Techniques of Water-Resources Investigations
of the United States Geological Survey

Chapter A8

DISCHARGE MEASUREMENTS AT GAGING STATIONS

By Thomas J. Buchanan and William P. Somers

Book 3

APPLICATIONS OF HYDRAULICS

determine depth when using a handline, lower the sounding weight to the streambed, then raise the weight until one of the tags is at the water surface. Measure along the rubber-covered service cord with a steel or metallic tape or a graduated rod to determine the distance the weight is raised. 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 was raised, and (3) the distance from the bottom of the weight to the meter cups.

Another method of determining depths is to set the meter cups at the water surface and then lower the sounding weight to the streambed while measuring the amount of line that has been let out by one of the methods mentioned previously. 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, unwind enough cable 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 cross section. If the bridge is high enough above the water surface, raise and lower the weight and meter by the rubber-covered cable rather than by the bare cable. When the meter is set for the velocity observation, stand on the rubber-covered cable or tie it to the handrail to hold the meter in place. This arrangement frees the hands to record the data.

The handline can be disconnected from the headphone wire and passed around a 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 are made under the most severe conditions (fig. 59) but are extremely important because a large part of the discharge record during a winter period may depend on one measurement.

Select the possible locations of the cross section to be used for a measurement from ice cover during the open-water season when channel conditions can be evaluated.

Figure 59.—Ice rod being used to support current meter for a discharge measurement, top; and ice drill being used to cut holes, bottom.

The equipment used for cutting or drilling the holes in the ice is described on page 27.

Never underestimate the danger of working on ice-covered streams. When crossing, 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 bridged above the water may be weak, although thick.

Cut the first three holes in the selected cross section at the quarter points to detect the presence of slush ice or poor distribution of the flow in the measuring section. If poor conditions are found, investigate other sections to find one that is free of slush ice and that has good distribution of flow. Make at least 20 holes in the ice for a current-meter measurement. Space the holes so that no partial section has more than 10 percent of the total discharge in it.

The effective depth of the water (fig. 60) 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.

Measure the distance from the water surface to the bottom of the ice with an ice-measuring stick. (See p. 27) If there is slush under the solid ice at a hole, the ice-measuring stick is not used. To find the depth at which the slush ice ends, suspend the current meter below the slush ice with the meter rotor turning freely. Raise the meter slowly until the rotor stops. This point is used as the depth of the interface between water and slush.

After the effective depth of the water has been determined, compute the proper position of the meter in the vertical as shown in figure 60.

The vane ice meter is recommended for use under ice cover because the vanes do not become filled with slush ice as the cups of the Price meter often do, because the yoke of the vane meter will fit in the hole made by the ice drill, and because 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, so the binding post is placed perpendicular to the axis of the yoke to avoid interference when using the top of the yoke to determine the underside of the ice.

The velocity distribution under ice cover is similar to that in a pipe with a lower velocity nearer the underside of the ice. (See fig. 61.) The 0.2- and 0.8-depth method is recommended for effective depths 2.5 feet or greater and the 0.6-depth method is recommended for effective depths less than 2.5 feet. It is recommended

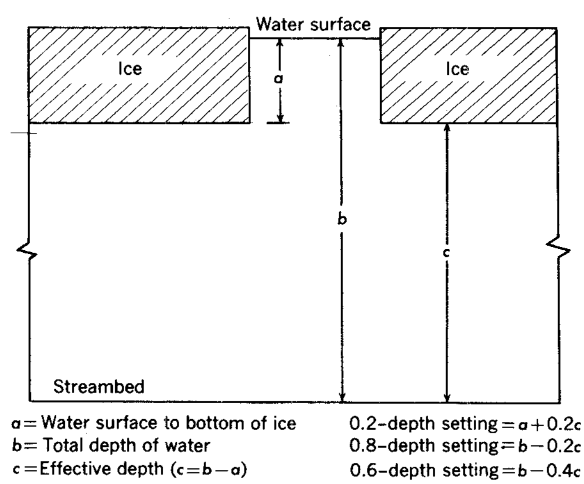


Figure 60.—Method of computing meter settings for measurements under ice cover.

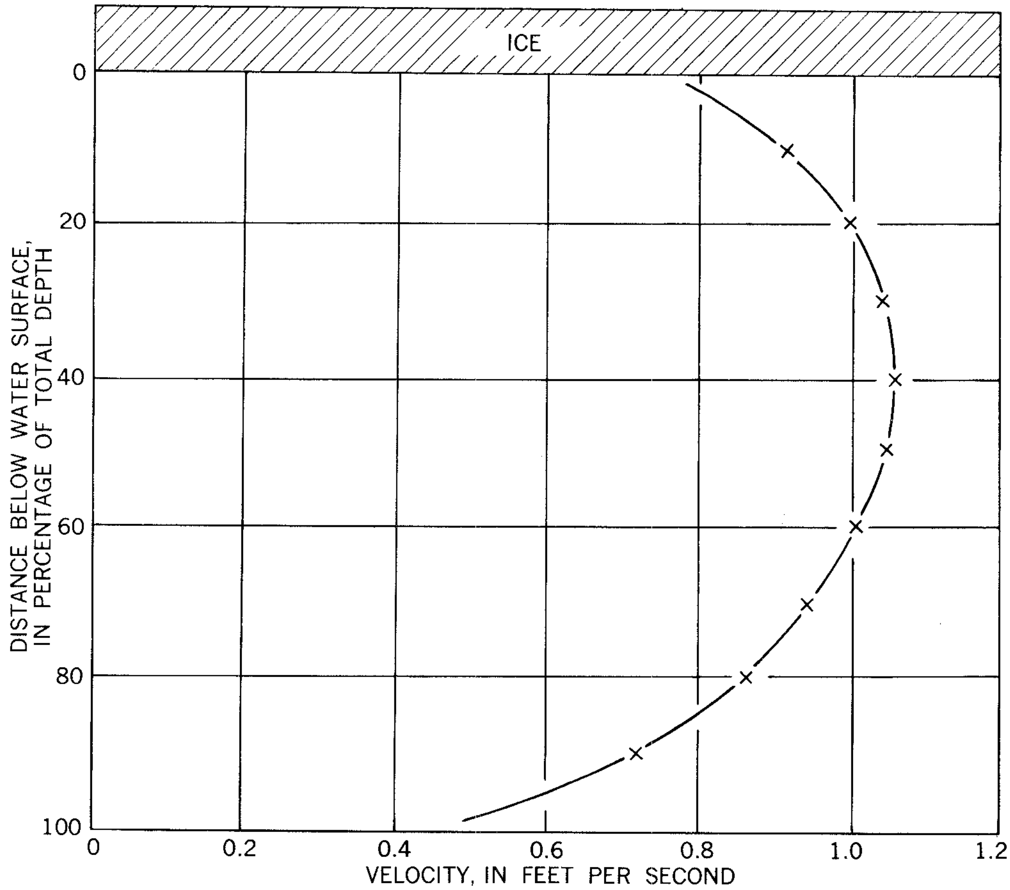


Figure 61.—Typical vertical-velocity curve under ice cover.

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 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.

When measuring the velocity, keep the meter as far upstream as possible to avoid any effect that the vertical pulsation of water in the hole might have on the meter. Eliminate as much as possible the exposure of the meter to the cold air during the measurement. The meter must be free of ice when the velocity is being observed.

If there is partial ice cover at a cross section, use the procedure described above where there is ice cover, and use open-water methods elsewhere.

A sample sheet of discharge-measurement notes under ice cover is shown in figure 62. In this measurement the vertical-velocity curves indicate that the 0.2- and 0.8-depth method gives the mean velocity and that the 0.6-depth method requires 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 the stream is too deep to wade. Personal safety is the limiting factor in the use of boats on streams having high velocity of flow.

String the tag line at the measuring section by unreeling the line as the boat moves across the stream. Some tag-line reels are equipped with brakes to control the line tension while

9-275a
(September 1960)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
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.

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
30	6	2.6	1.6	1.0	2.2	10	47	.50	.46	6.0	2.8
36	6	3.6	1.8	1.8	2.9	15	49	.71	.65	10.8	7.0
42	5	4.3	2.0	2.3	3.4	15	44	.79	.73	11.5	8.4
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

No. 2 of 4 Sheets. Comp. by TJB Chk. by JRK

U. S. GOVERNMENT PRINTING OFFICE 16—63225-1

Figure 62.—Part of notes for discharge measurement under ice cover.

unreeling. (See p. 24.) After a tag line without a brake has been stretched across the stream, take up the slack 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 the river traffic to pass. Place streamers on the tag line so that it may be seen by boat pilots. If there is a continual flow of traffic on the river, or if the width of the river is too great to stretch a tag line, other means will be needed to position the boat.

When no tag line is used, the boat can be kept in the cross section by lining up with flags positioned on each end of the cross section. (See fig. 63.) 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 a transit on the shore and a stadia rod held in the boat. (See fig. 63.) Another method of determining the position

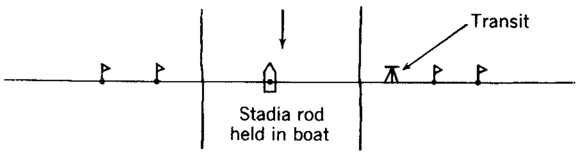


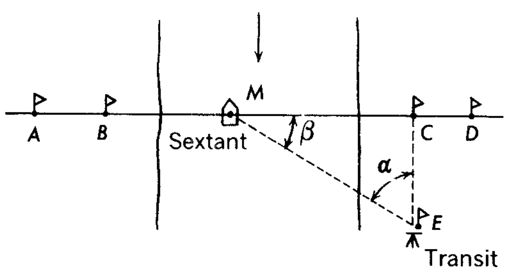
Figure 63.—Determining position in the cross section, stadia method.

of the boat is by setting a transit on one bank some convenient known distance from and at right angles to the cross-section line. The position of the boat is computed by measuring the angle α to the boat. (See fig. 64.) A third method of determining the position of the boat is done with a sextant read from the boat. Position a flag on the cross-section line and another at a known distance perpendicular to the line. The boat position can be computed by measuring the angle β with the sextant.

Unless anchoring is more convenient, the motor must hold the boat stationary when readings are being taken.

If the maximum depth in the cross section is less than 10 feet and the velocity is low, use a rod for measuring the depth and supporting the current meter. For greater depths, use a cable suspension with a reel and sounding weight.

Boat measurements are not recommended at velocities less than 1 fps when the boat is subject to wave action. The up-and-down movement of the boat (and the meter) seriously affects the velocity observations.



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

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

Figure 64.—Determining position in the cross section, angular method.

The procedure for measuring from a boat using the boat boom and crosspiece is the same as that for measuring from a bridge or a cableway, once the special equipment has been set up and the method of positioning the boat has been established.

Moving-boat measurements of discharge

On large streams and estuaries the conventional methods of measuring discharge are frequently impractical and involve costly and tedious procedures. There may be no facilities at remote sites. Where facilities do exist, they may be inundated or inaccessible during floods. At some sites, unsteady flow conditions require that measurements be made as rapidly as possible. Measurements on tide-affected rivers must not only be made frequently but continually throughout a tidal cycle. The moving-boat technique is a method of measuring rapidly on large streams. It requires no fixed facilities, and it lends itself to the use of alternate sites if conditions make this desirable.

The moving-boat technique is described in detail by Smoot and Novak (1968). It is similar to the conventional current-meter measurement in that the velocity-area approach to determine discharge is used; the total discharge is the summation of the products of the partial areas of the stream cross section and their respective average velocities. During the traverse of a boat across a stream, a sonic sounder records the geometry of the cross section, and a continuously operating current meter senses the combined stream and boat velocities. Three men are required to operate the boat and equipment. The data they collect are converted to discharge quickly, efficiently, and inexpensively. Experience has shown that measurements obtained by the moving-boat technique compare within 5 percent of measurements obtained by conventional means.

Networks of current meters

Occasional special measurements require simultaneous 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 these changes. In another example, for the measurement of tide-affected streams, it is desirable to measure the total discharge continuously during at least a full tidal cycle, approximately 13 hours. The need for so many simultaneous velocity determinations (one at each vertical in the cross section) for so long a period could be an expensive and laborious process using conventional techniques of discharge measurement.

A grouping of 21 current meters and special instrumentation has been devised by the Water Resources Division to facilitate measurements of the types just described. Only a few persons are required. The 21 meters are connected together so that the spacing between any two adjacent meters can be varied up to 200 feet. Furthermore, each meter has sufficient handline cable to be suspended vertically from a bridge as much as 200 feet. The meters have a uniform calibration. Revolutions of the rotors are recorded by electronic counters which 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.

Measurement of deep, swift streams

Discharge measurements of deep, swift streams present no serious problems when adequate sounding weights are used and when floating drift or ice is not excessive. Normal procedures must sometimes be altered, however, when measuring these streams. The four most common circumstances are:

1. Possible to sound, but weight and meter drift downstream.
2. Not possible to sound, but a standard cross section is available.
3. Not possible to sound, and a standard cross section is not available.
4. Not possible to put the meter in the water.

Procedures are described below for use during measurements made under these conditions. The procedures for items 2, 3, and 4 are used where there is a stable cross section. The procedure to be used in unstable channels must be determined by conditions at each location.

Possible to sound; weight and meter drift downstream

Where it is possible to sound but the weight and meter drift downstream, the depths measured by the usual methods are too large. (See fig. 65.) The correction for this error has two parts, the air correction and the wet-line correction. The air correction is shown in figure 65 as the distance *cd*. The wet-line correction in figure 65 is shown as the difference between the wet-line depth *de* and the vertical depth *dg*.

As shown in figure 65, the air correction depends on the vertical angle *P* and the distance *ab*. The correction is computed as follows:

$$ab=ac$$

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

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

$$cd=\frac{ab}{\cos P}-ab=ab\left[\frac{1}{\cos P}-1\right]. \qquad (3)$$

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

The air correction may be nearly eliminated by using tags at selected intervals on the sounding line and using the tags to refer to the water surface. This practice is almost equivalent to moving the reel to a position just above the water surface.

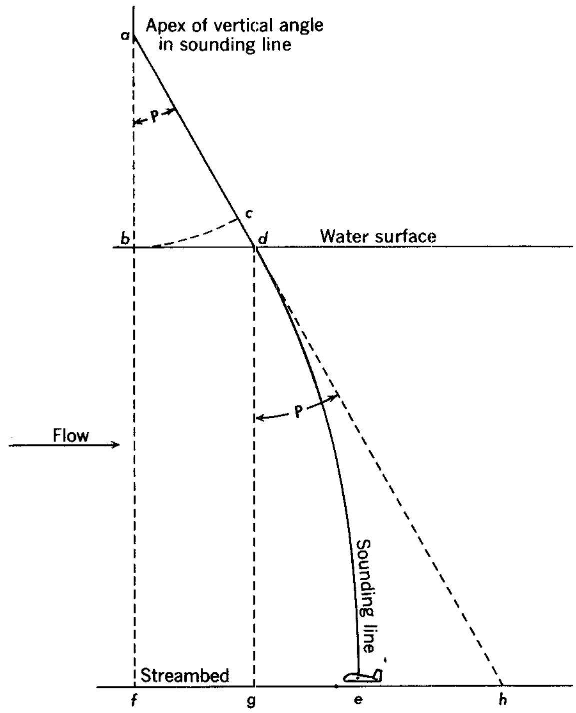


Figure 65.—Position of sounding weight and line in deep, swift water.

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 owing to 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 $\left(\frac{1}{\cos P}-1\right)$ of the corresponding angles 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 wet-line depths between 10 and 100 feet is shown in table 5. 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 points concerning the wet-line correction should be kept in mind:

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.

Table 4.—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 (feet)	Vertical angle of sounding line at protractor																	Vertical length (feet)
	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

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, provided they are designed to offer little resistance to the current.

If the direction of flow is not perpendicular to the measuring section, the angle in the measuring line as indicated by the protractor will be less than the actual angle in the line. The air correction and wet-line correction will then be too small. To correct for this the horizontal angle between the direction of flow and a perpendicular to the measuring section is measured by using a protractor or by determining the horizontal angle coefficient as described on page 38.

If the horizontal angle of the direction of flow may be called H, the measured vertical angle P, and the actual vertical angle X, the relation between the angles is expressed by the formula

$$\tan X = \frac{\tan P}{\cos H} \text{ (fig. 66)}. \qquad (4)$$

Table 6 gives the amounts in tenths of degrees to be added to observed vertical angles to obtain the actual 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 placing of the meter at selected depths.

The correction tables are not strictly applicable to the problem of placing the meter

Table 5.—Wet-line table, giving difference, in feet, between wet-line length and vertical depth for selected vertical angles

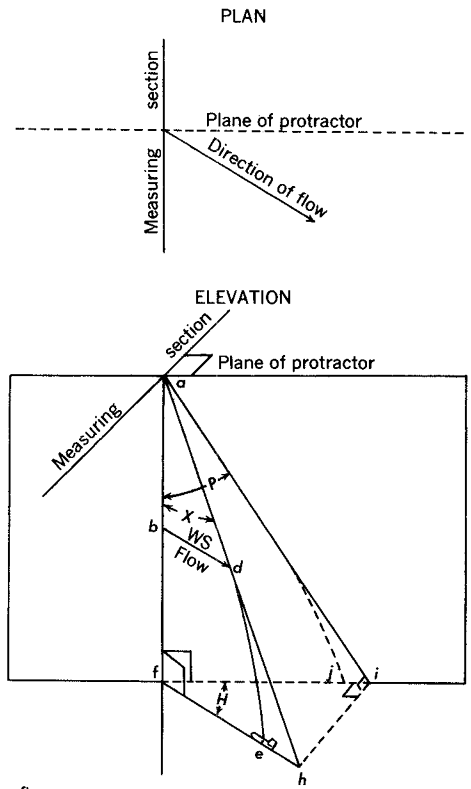
Wet-line length, in feet	Vertical angle of sounding line at protractor																	Wet-line length, in feet
	4°	6°	8°	10°	12°	14°	16°	18°	20°	22°	24°	26°	28°	30°	32°	34°	36°	
10	0.01	0.02	0.03	0.05	0.07	0.10	0.13	0.16	0.20	0.25	0.30	0.35	0.41	0.47	0.54	0.62	0.70	10
12	.01	.02	.04	.06	.09	.12	.15	.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 6.—Degrees to be added to observed angles to obtain actual vertical angles

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

because of the increased pressure placed on the sounding weight by higher velocities when it 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 4 and 5 will tend to eliminate this error in 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



$\tan P = \frac{fi}{af}$ $\cos H = \frac{fi}{fh}$

H = horizontal angle

P = measured vertical angle

X = actual vertical angle

$hfa = 90°$

$ifa = 90°$

$fih = 90°$

$aih = 90°$

$$\frac{\tan P}{\cos H} = \frac{fi}{af} \times \frac{fh}{fi} = \frac{fh}{af}$$

$$\tan X = \frac{fh}{af} = \frac{\tan P}{\cos H}$$

Figure 66.—Sketch of geometry of relationship of actual to measured vertical angle when flow direction is not normal to measuring section.

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:

1. Compute the 0.2 value of the vertica depth.
2. Lower the meter this depth into the water and read the vertical angle.

3. Obtain the air correction from table 4. The vertical length used to obtain the air correction is the sum of 0.2 of the vertical depth, of the distance the apex of the angle is above water, and of the distance the meter is above the bottom of the weight.
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 place 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 air correction for the sounding position and that for the 0.8-depth position. This difference is designated as *m* in table 7. f the angle increases for the 0.8-depth position, the meter must be lowered; if it decreases, the meter must be raised.

For the 0.8-depth position of the meter, the wet-line correction may require consideration if the depths are more than 40 feet 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 5) 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 7. If the vertical angle increases, the difference in correction *n* diminishes until the increase in angle is about 10 percent; for greater increases in angle, the difference between corrections increases also. Table 7 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 small and usually can be ignored. Table 7 indicates that the meter may be placed a little too deep 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 with no adjustments for the differences *m* and *n*.

Not possible to sound; standard cross section available

When it is not possible to sound the bottom but a standard cross section is available, the procedure to follow is:

1. Determine the depths from the standard cross section.
2. Measure the velocity at 0.2 of the depth.
3. Determine coefficients to adjust the 0.2-depth velocity to mean velocity on the basis of previous measurements at the site by the two-point method.
4. Compute the measurement in the normal manner using the depths from the standard cross section and the velocities measured.

The coefficient is then applied to the computed discharge.

Not possible to sound; standard cross section not available

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

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.

Table 7.—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*.

2. Estimate the depth and observe the velocity at 0.2 of the estimated depth. The meter should be at least 2.0 feet 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 feet below the water surface and observe the velocity there.
3. Make a complete measurement at a lower stage, including 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 taken for 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.

Not possible to put meter in water

If it is impossible to keep the weight and meter in the water, the procedure to follow is:

1. Repeat step 1 for conditions when it is not possible to sound the bottom and a standard cross section is not available.
2. Measure surface velocities by timing floating drift, or by use of an optical flowmeter.
3. Repeat steps 3–6 for conditions when it is not possible to sound the bottom and a standard cross section is not available.

An optical flowmeter has been described by Smith (1961). It is portable, battery operated, and requires no great skill for quick and accurate readings of the surface rate of flow. It is not immersed, so it does not disturb the flow, and it is in no danger of damage from floating debris or ice.

It is well to note that just after the crest, the amount of floating drift or ice is usually greatly reduced, and it may be possible to obtain velocity observations with a current meter.

Measurements during rapidly changing stage

During periods of rapidly changing stage, measurements should be made as quickly as possible to keep the change in stage to a minimum. This speed will minimize errors caused by shifting of flow patterns as the stage changes. The procedure to follow to speed up a measurement is:

1. Use the 0.6-depth method. The 0.2-depth method or the subsurface method could 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 seconds.
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 minutes. If the subsurface method for observing velocities is used, then 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 sections and using the two-point method of observation with a 45-second period of observation will have a standard error of 2.2 percent. This means that two-thirds of the measurements made using this procedure would be in error by 2.2 percent or less. They have also shown that the standard error for a 25-second period of observation and using the 0.6-depth method of velocity observations with depth and velocity observed at 16 sections is 4.2 percent. The error caused by using the shortcut method is generally less than the error that can be expected by shifting of flow patterns during periods of rapidly changing stage.

Series of measurements during a peak of short duration

The procedure to follow if a series of measurements is wanted during a peak of short duration is:

1. Take about 10 sections.
2. Take velocity observations at 0.6 depth.

3. Repeat velocity and depth observations at the same 10 sections with corresponding stages as often as possible throughout the period of the flood wave.
4. Develop stage-velocity and stage-area curves for each of the 10 sections.
5. Compute the discharge corresponding to selected stages by summation of the partial discharges from the curves thus defined.

Mean gage height of discharge measurements

The mean gage height of a discharge measurement represents the mean height of the stream during the period the measurement was made and is referred to the datum of the gaging station.

The mean gage height for a discharge measurement is one of the coordinates used in plotting the measurements to establish the stage-discharge relation, often called the rating curve. An accurate determination of the mean gage height is therefore as important as an accurate measurement of the discharge to define the stage-discharge relationship.

The computation of the mean gage height presents no problem when the change in stage is 0.1 foot or less, for then the mean may be obtained by inspection. However, measurements must sometimes be made during floods or regulation regardless of how rapidly stage changes.

To obtain an accurate mean gage height, the gage must be read before and after the discharge measurement, and the recorder chart must be read at breaks in the slope of the gage-height graph 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 during the measurement once or twice to read the gage, or to have someone else do this for him.

If the change in stage is greater than 0.1 foot, the mean is obtained by weighting the gage-height readings rather than by inspection of the available readings.

The mean gage heights during periods of constant slope of the gage-height graph and the corresponding measured partial discharges are used to compute the mean gage height of the measurement. The formula used is:

$$H=\frac{q_1h_1+q_2h_2+q_3h_3\,.\,.\,.\,.\,.\,.\,.\,.\,.+q_nh_n}{Q} \tag{5}$$

in which

H=mean gage height, in feet,
Q=total discharge measured, in cubic feet per second= $q_1+q_2+q_3\,.\,.\,.\,.\,.\,.\,+q_n$,
$q_1, q_2, q_3, \ldots q_n$=amount of discharged measured during time interval 1, 2, 3, . . . n, in cubic feet per second,
$h_1, h_2, h_3, \ldots h_n$=average gage height during time interval 1, 2, 3, . . . n, in feet.

Figure 67 shows the computation of a weighted mean gage height. The graph at the bottom is a reproduction of the gage-height graph during the discharge measurement. The discharges are taken from the current-meter measurement shown in figure 2. The upper computation of the mean gage height in figure 67 shows the computation using the given formula. The lower computation has been done by a shortcut method to eliminate the multiplication of large numbers. In this 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 difference between the base gage height and the average gage heights is used to weight the discharges. When the mean difference has been computed, the base gage height is added to it.

If a discharge measurement is made at a 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 measuring section because of the effects of channel storage between the measuring 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 formula is:

$$Q_G=Q_m\pm WL\frac{\Delta h}{\Delta t}, \tag{6}$$