


FIGURE 74.—Type-A crane with three-wheel base. (During soundings and velocity observations the crane is tilted against the bridge rail. An A-55 reel is mounted on the crane.)

the plate, is the protractor index. A stainless-steel rod is attached to the lower end of the plate to ride against the downstream side of the sounding cable. The protractor will measure vertical angles from −25° to +90°. The cranes in figures 74 and 75 are equipped with protractors at the outer end of the boom.

Bridge boards may be used with an A-pack or A-55 sounding reel and with weights up to 50 lb (22.7 kg). A bridge board is usually a plank about 6 to 8 ft (1.8 to 2.4 m) long with a sheave at one end over which the meter cable passes and a reel seat near the other end. The board is placed on the bridge rail so that the force exerted by the sounding weight suspended from the reel cable is counterbalanced by the weight of the sounding reel (fig. 76). The bridge board may be hinged near the middle to allow one end to be placed on the sidewalk or roadway.

Many special arrangements for measuring from bridges have been

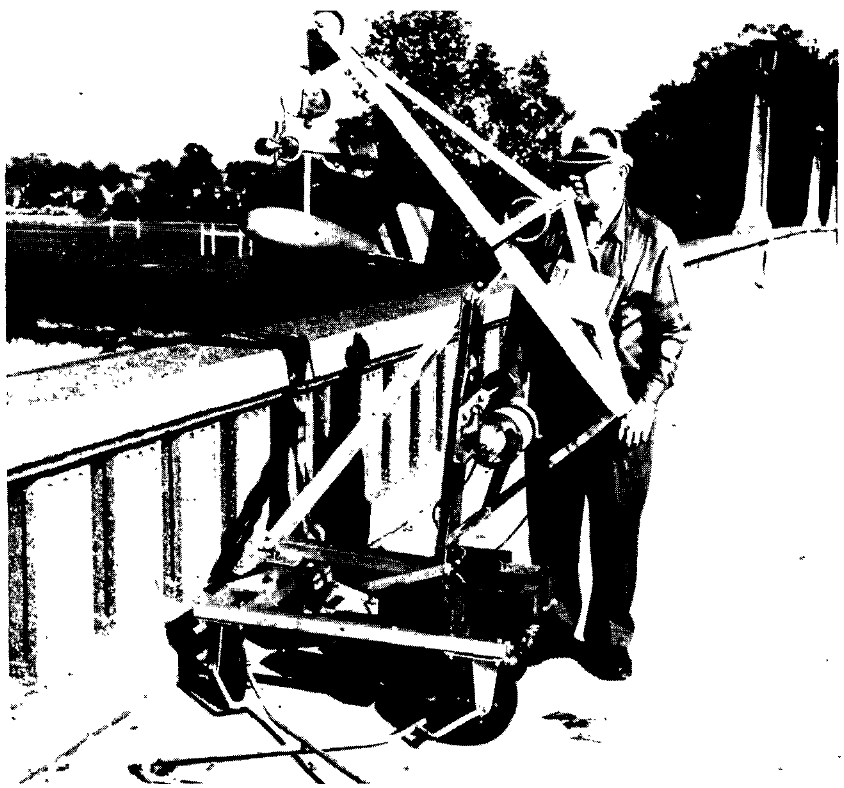


FIGURE 75.—Type-A crane with four-wheel base with boom in retracted position. (A B-56 reel is mounted on crane. Note fluid protractor on outer end of boom.)

devised to suit particular purposes. Truck-mounted cranes are often used for measuring from bridges over the larger rivers. (See fig. 77.) Monorail stream-gaging cars have been developed for large rivers. The car is suspended from the substructure of the bridge by means of an I-beam. The car is attached to the I-beam track by trolleys and is propelled by a forklift motor having a wheel in contact with the bottom of the beam. The drive mechanism and sounding equipment are powered by a 430-ampere-hour, 450-lb (204-kg), 12-volt battery.

BOAT EQUIPMENT

Measurements made from boats require special equipment not used for other types of measurement. Extra-large tag-line reels are used on wide streams. Three different tag-line reels are used by the U.S. Geological Survey for boat measurements:

1. A heavy duty horizontal-axis reel without a brake and with a capacity of 2,000 ft (610 m) of ⅛-in (3.18-mm)-diameter cable (fig. 78).

FIGURE 76.—Bridge board in use.

2. A heavy-duty horizontal-axis reel with a brake and with a capacity of 3,000 ft (914 m) of ⅛-in-diameter cable (fig. 79).
3. A vertical-axis reel without a brake and with a capacity of 800 ft (244 m) of ⅛-in-diameter cable (fig. 80).

A utility line of 30 ft (9 m) of 3/32-in (2.38-mm)-diameter cable with a harness snap at one end and a pelican hook at the other is connected to the free end of the boat tag line and fastened around a tree or post, thereby preventing damage to the tag line. After the tag line is strung across the stream, the reel is usually bolted to a plank and chained to a tree. The tag line has station markers at appropriate intervals.

Special equipment is necessary to suspend the meter from the boat when the depths are such that a rod suspension cannot be used. A crosspiece reaching across the boat is clamped to the sides of the boat and a boom attached to the center of the cross piece extends out over the bow. (See fig. 81.) The crosspiece is equipped with a guide sheave and clamp arrangement at each end to attach the boat to the tag line and make it possible to slide the boat along the tag line from one station to the next. A small rope can be attached to these clamps so

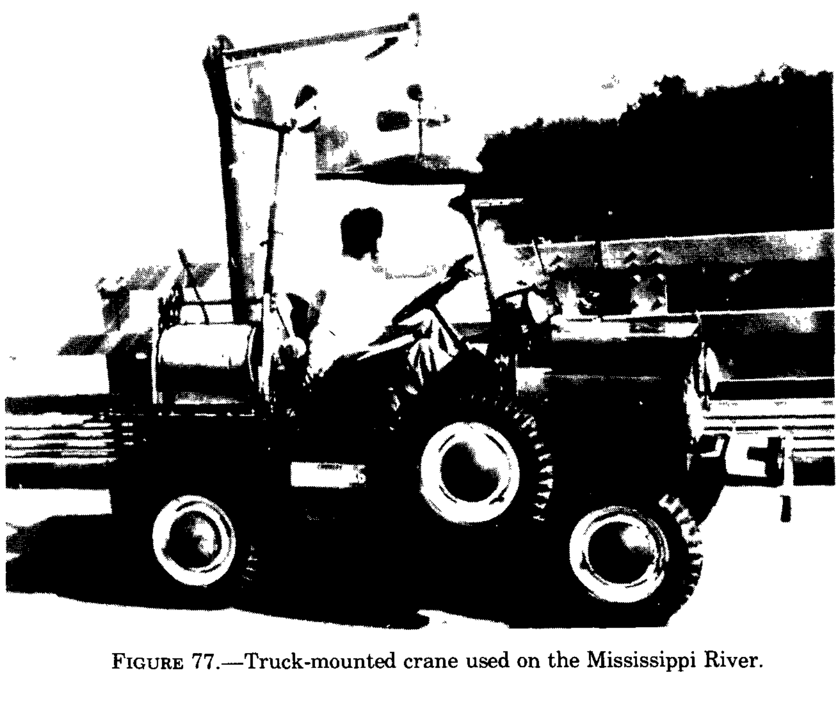


FIGURE 77.—Truck-mounted crane used on the Mississippi River.

that in an emergency a tug on the rope will release the boat from the tag line. The crosspiece also has a clamp that prevents lateral movement of the boat along the tag line when readings are being made. The boom consists of two structural aluminum channels, one telescoped within the other to permit adjustments in length. The boom is equipped with a reel plate on one end; on the other end is a sheave over which the meter cable passes. The sheave end of the boom is designed so that by adding a cable clip to the sounding cable, a short distance above the connector, the sheave end of the boom can be retracted when the meter is to be raised out of the water. The raised

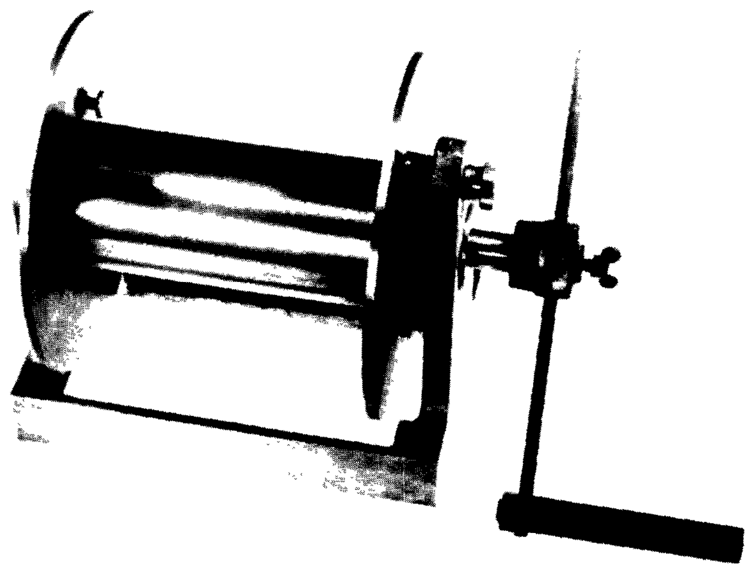


FIGURE 78.—Horizontal-axis boat tag-line reel without a brake.

meter is easy to clean and is in a convenient position when not being operated.

All sounding reels fit the boat boom except the A-pack and the Canfield reels, which can be made to fit by drilling additional holes in the reel plate on the boom.

In addition to the equipment already mentioned, the following items are needed when making boat measurements:

1. A stable boat big enough to support the hydrographers and equipment.
2. A motor that can move the boat with ease against the maximum current in the stream.
3. A pair of oars for standby use.
4. A life preserver for each hydrographer.
5. A bailing device.

Figure 82 shows the equipment assembled in a boat.

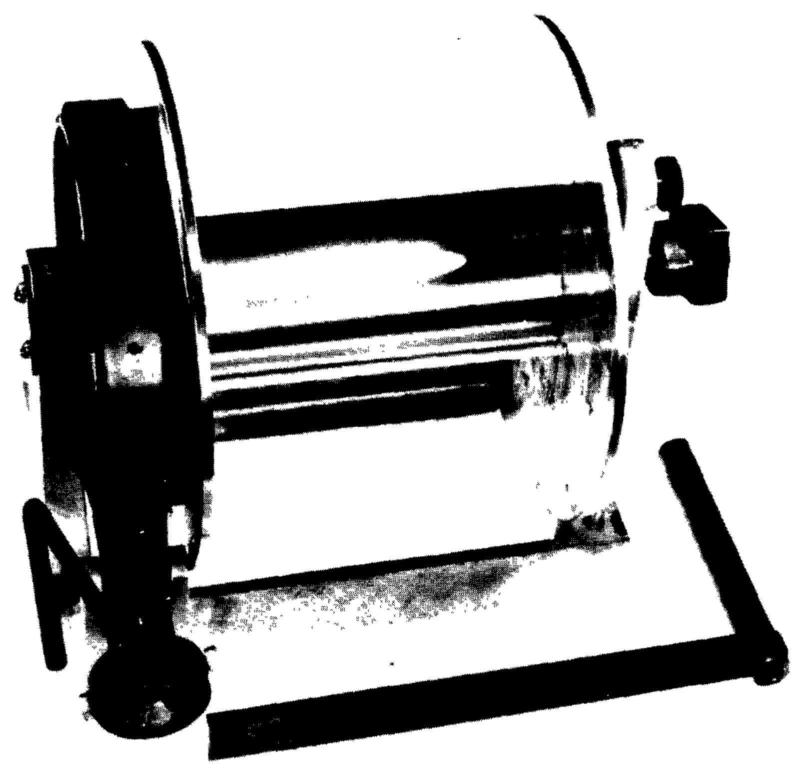


FIGURE 79.—Horizontal-axis boat tag-line reel with a brake.

ICE EQUIPMENT

Current-meter measurements made under ice cover require special equipment for cutting holes in the ice through which to suspend the meter.

Cutting holes through the ice on streams to make discharge measurements has long been a laborious and time-consuming job. The development of power ice drills, however, has eliminated many of the difficulties and has reduced considerably the time required to cut the holes. Holes are often cut with a commercial ice drill that cuts a 6-in (0.15-m) diameter hole (fig. 83). The drill weighs about 30 lb (13.6

FIGURE 80.—Vertical-axis boat tag-line reel (when in use the axis of the reel is vertical).

kg) and under good conditions will cut through 2 ft (0.6 m) of ice in about a minute.

Where it is impractical to use the ice drill, ice chisels are used to cut the holes. Ice chisels used are usually 4 or 4½ ft (about 1.3 m) long and weigh about 12 lb (5.5 kg). The ice chisel is used when first crossing an ice-covered stream to determine whether the ice is strong enough to support the hydrographer. If a solid blow of the chisel blade does not penetrate the ice, it is safe to walk on the ice, providing the ice is in contact with the water.

Some hydrographers supplement the ice chisel with a Swedish ice auger. The cutting blade of this auger is a spadelike tool of hardened steel that cuts a hole 6–8 in (0.15–0.20 m) in diameter. The auger is operated by turning a bracelike arrangement on top of the shaft.

When holes are cut in the ice the water, which is usually under pressure because of the weight of the ice, rises in the hole. To determine the effective depth of the stream (p. 153–154), ice-measuring sticks are used to measure the distance from the water surface to the

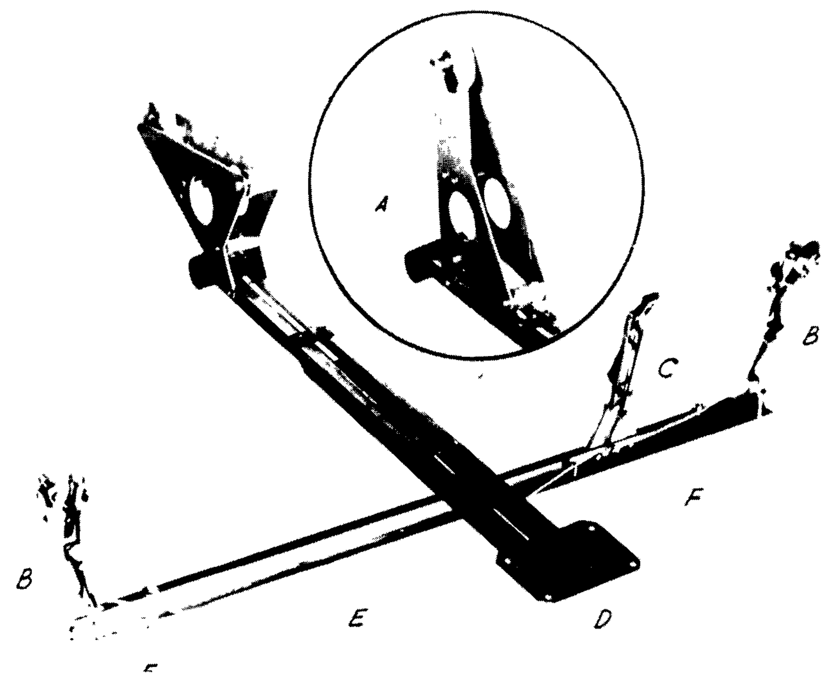


FIGURE 81.—Boom and crosspiece for use on boats. (*A*, retractable end of boom; *B*, guide sheave and clamp for attaching to tag line; *C*, clamp to prevent movement of the boat along the tag line; *D*, plate to accomodate reel; *E*, rope to release clamps (*B*) to free boat from tag line; and *F*, clamps to attach crosspiece to boat.)

bottom of the ice. This is done with a bar about 4 ft long (1.2 m), made of strap steel or wood, which is graduated in feet and tenths of a foot and has an L-shaped projection at the lower end. The horizontal part of the L is held on the underside of the ice, and the depth to that point

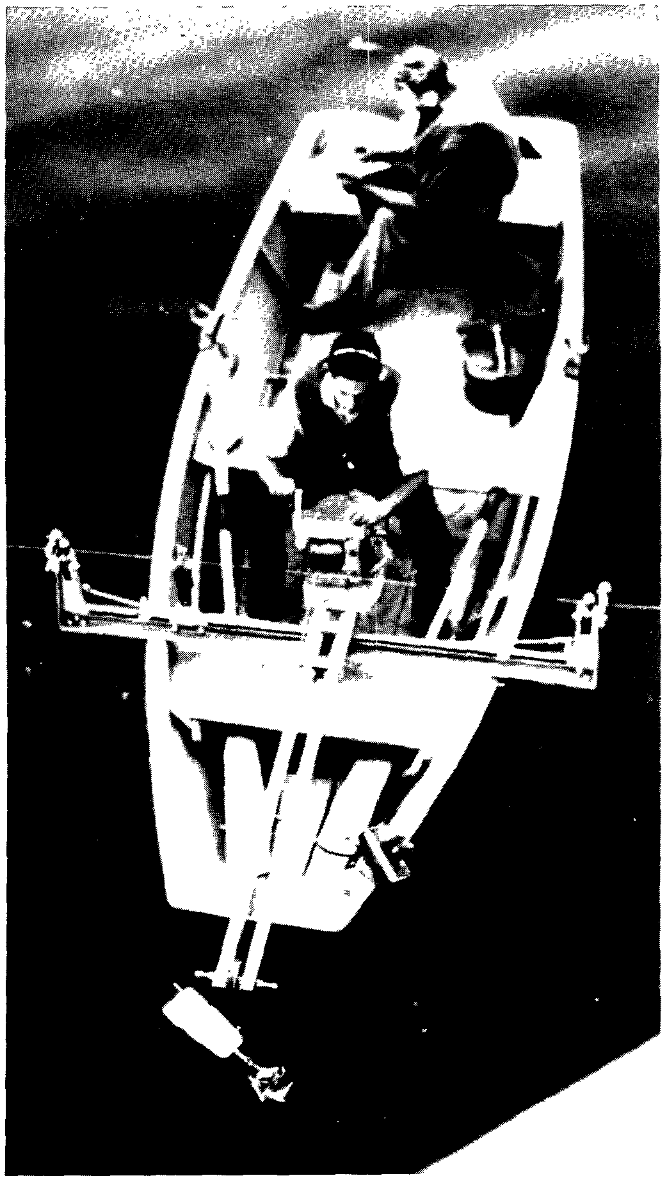


FIGURE 82.—Measuring equipment set up in a boat.

is read at the water surface on the graduated part of the stick. The horizontal part of the L is at least 4 in (0.1 m) long so that it may

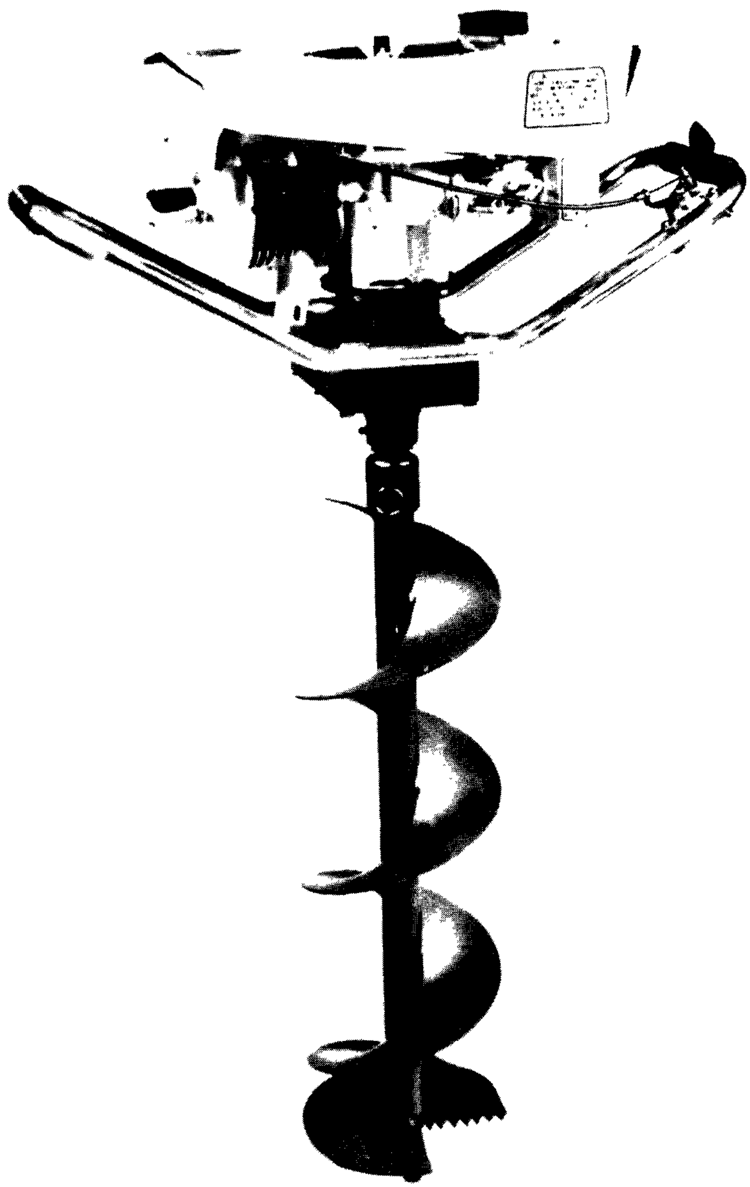


FIGURE 83.—Gasoline-powered ice drill. (Photograph by permission of General Equipment Co.)

extend beyond any irregularities on the underside of the ice.

When the total depth of water under ice cover is greater than 10 or 12 ft (3.0 or 3.6 m), a sounding reel or handline is usually used. The sounding reel is mounted on a collapsible support set on runners. (See fig. 84.)

A special ice-weight assembly is used for sounding under ice be-

FIGURE 84.—Collapsible reel support and ice-weight assembly.

cause a regular sounding weight will not fit through the hole cut by the ice drill (fig. 84). The weights and meter are placed in a framework that will pass through the drilled hole.

VELOCITY-AZIMUTH-DEPTH ASSEMBLY

The velocity-azimuth-depth assembly, commonly called VADA, combines a sonic sounder with a remote-indicating compass and Price current meter to record depth, indicate the direction of flow, and permit observations of velocity at any point.

In figure 85, the azimuth-indicating unit is shown mounted on a four-wheel crane. Incorporated within the remote-indicator box is the battery for the current-meter circuit, the headphone jacks, and the two-conductor jack for the sonic sounder. A switch allows the remote-indicating unit to be used separately or in conjunction with the sonic sounder. The sonic sounder is described on page 108. This assembly is useful in tidal investigations and in other special studies, as well as at regular gaging stations, where it is desirable to determine the

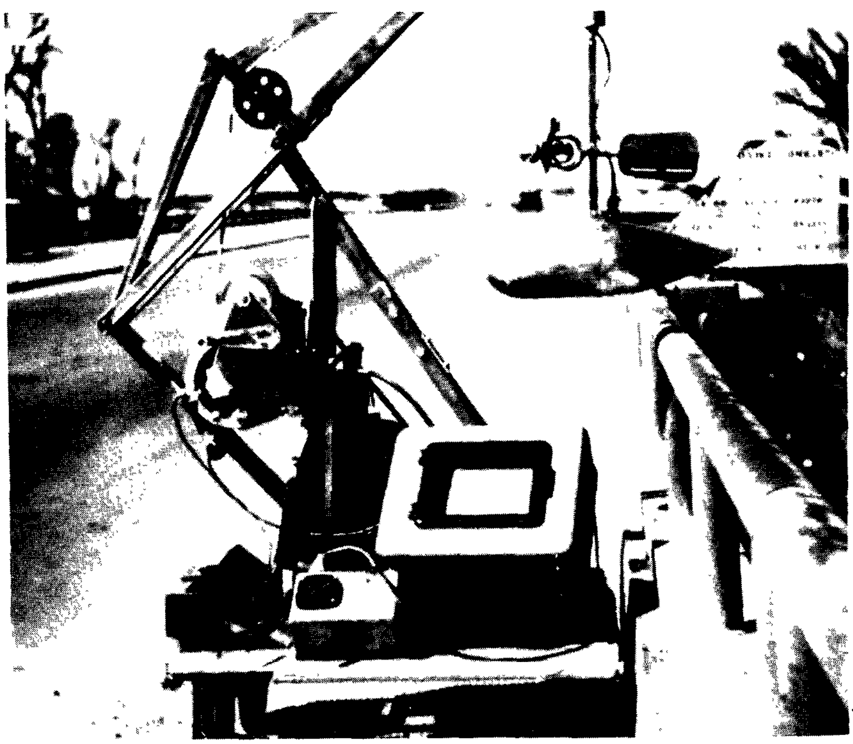


FIGURE 85.—Velocity-azimuth-depth assembly.

direction of flow beneath the water surface, because of the possibility that it may differ from that at the surface.

MISCELLANEOUS EQUIPMENT

Several miscellaneous items that have not been described are necessary when current-meter measurements are made. Three classifications of this equipment are timers, counting equipment, and waders and boots.

In order to determine the velocity at a point with a current meter, it is necessary to count the revolutions of the rotor in a measured interval of time, usually 40–70 s. The velocity is then obtained from the meter-rating table (fig. 51). The time interval is measured to the nearest second with a stopwatch.

The revolutions of the meter rotor during the observation of velocity are counted by an electric circuit that is closed each time the contact wire touches the single or penta eccentric of the current meter. A battery and headphone are part of the electrical circuit, and a click is heard in the headphone each time the contact wire touches. (See fig. 86.) Compact, comfortable hearing-aid phones have been adapted by some to replace the headphones.

A magnetic-switch contact chamber has been developed to replace the contact-wire chamber (p. 87). An automatic electric counter has also been developed for use with the magnetic contact chamber (fig. 86). The counter can register up to 999 and has a reset button. A metal clip is attached to the counter so that it may be easily carried on the hydrographer's belt. The electric counter should not be used with the contact-wire chamber, because at low velocities the contact wire wipes irregularly thereby sending several signals to the counter for each revolution.

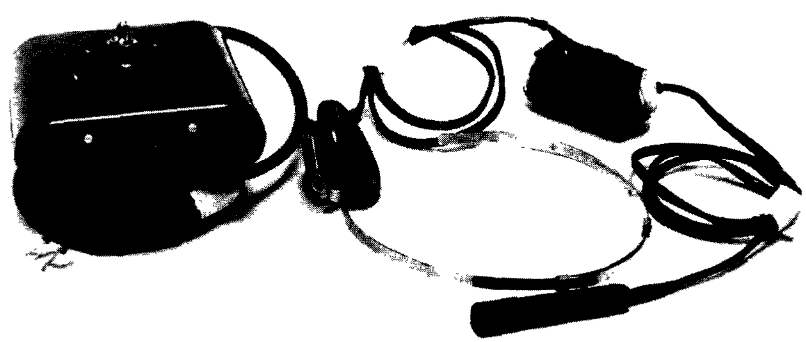


FIGURE 86.—Automatic counter (left) and headphone (right).

Waders or boots are needed when wading measurements are made. Waders should be loose fitting even after allowance has been made for heavy winter clothing. Ice creepers strapped on the shoe of boots or waders should be used on steep or icy streambanks and on rocky or smooth and slippery streambeds. (See fig. 87.)

MEASUREMENT OF VELOCITY

The current meter measures velocity at a point. The method of making discharge measurements at a cross section requires determination of the mean velocity in each of the selected verticals. The mean velocity in a vertical is obtained from velocity observations at many points in that vertical, but it can be approximated by making a few velocity observations and using a known relation between those velocities and the mean in the vertical. The more commonly used methods of determining mean vertical velocity are:

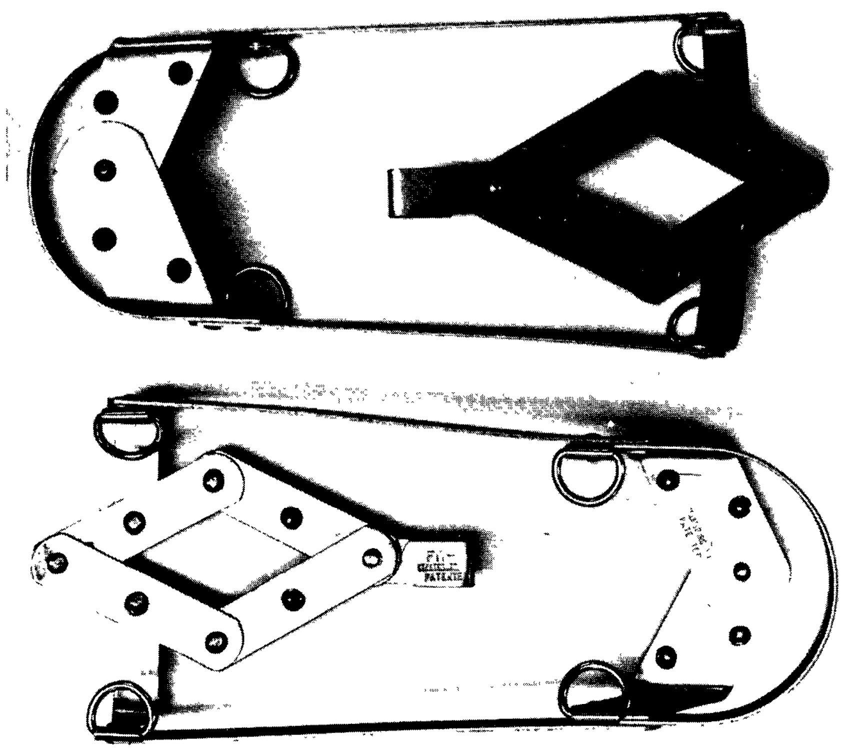


FIGURE 87.—Ice creepers for boots and waders.

1. Vertical-velocity curve.
2. Two-point.
3. Six-tenths-depth.
4. Three-point.
5. Two-tenths depth.
6. Subsurface-velocity.
7. Surface-velocity.
8. Integration.

Less commonly used are the following multipoint methods of determining mean vertical velocity:

9. Five-point.
10. Six-point.

VERTICAL-VELOCITY CURVE METHOD

In the vertical-velocity curve method a series of velocity observations at points well distributed between the water surface and the streambed are made at each of the verticals. If there is considerable curvature in the lower part of the vertical-velocity curve, it is advisable to space the observations more closely in that part of the depth. Normally, the observations are taken at 0.1-depth increments between 0.1 and 0.9 of the depth. Observations are always taken at 0.2, 0.6, and 0.8 of the depth so that the results obtained by the vertical-velocity curve method may be compared with those obtained by the more commonly used methods of velocity observation. Observations are made at least 0.5 ft (0.15m) below the water surface and above the streambed when the Price AA meter or the vane meter is used and are made at least 0.3 ft (0.09 m) from those boundaries when the Price pygmy meter is used; those meters underregister velocity when placed closer to the water surface or streambed.

The vertical-velocity curve for each vertical is based on observed velocities plotted against depth (fig. 88). In order that vertical-velocity curves at different verticals may be readily compared, it is customary to plot depths as proportional parts of the total depth. The mean velocity in the vertical is obtained by measuring the area between the curve and the ordinate axis with a planimeter, or by other means, and dividing the area by the length of the ordinate axis.

The vertical-velocity curve method is valuable in determining coefficients for application to the results obtained by other methods but is not generally adapted to routine discharge measurements because of the extra time required to collect field data and to compute the mean velocity.

Intensive investigation of vertical-velocity curves by Hulsing, Smith, and Cobb (1966) resulted in table 2 which shows average ordinates of the vertical-velocity curve.

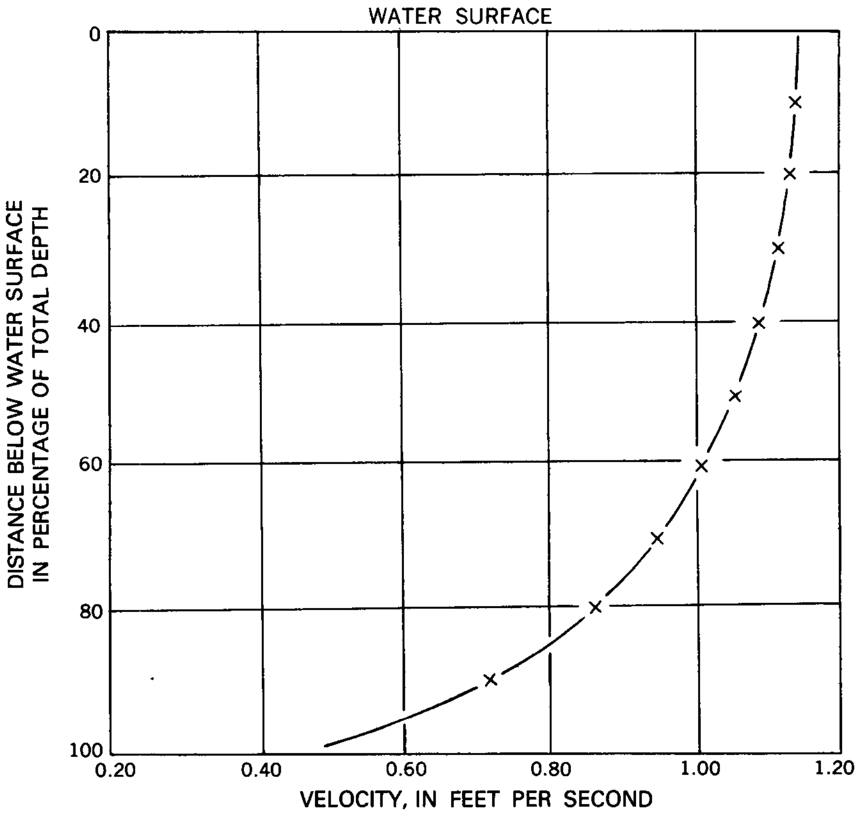


FIGURE 88.—Typical vertical-velocity curve.

TABLE 2.—*Coefficients for standard vertical-velocity curve*

Ratio of observation depth to depth of water	Ratio of point velocity to mean velocity in the vertical
0.05	1.160
.1	1.160
.2	1.149
.3	1.130
.4	1.108
.5	1.067
.6	1.020
.7	.953
.8	.871
.9	.746
.95	.648

TWO-POINT METHOD

In the two-point method of measuring velocities, observations are made in each vertical at 0.2 and 0.8 of the depth below the surface. The average of those two observations is taken as the mean velocity in the vertical. This method is based on many studies involving actual observation and mathematical theory. Experience has shown that this method gives more consistent and accurate results than any of the other methods listed, other than the five-point, six-point, and vertical-velocity curve methods. The two-point method is the one generally used by the U.S. Geological Survey. Table 2 indicates that the two-point method, on the average, gives results that are within 1 percent of the true mean velocity in the vertical.

The two-point method is not used at depths less than 2.5 ft (0.76 m) when measuring with a Price current meter, because the meter would then be too close to the water surface and to the streambed to give dependable results.

The vertical-velocity curve will be distorted by overhanging vegetation that is in contact with the water or by submerged objects, such as large rocks and aquatic growth, if those elements are in close proximity, either in the upstream or downstream direction, to the vertical in which velocity is being measured. Where that occurs the two-point method will not give a reliable value of the mean velocity in the vertical, and an additional velocity observation at 0.6 of the depth should be made. The three observed velocities should then be used in the three-point method (p. 135). A rough test of whether or not the velocities at the 0.2 and 0.8 depths are sufficient for determining mean vertical velocity is given in the following criterion: the 0.2-depth velocity should be greater than the 0.8-depth velocity but less than twice as great.

SIX-TENTHS DEPTH METHOD

In the 0.6-depth method, an observation of velocity made in the vertical at 0.6 of the depth below the surface is used as the mean velocity in the vertical. Actual observation and mathematical theory have shown that the 0.6-depth method gives reliable results. (See table 2.) The U.S. Geological Survey uses the 0.6-depth method under the following conditions:

1. Whenever the depth is between 0.3 ft (0.09 m) and 1.5 ft (0.46 m) and a Price pygmy meter is being used, or between 1.5 ft (0.46 m) and 2.5 ft (0.76 m) and a Price type AA (or type A) meter is being used. (See table 3 for depth and velocity limitations of each meter.)
2. When large amounts of slush ice or debris make it impossible to

observe the velocity accurately at the 0.2 depth. That condition prevents the use of the two-point method.

3. When the distance between the meter and the sounding weight is too great to permit placing the meter at the 0.8 depth. That circumstance prevents the use of the two-point method.
4. When the stage in a stream is changing rapidly and a measurement must be made quickly.

Although, the preceding paragraph states that the 0.6-depth method may be used with a pygmy meter when water depths are as shallow as 0.3 ft (0.09 m), strictly speaking, the 0.6-depth method should not be used when depths are less than 0.75 ft (0.23 m). This follows from the fact that the pygmy meter underregisters when set closer to the streambed than 0.3 ft (p. 132). From a practical standpoint, however, when it is necessary to measure velocities where water depths are as shallow as 0.3 ft, the 0.6-depth method is used. It is recognized, however, that the results obtained in that situation are only approximate values that underestimate the true velocity. Efforts made to date to define shallow-depth coefficients for natural streams have been unsuccessful.

THREE-POINT METHOD

In the three-point method velocities are observed at 0.2, 0.6, and 0.8 of the depth, thereby combining the two-point and 0.6-depth methods. The mean velocity is computed by averaging the 0.2- and 0.8-depth observations and then averaging that result with the 0.6-depth observation. When more weight to the 0.2- and 0.8-depth observations is desired, the arithmetical mean of the three observations may be used. The first procedure is usually followed, however.

The three-point method is used when the velocities in the vertical are abnormally distributed, as explained on page 134. When a Price type AA (or type A) current meter is used, the three-point method cannot be applied unless the depths are greater than 2.5 ft (0.76 m). (See table 3.)

TWO-TENTHS-DEPTH METHOD

In the 0.2-depth method the velocity is observed at 0.2 of the depth below the surface and a coefficient is applied to the observed velocity to obtain the mean in the vertical. The method is principally used for measuring flows of such high velocity that it is not possible to obtain depth soundings or to position the meter at the 0.8 or 0.6 depth.

A standard cross section or a general knowledge of the cross section at a site is used to compute the 0.2 depth when it is impossible to obtain soundings. A sizable error in an assumed 0.2 depth is not critical in the determination of velocity because the slope of the vertical-velocity curve at this point is usually nearly vertical. (See fig. 88.) The 0.2 depth is also used in conjunction with the sonic sounder for flood measurements. (See p. 108.)

The measurement made by the 0.2-depth method is normally computed by using the 0.2-depth velocity observations without coefficients, as though each observation were a mean in the vertical. The approximate discharge thus obtained divided by the area of the measuring section gives the weighted mean value of the 0.2-depth velocity. Studies of many measurements made by the two-point method show that for a given measuring section the relation between the mean 0.2-depth velocity and the true mean velocity either remains constant or varies uniformly with stage. In either circumstance, this relation may be determined for a particular 0.2-depth measurement by recomputing measurements made at the site by the two-point method using only the 0.2-depth velocity observation as the mean in the vertical. The plotting of the true mean velocity versus the mean 0.2-depth velocity for each measurement will give a velocity-relation curve for use in adjusting the mean velocity for measurements made by the 0.2-depth method.

If at a site too few measurements have been made by the two-point method to establish a velocity-relation curve, vertical-velocity curves are needed to establish a relation between the mean velocity and the 0.2-depth velocity. The usual coefficient to adjust the 0.2-depth velocity to the mean velocity is about 0.87. (See table 2.)

The 0.2-depth method is not as reliable as either the two-point method or the 0.6-depth method when conditions are equally favorable for a current-meter measurement by any of the three methods.

SUBSURFACE-VELOCITY METHOD

In the subsurface-velocity method the velocity is observed at some arbitrary distance below the water surface. That distance should be at least 2 ft (0.6 m), and preferably more for deep swift streams to avoid the effect of surface disturbances. The subsurface-velocity method is used, in the absence of an optical current meter, when it is impossible to obtain soundings and the depths cannot be estimated with sufficient reliability to even approximate a 0.2-depth setting for a conventional current-meter measurement. Coefficients are necessary to convert the velocities observed by the subsurface-velocity method to the mean velocity in the vertical. A prerequisite in obtaining those coefficients is to determine the depths during the measurement from soundings made after the stage has receded enough for that purpose. Those depths are used with the known setting of the current meter below the water surface to compute ratios of depth of observation to total depth during the measurement. The coefficients to be used with the subsurface-velocity observations can then be computed either by use of the data in table 2 or by obtaining vertical-velocity curves at the reduced stage of the stream.

SURFACE-VELOCITY METHOD

If an optical current meter (p. 91–93) is available, the surface-velocity method is used in preference to the subsurface-velocity method described above. In a natural channel a surface-velocity coefficient of 0.85 or 0.86 is used to compute mean velocity on the basis of the data in table 2. In a smooth artificial channel a surface-velocity coefficient of 0.90 is used. If the artificial channel has smooth vertical walls, the coefficients shown in figure 89 are used in the vicinity of the walls. Figure 89 is based on data obtained in a laboratory study. The fact that the coefficients close to the wall are greater than unity is explained by the fact that the secondary currents that form near

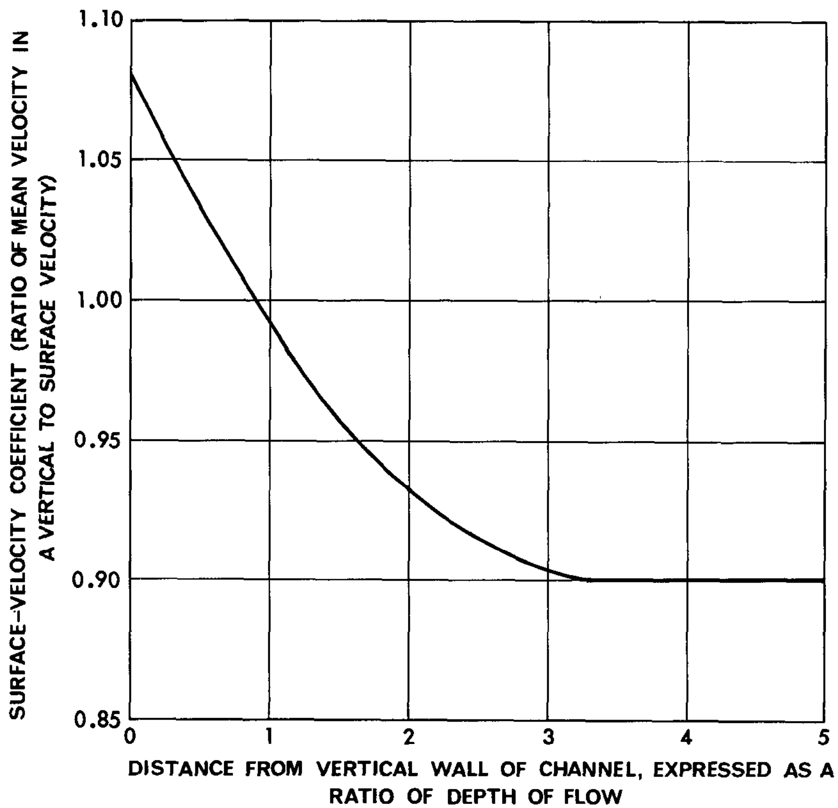


FIGURE 89.—Relation of surface-velocity coefficient to distance from vertical wall of a smooth rectangular channel.

the walls depress the position of the filaments of maximum velocity; that is, the maximum velocity in a vertical close to the wall does not occur at the water surface.

INTEGRATION METHOD

In the integration method the meter is lowered in the vertical to the bed of the stream and then raised to the surface at a uniform rate. During this passage of the meter the total number of revolutions and the total elapsed time are used with the current-meter rating table to obtain the mean velocity in the vertical. The integration method cannot be used with a vertical-axis current meter because the vertical movement of the meter affects the motion of the rotor; consequently, the method is not used in the U.S.A., where the Price meter is the standard current meter. However, the integration method is used to a degree in European countries where horizontal-axis meters are the standard current meters. The accuracy of the measurement is dependent on the skill of the hydrographer in maintaining a uniform rate of movement of the meter. A disadvantage of the method is the inability of the meter to measure streambed velocities because the meter cannot be placed that low. Coefficients smaller than unity are therefore required to correct the observed integrated velocity.

FIVE-POINT METHOD

The five-point method is rarely used in the U.S.A. Velocity observations are made in each vertical at 0.2, 0.6, and 0.8 of the depth below the surface, and as close to the surface and to the streambed as practical. The European criteria for surface and bottom observations state that the horizontal axis of the current meter should not be situated at a distance less than 1½ times the rotor height from the water surface, nor should it be situated at a distance less than 3 times the rotor height from the streambed. In addition, no part of the meter should break the surface of the water.

The velocity observations at the five meter positions are plotted in graphical form, and the mean velocity in the vertical is determined by the use of a planimeter, as explained on page 132. As an alternative, the mean velocity may be computed from the equation

$$V_{mean} = 0.1(V_{surface} + 3V_{0.2} + 3V_{0.6} + 2V_{0.8} + V_{bed}).$$

SIX-POINT METHOD

The six-point method is rarely used in the U.S.A., but is sometimes used in European countries in situations where the existence of a distorted vertical-velocity distribution is known or suspected; for example, in the presence of aquatic growth or under ice cover. Velocity observations are made in each vertical at 0.2, 0.4, 0.6, and 0.8 of the depth below the surface, and also close to the surface and to the streambed. The criteria for surface and streambed observations are those given in the discussion above.

The velocity observations at the six meter positions are plotted in graphical form and the mean velocity in the vertical is determined by planimetering the area bounded by the vertical-velocity curve and the ordinate axis, as explained on page 132. The mean velocity may also be computed mathematically from the equation,

$$V_{mean} = 0.1(V_{surface} + 2V_{0.2} + 2V_{0.4} + 2V_{0.6} + 2V_{0.8} + V_{bed}).$$

PROCEDURE FOR CONVENTIONAL CURRENT-METER MEASUREMENT OF DISCHARGE

The first step in making a conventional current-meter measurement of discharge is to select a measurement cross section of desirable qualities. If the stream cannot be waded, and high-water measurements are made from a bridge or cableway, the hydrographer has no choice with regard to selection of a measurement cross section. If the stream can be waded, the hydrographer looks for a cross section of channel with the following qualities:

1. Cross section lies within a straight reach, and streamlines are parallel to each other.
2. Velocities are greater than 0.5 ft/s (0.15 m/s) and depths are greater than 0.5 ft (0.15 m).
3. Streambed is relatively uniform and free of numerous boulders and heavy aquatic growth.
4. Flow is relatively uniform and free of eddies, slack water, and excessive turbulence.
5. Measurement section is relatively close to the gaging-station control to avoid the effect of tributary inflow between the measurement section and control and to avoid the effect of storage between the measurement section and control during periods of rapidly changing stage.

It will often be impossible to meet all of the above criteria, and when that is the case, the hydrographer must exercise judgment in selecting the best of the sites available for making the discharge measurement.

If the stream cannot be waded and the measurement must be made from a boat, the measurement section selected should have the attributes listed above, except for those listed in item 2 concerning depth and velocity. Depth is no consideration in a boat measurement; if the stream is too shallow to float a boat, the stream can usually be waded. However, velocity in the measurement section is an important consideration. If velocities are too slow, meter registration may be affected by an oscillatory movement of the boat, in which the boat, even though fastened to the tag line, moves upstream and downstream as a result of wind action; or, where a vertical-axis meter is used, meter registration may be affected by vertical movement of the boat as a result of wave action (p. 180–181). If velocities are too fast, it becomes difficult to string the tag line across the stream.

Regardless of the type of measurement that is to be made, if the gaging station is downstream from a hydroelectric powerplant, the stage will be changing too rapidly, most of the time, to assure a satisfactory discharge measurement. The hydrographer should obtain a schedule of operations from the powerplant operator, or determine the operating schedule from the gage-height chart, and plan to make his discharge measurements near the crest or trough of the stage hydrograph, or during periods of near-constant discharge from the powerplant.

After the cross section has been selected, the width of the stream is determined. A tag line or measuring tape is strung across the measurement section for measurements made by wading, from a boat, from ice cover, or from an unmarked bridge. Except where a bridge is used, the line is strung at right angles to the direction of flow to avoid horizontal angles in the cross section. For cableway or bridge measurements, use is made of the graduations painted on the cable or bridge rail as described on page 110. Next the spacing of the verticals is determined to provide about 25 to 30 subsections. If previous discharge measurements at the site have shown uniformity of both the cross section and the velocity distribution, fewer verticals may be used. The verticals should be so spaced that no subsection has more than 10 percent of the total discharge. The ideal measurement is one in which no subsection has more than 5 percent of the total discharge, but that is seldom achieved when 25 subsections are used. (The discharge measurement notes in figure 42 show that the subsection with the greatest discharge had 6.2 percent of the total discharge.) It is not recommended that all observation verticals be spaced equally unless the discharge is evenly distributed across the stream. The spacing between verticals should be closer in those parts of the cross section that have the greater depths and velocities.

After the stationing of the observation verticals has been determined, the appropriate equipment for the current-meter measurement is assembled and the measurement note sheets for recording observations are prepared. (See fig. 42.) The following information will be recorded for each discharge measurement:

1. Name of stream and location to correctly identify the established gaging station; or name of stream and exact location of site for a miscellaneous measurement.

2. Date, party, type of meter suspension, and meter number.
3. Time measurement was started using military time (24-hr clock system).
4. Bank of stream that was the starting point.
5. Control conditions.
6. Gage heights and corresponding times.
7. Water temperature.
8. Other pertinent information regarding the accuracy of the discharge measurement and conditions which might affect the stage-discharge relation.

The streambank is identified by the letters LEW or REW (left edge of water or right edge of water, respectively, when facing downstream). The time is recorded periodically in the notes during the course of the measurement. If the gaging station is equipped with a digital recorder it is advantageous to synchronize the time observations with the punch cycle of the recorder. (See fig. 42.) The time observations are important for computing the mean gage height of the discharge measurement, if the measurement is made during a period of appreciable change in stage. (See p. 170–173.) When the discharge measurement is completed, the time is recorded along with the streambank (LEW or REW) where the measurement ended.

We have digressed somewhat in discussing the measurement notes and now return to the details of the discharge measurement. After the note sheet is readied, the meter assembly is checked. The meter should balance on the hanger used and should spin freely; the electric circuit through the meter should operate satisfactorily; and the stopwatch should check satisfactorily in a comparison with the hydrographer's watch. After recording on the note sheet the station (distance from initial point) of the edge of water, the actual measurement is ready to be started.

Depth (if any) at the edge of water is measured and recorded. The depth determines the method of velocity measurement to be used, normally the two-point method (p. 134) or the 0.6-depth method (p. 134). The setting of the meter for the particular method to be used is then computed, and the meter position is recorded, using a designation such as 0.8 or 0.6 or 0.2, as the case may be. After the meter is placed at the proper depth and pointed into the current, the rotation of the rotor is permitted to become adjusted to the speed of the current before the velocity observation is started. The time required for such adjustment is usually only a few seconds if velocities are greater than 1 ft/s (0.3 m/s), but for slower velocities, particularly if the current meter is suspended on a cable, a longer period of adjustment is needed. After the meter has become adjusted to the current, the number of revolutions made by the rotor is counted for a period of 40 to 70 s. The stopwatch is started simultaneously with the first signal or click, which is counted as "zero," and not "one." The count is ended on a convenient number coinciding with one of those given in the column headings of the meter rating table. The stopwatch is stopped on that count and is read to the nearest second or to the nearest even second if the hand of the stopwatch is on a half-second mark. That number of seconds and the number of revolutions are then recorded.

If the velocity is to be observed at more than one point in the vertical, the meter setting for the additional observation is determined, the revolutions are timed, and the data are recorded. The hydrographer moves to each of the observation verticals and repeats the above procedure until the entire cross section has been traversed. For each vertical he records distance from initial point, water depth, meter-position depth, revolutions of the meter, and the time interval associated with those revolutions (fig. 42).

Consideration must be given to the direction of flow, because it is the component of velocity normal to the measurement section that must be determined. The discussion that follows concerns currents that approach the measurement section obliquely, at angle α (fig. 47). If, in a wading measurement, the meter used is a horizontal-axis meter with a component propellor, such as the Ott meter, the propellor should be pointed upstream at right angles to the cross section, but only if α is less than 45°. Such a meter will register the desired component of velocity normal to the cross section, when α is less than 45°. If α is greater than 45°, the component meter should be pointed into the current. All other meters on a wading-rod suspension should likewise be pointed into the current. Any meter on a cable suspension, as is used for the higher stages, will automatically point into the current because of the effect of the meter vanes. When the meter is pointed into an oblique current the measured velocity must be multiplied by the cosine of the angle (α) between the current and a perpendicular to the measurement section in order to obtain the desired normal component of the velocity.

In the U.S.A., either of two methods is used to obtain cosine α (fig. 47). In the first method, use is made of the field notes which have a point of origin (o) printed on the left margin and cosine values on the right margin (fig. 42). The cosine of the angle of the current is measured by holding the note sheet in a horizontal position with the point of origin on the tag line, bridge rail, cable rail, or any other feature parallel to the cross section (fig. 90). With the long side of the note sheet parallel to the direction of flow, the tag line or bridge rail will intersect the value of cosine α on the top, bottom, or right edge of the note sheet. The direction of the current will be apparent from the direction of movement of floating particles. If the water is clear of floating material, small bits of floating material are thrown into the stream and the edge of the note sheet is alined parallel to the direction of movement. If no such material is available, the inelegant, but time-honored method of spitting into the stream is used to obtain an indicator of the direction of flow. The measured velocity is multiplied by the cosine of the angle to determine the velocity component normal to the measurement section.

The second, and more reliable, method of obtaining cosine α involves the use of a folding foot-rule. These rules, which are either 3 or 6 ft long, are graduated in hundredths of a foot and are jointed every half foot. The first 2 ft of the rule is extended, the 2.00-ft marker is placed on the tag line or bridge rail (fig. 91), and the rule is alined with the direction of the current. The rule is folded at the 1-ft mark so that the first foot of the rule is normal to the tag line or bridge rail. That reading, subtracted from 1.00, is cosine α. For example, if the reading on the rule is 0.09 ft, cosine α equals 0.91.

Details peculiar to each of the various types of current-meter measurement are described in the sections of the manual that follow.

CURRENT-METER MEASUREMENT BY WADING

Current–meter measurements are best made by wading, if conditions permit. (See fig. 92.) Wading measurements have a distinct advantage over measurements made from cableways or bridges in that it is usually possible to select the best of several available cross sections for the measurement. The type AA or pygmy meter is used for wading measurements in the U.S.A. Table 3 lists the type of meter and velocity method to be used for wading measurements at various depths.

Some departure from table 3 is permissible. For example, if a type

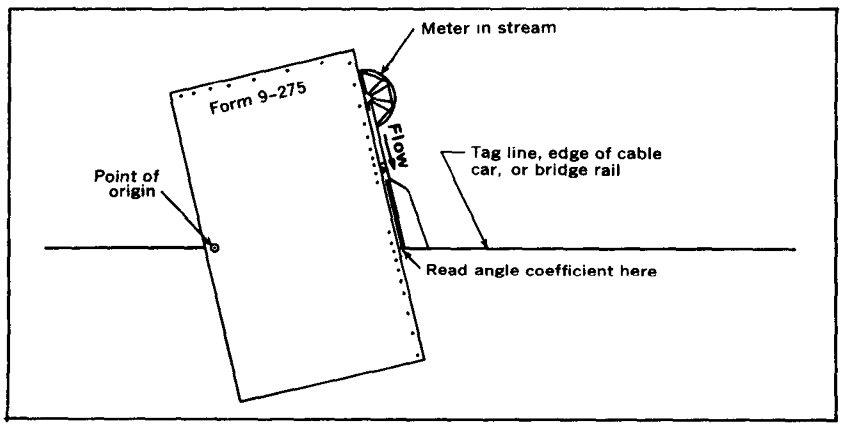


FIGURE 90.—Measurement of horizontal angle with measurement-note sheet.

AA meter is being used in a measurement section that has almost all its depths greater than 1.5 ft (0.46 m), the pygmy meter should not be substituted for the few depths that are less than 1.5 ft, or vice versa. With regard to the use of the type AA meter in depths less than 1.5 ft, strictly speaking, that meter should not be used in depths less than 1.25 ft (0.38 m). A depth of 1.25 ft will accommodate the 0.6-depth method without causing the meter to be set closer than 0.5 ft from the streambed; if the meter is set any closer to the streambed it will underregister the velocity (p. 132). However, if the hydrographer is using the type AA meter in a measurement section that has only few verticals shallower than 1.25 ft, he may use that meter for depths that are even as shallow as 0.5 ft (0.15 m) without changing to a pygmy meter. The hydrographer must make a judgment decision. He knows that his meter is underregistering the velocity by some unknown percentage in the depths shallower than 1.25 ft, but if that shallow-depth flow represents less than 10 percent of the total discharge, his total measured discharge should not be too greatly in error.

Neither the type AA meter nor the pygmy meter should be used for measuring velocities slower than 0.2 ft/s, unless absolutely necessary.

If depths or velocities under natural conditions are too low for a dependable current-meter measurement, the cross section should be modified, if practical, to provide acceptable conditions. It is often pos-

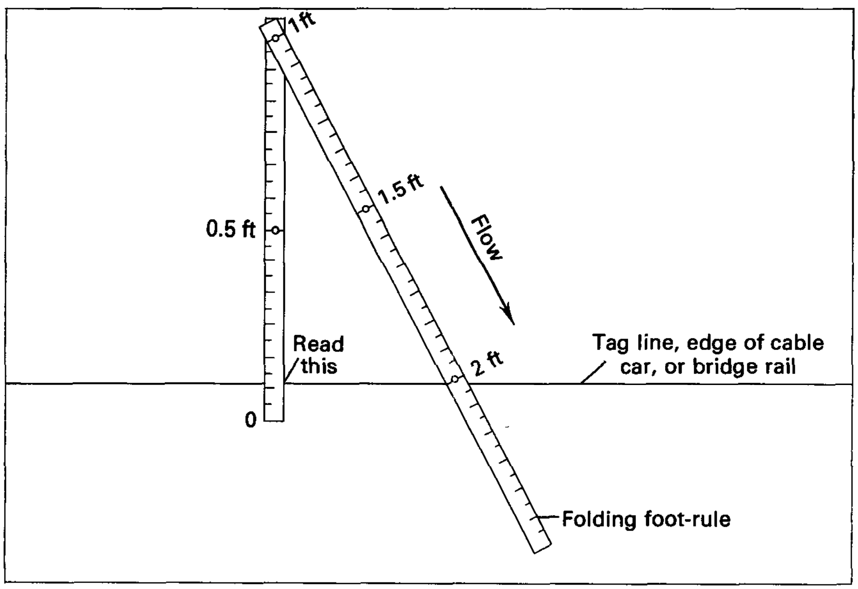


FIGURE 91.—Measurement of horizontal angle with folding foot-rule.

sible to build temporary dikes to eliminate slack water or shallow depths in a cross section, or to improve the cross section by removing rocks and debris within the section and in the reach of channel im-

FIGURE 92.—Wading measurement using top-setting rod.

TABLE 3.—*Current-meter and velocity-measurement method for various depths (wading measurement)*

Depth		Meter	Velocity method
(ft)	(m)		
2.5 or more	0.76 or more	Type AA (or type A)	0.2 and 0.8
1.5–2.5	0.46–0.76	---- do ----	.6
.3–1.5	.09– .46	Pygmy[1]	.6

[1]Used when velocities are less than 2 5 ft/s (0 76 m/s)

mediately upstream and downstream from the section. After the cross section has been modified, the flow should be allowed to stabilize before starting the discharge measurement.

The hydrographer should stand in a position that least affects the velocity of the water passing the current meter. That position is usually obtained by facing the bank so that the water flows against the side of the leg. The wading rod is held at the tag line by the hydrographer who stands about 3 in (0.07 m) downstream from the tag line and at least 1.5 ft (0.46 m) from the wading rod. He should avoid standing in the water if his feet and legs occupy a significantly large percentage of a narrow cross section. In small streams where the width permits, the hydrographer stands on an elevated plank or other support, rather than in the water.

The wading rod should be held in a vertical position with the meter parallel to the direction of flow while the velocity is being observed. If the flow is not at right angles to the tag line, the angle coefficient should be carefully measured (figs. 90 and 91).

When measuring streams having shifting beds, the soundings or velocities can be affected by the scoured depressions left by the hydrographer's feet. For such streams, the meter should be placed ahead of and upstream from the feet. For such streams, too, the hydrographer's notes should accurately describe the configuration of the streambed and water surface. (See p. 376–379.)

A measurement should be made of the depth of water over the lowest point of the control, either before or after the discharge measurement. The gage height corresponding to this lowest point (gage height of zero flow) is very useful in analyzing the stage-discharge relation for the gaging station. (See p. 333–334).

When the flow is too low for a reliable measurement of discharge by current meter, the discharge is determined by use of (1) a volumetric method of measurement, (2) a portable Parshall flume, or (3) a portable weir plate. Those three methods of discharge determination are discussed in chapter 8.

CURRENT-METER MEASUREMENTS FROM CABLEWAYS

The equipment assemblies for use on cableways are described on pages 110–117.

The size of the sounding weight used in current-meter measurements depends on the depth and velocity in the measurement cross section. A rule of thumb generally used is that the size of the weight (lb) should be greater than the maximum product of velocity (ft/s) and depth (ft) in the cross section. If insufficient weight is used, the meter assembly will be dragged downstream. If debris or ice is flowing or if the stream is shallow and swift, the weight used should be appreciably heavier than that indicated by the above rule. The rule is not rigid, but it does provide a starting point for deciding on the size of weight required at various stages.

The Price type AA current meter is generally used in the U.S.A. when making discharge measurements from a cableway. The depth is measured by use of a sounding reel, and the velocity is measured by setting the meter at the proper position in the vertical. (See table 4.) Table 4 is designed so that no velocity observations will be made with the meter closer than 0.5 ft (0.15 m) to the water surface. In the zone from the water surface to a depth of 0.5 ft, the current meter is known to give erroneous results.

Some sounding reels are equipped with a computing depth indicator. To use the computing spiral, the indicator is set at zero when the center of the current-meter rotor is at the water surface. The sounding weight and meter are then lowered until the weight touches the streambed. If, for example, a 30 C .5 (see table 4) suspension is used and if the indicator reads 18.5 ft when the sounding weight touches the bottom, the depth would be 19.0 ft (18.5 ft + 0.5 ft). To move the meter to the 0.8-depth position (0.8×19.0 ft), the weight and meter are raised until the hand on the indicator is over the 19-ft mark on the graduated spiral (fig. 60); the hand will then be pointing to 15.2 on the main dial. To set the meter at the 0.2-depth position (0.2×19.0 ft), the weight and meter are raised until the hand on the indicator is pointing to 3.8 ft on the main dial.

One problem found in observing velocities from a cableway is that movement of the cable car from one station to the next causes the car to oscillate for a short time after coming to a stop. The hydrographer should wait until this oscillation has been dampened to the extent that it is negligible before counting meter revolutions.

Tags can be placed on the sounding line at known distances above the center of the meter cups as an aid in determining depths. Furthermore, the use of tags allows the meter to be kept submerged throughout the discharge measurement to prevent freezing in cold air during the winter measurements. The tags, which are usually streamers of different colored binding tape, are fastened to the sounding line by solder beads or by small cable clips. Tags are used for determining depth in either of two ways.

1. In the procedure that is usually preferred, a tag is set at the water surface, after which the depth indicator is set at the distance between that particular tag and the center of the meter cups. This is equivalent to setting the indicator at zero when the center of the meter rotor is at the water surface, and the hydrographer then proceeds with his depth settings as described in a preceding paragraph. If debris or ice is flowing, this method prevents damage to the meter.

TABLE 4.—*Velocity-measurement method for various meter suspensions and depths*

Suspension[1]	Minimum depth			
	0.6 method		0.2 and 0.8 method	
	(ft)	(m)	(ft)	(m)
15 C .5, 30 C .5	1.2	0.37	2.5	0.76
50 C .55	1.4	.43	2.8	.85
50 C .9	2.2	.67	4.5	1.37
75 C 1.0, 100 C 1.0, 150 C 1.0	2.5	.76	5.0	1.52
200 C 1.5, 300 C 1.5	[2]3.8	1.16	7.5	2.29

[1]Suspensions shown indicate the size of the sounding weight and the distance from the bottom of the weight to the current-meter axis. Thus "50 C .9" refers to a 50-pound Columbus-type weight, the suspension for which puts the meter 0.9 ft above the bottom of the weight.

[2]Use 0.2-depth method for depths between 2.5 and 3.7 ft, and apply appropriate coefficient (usually 0.87 from table 2).

2. In the second method the sounding weight is first lowered to the streambed, and the depth is then determined by raising the weight until the first tag below the water surface appears at the surface. The total depth is then sum of (a) the distance the weight was raised to bring the tag to the water surface, (b) the distance the tag is above the center of the meter cups, and (c) the distance from the bottom of the weight to the center of the cups. This method is usually used with handlines, and it is also used to simplify the measurement of deep, swift streams (p. 159–163).

If large quantities of debris are carried by the stream, the meter should be periodically raised to the cable car for inspection during the measurement to be certain that the pivot and rotor of the meter are free of debris. However, the meter should be kept in the water during the measurement if the air temperature is well below freezing. The hydrographer should carry a pair of lineman's side-cutter pliers when making measurements from a cableway. These can be used to cut the sounding line to insure safety if the weight and meter become caught on a submerged object or on heavy floating debris and it is impossible to release them. Sometimes the cable car can be pulled to the edge of the water where the entangling debris can be removed.

When a measurement of a deep, swift stream is made from a cableway, the meter and weight do not hang vertically but are dragged downstream. The vertical angle, that is, the angle between the meter-suspension cable and the vertical, should be measured by protractor in order to correct the soundings to give the actual vertical depth. The procedure used to correct soundings is described on pages 159–168.

If a handline is used to suspend the current meter and sounding weight, the measurement procedure to be followed is that described in the section on bridge measurements (p. 150–151).

CURRENT-METER MEASUREMENTS FROM BRIDGES

Bridges are often used for making discharge measurements of streams that cannot be waded. Measurement cross sections under bridges are often satisfactory for current-meter measurements, but cableway sections are usually superior.

No set rule can be given for choosing between the upstream or downstream side of the bridge for making a discharge measurement. The advantages of using the upstream side of the bridge are:

1. Hydraulic characteristics at the upstream side of bridge openings usually are more favorable.
2. Approaching drift can be seen and thus can be more easily avoided.
3. The streambed at the upstream side of the bridge is not likely to be scoured as badly as the downstream side.

The advantages of using the downstream side of the bridge are:

1. Vertical angles are more easily measured because the sounding line will move away from the bridge.
2. The flow lines of the stream may be straightened by passing through a bridge opening with piers.

Whether to use the upstream side or the downstream side of a bridge for a current-meter measurement should be decided individually for each bridge after considering the above factors. Other pertinent factors relate to physical conditions at the bridge, such as location of the walkway, traffic hazards, and accumulation of trash on pilings and piers.

In making the discharge measurement either a handline, or a sounding reel supported by a bridge board or by a portable crane, is used to suspend the current meter and sounding weight from the bridge. The velocity is measured by setting the meter at positions in the vertical as indicated in table 4. If velocities are high, the equipment is used no closer than several feet from piers and abutments. In that situation depths and velocities at the pier or abutments are estimated on the basis of observations in the vertical nearest the pier. (See p. 82.)

Where piers are in the measuring section, it is usually necessary to use more than 25–30 subsections to obtain results as reliable as those obtained with a similar measuring section that has no piers. Piers not only affect the horizontal distribution of velocities, but they frequently affect the direction of the current, causing horizontal angles that must be carefully measured.

Whether or not to exclude the area of a bridge pier from the area of the measurement cross section depends primarily on the relative locations of the measurement section and the end of the pier. If measurements are made from the upstream side of the bridge, it is the relative location of the upstream end (nose) of the pier that is relevant; for measurements made from the downstream side it is the location of the downstream end (tail) of the pier that is relevant. If any part of the pier extends into the measurement cross section, the area of the pier is excluded. However, bridges quite commonly have cantilevered walkways from which discharge measurements are made. In that case the measurement cross section lies beyond the end of the pier—upstream from the nose or downstream from the tail, depending on which side of the bridge is used. In that situation it is the position and direction of the streamlines that determines whether or not the pier area is to be excluded. The hydrographer, if he had not previously noted the stationing of the sides of the pier when projected to the measurement cross section, does so now. If there is negligible or no downstream flow in that width interval (pier subsection)—that is, if only stagnation and (or) eddying exists upstream from the nose or downstream from the tail, whichever is relevant—the area of the pier is excluded. If there is significant downstream flow in the pier subsection, the area of the pier is included in the area of the measurement cross section. The horizontal angles of the streamlines in and near the pier subsection will usually be quite large in that circumstance.

Footbridges are sometimes used for measuring the discharge of canals, tailraces, and small streams. Often a rod suspension can be used for the meter when measuring from a footbridge. In low velocities the procedure for determining depth when using a rod suspension is the same as that used for wading measurements. For higher velocities depth is obtained from the difference in readings at an index point on the bridge when the base plate of the rod is at the water surface and when it is on the streambed. The measurement of depth by that method eliminates errors in reading the depth caused by the fast-moving water piling up on the upstream face of the rod. Handlines, bridge cranes, and bridge boards are also used from footbridges.

When using a sounding reel, depths and velocities are measured by the methods described in the preceding section of the manual on cableway measurements (p. 146–148). When using a handline, depth is determined by first lowering the sounding weight to the streambed and then raising the weight until one of the tags is at the water surface. The distance that the weight is raised is measured along the rubber-covered cable (p. 106) with either a steel or metallic tape, a folding foot-rule, or a graduated rod. The total depth of water is then the summation of (1) the distance the particular tag is above the meter cups, (2) the measured distance the meter and weight were raised, and (3) the distance from the bottom of the weight to the meter cups.

Another, less widely used, method of determining depth requires that the meter cups be set at the water surface, after which the sounding weight is lowered to the streambed while measuring, with tape or rule, the length of line that is let out. This measured distance, plus the distance from the bottom of the sounding weight to the meter cups, is the depth of water.

When using a handline, enough cable is unwound from the handline reel to keep the reel out of water when the sounding weight is on the streambed at the deepest part of the measuring section. That prevents submergence of the reel and thick rubber-covered cable and attendant drag on the equipment in high-velocity flow, and unless the bridge is relatively close to the water surface, it still permits the hydrographer to raise and lower the meter by means of the rubber-covered cable rather than the bare-steel cable. When the meter is set for a velocity observation, the hydrographer stands on the rubber-covered cable or ties it to the handrail to hold the meter in place. By doing so his hands are free to operate the stopwatch and record the data.

If the bridge has vertical truss members in the plane of the measurement cross section, the handline can be disconnected from the headphone wire and passed around the truss member with the sounding weight on the bottom. This eliminates the need for raising the weight and meter to the bridge each time a move is made from one vertical to another and is the principal advantage of a handline.

CURRENT-METER MEASUREMENTS FROM ICE-COVER

Discharge measurements under ice cover (fig. 93) are usually made under conditions that range from uncomfortable to severe, but it is extremely important that they be made, because the reliability of a large part of the computed discharge record for a winter period may depend on one such measurement.

Cross sections for possible use for measuring under ice cover should be selected during the open-water season when channel conditions can be observed and evaluated. Commonly the most desirable measurement section will be just upstream from a riffle because slush ice that collects under the ice cover is usually thickest at the upstream end of the pools created by riffles. The equipment used for cutting or drilling holes in the ice was described on pages 124–129.

The danger of working on ice-covered streams should never be underestimated. When crossing the stream, the hydrographer should test the strength of the ice with solid blows using a sharp ice chisel. Ice thickness may be irregular, especially late in the season when a thick snow cover may act as an insulator. Water just above freezing can slowly melt the underside of the ice, creating thin spots. Ice

FIGURE 93.—Ice rod being used to support current meter for a discharge measurement, top; ice drill being used to cut holes, bottom.

bridged above the water may be weak, even though relatively thick.

At the cross section selected for measurement three holes, one at each quarter point of the width, are cut to check on the possible presence of slush ice or possible maldistribution of flow. If poor conditions are found, other cross sections are similarly investigated to find one that is free of slush ice and has a favorable horizontal distribution of flow. After finding a favorable cross section, at least 20 holes are cut for the current-meter measurement of discharge. The holes should be spaced so that no subsection carries more than 10 percent of the total discharge. On narrow streams it may be simpler to remove all the ice in the cross section.

The effective depth of the water (fig. 94) is the total depth of water minus the distance from the water surface to the bottom of the ice. The vertical pulsation of water in the holes in the ice sometimes causes difficulty in determining the depths. The total depth of water is usually measured with an ice rod or with a sounding weight and reel, depending on the depth.

The distance from the water surface to the bottom of the ice is measured with an ice-measuring stick (p. 125), unless slush is present at the hole. In that situation the effective depth is the total depth

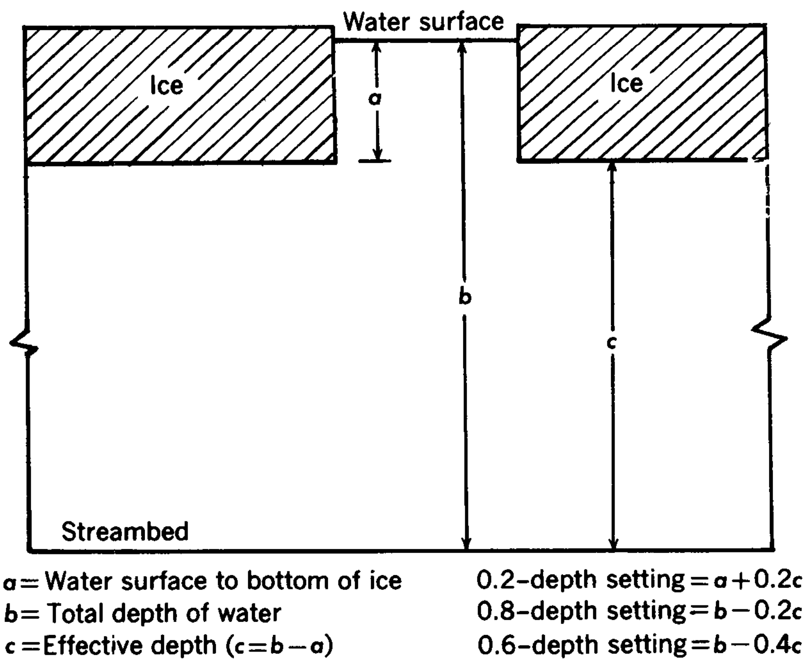


FIGURE 94.—Method of computing meter settings for measurements under ice cover.

minus the distance from the water surface to the interface between water and slush. To locate that interface, the current meter is suspended at a depth below the slush ice where the meter rotor turns freely. The meter is then slowly raised until the rotor stops; that point is considered the interface, and its depth below the water surface is measured for determining the effective depth. The effective depth is then used to compute the proper position of the meter in the vertical.

The vane ice meter is recommended for use under ice cover because (1) the vanes do not become filled with slush ice as the cups of the Price meter often do, (2) the yoke of the vane meter will fit in the hole made by the ice drill, and (3) the yoke and ice rod can serve as an ice-measuring stick. The contact chamber of the vane meter can be rotated to any position; its binding post is therefore placed perpendicular to the axis of the yoke to avoid interference when using the top of the yoke as the horizontal leg of an ice-measuring stick.

Because of the roughness of the underside of the ice cover, the location of the filament of maximum velocity is some distance below the underside of the ice. Figure 95 shows a typical vertical-velocity

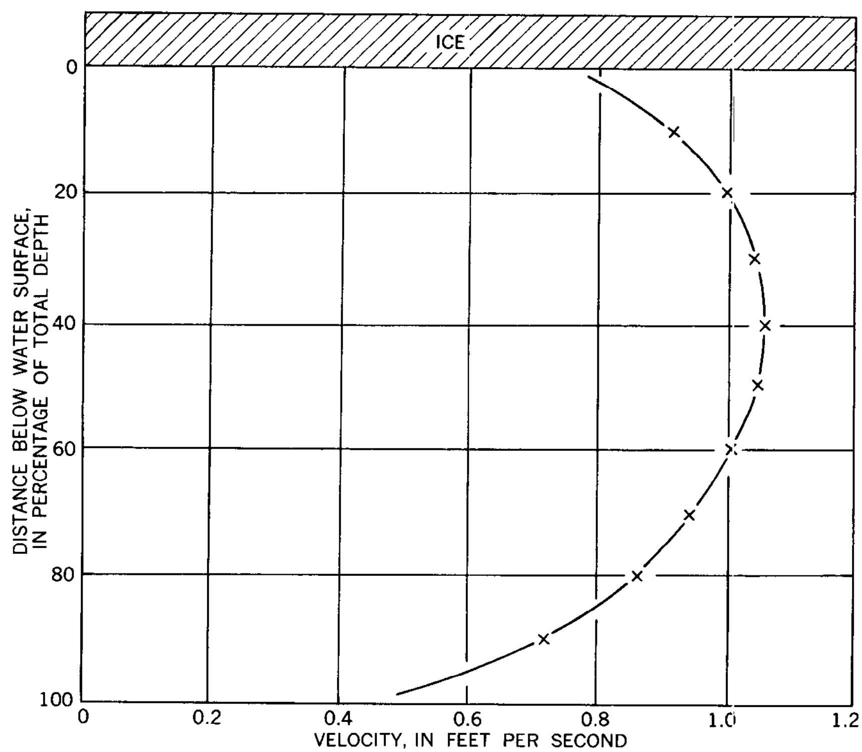


FIGURE 95.—Typical vertical-velocity curve under ice cover.

curve under ice cover. In making a discharge measurement the 0.2- and 0.8-depth method is recommended in the U.S.A. for effective depths equal to or greater than 2.5 ft, and the 0.6-depth method for effective depths less than 2.5 ft. It is also recommended that two vertical-velocity curves be defined when ice measurements are made to determine whether any coefficients are necessary to convert the velocity obtained by the 0.2- and 0.8-depth method, or by the 0.6-depth method, to the mean velocity. Normally the average of the velocities obtained by the 0.2- and 0.8-depth method gives the mean velocity, but a coefficient of about 0.92 usually is applicable to the velocity obtained by the 0.6-depth method. In Europe a three-point method is commonly used in which velocity observations are made at 0.15, 0.5, and 0.85 of the effective depth.

When measuring the velocity, the meter is kept as far upstream as possible to minimize any effect that the vertical pulsation of water in the hole might have on the meter registration. The meter is exposed as little as possible to the cold air so that its operation will not be impaired by the formation of ice on exposed parts.

If there is only partial ice cover on the measuring section, the procedure described above is used for the ice-covered observation verticals, and open-water methods are used for the open-water verticals.

A sample sheet of discharge-measurement notes for a measurement made under ice cover is shown in figure 96. Vertical-velocity curves that had been defined for that measurement had indicated that mean velocity in a vertical was given by the 0.2- and 0.8-depth method, and that the 0.6-depth method required a coefficient of 0.92.

CURRENT-METER MEASUREMENTS FROM BOATS

Discharge measurements are made from boats where no cableways or suitable bridges are available and where streams are too deep to wade. Personal safety is the limiting factor in the use of boats on streams having high velocities.

In making a boat measurement the tag line is first strung across the measurement section by unreeling the line as the boat moves across the stream. Some tag-line reels are equipped with brakes (fig. 79) to control the line tension during the unreeling. If a tag line whose reel is unequipped with a brake has been strung across a stream, the slack is taken up by means of a block and tackle attached to the reel and to an anchored support on the bank. If there is traffic on the river, one man must be stationed on the bank to lower and raise the tag line to allow river traffic to pass. Streamers should be attached to the tag line so that it may be seen by boat pilots. The method of positioning the boat for measuring depths and velocities, by sliding the boat along the tag line from one observation vertical to another, was described on page 121.

If the flow of traffic on the river is continual or if the width of the river is too great for a tag line to be used, other means are needed to position the boat. One method that dispenses with the tag line involves keeping the boat lined up with flags positioned on each end of

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WATER RESOURCES DIVISION

Meter
V-378

Date March 18, 1962 Number of Meas. 365

DISCHARGE MEASUREMENT NOTES—ICE COVER

Frozen ~~River at~~ Creek, near Hot Springs, N.Y.

Veloc. coef.	REW Dist. from initial point	Width	Total depth of water	W.S. to bot. ice	Effective depth	Depth of meter below water surface	Revolutions	Time in seconds	Velocity At point	Velocity Mean in vertical	Area	Discharge
	1315											
	24	3	0	-	-	-	-	-		0	0	0
.92	30	6	2.6	1.6	1.0	2.2	10	47	.50	.46	6.0	2.8
.92	36	6	3.6	1.8	1.8	2.9	15	49	.71	.65	10.8	7.0
.92	42	5	4.3	2.0	2.3	3.4	15	44	.79	.73	11.5	8.4
1.0	46	4	4.5	1.8	2.7	2.3	20	43	1.07	.87	10.8	9.4
						4.0	15	52	.67			
	50	4	4.7	1.7	3.0	2.3	20	40	1.15	.92	12.0	11.0
						4.1	15	50	.70			
	54	4	4.6	1.7	2.9	2.3	25	49	1.17	.96	11.6	11.1
	1325					4.0	15	46	.76			
	58	4	4.9	1.6	3.3	2.3	20	40	1.15	.92	13.2	12.1
						4.2	15	50	.70			
	62	4	4.8	1.6	3.2	2.2	25	48	1.20	.98	12.8	12.5
						4.2	15	46	.76			
	66	3.5	5.0	1.5	3.5	2.2	25	44	1.30	1.08	12.2	13.2
						4.3	15	41	.85			
	69	3	5.3	1.6	3.7	2.3	25	40	1.43	1.15	11.1	12.8
						4.6	15	40	.87			
	72	3	5.1	1.5	3.6	2.2	25	41	1.40	1.16	10.8	12.5
	1335					4.4	20	51	.91			
		49.5									122.8	112.8

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FIGURE 96.—Part of notes for discharge measurement under ice cover.

the measurement cross section. Flags on one bank would suffice, but it is better to have them on both banks. The position of the boat in the cross section can be determined by means of a transit on the shore and a stadia rod held in the boat (fig. 97). Another method of determining the position of the boat is by setting a transit on one bank at a convenient measured distance from, and at right angles to, the cross section. The position of the boat is computed by measuring the angle to the boat, as shown in figure 98. A third method of determining the position of the boat requires a sextant in the boat. The sextant is used to read the angle between a flag at the end of the cross section and another at a known distance perpendicular to the cross section (fig. 98). The boat position can be computed from the measured angle and the known distance between the flags on the shore. Unless anchoring is more convenient, the boat must be held stationary by its motor when readings are being taken.

Boat measurements are not recommended where velocities are

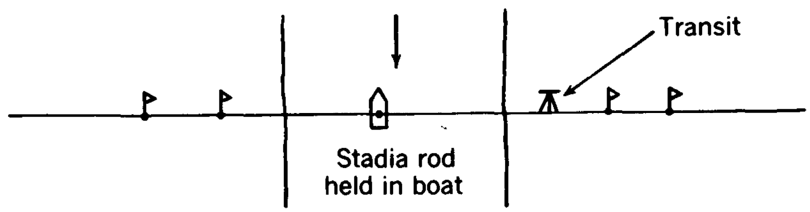
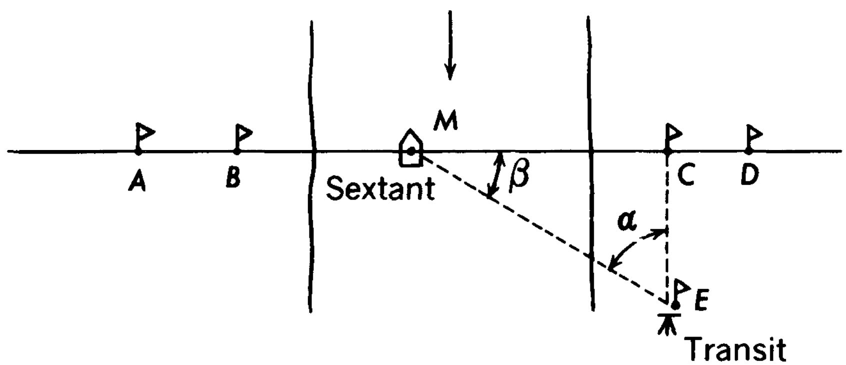


FIGURE 97.—Determining position in the cross section, stadia method.



$$MC = CE \tan \alpha \text{ (transit)}$$

$$MC = \frac{CE}{\tan \beta} \text{ (sextant)}$$

FIGURE 98.—Determining position in the cross section, angular method.

slower than 1 ft/s (0.3 m/s) when the boat is subject to the action of wind and waves. (See p. 180–181.) If the maximum depth in the cross section is less than 10 ft (3 m) and the velocity is low, a rod is usually used for measuring the depth and supporting the current meter. For greater depths and velocities, a cable suspension with reel, boat boom, and sounding weight is used. The procedure for measuring discharge from a boat using the boat boom and crosspiece (p. 122–123) is the same as that for measuring from a bridge or cableway, once the special equipment has been set up and the method of positioning the boat has been established.

A special method of measuring discharge from a boat without stopping the boat at observation stations—the moving-boat method—is described in detail in chapter 6.

NETWORKS OF CURRENT METERS

Occasional special measurements require the simultaneous determination of velocities at several points in a cross section, distributed either laterally or vertically. For example, it may be necessary to measure a vertical-velocity profile quickly in unsteady flows and to check it frequently in order to determine the changes in shape of the vertical profile as well as the rates of those changes. Another example is the measurement of tide-affected streams where it is desirable to measure the total discharge continously during at least a full tidal cycle (approximately 13 hr). The need for so many simultaneous velocity determinations (one at each vertical in the cross section) for so long a period can be an expensive and laborious process using conventional techniques of discharge measurement.

A grouping of 21 current meters and special supplemental instrumentation has been used by the U.S. Geological Survey to facilitate measurements of the types just described. Only a few persons are required to operate the system. The 21 meters are connected so that the spacing between any two adjacent meters can be varied to distances as great as 200 ft (61 m). Furthermore, each meter has sufficient handline cable to be suspended vertically from a bridge for as much as 200 ft. The meters have a standard calibration. Revolutions of the rotors are recorded by electronic counters that are grouped compactly in one box at the center of the bank of meters. The operator, by flipping one switch, starts all 21 counters simultaneously and, after an interval of several minutes, stops all counters. The indicated number of revolutions for the elapsed time interval is converted to a velocity for each meter. The distance between meters is known; a record of stage is maintained to evaluate depth; prior information at the site is obtained to convert point velocities in the verticals to mean velocities in those verticals. All of the information necessary to compute discharge in the cross section is therefore available and is tabulated for easy conversion to discharge.

Other countries have developed similar equipment; for example, a grouping of 40 meters is used in the United Kingdom.

SPECIAL PROBLEMS IN CONVENTIONAL CURRENT-METER MEASUREMENTS

MEASUREMENT OF DEEP, SWIFT STREAMS

The measurement of deep, swift streams by current meter usually presents no serious problems when adequate sounding weights are used and when floating ice or drift is not excessive. Normal procedures must sometimes be altered, however, when measuring streams under particularly adverse conditions, the four most common situations of that kind being represented by the following cases:

Case A. Possible to sound, but weight and meter drift downstream.

Case B. Not possible to sound, but a standard cross section is available.

Case C. Not possible to sound, and no standard cross section is available.

Case D. Not possible to submerge the meter in the water.

Procedures are described below for discharge measurements made under those adverse conditions. The procedures for cases B, C, and D are actually applicable only where channel conditions in the measurement cross section or reach are stable, meaning that no significant scour or deposition occurs.

CASE A. DEPTH CAN BE SOUNDED

Where it is possible to sound the depth but the weight and meter drift drownstream, the depths as measured by the usual methods will be in error, being too large (fig. 99). The correction for the error has two parts, the air correction and the wet-line correction. The air correction is shown in figure 99 as the distance *cd*. The wet-line correction in figure 99 is shown as the difference betwen the wet-line depth *de* and the vertical depth *dg*.

As shown in figure 99, the air correction depends on the vertical angle *P* and the distance *ab*. The correction is computed as follows:

$$ab=ac$$

$$\cos P=\frac{ab}{ad}=\frac{ab}{ac+cd}=\frac{ab}{ab+cd}$$

$$ab+cd=\frac{ab}{\cos P}$$

$$cd=\frac{ab}{\cos P}-ab=ab\left[\frac{1}{\cos P}-1\right]. \qquad (11)$$

The air correction for even-numbered angles between 4° and 36° and for vertical lengths between 10 and 100 ft is shown in table 5. The correction is applied to the nearest tenth of a foot; hundredths are given to aid in interpolation. Table 6 is a similar table in metric units.

The air correction may be nearly eliminated by using tags at

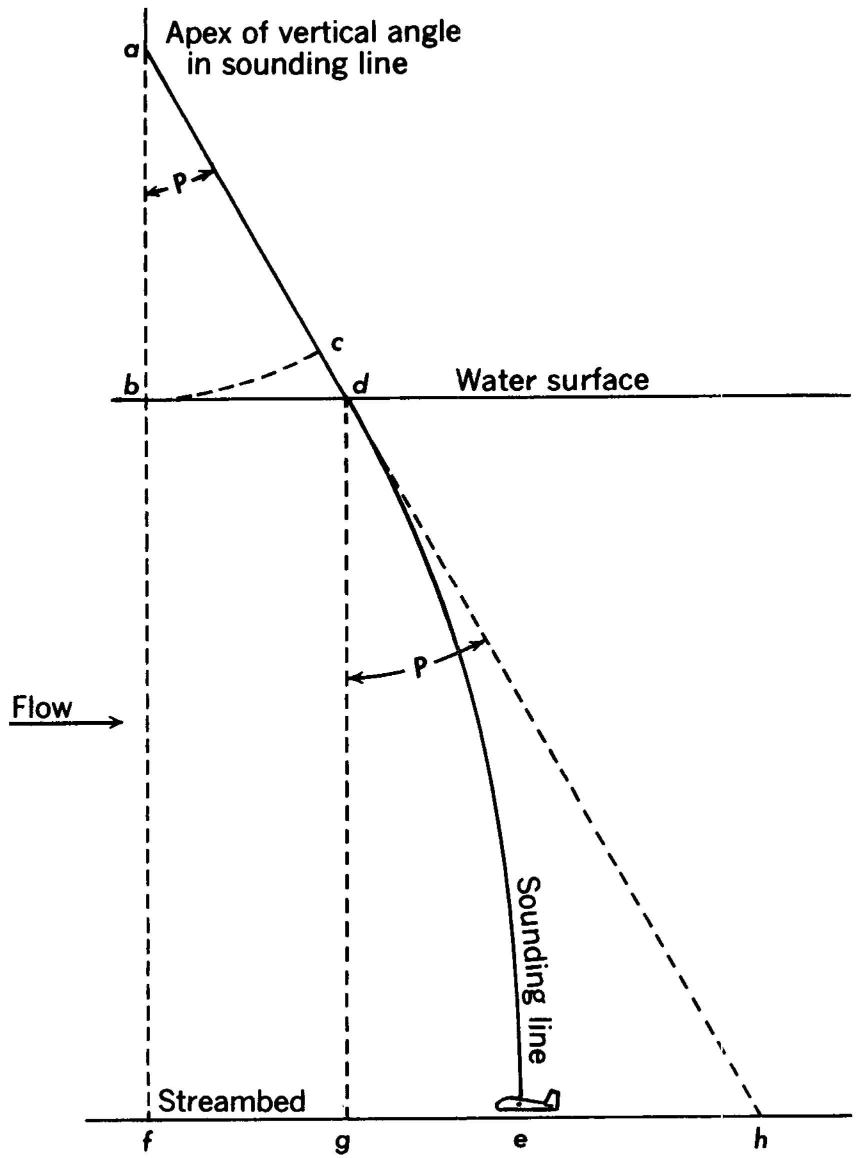


FIGURE 99.—Position of sounding weight and line in deep, swift water.

TABLE 5.—*Air-correction table, giving difference, in feet, between vertical length and slant length of sounding line above water surface for selected vertical angles*

Vertical length (ft)	Vertical angle of sounding line at protractor																	Vertical length (ft)
	4°	6°	8°	10°	12°	14°	16°	18°	20°	22°	24°	26°	28°	30°	32°	34°	36°	
10	0.02	0.06	0.10	0.15	0.22	0.31	0.40	0.51	0.64	0.79	0.95	1.13	1.33	1.55	1.79	2.06	2.36	10
12	.03	.07	.12	.19	.27	.37	.48	.62	.77	.94	1.14	1.35	1.59	1.86	2.15	2.47	2.83	12
14	.03	.08	.14	.22	.31	.43	.56	.72	.90	1.10	1.32	1.58	1.86	2.17	2.51	2.89	3.30	14
16	.04	.09	.16	.25	.36	.49	.64	.82	1.03	1.26	1.51	1.80	2.12	2.48	2.87	3.30	3.78	16
18	.04	.10	.18	.28	.40	.55	.73	.93	1.16	1.41	1.70	2.03	2.39	2.78	3.23	3.71	4.25	18
20	.05	.11	.20	.31	.45	.61	.81	1.03	1.28	1.57	1.89	2.25	2.65	3.09	3.58	4.12	4.72	20
22	.05	.12	.22	.34	.49	.67	.89	1.13	1.41	1.73	2.08	2.48	2.92	3.40	3.94	4.54	5.19	22
24	.06	.13	.24	.37	.54	.73	.97	1.24	1.54	1.88	2.27	2.70	3.18	3.71	4.30	4.95	5.67	24
26	.06	.14	.26	.40	.58	.80	1.05	1.34	1.67	2.04	2.46	2.93	3.45	4.02	4.66	5.36	6.14	26
28	.07	.15	.28	.43	.63	.86	1.13	1.44	1.80	2.20	2.65	3.15	3.71	4.33	5.02	5.77	6.61	28
30	.07	.17	.29	.46	.67	.92	1.21	1.54	1.93	2.36	2.84	3.38	3.98	4.64	5.38	6.19	7.08	30
32	.08	.18	.31	.49	.71	.98	1.29	1.65	2.05	2.51	3.03	3.60	4.24	4.95	5.73	6.60	7.55	32
34	.08	.19	.33	.52	.76	1.04	1.37	1.75	2.18	2.67	3.22	3.83	4.51	5.26	6.09	7.01	8.03	34
36	.09	.20	.35	.56	.80	1.10	1.45	1.85	2.31	2.83	3.41	4.05	4.77	5.57	6.45	7.42	8.50	36
38	.09	.21	.37	.59	.85	1.16	1.53	1.96	2.44	2.98	3.60	4.28	5.04	5.88	6.81	7.84	8.97	38
40	.10	.22	.39	.62	.89	1.22	1.61	2.06	2.57	3.14	3.79	4.50	5.30	6.19	7.17	8.25	9.44	40
42	.10	.23	.41	.65	.94	1.29	1.69	2.16	2.70	3.30	3.97	4.73	5.57	6.50	7.53	8.66	9.91	42
44	.11	.24	.43	.68	.98	1.35	1.77	2.26	2.82	3.46	4.16	4.95	5.83	6.81	7.88	9.07	10.39	44
46	.11	.25	.45	.71	1.03	1.41	1.85	2.37	2.95	3.61	4.35	5.18	6.10	7.12	8.24	9.49	10.86	46
48	.12	.26	.47	.74	1.07	1.47	1.93	2.47	3.08	3.77	4.54	5.40	6.36	7.43	8.60	9.90	11.33	48
50	.12	.28	.49	.77	1.12	1.53	2.02	2.57	3.21	3.93	4.73	5.63	6.63	7.74	8.96	10.31	11.80	50
52	.13	.29	.51	.80	1.16	1.59	2.10	2.68	3.34	4.08	4.92	5.86	6.89	8.04	9.32	10.72	12.28	52
54	.13	.30	.53	.83	1.21	1.65	2.18	2.78	3.47	4.24	5.11	6.08	7.16	8.35	9.68	11.14	12.75	54
56	.14	.31	.55	.86	1.25	1.71	2.26	2.88	3.59	4.40	5.30	6.31	7.42	8.66	10.03	11.55	13.22	56
58	.14	.32	.57	.89	1.30	1.78	2.34	2.98	3.72	4.55	5.49	6.53	7.69	8.97	10.39	11.96	13.69	58
60	.15	.33	.59	.93	1.34	1.84	2.42	3.09	3.85	4.71	5.68	6.76	7.95	9.28	10.75	12.37	14.16	60
62	.15	.34	.61	.96	1.39	1.90	2.50	3.19	3.98	4.87	5.87	6.98	8.22	9.59	11.11	12.79	14.64	62
64	.16	.35	.63	.99	1.43	1.96	2.58	3.29	4.11	5.03	6.06	7.21	8.48	9.90	11.47	13.20	15.11	64
66	.16	.36	.65	1.02	1.47	2.02	2.66	3.40	4.24	5.18	6.25	7.43	8.75	10.21	11.83	13.61	15.58	66
68	.17	.37	.67	1.05	1.52	2.08	2.74	3.50	4.36	5.34	6.44	7.66	9.01	10.52	12.18	14.02	16.05	68
70	.17	.39	.69	1.08	1.56	2.14	2.82	3.60	4.49	5.50	6.62	7.88	9.28	10.83	12.54	14.44	16.52	70
72	.18	.40	.71	1.11	1.61	2.20	2.90	3.71	4.62	5.65	6.81	8.11	9.55	11.14	12.90	14.85	17.00	72
74	.18	.41	.73	1.14	1.65	2.27	2.98	3.81	4.75	5.81	7.00	8.33	9.81	11.45	13.26	15.26	17.47	74
76	.19	.42	.75	1.17	1.70	2.33	3.06	3.91	4.88	5.97	7.19	8.56	10.08	11.76	13.62	15.67	17.94	76
78	.19	.43	.77	1.20	1.74	2.39	3.14	4.01	5.01	6.13	7.38	8.78	10.34	12.07	13.98	16.09	18.41	78
80	.20	.44	.79	1.23	1.79	2.45	3.22	4.12	5.13	6.28	7.57	9.01	10.61	12.38	14.33	16.50	18.89	80
82	.20	.45	.81	1.27	1.83	2.51	3.30	4.22	5.26	6.44	7.76	9.23	10.87	12.69	14.69	16.91	19.36	82
84	.20	.46	.83	1.30	1.88	2.57	3.39	4.32	5.39	6.60	7.95	9.46	11.14	12.99	15.05	17.32	19.83	84
86	.21	.47	.85	1.33	1.92	2.63	3.47	4.43	5.52	6.75	8.14	9.68	11.40	13.30	15.41	17.73	20.30	86
88	.21	.48	.87	1.36	1.97	2.69	3.55	4.53	5.65	6.91	8.33	9.91	11.67	13.61	15.77	18.15	20.77	88
90	.22	.50	.88	1.39	2.01	2.75	3.63	4.63	5.78	7.07	8.52	10.13	11.93	13.92	16.13	18.56	21.25	90
92	.22	.51	.90	1.42	2.06	2.82	3.71	4.73	5.90	7.22	8.71	10.36	12.20	14.23	16.48	18.97	21.72	92
94	.23	.52	.92	1.45	2.10	2.88	3.79	4.84	6.03	7.38	8.90	10.58	12.46	14.54	16.84	19.38	22.19	94
96	.23	.53	.94	1.48	2.14	2.94	3.87	4.94	6.16	7.54	9.09	10.81	12.73	14.85	17.20	19.80	22.66	96
98	.24	.54	.96	1.51	2.19	3.00	3.95	5.04	6.29	7.70	9.27	11.03	12.99	15.16	17.56	20.21	23.13	98
100	.24	.55	.98	1.54	2.23	3.06	4.03	5.15	6.42	7.85	9.46	11.26	13.26	15.47	17.92	20.62	23.61	100

TABLE 6.—*Air-correction table, giving difference, in meters, between vertical length and slant length of sounding line above water surface for selected vertical angles*

Vertical length (m)	Vertical angle of sounding line at protractor (degrees)											
	5	8	10	11	12	13	14	15	16	17	18	19	20
1	0 00	0 01	0 02	0 02	0 02	0 03	0 03	0 04	0 04	0 05	0 05	0.06	0 06
2	01	02	03	.04	04	05	06	07	08	09	.10	11	13
3	01	03	04	05	07	08	09	10	12	.14	16	17	19
4	02	04	06	07	.09	.11	12	14	16	18	.21	23	26
5	02	05	08	09	11	14	16	18	20	23	26	29	32
6	05	05	10	.10	15	.15	20	20	25	.30	30	35	40
7	05	05	10	15	.15	20	20	25	30	30	35	40	45
8	05	10	10	15	20	20	25	30	35	35	.40	45	50
9	05	10	15	15	20	25	.30	30	35	40	45	50	60
10	.05	.10	15	20	20	25	30	35	.40	45	50	55	65
11	1	.1	2	.2	2	3	3	4	4	.5	6	6	7
12	1	1	2	2	3	3	4	4	5	6	6	7	8
13	1	1	.2	2	3	4	4	.5	5	6	7	7	9
14	1	1	2	2	3	4	4	5	.6	6	7	8	.9
15	.1	2	2	3	3	4	5	5	6	7	8	9	1 0
16	1	2	2	.3	.4	4	5	6	7	.7	8	9	1 0
17	1	2	3	.3	.4	.5	5	6	7	8	.9	1 0	1 1
18	1	2	3	.3	4	5	6	6	7	8	9	1 0	1.2
19	1	2	.3	3	4	5	6	.7	.8	9	1 0	1 1	1 2
20	1	2	.3	4	4	5	.6	7	.8	9	1 0	1 1	1 3

Vertical length (m)	Vertical angle of sounding line at protractor (degrees)														
	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1	0 07	0 08	0 09	0.09	0 10	0 11	0.12	0 13	0.14	0 16	0 17	0 18	0.19	0 21	0.22
2	14	16	.17	.19	.21	22	24	26	29	.31	33	36	38	41	44
3	21	.24	26	28	31	34	37	40	43	46	50	54	58	.62	.66
4	28	.32	.34	.38	42	45	.49	.53	57	62	67	72	.77	82	88
5	35	40	43	47	.52	.56	61	66	72	78	.84	90	96	1 03	1 10
6	45	.45	50	.55	60	.65	75	.80	.85	95	1.00	1.05	1.15	1 25	1 35
7	50	.55	.60	65	.75	80	85	90	1 00	1 10	1 15	1 25	1 35	1 45	1 55
8	55	65	.70	75	85	90	1.00	1 05	1.15	1 25	1.35	1.45	1.55	1 65	1.75
9	65	70	.75	.85	95	1 00	1.10	1 20	1.30	1 40	1.50	1 60	1.75	1 85	2 00
10	70	.80	85	95	1 05	1 10	1.20	1 30	1.45	1 55	1.65	1 80	1.90	2 05	2.20
11	8	.9	1 0	1 0	1.1	1 2	1.3	1 4	1 6	1 7	1.8	2 0	2.1	2 3	2 4
12	8	1 0	1.0	1 1	1 2	1 3	1.5	1 6	1 7	1 9	2 0	2 2	2.3	2.5	2 6
13	9	1 0	1 1	1 2	1 4	1 5	1 6	1.7	1.9	2 0	2.2	2.3	2 5	2 7	2 9
14	1.0	1 1	1 2	1 3	1 5	1.6	1 7	1.8	2 0	2 2	2 3	2 5	2 7	2 9	3 1
15	1.1	1.2	1 3	1.4	1 6	1.7	1.8	2.0	2 1	2 3	2.5	2 7	2 9	3.1	3.3
16	1 1	1 3	1 4	1 5	1 7	1 8	2 0	2 1	2 3	2 5	2 7	2.8	3.1	3 3	3.5
17	1 2	1 3	1.5	1.6	1 8	1 9	2.1	2 2	2.4	2.6	2 8	3 0	3.3	3 5	3 8
18	1.3	1 4	1 5	1 7	1 9	2 0	2 2	2 4	2 6	2 8	3 0	3 2	3 5	3 7	4.0
19	1 4	1 5	1 6	1 8	2 0	2.1	2 3	2.5	2 7	2 9	3 2	3.4	3 6	3 9	4.2
20	1 4	1.6	1 7	1 9	2.1	2.2	2 4	2.6	2 9	3.1	3 3	3.6	3.8	4 1	4.4

selected intervals on the sounding line, and then using the tags to reference the water surface. This practice is almost equivalent to moving the reel to a position just above the water surface.

The correction for excess length of line below the water surface is obtained by using an elementary principle of mechanics. If a known horizontal force is applied to a weight suspended on a cord, the cord takes a position of rest at some angle with the vertical, and the tangent of the vertical angle of the cord is equal to the horizontal force divided by the vertical force of the weight. If several additional horizontal and vertical forces are applied to the cord, the tangent of the angle in the cord above any point is equal to a summation of the horizontal forces below that point, divided by the summation of the vertical forces below the point.

The distribution of total horizontal drag on the sounding line is in accordance with the variation of velocity with depth. The excess in length of the curved line over the vertical depth is the sum of the products of each tenth of depth and the function $(1/\cos P)-1$ of the corresponding angles; the function is derived for each tenth of depth by means of the tangent relation of the forces acting below any point.

The wet-line correction for even-numbered angles between 4° and 36° and for wet-line depths between 10 and 100 ft is shown in table 7. (Table 8 is a similar table in metric units.) The correction is applied to the nearest tenth of a foot. The wet-line correction cannot be determined until the air correction has been deducted from the observed depth.

The following assumptions were used in deriving the wet-line correction tables:

1. The weight will go to the bottom despite the force of the current.
2. The sounding is made when the weight is at the bottom but entirely supported by the line.
3. Drag on the streamlined weight in the sounding position is neglected.
4. The table is general and can be used for any size sounding weight or line that is designed to offer little resistance to the current.

If the direction of flow is not perpendicular to the measuring section, the angle of the measuring line as indicated by the protractor will be less than the true angle of the line. The air correction and wet-line correction will then be too small. To correct for this it is necessary to either measure by protractor the horizontal angle between the direction of flow and a perpendicular to the measurement section, or determine the horizontal-angle coefficient by the methods described on pages 142–143.

If the horizontal angle of the direction of flow is called H, the measured vertical angle P, and the true vertical angle X, the relation

TABLE 7.—*Wet-line table, giving difference, in feet, between wet-line length and vertical depth for selected vertical angles*

Wet-line length (ft)	Vertical angle of sounding line at protractor																	Wet-line length (ft)
	4°	6°	8°	10°	12°	14°	16°	18°	20°	22°	24°	26°	28°	30°	32°	34°	36°	
10	0.01	0.02	0.03	0.05	0.07	0.10	0.13	0.16	0.20	0.25	0.30	0.35	0.41	0.47	0.54	0.62	0.70	10
12	.01	.02	.04	.06	.09	.12	.15	.20	.24	.30	.36	.42	.49	.57	.65	.74	.84	12
14	.01	.02	.04	.07	.10	.14	.18	.23	.29	.35	.41	.49	.57	.66	.76	.87	.98	14
16	.01	.03	.05	.08	.12	.16	.20	.26	.33	.40	.47	.56	.65	.76	.87	.99	1.12	16
18	.01	.03	.06	.09	.13	.18	.23	.30	.37	.45	.53	.63	.73	.85	.98	1.12	1.26	18
20	.01	.03	.06	.10	.14	.20	.26	.33	.41	.50	.59	.70	.82	.94	1.09	1.24	1.40	20
22	.01	.04	.07	.11	.16	.22	.28	.36	.45	.55	.65	.77	.90	1.04	1.20	1.36	1.54	22
24	.01	.04	.08	.12	.17	.24	.31	.39	.49	.60	.71	.84	.98	1.13	1.31	1.49	1.68	24
26	.02	.04	.08	.13	.19	.25	.33	.43	.53	.64	.77	.91	1.06	1.23	1.41	1.61	1.81	26
28	.02	.04	.09	.14	.20	.27	.36	.46	.57	.69	.83	.98	1.14	1.32	1.52	1.74	1.95	28
30	.02	.05	.10	.15	.22	.29	.38	.49	.61	.74	.89	1.05	1.22	1.42	1.63	1.86	2.09	30
32	.02	.05	.10	.16	.23	.31	.41	.52	.65	.79	.95	1.12	1.31	1.51	1.74	1.98	2.23	32
34	.02	.05	.11	.17	.24	.33	.44	.56	.69	.84	1.01	1.19	1.39	1.60	1.85	2.11	2.37	34
36	.02	.06	.12	.18	.26	.35	.46	.59	.73	.89	1.07	1.26	1.47	1.70	1.96	2.23	2.51	36
38	.02	.06	.12	.19	.27	.37	.49	.62	.78	.94	1.12	1.33	1.55	1.79	2.07	2.36	2.65	38
40	.02	.06	.13	.20	.29	.39	.51	.66	.82	.99	1.18	1.40	1.63	1.89	2.18	2.48	2.79	40
42	.03	.07	.13	.21	.30	.41	.54	.69	.86	1.04	1.24	1.47	1.71	1.98	2.28	2.60	2.93	42
44	.03	.07	.14	.22	.32	.43	.56	.72	.90	1.09	1.30	1.54	1.80	2.08	2.39	2.73	3.07	44
46	.03	.07	.15	.23	.33	.45	.59	.75	.94	1.14	1.36	1.61	1.88	2.17	2.50	2.85	3.21	46
48	.03	.08	.15	.24	.35	.47	.61	.79	.98	1.19	1.42	1.68	1.96	2.27	2.61	2.98	3.35	48
50	.03	.08	.16	.25	.36	.49	.64	.82	1.02	1.24	1.48	1.75	2.04	2.36	2.72	3.10	3.49	50
52	.03	.08	.17	.26	.37	.51	.67	.85	1.06	1.29	1.54	1.82	2.12	2.45	2.83	3.22	3.63	52
54	.03	.09	.17	.27	.39	.53	.69	.89	1.10	1.34	1.60	1.89	2.20	2.55	2.94	3.35	3.77	54
56	.03	.09	.18	.28	.40	.55	.72	.92	1.14	1.39	1.66	1.96	2.28	2.64	3.05	3.47	3.91	56
58	.03	.09	.19	.29	.42	.57	.74	.95	1.18	1.44	1.72	2.03	2.37	2.74	3.16	3.60	4.05	58
60	.04	.10	.19	.30	.43	.59	.77	.98	1.22	1.49	1.78	2.10	2.45	2.83	3.26	3.72	4.19	60
62	.04	.10	.20	.31	.45	.61	.79	1.02	1.26	1.54	1.84	2.17	2.53	2.93	3.37	3.84	4.33	62
64	.04	.10	.20	.32	.46	.63	.82	1.05	1.31	1.59	1.89	2.24	2.61	3.02	3.48	3.97	4.47	64
66	.04	.11	.21	.33	.48	.65	.84	1.08	1.35	1.64	1.95	2.31	2.69	3.12	3.59	4.09	4.61	66
68	.04	.11	.22	.34	.49	.67	.87	1.12	1.39	1.69	2.01	2.38	2.77	3.21	3.70	4.22	4.75	68
70	.04	.11	.22	.35	.50	.69	.90	1.15	1.43	1.74	2.07	2.45	2.86	3.30	3.81	4.34	4.89	70
72	.04	.12	.23	.36	.52	.71	.92	1.18	1.47	1.79	2.13	2.52	2.94	3.40	3.92	4.46	5.03	72
74	.04	.12	.24	.37	.53	.73	.95	1.21	1.51	1.84	2.19	2.59	3.02	3.49	4.03	4.59	5.17	74
76	.05	.12	.24	.38	.55	.74	.97	1.25	1.55	1.88	2.25	2.66	3.10	3.59	4.13	4.71	5.30	76
78	.05	.12	.25	.39	.56	.76	1.00	1.28	1.59	1.93	2.31	2.73	3.18	3.68	4.24	4.84	5.44	78
80	.05	.13	.25	.40	.58	.78	1.02	1.31	1.63	1.98	2.37	2.80	3.26	3.78	4.35	4.96	5.58	80
82	.05	.13	.26	.41	.59	.80	1.05	1.34	1.67	2.03	2.43	2.87	3.35	3.87	4.46	5.08	5.72	82
84	.05	.13	.27	.42	.60	.82	1.08	1.38	1.71	2.08	2.49	2.94	3.43	3.96	4.57	5.21	5.86	84
86	.05	.14	.28	.43	.62	.84	1.10	1.41	1.75	2.13	2.55	3.01	3.51	4.06	4.68	5.33	6.00	86
88	.05	.14	.28	.44	.63	.86	1.13	1.44	1.80	2.18	2.60	3.08	3.59	4.15	4.79	5.46	6.14	88
90	.05	.14	.29	.45	.65	.88	1.15	1.48	1.84	2.23	2.66	3.15	3.67	4.25	4.90	5.58	6.28	90
92	.06	.15	.29	.46	.66	.90	1.18	1.51	1.88	2.28	2.72	3.22	3.75	4.34	5.00	5.70	6.42	92
94	.06	.15	.30	.47	.68	.92	1.20	1.54	1.92	2.33	2.78	3.29	3.84	4.44	5.11	5.83	6.56	94
96	.06	.15	.31	.48	.69	.94	1.23	1.57	1.96	2.38	2.84	3.36	3.92	4.53	5.22	5.95	6.70	96
98	.06	.16	.31	.49	.71	.96	1.25	1.61	2.00	2.43	2.90	3.43	4.00	4.63	5.33	6.08	6.84	98
100	.06	.16	.32	.50	.72	.98	1.28	1.64	2.04	2.48	2.96	3.50	4.08	4.72	5.44	6.20	6.98	100

TABLE 8.—*Wet-line table, giving difference, in meters, between wet-line length and vertical depth for selected vertical angles*

Wet-line length (m)	Vertical angle of sounding line at protractor (degrees)																									
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.05	0.05	0.06	0.06	0.07	0.07	0.08	0.08	0.09	0.10	0.10	0.11	0.12	0.12
2	.02	.02	.03	.03	.04	.04	.05	.05	.06	.06	.07	.08	.08	.09	.09	.10	.11	.11	.12	.13	.14	.15	.16	.17	.18	.19
3	.03	.04	.04	.05	.05	.06	.06	.07	.08	.08	.09	.10	.11	.12	.13	.14	.15	.16	.18	.19	.20	.21	.23	.24	.26	.27
4	.03	.04	.04	.05	.06	.07	.08	.09	.10	.11	.12	.13	.14	.16	.17	.18	.19	.21	.22	.24	.25	.27	.28	.30	.32	.34
5	.04	.05	.05	.05	.07	.08	.09	.10	.11	.13	.14	.15	.17	.18	.20	.22	.24	.26	.27	.29	.31	.33	.35	.38	.40	.42
6	.05	.05	.05	.05	.10	.10	.10	.10	.15	.15	.15	.15	.20	.20	.25	.25	.25	.30	.30	.35	.35	.40	.40	.45	.45	.50
7	.05	.05	.05	.10	.10	.10	.10	.15	.15	.15	.20	.20	.25	.25	.25	.30	.30	.35	.35	.40	.40	.45	.50	.50	.55	.55
8	.05	.05	.10	.10	.10	.10	.15	.15	.15	.20	.20	.25	.25	.30	.30	.35	.35	.40	.40	.45	.45	.50	.55	.55	.60	.65
9	.05	.10	.10	.10	.10	.15	.15	.20	.20	.20	.25	.25	.30	.30	.35	.35	.40	.45	.45	.50	.55	.55	.60	.65	.70	.70
10	.05	.10	.10	.10	.15	.15	.15	.20	.20	.25	.25	.30	.30	.35	.35	.40	.45	.45	.50	.55	.60	.60	.65	.70	.75	.80
11	.1	.1	.1	.1	.2	.2	.2	.2	.2	.3	.3	.3	.3	.4	.4	.4	.5	.5	.6	.6	.6	.7	.7	.8	.8	.9
12	.1	.1	.1	.1	.2	.2	.2	.2	.3	.3	.3	.3	.4	.4	.4	.5	.5	.6	.6	.6	.7	.7	.8	.8	.9	.9
13	.1	.1	.1	.1	.2	.2	.2	.2	.3	.3	.3	.4	.4	.4	.5	.5	.6	.6	.7	.7	.8	.8	.9	.9	1.0	1.0
14	.1	.1	.1	.1	.2	.2	.2	.3	.3	.3	.4	.4	.4	.5	.5	.6	.6	.7	.7	.8	.8	.9	.9	1.0	1.0	1.1
15	.1	.1	.1	.2	.2	.2	.2	.3	.3	.3	.4	.4	.5	.5	.5	.6	.6	.7	.7	.8	.8	.9	1.0	1.0	1.1	1.2
16	.1	.1	.1	.2	.2	.2	.3	.3	.3	.4	.4	.4	.5	.5	.6	.6	.7	.7	.8	.9	.9	1.0	1.1	1.1	1.2	1.2
17	.1	.1	.2	.2	.2	.2	.3	.3	.3	.4	.4	.5	.5	.6	.6	.7	.7	.8	.8	.9	1.0	1.0	1.1	1.2	1.2	1.3
18	.1	.1	.2	.2	.2	.3	.3	.3	.4	.4	.5	.5	.6	.6	.7	.7	.8	.8	.9	1.0	1.0	1.1	1.2	1.2	1.3	1.4
19	.1	.1	.2	.2	.2	.3	.3	.3	.4	.4	.5	.5	.6	.6	.7	.7	.8	.9	.9	1.0	1.1	1.2	1.2	1.3	1.4	1.5
20	.1	.2	.2	.2	.2	.3	.3	.4	.4	.5	.5	.6	.6	.7	.7	.8	.8	.9	1.0	1.1	1.1	1.2	1.3	1.4	1.5	1.6

between the angles is expressed by the equation

$$\tan X = \frac{\tan P}{\cos H} \text{ (fig. 100).} \qquad (12)$$

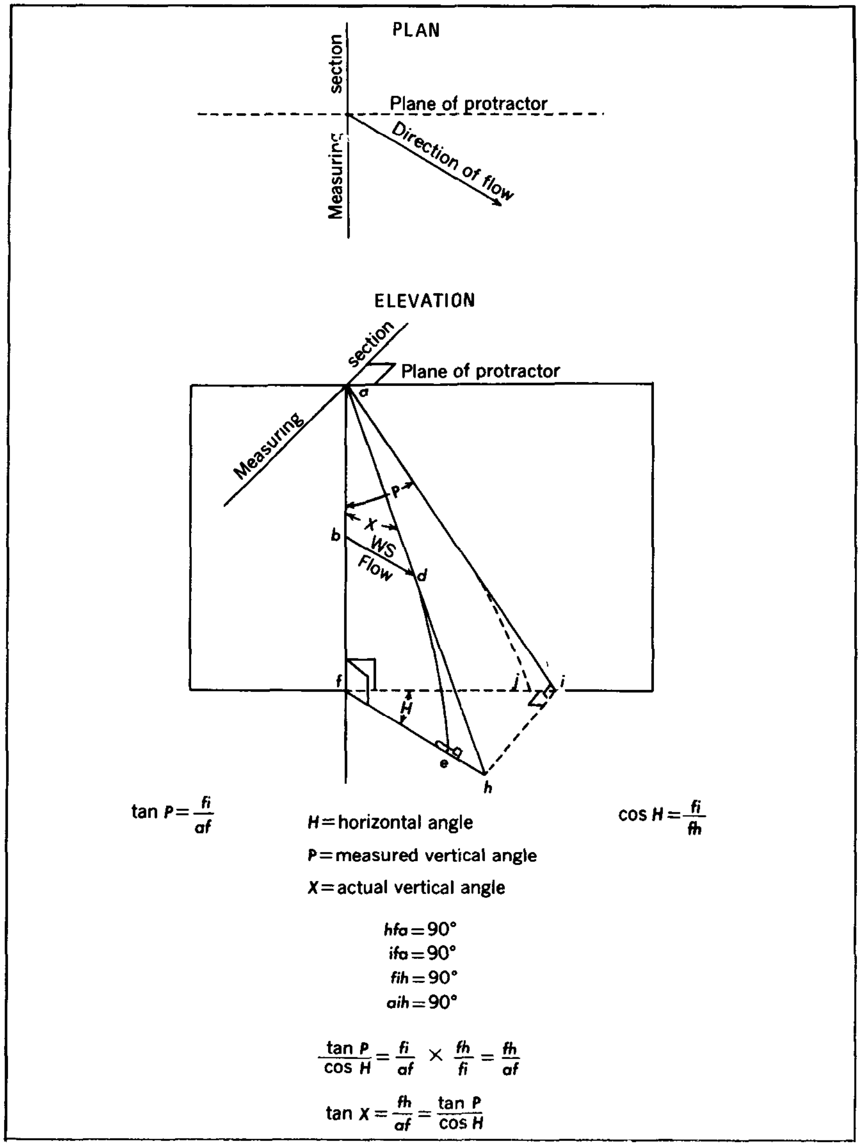


FIGURE 100.—Sketch of geometry of relation of actual to measured vertical angle when flow direction is not normal to measurement section.

Table 9 gives the quantities in tenths of degrees, to be added to observed vertical angles to obtain the true vertical angles for a range of horizontal angles between 8° and 28°.

The conditions that cause error in sounding the depth also cause error in setting the meter at selected depths. The correction tables are not strictly applicable to the problem of setting the meter for velocity observations because of the increased horizontal force on the sounding weight caused by higher velocities when the weight is raised from the streambed. A meter placed in deep, swift water by the ordinary methods for observations at selected percentages of the depth will be too high in the water. The use of tables 5–9 will tend to eliminate this error in the placement of the meter, and although not strictly applicable, their use for this purpose has become general.

For the 0.2-depth position, the curvature of the wet line is assumed to be negligible, and the length of sounding line from the apex of the vertical angle to the weight is considered a straight line. The method used to place the meter at the 0.2-depth position is as follows:

1. Compute the 0.2 value of the vertical depth.
2. Lower the meter this depth into the water and read the vertical angle.
3. Obtain the air correction from table 5 or 6. The vertical length used to obtain the air correction is the sum of (a) 0.2 of the vertical depth, (b) the distance from the water surface to the apex of the angle, and (c) the distance from the bottom of the weight to the meter.
4. Let out an additional amount of line equal to the air correction.
5. If the angle increases appreciably when the additional line is let out, let out more line until the total additional line, the angle, and the vertical distance are in agreement with figures in the air-correction table.

To set the meter at the 0.8-depth position, a correction to the amount of line reeled in must be made for the difference, if any, between the

TABLE 9.—*Degrees to be added to observed vertical angles to obtain actual vertical angles when flow direction is not normal to measurement section*

Observed vertical angle	Horizontal angle					
	8° cos=0.99	12° cos=0 98	16° cos=0 96	20° cos=0 94	24° cos=0 91	28° cos=0.88
8°	0.1	0.2	0.3	0.5	0.8	1.0
12°	.1	.3	.5	.8	1.1	1.5
16°	.1	.4	.6	1.0	1.4	2.0
20°	.2	.4	.7	1.2	1.7	2.4
24°	.2	.5	.8	1.4	2.0	2.8
28°	.2	.5	1.0	1.5	2.2	3.0
32°	.2	.6	1.0	1.6	2.4	3.3
36°	.2	.6	1.1	1.7	2.5	3.4

air correction for the sounding position and that for the 0.8-depth position. This difference is designated as m in table 10. If the angle increases for the 0.8-depth position, the meter must be lowered; if the angle decreases the meter must be raised.

In setting the 0.8-depth position of the meter, the wet-line correction may require consideration if the depths are more than 40 ft and if the change in vertical angle is more than 5 percent. If the vertical angle remains the same or decreases, the wet-line correction (table 7 or 8) for the 0.8-depth position is less than the wet-line correction for the sounding position by some difference designated as n in table 10. If the vertical angle increases, the difference in correction n deminishes until the increase in angle is about 10 percent; for greater increases in angle, the difference between corrections also increases. Table 10 summarizes the effect on air- and wet-line corrections caused by raising the meter from the sounding position to the 0.8-depth position.

For slight changes in the vertical angle, because of the differences m and n in the air- and wet-line corrections, the adjustments to the wet-line length of the 0.8-depth position are generally small and usually can be ignored. Table 10 indicates, however, that the meter may be placed a little too low if the adjustments are not made. Because of this possibility, the wet-line depth instead of the vertical depth is sometimes used as the basis for computing the 0.8-depth position, and no adjustments are made for the differences m and n.

CASE B. DEPTH CANNOT BE SOUNDED BUT STANDARD CROSS SECTION IS AVAILABLE

On occasion it is not possible to sound the bottom, but a standard measurement cross section at the bridge or cableway may be available from previous measurements that were made. Such a cross section

TABLE 10.—*Summary table for setting the meter at 0.8-depth position in deep, swift streams*

Change in vertical angle	Air correction		Wet-line correction	
	Direction of change	Correction to meter position	Direction of change	Correction to meter position
None	None	None	Decrease	Raise meter the distance n.
Decrease	Decrease	Raise meter the distance m.	do	Do.
Increase	Increase	Lower meter the distance m.	Decrease, then increase.	[1]

[1]Raise meter the distance n unless the increase in angle is greater than about 10 percent, then it is necessary to lower the meter the distance n.

will be useful only if all discharge measurements use the same permanent initial point for the stationing of verticals across the width of the stream, and if there is an outside reference gage or reference point on the bank or bridge to which the water-surface elevation at the measurement cross section may be referred. In the situation described above, the following procedure is used:

1. Determine depths at the observation verticals from the standard cross section and the known water-surface elevation at the measurement cross section.
2. Measure the velocity at 0.2 of the depth.
3. Compute the measurement in the normal manner using the measured velocities as though they were the mean velocities in the vertical, and using the depths from step 1.
4. Determine the coefficient to adjust the 0.2-depth velocity to mean velocity in the cross section, as explained on pages 135–136.
5. Apply the coefficient from step 4 to the computed discharge from step 3.

CASE C. DEPTH CANNOT BE SOUNDED AND NO STANDARD CROSS SECTION IS AVAILABLE

When it is not possible to sound the depth and a standard cross section is not available, the following procedure is used:

1. Refer the water-surface elevation before and after the measurement to an elevation reference point on a bridge, on a driven stake, or on a tree at the water's edge. (It is assumed here that no outside reference gage is available at the measurement cross section.)
2. Estimate the depth and observe the velocity at 0.2 of the estimated depth. The meter should be at least 2.0 ft (0.6 m) below the water surface. Record in the notes the actual depth the meter was placed below the water surface. If an estimate of the depth is impossible, place the meter 2.0 ft below the water surface and observe the velocity there.
3. Make a complete measurement at a lower stage and include some vertical-velocity curves.
4. Use the complete measurement and difference in stage between the two measurements to determine the cross section of the first measurement. To determine whether the streambed has shifted, the cross section should be compared with one obtained in a previous measurement at that site.
5. Use vertical-velocity curves, or the relationship between mean velocity and 0.2-depth velocity, to adjust the velocities observed in step 2 to mean velocity.
6. Compute the measurement in the normal manner using the depths from step 4 and the velocities from step 5.

CASE D. METER CANNOT BE SUBMERGED

If it is impossible to keep the meter and weight in the water because of high velocities and (or) floating drift, use the following procedure:

1. Obtain depths at the measurement verticals by the method explained for case B if a standard cross section is available, or by the method explained above for case C if no standard cross section is available.
2. Measure surface velocities with an optical current meter, as explained on pages 91–93, 137–138.
3. Compute the measurement in the normal manner using the surface velocities as though they were the mean velocities in the vertical, and using the depths from step 1.
4. Apply the appropriate velocity coefficient to the discharge computed in step 3; use a coefficient of 0.86 for a natural channel and 0.90 for an artificial channel.

If an optical current meter is not available, time floating drift over a measured course. (See p. 261–262.)

It should be noted here that the amount of floating drift or ice is usually greatly reduced just after the crest of a rise in stage. It may be possible at that time to obtain velocity observations with a standard current meter.

COMPUTATION OF MEAN GAGE HEIGHT OF A DISCHARGE MEASUREMENT

The mean gage height of a discharge measurement represents the mean stage of the stream during the measurement period. Because the mean gage height for a discharge measurement is one of the coordinates used in plotting the measurements to establish the stage-discharge relation, an accurate determination of the mean gage height is as important as an accurate measurement of the discharge. The computation of the mean gage height presents no problem when the change in stage is uniform and no greater than about 0.15 ft (0.05 m), for then the mean may be obtained by averaging the stage at the beginning and end of the measurement. However, measurements must often be made during periods when the change of stage is neither uniform nor slight.

As a prerequisite for obtaining an accurate mean gage height, the clock time at the beginning and end of the measurement should be recorded on the measurement notes, and additional readings of the clock time should be recorded on the notes at intervals of 15 to 20 min during the measurement. After the discharge measurement has been completed, the recorder chart should be read, and breaks in the slope of the gage-height graph that occurred during the measurement should be noted The breaks in slope are useful in themselves and are also used to determine the gage height corresponding to the clock times noted during the measurement. If the station is equipped with a digital recorder, the gage-height readings punched during the measurement are to be read. At nonrecording stations the only way to obtain intermediate readings is for the stream gager to stop a few times during the measurement to read the gage, or to have someone else do this for him.

If the change in stage is greater than 0.15 ft (0.05 m) or if the change in stage has not been uniform, the mean gage height is obtained by weighting the gage heights corresponding to the clock-time observations. The weighting is done by using either partial discharge or time as the weighting factor. In the past the weighting in the U.S.A. was always done on the basis of partial discharges, but recent study indicates that discharge-weighting usually tends to overestimate the mean gage height, whereas time-weighting usually tends to underestimate the mean gage height. On the basis of the present state of our knowledge, it is suggested that the mean gage height for a discharge measurement be computed by both methods, after which the two results are averaged. A description of the two methods follows.

In the discharge-weighting process, the partial discharges measured between clock observations of gage height are used with the mean gage heights for the periods when the partial discharges were measured. The formula used to compute mean gage height is

$$H = \frac{q_1h_1 + q_2h_2 + q_3h_3 \ldots\ldots\ldots + q_nh_n}{Q}, \qquad (13)$$

in which

H = mean gage height (ft or m),

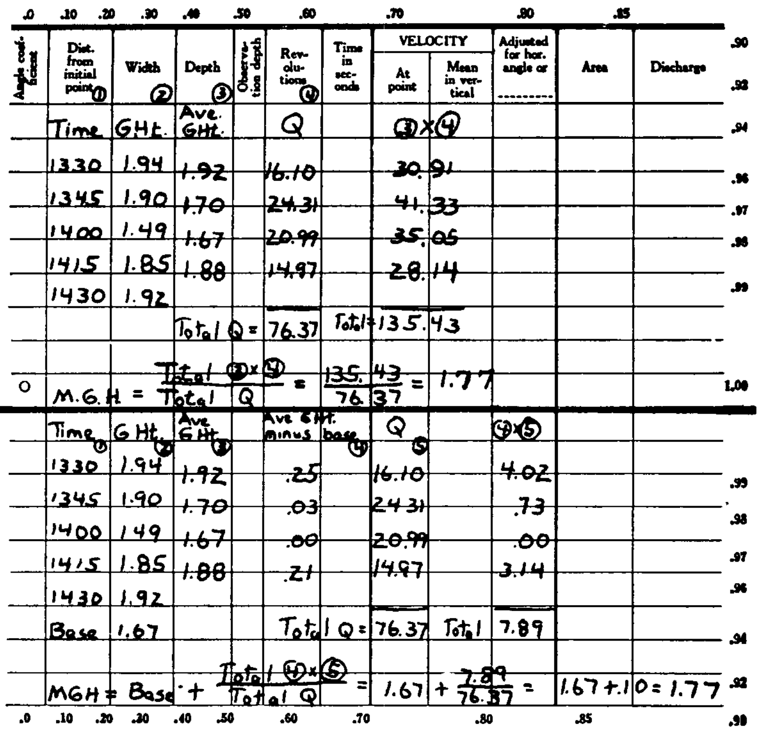
Q = total discharge measured (ft^3/s or m^3/s) = $q_1 + q_2 + q_3 \ldots . +$ q_n,

where

$q_1, q_2, q_3, \ldots . q_n$ = discharge (ft^3/s or m^3/s) measured during time interval 1, 2, 3, ... n and

$h_1, h_2, h_3, \ldots . h_n$ = average gage height (ft or m) during time interval 1, 2, 3, ... n.

Figure 101 shows the computation of a discharge-weighted mean gage height. The graph at the bottom of figure 101 is a reproduction of the gage-height graph during the discharge measurement. The discharges are taken from the current-meter measurement notes shown in figure 42. The upper computation of the mean gage height in figure 101 shows the computation using equation 13. The lower computation has been made by a shortcut method to eliminate the multiplication of large numbers. In that method, after the average gage height for each time interval has been computed, a base gage height, which is usually equal to the lowest average gage height, is chosen. Then, the



Time ①	GHt. ②	Ave. GHt. ③	Q ④	③×④
1330	1.94	1.92	16.10	30.91
1345	1.90	1.70	24.31	41.33
1400	1.49	1.67	20.99	35.05
1415	1.85	1.88	14.97	28.14
1430	1.92			
		Total Q =	76.37	Total = 135.43

M.G.H = Total ③×④ / Total Q = 135.43 / 76.37 = 1.77

Time ①	G Ht. ②	Ave. G Ht. ③	Ave GHt. minus base ④	Q ⑤	④×⑤
1330	1.94	1.92	.25	16.10	4.02
1345	1.90	1.70	.03	24.31	.73
1400	1.49	1.67	.00	20.99	.00
1415	1.85	1.88	.21	14.97	3.14
1430	1.92				
Base	1.67		Total Q =	76.37	Total 7.89

MGH = Base + Total ④×⑤ / Total Q = 1.67 + 7.89 / 76.37 = 1.67+.10 = 1.77

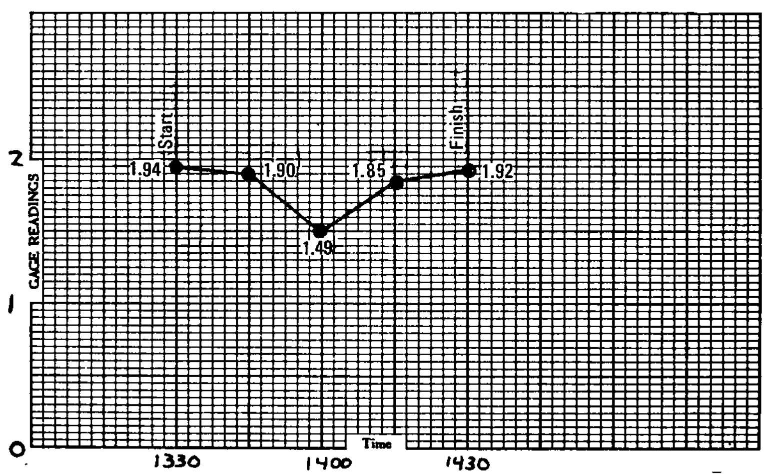


FIGURE 101.—Computation of discharge-weighted mean gage height.

differences between the base gage height and the average gage heights are used to weight the discharges. When the mean difference has been computed, the base gage height is added to it.

In the time-weighting process, the arithmetic mean gage height for time intervals between breaks in the slope of the gage-height graph are used with the duration of those time periods. The formula used to compute mean gage height is

$$H = \frac{t_1h_1 + t_2h_2 + t_3h_3 \ldots\ldots + t_nh_n}{T} \quad (14)$$

in which

H = mean gage height, in feet or meters,

T = total time for the measurement, in minutes = $t_1 + t_2 + t_3 \ldots\ldots t_n$,

$t_1, t_2, t_3 \ldots\ldots t_n$ = duration of time intervals between breaks in slope of the gage-height graph, in minutes, and

$h_1, h_2, h_3 \ldots\ldots h_n$ = average gage height, in feet or meters, during time interval 1, 2, 3, ... n.

Using the data from figure 101, the computation of the time-weighted mean gage height is as follows:

Average gage height (h)	*Time interval* (t)	$h \times t$
1.92	15	28.80
1.70	15	25.50
1.67	15	25.05
1.88	15	28.20
Total	60	107.55

Mean gage height = 107.55/60 = 1.79 ft

In the example used above there is little difference between the discharge-weighted mean gage height (1.77 ft) and the time-weighted mean gage height (1.79 ft); the average of the two values, 1.78 ft, is the preferred mean gage height for the discharge measurement.

When extremely rapid changes in stage occur during a measurement, the weighted mean gage height is not truly applicable to the discharge measured. To reduce the range in stage during the measurement, measurements under those conditions should be made more rapidly than those made under constant or slowly changing stage. It should be realized, however, that shortcuts in the measurement procedure usually reduce the accuracy of the measured discharge. Therefore measurement procedures during rapidly changing stage must be optimized to produce a minimal combined error in measured discharge and computed mean gage height.

MEASUREMENT PROCEDURES DURING RAPIDLY CHANGING STAGE

The preceding discussion on computing the mean gage height of discharge measurements demonstrated that under conditions of rapidly changing stage, measurement procedures must be streamlined, even at the expense of some accuracy. The reduction in measurement time makes it possible to obtain a gage-height value that is representative of the measured discharge. Where streams are uncontrolled, flood rises are more rapid on small streams than on large streams, because small streams are subject to flash floods that may rise and fall with sufficient rapidity to produce peak flows of almost momentary duration. Consequently the discussion that follows distinguishes between the procedures to be followed for measuring large streams and those for small streams, during periods of rapidly changing stage. The procedure to be followed for measuring streams whose flow is controlled by hydroelectric powerplants was discussed on page 140.

CASE A. LARGE STREAMS

During periods of rapidly changing stage on large streams, the time consumed in making a discharge measurement may be reduced by modifying the standard measurement procedure in the following manner:

1. Use the 0.6-depth method (p. 134). The 0.2-depth method (p. 135) or the subsurface method (p. 136) may be used if placing the meter at the 0.6-depth creates vertical angles requiring time-consuming corrections, or if the vertical angle increases because of drift collecting on the sounding line.
2. Reduce the velocity-observation time to about 20–30 s.
3. Reduce the number of sections taken to about 15–18.

By incorporating all three of the above practices a measurement can be made in 15–20 min. If the subsurface method of observing velocities is used, some vertical-velocity curves will be needed later to establish coefficients to convert observed velocity to mean velocity.

Carter and Anderson (1963) have shown that discharge measurements having 30 verticals, for which the two-point method of observation was used with a 45-s period of observation, will have a standard error of 2.2 percent (see p. 181–183). That means that two-thirds of the measurements made using standard procedures would be in error by 2.2 percent or less. They have also shown that the standard error for a 25-s period of observation, using the 0.6-depth method with depth and velocity observed at 16 verticals, is 4.2 percent. The error caused by using the shortcut method is generally less than the error to be expected as a result of the shifting flow patterns that commonly occur during periods of rapidly changing stage, and in addition, uncertainty concerning the appropriate mean gage height for the measurement is eliminated.

CASE B. SMALL STREAMS

The discussion that follows deals with the measurement of flash floods on small streams. Flash floods begin and end with such abruptness that if the flow is to be measured, the hydrographer must have advance warning of the occurrence of such an event. The warning will enable him to reach the measuring site and make all necessary preparations for current-meter measurements before the stream starts to rise at the site. Once the rise begins it is essential that the many point observations required be made as rapidly as possible because of the rapidly changing discharge.

After arriving at the measuring site where the flash flood is expected, the hydrographer first marks the location of the observation verticals he intends to use. These marks are placed on the bridge rail or cableway that is used for discharge measurements. He then determines the elevation of the streambed, referred to gage datum, at those verticals. That is done both to save time during the actual discharge measurement and because he may be unable to sound the streambed when the flood is in progress. An auxiliary staff gage that can be read from the measuring bridge or cableway should be part of the gaging equipment.

In measuring the discharge during a flash flood, the procedure differs in the following ways from that used in making a conventional current-meter discharge measurement.

1. *Use 6 to 10 observation verticals in the measurement cross section.*—The actual number of verticals used will depend on the width and uniformity of the cross section. Current-meter observations are started when the stage starts to rise and are continued until the flow recedes to normal, or near-normal stage. After completing one traverse of the cross section, the next traverse is started immediately in the opposite direction, and observations continue to be made back and forth across the stream.

2. *Time is saved by making a single velocity observation at each observation vertical.*—If depths, velocities, and the absence of floating drift permit, the 0.6-depth method (p. 134) or 0.2-depth method (p. 135) is used. Otherwise, an optical current meter is used in the surface-velocity method (p. 137).

3. *Readings of the auxiliary staff gage are made at every third velocity observation and clock time is also recorded.*—That is done because the rapid change in stage will commonly make it impossible to later obtain accurate stages, corresponding to the time of each velocity

observation, from the automatic gaging-station record. Furthermore, during periods of rapidly changing stage, a staff-gage record is usually more reliable than an automatic-gage record because of "drawdown" at the intake or because of well or intake lag. Moreover if the gaging station is equipped with a digital recorder, the frequency of punches will seldom be adequate for a flash flood.

After the stream has receded, determinations of streambed elevation at the observation verticals are again made to learn if scour or fill has occurred. If there has been a change in streambed elevation, the change is prorated with time, or in accordance with the best judgment of the hydrographer, to provide the values of depth needed to compute discharge. The most reliable discharge results are obtained, of course, where the streambed is stable or relatively so, leaving no serious uncertainty about stream depths during the measurement.

4. *Computation procedure*—Normally, the discharge of a stream is computed for each current-meter traverse of the measurement cross section, using observed velocities, depths, and incremental channel widths. Because of the rapid change of stage that occurs during the course of a velocity-observation traverse, that conventional computation procedure should not be used when measuring the discharge of flash floods. If the conventional procedure is used there is great uncertainty as to the stage that applies to the computed discharge value. The recommended computation procedure for a flash flood is as follows.

The first step is to construct an individual relation of mean velocity to stage for each observation vertical. The mean velocity, it will be recalled, is obtained by applying an appropriate coefficient to each observed value of surface or subsurface velocity. For each vertical, mean velocity is plotted against stage, and each point is identified by clock time. A single smooth curve is usually fitted to the points, but the scatter of the points may indicate the need for two curves—one for the rising limb of the hydrograph and the other for the falling limb.

In either event, all the data needed are now available for constructing the stage-discharge relation for the entire cross section. The distance between observation verticals (incremental width) is known, and for any selected stage the corresponding depth and mean velocity at each observation vertical are likewise known. Those data are then used, in the conventional manner, to compute the total discharge corresponding to the selected stage. By repeating that operation for several stages, one obtains a stage-discharge relation for the entire range of stage, or, if necessary, two such relations—one for the rising limb of the hydrograph and one for the falling limb. As a final step, the stage-discharge relation(s) is applied to the stage hydrograph to compute the discharge hydrograph. In the absence of a reliable automatic stage record, the numerous visually observed values of stage provide the stage hydrograph.

CORRECTION OF DISCHARGE FOR STORAGE DURING MEASUREMENT

If a discharge measurement is made at a significant distance from the gage during a change in stage, the discharge passing the gage during the measurement will not be the same as the discharge at the measurement section because of the effect of channel storage between the measurement section and the gage.

Adjustment is made for channel storage by applying to the measured discharge a quantity obtained by multiplying the channel surface area by the average rate of change in stage in the reach. The equation used is

$$Q_G = Q_m \pm WL \frac{\Delta h}{\Delta t}, \qquad (15)$$

where

Q_G = discharge passing the gage control (ft^3/s or m^3/s),

Q_m = measured discharge (ft^3/s or m^3/s),

W = average width of stream between measurement section and control (ft or m),

L = length of reach between measurement section and control (ft or m),

Δh = average change in stage in the reach L during the measurement (ft or m), and

Δt = elapsed time during measurement (s).

A reference point or a temporary gage is set at the measurement cross section if channel storage is likely to be significant. The water-surface elevations at the section and at the gage are determined before and after the measurement to compute Δh. If the measurement is made upstream from the control, the adjustment will be plus for falling stages and minus for rising stages; if made downstream from the control, the adjustment will be minus for falling stages and plus for rising stages.

Figure 102 shows the front sheet of a measurement that has been made 0.6 mi upstream from the control during a period of changing stage. The computation of the adjustment for storage for the measurement shown in figure 102 follows:

Measurement made 0.6 mi upstream, L = 3,170 ft.

Average width (W) between measurement section and control = 150 ft.

Change in stage at control, 5.84 to 6.74 ft = +0.90 ft.

Change in stage at measurement section, 12.72 to 13.74 = +1.02 ft. (Readings taken at measurement section from a reference point before and after measurement.)

Average change in stage (Δh) = (0.90 + 1.02) ÷ 2 = 0.96 ft.
Elapsed time during measurement = 1¼ hr = 4,500 s.
Measured discharge Q_m = 8,494 ft³/s.

$$Q_G = 8{,}494 - 150\,(3{,}170)\,\frac{0.96}{4{,}500} = 8{,}494 - 101 = 8{,}393 \text{ ft}^3/\text{s. Use}$$

8,390 ft³/s.

9-275-F
Jan. 1960

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Meas. No. 264
Comp. by TJB
Checked by

DISCHARGE MEASUREMENT NOTES

Sta. No. 1-9946.5
Big Creek near Dogwood, Va.
Date Mar. 26 1962 Party T. J. Buchanan
Width 140 Area 1,040 Vel 8.07 G. H. 6.29 Disch.* 8,390
Method .2-.8 No. secs. 30 G. H. change +.90 in 1¼ hrs Susp 75C
Method coef. 1 Hor. angle coef Varies Susp. coef. 1.00 Meter No. 3684

EST Time	El. T	Recorder	T Inside	Outside
1415	5.54	5.54	5.54	5.52
1440	Start	5.84		
1500		6.08		
1530		6.44		
1555	Finish	6.74		
1630	7.16	7.16	7.16	7.14
Weighted M. G. H.				
G. H. correction				
Correct M. G. H.				

Date rated 2-16-62 Used rating for rod ✓ susp Meter 1.0 ft above bottom of wt Tags checked Yes
Spin before meas 2:55 after 2:50
Meas plots % diff from rating
Wading, cable, ice, boat, upstr., downstr., side bridge 0.6 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 Fairly even; stone and gravel bottom.
Flow Good distribution; some Weather Raining
Other debris flowing. Air 44 °F @ 1635
Gage OK Water 38 °F @ 1635
Record removed Yes Intake flushed
Observer Talked with
Control Clear
Remarks * Discharge adjusted for storage effect
Qm = 8,494
G. H. of zero flow ft. Elev. RP = 30.00
RP to WS @ 1440 = 17.28; 30.00 − 17.28 = 12.72
RP to WS @ 1555 = 16.26; 30.00 − 16.26 = 13.74

16—76791-1

FIGURE 102.—Discharge-measurement notes with discharge adjusted for channel storage.

The adjusted discharge figure is the one used for defining the stage-discharge relation.

The adjustment of measured discharge for storage during a period of changing discharge is a separate and distinct problem from that of making adjustments for variable slope caused by changing discharge. (See p. 418–421.) Regardless of whether or not the discharge is to be adjusted later for variable slope, the storage adjustment to discharge is made immediately after completion of the discharge measurement.

SUMMARY OF FACTORS AFFECTING THE ACCURACY OF A DISCHARGE MEASUREMENT

The factors that affect the accuracy of a discharge measurement have been discussed in appropriate sections of the preceding text. This section provides a brief recapitulation of those factors.

1. *Equipment.*—Accurate measurement requires that measurement equipment be properly assembled and maintained in good condition. To avoid damage in transport, the equipment should be packed in appropriate containers or compartments of the vehicle used by the hydrographer. Current meters are especially susceptible to damage when in use, because measurements must often be made when drift or floating ice is present in a stream.

2. *Characteristics of the measurement section.*—The basic characteristics of the measurement section affect measurement accuracy. The attributes desired in a measurement section are those listed on page 139. If possible, the section should be deep enough to permit use of the two-point method of measuring velocity. The presence of bridge piers in or near the measurement section adversely affects the distribution of velocities. Piers also tend to induce local bed scour which affects the uniformity of depth. Those adverse effects are increased if the bridge piers tend to collect drift on their upstream faces.

3. *Spacing of observation verticals.*—The spacing of observation verticals in the measurement section can affect the accuracy of the measurement. Twenty-five to 30 verticals should normally be used, and the verticals should be spaced so that each subsection will have approximately equal discharge. However, a measurement vertical should be located fairly close to each bank and at "breaks" in depth. The spacing of the verticals should also be reduced in the vicinity of bridge piers. If many bridge piers are present in the section or if the streambed is nonuniform, more verticals than the recommended 25–30 should be used.

4. *Rapidly changing stage.*—When the stage changes rapidly during a discharge measurement, the computed discharge figure loses some of its significance, and there is uncertainty as to the appropriate gage height to apply to that discharge figure. Consequently, the standard procedure for making discharge measurements should be

shortened when the stage is changing rapidly, as explained on pages 174–177, even at the expense of some accuracy. The reduction in measurement time makes it possible to obtain a mean gage height that is representative of the measured discharge.

5. *Measurement of depth and velocity.*—Inaccuracies in sounding and in the placement of the current meter are most likely to occur in those sections having great depths and velocities. Heavy sounding weights should be used to reduce the vertical angle made by the sounding line, and where vertical angles exist, tags and (or) correction tables should be used in determining vertical distances. Where velocities are not perpendicular to the measurement section, the cosine of the angle between the perpendicular and the direction of the current must be determined. If a velocity-azimuth-depth assembly (p. 129–130) is not used, it is necessary to assume that the angle of the surface current prevails throughout the vertical; that assumption may be erroneous.

6. *Ice in the measuring section.*—Reliable measurements may usually be made when measuring from ice cover if the measurement verticals are free of slush ice. Slush ice interferes with the operation of the current-meter rotor and also causes difficulty in determining the effective depth of water. If the effective depth is considered to be that portion of the depth in which the current meter indicates velocity, the assumed effective depth may be too small if slush ice is interfering with free operation of the rotor. Collections of slush ice are generally thickest near the upstream end of ice-covered pools, and those areas should therefore be given little consideration as measurement sections. If the ice cover is layered so that there is water flowing between ice layers, it is almost impossible to obtain a reliable discharge measurement, particularly if the water layers are too thin to permit insertion of the meter between ice layers. The exposure of a wet current meter to subfreezing air temperatures may cause serious underregistration of the current meter as a result of ice forming in the meter bearings and contact chamber. Therefore, once the measurement is started, the current meter should be kept in the water as much as possible to avoid exposure to the cold air.

7. *Wind.*—Wind may affect the accuracy of a discharge measurement by obscuring the angle of the current, by creating waves that make it difficult to sense the water surface prior to sounding the depth, and by affecting the velocity at 0.2-depth in shallow streams, thereby distorting the vertical-velocity distribution. When making boat measurements, the wind-caused waves may induce vertical motion in a cable-suspended meter, or the wind may cause an oscillatory horizontal movement of the boat against the tag line; either movement may affect the operation of the current meter. Table 11 sum-

marizes the results of an investigation (Kallio, 1966) on the effect of vertical motion on the operation of Price, vane-type, and Ott (cosine rotor 8646–A) current meters. The plus signs in table 11 indicate overregistration by the meter; the minus signs indicate underregistration.

ACCURACY OF A DISCHARGE MEASUREMENT MADE UNDER AVERAGE CONDITIONS

Carter and Anderson (1963) made a statistical analysis of the error in discharge measurements made in natural streams under average measuring conditions. They tested the following four assumptions on which the computation of discharge measurements is based:

1. The rating of the current meter is applicable to the conditions of the measurement.
2. The velocity observed at a point is a true time-averaged velocity.
3. The ratio is known between the velocity of selected points in the vertical and the mean velocity in the vertical.

TABLE 11.—*Registration errors, in percentage of stream velocity, caused by vertical motion of current meter*

Stream velocity (ft/s)	Vertical motion (ft/s)						
	0.2	0.4	0.6	0.8	1.0	1.2	1.5
Price current meter (suspended by a cable)							
0.5	−2.0	+10	+36	+72	+120	+150	+210
1.0	−3.0	−1.0	+10	+24	+40	+50	+56
1.5	−6.7	−6.7	−4.0	+1.3	+8.0	+25	+27
2.0	−2.5	−2.5	−2.5	−2.0	0	+4.0	+14.0
2.5	0	0	0	0	0	+.8	+4.0
3.0	0	0	0	0	−2.3	−2.0	0
4.0	0	0	0	0	−1.3	−1.3	0
5.0	+.4	+1.0	+.6	0	−.2	0	+.8
7.0	−.7	−.4	0	+.1	−.4	−.7	−.4
10.0	−.5	−.3	0	0	−.3	−.7	−1.3
Vane-type current meter (suspended by a rod)							
0.5	+4.0	+6.0	+20	+44	+72	+100	+160
1.0	+5.0	+10	+12	+10	+11	+15	+26
1.5	+3.3	+8.7	+10	+6.7	+3.3	+3.3	+10
2.0	+2.0	+6.5	+9.0	+9.5	+8.5	+6.0	+7.5
2.5	+2.0	+4.4	+6.4	+7.6	+8.0	+7.2	+6.4
3.0	−1.7	+3.7	+5.3	+6.7	+7.3	+7.7	+6.7
4.0	+1.2	+.8	+.3	+1.0	+2.5	+3.8	+3.3
5.0	−1.0	−2.6	−2.8	−2.0	−.4	−.2	−2.0
7.0	−.7	−.7	−.3	0	0	+.3	−.4
Ott current meter (cosine rotor 8646-A, standard tailpiece without vertical stabilizer, and two-pin attachment to cable hanger)							
0.5	0	+6.0	+10	+20	+30	+44	+70
1.0	0	0	0	+4.0	+9.0	+15	+30
1.5	0	0	0	+1.3	+4.0	+7.3	+17
2.0	0	0	0	+.5	+2.0	+4.5	+9.5
2.5	0	0	0	0	+1.6	+2.8	+6.4
3.0	0	0	0	+.3	+1.0	+2.3	+6.0
4.0	0	0	+.5	+1.0	+1.8	+2.5	+3.8
5.0	+.4	+.6	+.4	+.6	+1.0	+1.4	−2.0
7.0	0	0	0	0	+.3	+.7	+1.4

4. The depth measurements are correct, and the velocity and depth vary linearly with distance between verticals.

Assumption 1 was tested by comparing the ratings obtained for Price current meters when rated in flumes of different sizes. It was found that the ratings can be repeated within a fraction of 1 percent. When a Price meter was tested in a wind tunnel under differing degrees of turbulence, its performance was not affected by increased turbulence. The similarity of results using the Price, Ott, and Neyrpic current meters has already been discussed on page 89. It was therefore assumed that the standard deviation (S_{R_i}) of the error ratio between measurement results obtained with different current meters equals 1 percent.

Assumption 2 was tested in 23 different rivers where velocities for consecutive time periods of 15, 30, 45, 90, 120, and 240 s were observed for a 1-hr period at points corresponding to 0.2, 0.4, 0.6, and 0.8 depth. The measurement verticals ranged in depth from 2.4 to 26.7 ft (0.7 to 8.1 m), and velocities ranged from 0.43 to 7.9 ft/s (0.13 to 2.4 m/s). Statistical analysis showed that velocity fluctuations were randomly distributed in time and space and that if 45-s observations were taken at the 0.2- and 0.8-depth positions in 30 verticals, the standard deviation (S_{R_t}) of the error ratio between observed and true point velocity was 0.8 percent.

Assumption 3 was tested using more than 100 stream sites. The standard deviation (S_{R_s}) of the error ratio between the mean velocity obtained from 0.2- and 0.8-depth observations and the true vertical velocity, using 30 verticals for the discharge measurement, was 1.15 percent.

Assumption 4 was tested using discharge measurements made at 127 stream sites, in which more than 100 verticals were measured in each cross section. The discharge for each site was again computed using the data for 1/2, 1/4, 1/5, 1/7, and 1/10 of the total number of verticals in each cross section. Error ratios between those computed discharges and the discharges computed using all observation verticals were determined. When 30 observation verticals were used, the standard deviation (S_N) of the error ratios was 1.6 percent.

The standard error of a discharge measurement (S_T) was computed from the equation

$$S_T = \sqrt{(S_{R_i})^2 + (S_{R_t})^2 + (S_{R_s})^2 + (S_N)^2}. \qquad (16)$$

For a measurement using velocity observations of 45 s at the 0.2- and 0.8-depth positions in each of 30 verticals, S_T equaled 2.2 percent. That means that if single discharge measurements were made at a number of gaging sites using the standard method recommended in this manual, the errors of two-thirds of the measured discharges would be less than 2.2 percent.

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