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

Chapter A11

# MEASUREMENT OF DISCHARGE BY THE MOVING-BOAT METHOD

By George F. Smoot and Charles E. Novak

Book 3

APPLICATIONS OF HYDRAULICS

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

V. E. McKelvey, Director

First printing 1969

Second printing 1977

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1969

**For sale by the Branch of Distribution, U.S. Geological Survey,
1200 South Eads Street, Arlington, VA 22202**

# PREFACE

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

The unit of publication, the chapter, is limited to a narrow field of subject matter. This format permits flexibility in revision and publication as the need arises.

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

# CONTENTS



# FIGURES



# TABLE

# SYMBOLS AND UNITS

| Symbol | Definition | Unit |
|---|---|---|
| $A$ | Area (cross-sectional). | $ft^2$ |
| $a$ | Area of individual subsection. | $ft^2$ |
| $B_c$ | Computed width of cross section. | ft |
| $B_m$ | Measured width of cross section. | ft |
| $b$ | Distance from initial point to observation point. | ft |
| $d$ | Depth of water at observation point. | ft |
| $k_B$ | Width-area adjustment factor, $B_m/B_c$. | |
| $k_V$ | Mean-in-vertical velocity adjustment factor. | |
| $L_b$ | Distance between two consecutive observation points ($L_b \approx L_V \cos \alpha$). | ft |
| $L_V$ | Relative distance through water between observation points. | ft |
| $Q$ | Total discharge. | $ft^3$/sec |
| $q$ | Discharge in subsection. | $ft^3$/sec |
| $t$ | Time. | sec |
| $V$ | Velocity of stream perpendicular to selected path at observation point. | ft/sec |
| $\boldsymbol{V_b}$ | Velocity of the boat with respect to the streambed. | ft/sec |
| $V_V$ | Relative velocity of water with respect to vane as indicated by the current meter. | ft/sec |
| 1, 2, 3, . . . $n$ | Subscripts which denote location points in cross section. | |
| $\alpha$ | Angle formed by velocity vectors $V_b$ and $V_V$. | deg |

# MEASUREMENT OF DISCHARGE BY THE MOVING-BOAT METHOD

By George F. Smoot and Charles E. Novak


## Abstract

This chapter describes the procedures for measuring discharge in large streams by the moving-boat technique. 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. These data are converted to discharge for the cross section quickly, efficiently, and inexpensively. Measurements obtained by the moving-boat technique compare within 5 percent of measurements obtained by conventional means.

Field and office procedures applicable to this method are outlined. Theory of technique is developed and equipment required is described. Selection and preparation of the cross section is detailed. A complete facsimile example of computation of a moving-boat measurement is given, and the determination and application of adjustment factors are described.


## Introduction

Conventional techniques for measuring discharge of streams by current meters are standardized and well known. Frequently, however, on larger streams and estuaries conventional methods are impractical and involve costly and tedious procedures. This is particularly true during floods when facilities may be inundated or inaccessible, at remote sites where no facilities exist, or at locations where unsteady flow conditions require that measurements be made as rapidly as possible. The moving-boat technique is a method applicable to the rapid measurement of 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 similar to the conventional current-meter measurement in that both use the velocity-area approach of determining discharge. In each method, a measurement is the summation of the products of the partial areas of the stream cross section and their respective average velocities. Both techniques require that the following information be obtained:

1. Location of sampling points 1, 2, 3, . . . $n$ across the stream in reference to the distance from an initial point.
2. Stream depth, $d$, at each observation point.
3. Stream velocity, $V$, perpendicular to the cross section at each observation point.

During a traverse of the boat across the stream, a sonic sounder records the geometry of the cross section, and a continuously operating current meter senses the combined stream and boat velocities. A vertical vane alines itself in a direction parallel to the movement of water past it, and an angle indicator attached to the vane assembly indicates the angle between the direction of the vane and the true course of the boat. The data from these instruments provide the information necessary for computing the discharge for the cross section. Normally, data are collected at 30–40 observation points in the cross section for each run. Experience has shown that measurements obtained by the moving-boat technique compare within 5 percent of measurements obtained by conventional means.

The principal difference between the conventional measurement and the moving-boat measurement lies in the method of data collection. The standard current-meter method of measurement uses what might be called a static approach in its manner of sampling; that is, the data are collected at each observation point in the cross section while the observer is in a stationary position. This method is in contrast to the dynamic approach to data collection utilized in the moving-boat method. Here, data are collected at each observation point while the observer is aboard a boat that is rapidly traversing the cross section.

# Theory of the Moving-Boat Measurement

The moving-boat measurement is made by traversing the stream along a preselected path that is normal to the streamflow. The traverse is made without stopping, and data are collected at intervals along the path. During a traverse of the cross section, the boat operator maintains course by "crabbing" into the direction of the flow sufficiently to remain on line (fig. 1). The velocity, $V_b$, of the boat with respect to the streambed along the selected cross-section path is the velocity at which the current meter is being pushed through the water by the boat. The force exerted on the current meter, then, is a combination of two forces acting simultaneously; one force resulting from the movement of the boat through the water along the cross-section path and the other a consequence of the natural streamflow normal to that path.

The velocity measurement taken at each of the sampling points in the cross section is a vector quantity which represents the relative velocity of water past the vane and meter. This velocity, $V_V$, is the vector sum of $V$, the component of stream velocity normal to the cross section at the sampling point, and $V_b$, the velocity of the boat with respect to the streambed along the selected path. The vector diagram in figure 2 depicts this relationship.

The sampling data recorded at each observation point provide the necessary information to define $V_V$. The pulses-per-second reading from the rate indicator unit is used in conjunction with a rating table to obtain the vector magnitude, $V_V$, and the angle reading, $\alpha$, representing

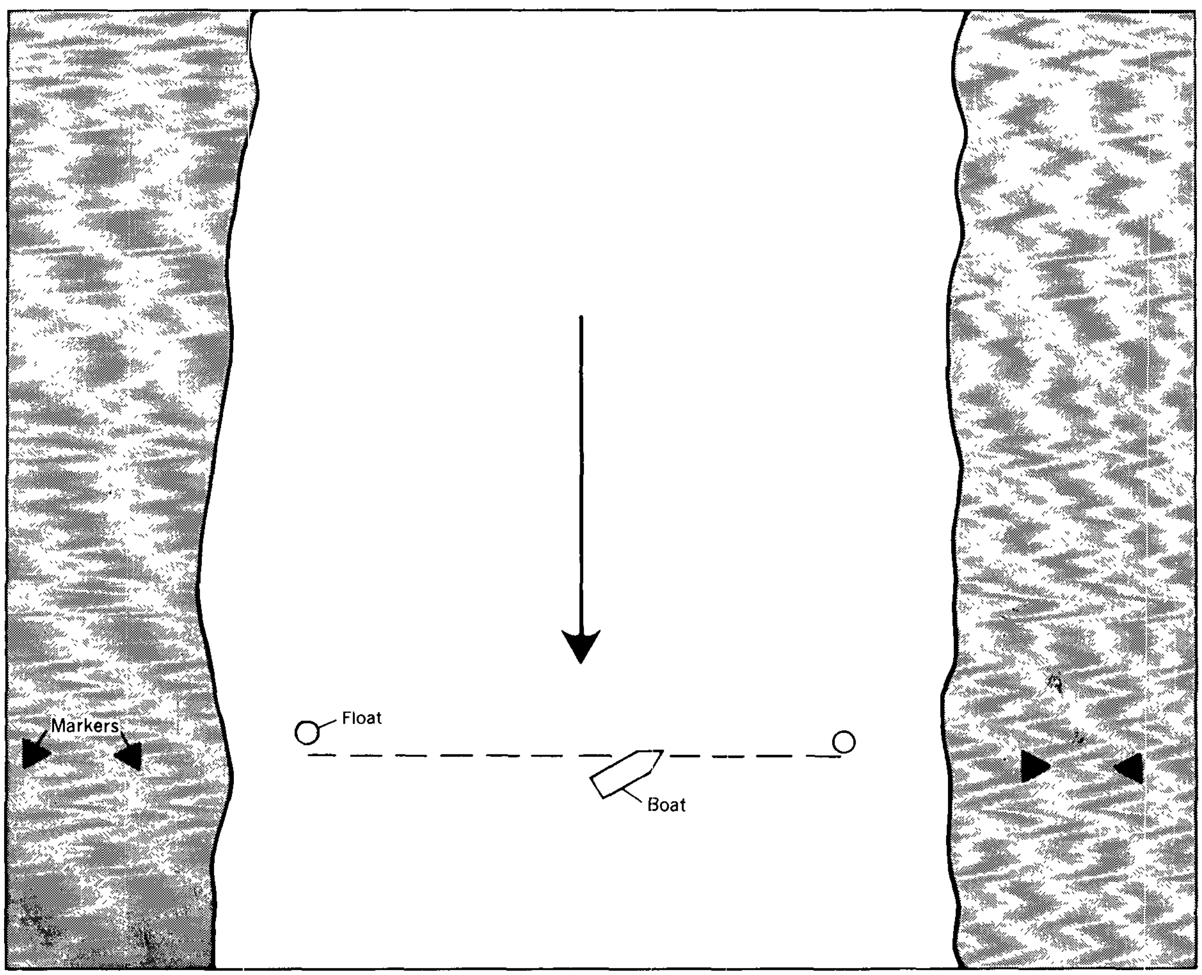



Figure 1.—Stream and markers.

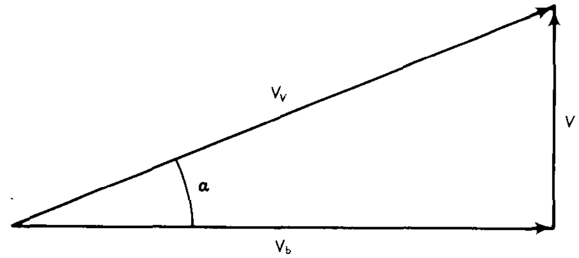



Figure 2.—Velocity vectors.

the angle the vane makes with the cross-section path, defines the direction of the vector.

Stream velocity, $V$, perpendicular to the boat path (true course) at each sampling point, 2, 3, 4, . . . ($n$-1) can be determined from the relationship

$$V=V_V \sin a. \qquad (1)$$

The solution of the above equation yields an answer which represents that component of the stream velocity which is perpendicular to the true course even though the direction of flow may not be perpendicular. This is the desired component.

From the same vector diagram, it can be seen that

$$L_b=\int V_V \cos a\, dt, \qquad (2)$$

where $L_b$ is the distance which the boat has traveled along the true course between two consecutive observation points, provided the stream velocity is perpendicular to the path. Where the velocity is not perpendicular, an adjustment is required as explained in the section "Correction for width." If one assumes that $a$ is approximately uniform over the relatively short distance which makes up any one increment, then it may be treated as a constant. Therefore, equation 2 becomes

$$L_b \approx \cos a \int V_V dt. \qquad (3)$$

Now

$$\int V_V dt=L_V, \qquad (4)$$

where $L_V$ is the relative distance through the water between two consecutive observation points as represented by the output from the rate indicator and counter. Therefore,

$$L_b \approx L_V \cos a. \qquad (5)$$

Finally, $d$, stream depth at each observation point, is obtained by adding the transducer depth to the depth obtained from the sonic-sounder chart. Upon determining $V$, $L_b$, and $d$ for each vertical, the midsection method of computing a discharge measurement is used.

Much of the accuracy of a moving-boat discharge measurement depends upon the skill of the boat operator in maintaining a true course. Although even the most experienced pilot cannot be expected to keep the boat absolutely on course for an entire run, it is still extremely important that the measurement begin and end on line and that any deviations from the true course be kept as few in number and as small in magnitude as possible.

If velocity readings are taken while the boat is moving off course in an upstream direction, then those readings will be greater than the true velocities; if the readings happen to be taken when the movement is toward the downstream direction, then the sampled velocity readings will be less than the true velocities. Thus, if one assumes the equal likelihood of over-registering or under-registering the stream velocities because of deviations from the true course, then the errors can be considered compensating in nature. However, to further insure the reliability of the measurement, it is recommended that the results of at least six individual runs, each with from 30 to 40 observation points, be averaged to obtain the discharge in steady-flow conditions. This is practicable because of the ease and speed with which the extra runs can be made. For unsteady-flow conditions on tidal streams, it will usually be desirable not to average the results from a series of runs but rather to keep them separate so as to better define the discharge cycle.

## Equipment

Specialized instrumentation consisting of a sonic sounder, a vane with indicator, a special current meter with its associated electronic equipment, and an easily maneuverable small boat with some modifications provide the capability needed for a moving-boat measurement.

### Vane and angle indicator

A vane with an indicating mechanism is mounted on the bow of the boat, with the vane centered approximately 3–4 feet below the water surface (fig. 3). This assembly consists of a vertical, stainless-steel shaft with a pointer connected to its upper end and a thin vertical aluminum fin, 1 foot high and 1½ feet long, attached to its lower end. The shaft is housed in an aluminum bearing tube and is mounted with ball bearings at the upper end and a teflon bearing (no lubrication needed) in the lower end of the tube so that the assembly (vane, shaft, pointer) is free to rotate as a unit. The vertical vane alines itself in a direction parallel to the movement of the water past it. The pointer is attached to the shaft so that it will be in line with the vane, pointing directly into the flow past the vane. The angle between the direction of the vane and the true course of the boat (the line of the cross section) is indicated on a dial by the pointer. The circular dial, calibrated in degrees to either side of an index point, swivels freely about the upper end of the vertical shaft, just below the pointer. A sighting device attached to the dial provides a means of alining the index point on the dial with the true course. In positive streamflow the pointer above the dial will always point to the upstream side of the true course. Because the upstream side may be to the left or right side, depending on which direction the boat is traveling, and also because of possible negative velocities, the dial is calibrated in degrees (from 0 to 90) on both sides of its index point.

## Current meter

The current meter used is a component propeller type with a custom body made for mounting on the leading edge of the vane (fig. 3). The component propeller is less susceptible than are other types of meters to vertical components of velocity and was chosen to minimize errors created by the bobbing of the boat.

A 24-toothed gear passing in the proximity of a magnetic field is used to generate 24 pulses per revolution of the propeller. The large number of pulses for each revolution facilitates the conversion of the pulse rate to an analog readout. An electronic pickup assembly registers these pulses and feeds them into a frequency-to-voltage converter, and they are then displayed as a reading on an electrical meter.

At one end of the meter cable is a small metallic probe that is screwed into the meter body at the opening just behind the propeller nut (fig. 4). The probe is a permanent magnet that provides the magnetic field necessary for pulse generation. To function properly, the probe tip must be positioned within a few thousandths of an inch of the 24-toothed gear located within the meter. Adjustment of the probe position, which is seldom required, should be done with care to prevent damage to the probe tip. The adjustment procedure includes the following steps:

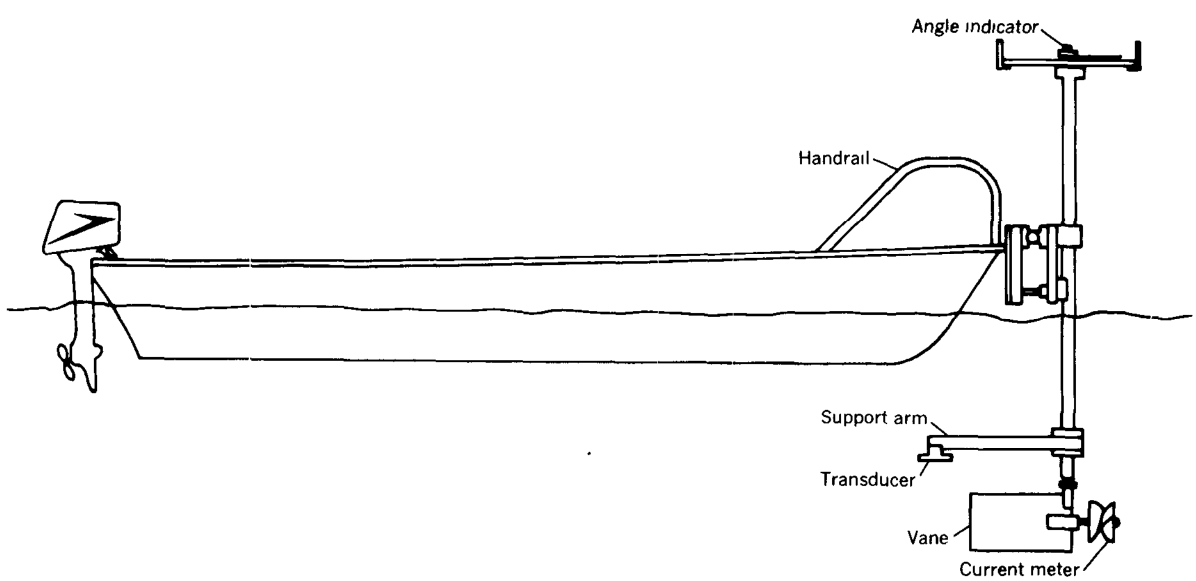



Figure 3.—Boat and equipment.

1. Screw the probe in until its tip just touches the top of a gear tooth.
2. Back the probe off very slightly to provide minimum clearance with the tooth.
3. Gently turn the propeller to test for clearance. Do not spin the propeller because the original position of the probe tip may have been in a gap between two of the gear teeth, and the slight adjustment called for in step 2 may not have been sufficient to provide proper clearance. If the probe tip still is in contact with the gear teeth, repeat step 2.
4. Once the propeller turns freely, secure its position by tightening the lock nut. Then spin the propeller to make certain it operates freely and does not stop abruptly.

Before the meter is used, the cup within the hub of the current-meter propeller should be filled with thin oil (Ott propeller oil) as shown in figure 4. The bearing assembly is then inserted into the hub, and the propeller nut is tightened. After the conclusion of a series of measurements, the cup should be emptied completely and cleaned before storage.

## Rate indicator and counter

One of the principal functions of the rate indicator and counter is to register the pulses received from the current meter, feed them into a frequency-to-voltage converter, and then display them as a reading on its electrical meter (fig. 5). These pulses are received through the current-meter cable which is plugged into the marked receptacle provided in the front panel of the unit. The current meter generating the pulses is calibrated so that the reading on the electrical meter in pulses per second can be converted to a particular velocity in feet per second through the use of a rating table (fig. 6). The value read from the electrical meter at any particular instant represents an instantaneous readout of velocity.

There are two scale selections available for the rate indicator unit. If the switch is set at the "500" selection, the readout is taken from the lower scale of the panel meter; at the 1,000 setting, the upper scale is used. During a measurement, if the velocity of the water past the meter is not sufficient to cause the needle to go off scale, the 500 scale can be used. Using this scale has the advantage of providing greater sensitivity in the readout.

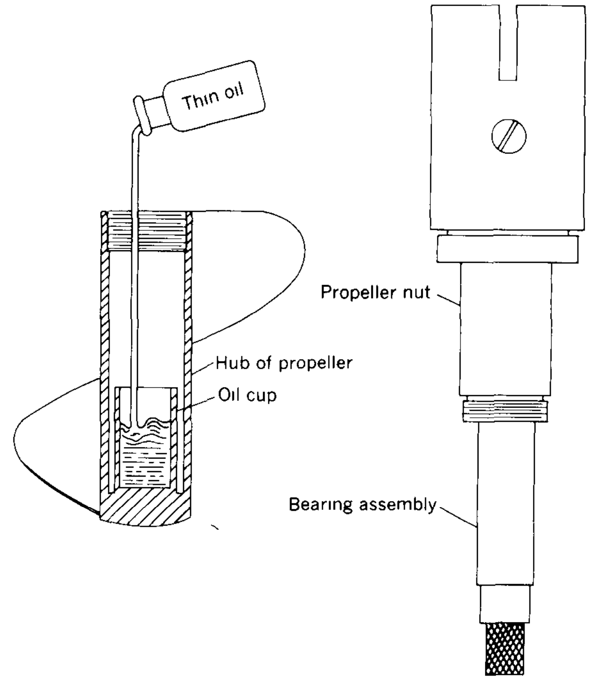



Figure 4.—Component propeller-type meter.

In addition to serving as a pulse-rate indicator from which velocity determinations can be made, this unit has also been designed to provide a method of automatically selecting measurement points in a section at regular intervals of distance traveled. This design makes use of the fact that each revolution of the meter propeller generates 24 evenly-spaced pulses, and that from the calibration of the meter it can be determined that one pulse is equal to some fraction of a foot of travel through the water or water past the meter. By using a set of frequency-dividing modules, provision is made for these pulses to be electronically counted to a preset number at which time an audible signal is generated and the sounder chart is automatically marked. The counter then automatically resets itself, and the process is repeated. The purpose of the audible signal is to let the boat crew know when a sampling location is reached. At this point they will take an angle reading from the pointer and a readout from the electrical meter. The markings on the sounder chart are automatically triggered by

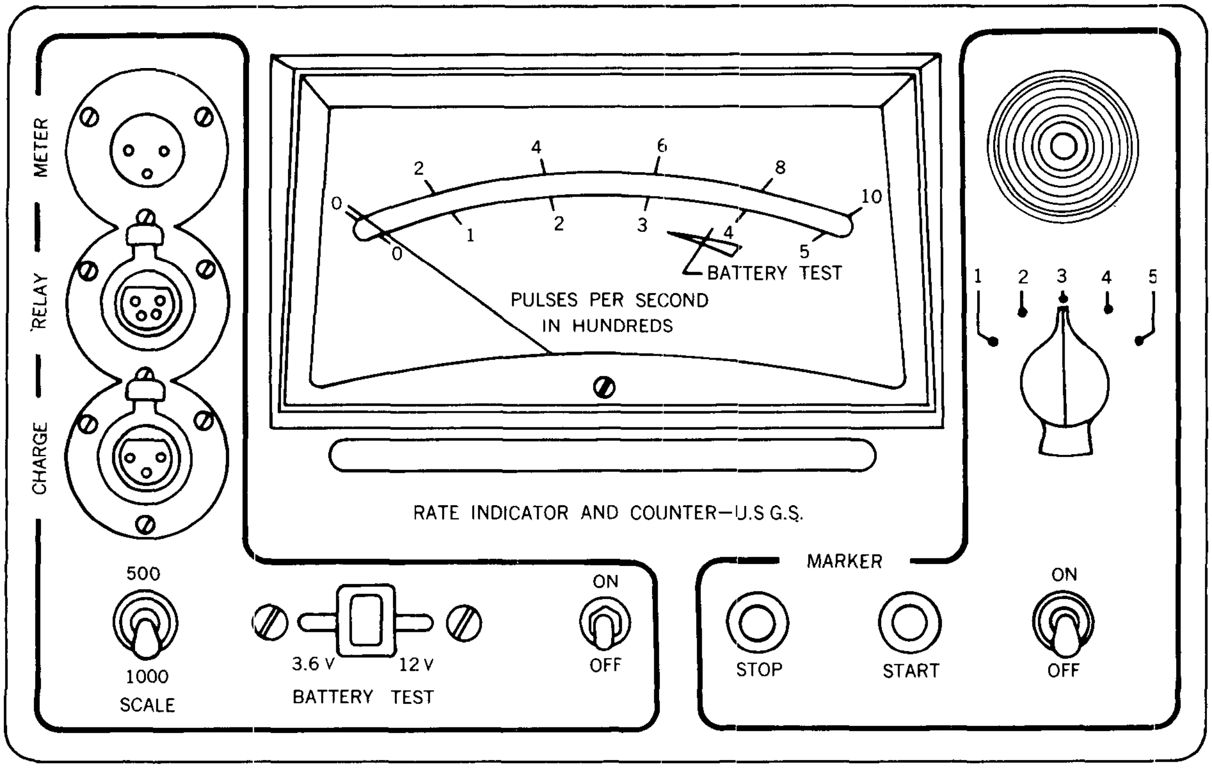



Figure 5.—Control panel of rate indicator and counter.

an electrical impulse transmitted to the depth-sounder unit by a relay in the meter electronics. The relay cable from the counter to the sounder should be plugged into the appropriately marked receptacle on the front panel of both units. The markings on the sounder chart locate observation points in the cross section and thus show where depth readings should be taken.

Preset intervals which are available on each unit are as follows:

| *Range selection* | *Pulse counts* | *Distance, in feet* |
|---|---|---|
| 1 | 1, 024 | 18. 75 |
| 2 | 2, 048 | 37. 5 |
| 3 | 4, 096 | 75 |
| 4 | 8, 192 | 150 |
| 5 | 16, 384 | 300 |

The distances listed above are typical; exact ones depend upon the calibration of the particular current meter used. If possible, the pulse-selector switch should be set for a distance that will divide the measured width between the two floats into 30–40 increments. For example, if the distance between floats is 500 feet, range 1 should be selected; for a distance of 1,000 feet, range 2, and so on. Each distance listed in the table above represents $L_V$, the relative distance through the water, and it will be somewhat larger than the corresponding $L_b$ value, the distance along the true course which the boat has traveled. $L_b$ is the distance one should use to determine the number of observation points that will be taken in a given cross section; however, the listed $L_V$ values can serve to furnish a rough estimate. One must keep in mind that the actual number of increments will be somewhat greater.

The rate indicator and counter has two internal power supply packs, both consisting of a set of nickel-cadmium rechargeable batteries. A battery test switch located on the front panel of the unit can be used to test the condition of either the 3.6-volt or the 12-volt power supply (fig. 5). Testing should be done with both the main power and the marker switches off. A reading of the panel meter above the test switch will indicate the degree of charge. A needle deflection greater than the battery testline mark indicates a satisfactory charge level for most measurement requiremets. A fully-charged battery pack will operate satisfactorily from 12

DEPARTMENT OF THE INTERIOR - GEOLOGICAL SURVEY
Water Resources Division
RATING TABLE FOR MOVING BOAT METER NO. 2-4
EQUATIONS: V = 0.01768 N + 0.078 . . . . . . Limits of actual rating . . 1.0 . . to . . 10 . . . feet per second. Rated: JULY 5, 1967.

| Counts per Second | VELOCITY IN FEET PER SECOND | | | | | | | | | | | | | | | | | | | | Counts per Second |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | |
| 0 | | | | | | | | | | | 0.96 | 1.05 | 1.14 | 1.23 | 1.32 | 1.40 | 1.49 | 1.58 | 1.67 | 1.76 | 0 |
| 100 | 1.85 | 1.93 | 2.02 | 2.11 | 2.20 | 2.29 | 2.38 | 2.46 | 2.55 | 2.64 | 2.73 | 2.82 | 2.91 | 3.00 | 3.08 | 3.17 | 3.26 | 3.35 | 3.44 | 3.53 | 100 |
| 200 | 3.61 | 3.70 | 3.79 | 3.88 | 3.97 | 4.06 | 4.14 | 4.23 | 4.32 | 4.41 | 4.50 | 4.59 | 4.67 | 4.76 | 4.85 | 4.94 | 5.03 | 5.12 | 5.21 | 5.29 | 200 |
| 300 | 5.38 | 5.47 | 5.56 | 5.65 | 5.74 | 5.82 | 5.91 | 6.00 | 6.09 | 6.18 | 6.27 | 6.35 | 6.44 | 6.53 | 6.62 | 6.71 | 6.80 | 6.88 | 6.97 | 7.06 | 300 |
| 400 | 7.15 | 7.24 | 7.33 | 7.42 | 7.50 | 7.59 | 7.68 | 7.77 | 7.86 | 7.95 | 8.03 | 8.12 | 8.21 | 8.30 | 8.39 | 8.48 | 8.56 | 8.65 | 8.74 | 8.83 | 400 |
| 500 | 8.92 | 9.01 | 9.09 | 9.18 | 9.27 | 9.36 | 9.45 | 9.54 | 9.63 | 9.71 | 9.80 | 9.89 | 9.98 | 10.07 | 10.16 | 10.24 | 10.33 | 10.42 | 10.51 | 10.60 | 500 |
| 600 | 10.69 | 10.77 | 10.86 | 10.95 | 11.04 | 11.13 | 11.22 | 11.30 | 11.39 | 11.48 | 11.57 | 11.66 | 11.75 | 11.84 | 11.92 | 12.01 | 12.10 | 12.19 | 12.28 | 12.37 | 600 |
| 700 | 12.45 | 12.54 | 12.63 | 12.72 | 12.81 | 12.90 | 12.98 | 13.07 | 13.16 | 13.25 | 13.34 | 13.43 | 13.51 | 13.60 | 13.69 | 13.78 | 13.87 | 13.96 | 14.05 | 14.13 | 700 |
| 800 | 14.22 | 14.31 | 14.40 | 14.49 | 14.58 | 14.66 | 14.75 | 14.84 | 14.93 | 15.02 | 15.11 | 15.19 | 15.28 | 15.37 | 15.46 | 15.55 | 15.64 | 15.72 | 15.81 | 15.90 | 800 |
| 900 | 15.99 | 16.08 | 16.17 | 16.26 | 16.34 | 16.43 | 16.52 | 16.61 | 16.70 | 16.79 | 16.87 | | | | | | | | | | 900 |

TABLES OF $L_b$, IN FEET

| Range No. | Angle $\alpha$ in degrees | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.1 | 18.1 | 18.1 | 18.0 |
| | 10 | 18.0 | 17.9 | 17.9 | 17.8 | 17.7 | 17.6 | 17.5 | 17.5 | 17.4 | 17.3 |
| | 20 | 17.1 | 17.0 | 16.9 | 16.8 | 16.7 | 16.5 | 16.4 | 16.3 | 16.1 | 16.0 |
| | 30 | 15.8 | 15.6 | 15.5 | 15.3 | 15.1 | 14.9 | 14.8 | 14.6 | 14.4 | 14.2 |
| | 40 | 14.0 | 13.8 | 13.6 | 13.3 | 13.1 | 12.9 | 12.6 | 12.4 | 12.2 | 11.9 |
| 2 | 0 | 36.5 | 36.5 | 36.5 | 36.5 | 36.4 | 36.4 | 36.3 | 36.2 | 36.1 | 36.1 |
| | 10 | 35.9 | 35.8 | 35.7 | 35.6 | 35.4 | 35.3 | 35.1 | 34.9 | 34.7 | 34.5 |
| | 20 | 34.3 | 34.1 | 33.8 | 33.6 | 33.3 | 33.1 | 32.8 | 32.5 | 32.2 | 31.9 |
| | 30 | 31.6 | 31.3 | 31.0 | 30.6 | 30.3 | 29.9 | 29.5 | 29.2 | 28.8 | 28.4 |
| | 40 | 28.0 | 27.5 | 27.1 | 26.7 | 26.3 | 25.8 | 25.4 | 24.9 | 24.4 | 23.9 |
| 3 | 0 | 73.0 | 73.0 | 73.0 | 72.9 | 72.8 | 72.7 | 72.6 | 72.5 | 72.3 | 72.1 |
| | 10 | 71.9 | 71.6 | 71.4 | 71.1 | 70.8 | 70.5 | 70.2 | 69.8 | 69.4 | 69.0 |
| | 20 | 68.6 | 68.2 | 67.7 | 67.2 | 66.7 | 66.2 | 65.6 | 65.0 | 64.4 | 63.8 |
| | 30 | 63.2 | 62.6 | 61.9 | 61.2 | 60.5 | 59.8 | 59.0 | 58.3 | 57.5 | 56.7 |
| | 40 | 55.9 | 55.1 | 54.2 | 53.4 | 52.5 | 51.6 | 50.7 | 49.8 | 48.8 | 47.9 |
| 4 | 0 | 146 | 146 | 146 | 146 | 146 | 145 | 145 | 145 | 145 | 144 |
| | 10 | 144 | 143 | 143 | 142 | 142 | 141 | 140 | 140 | 139 | 138 |
| | 20 | 137 | 136 | 135 | 134 | 133 | 132 | 131 | 130 | 129 | 128 |
| | 30 | 126 | 125 | 124 | 122 | 121 | 120 | 118 | 117 | 115 | 114 |
| | 40 | 112 | 110 | 108 | 107 | 105 | 103 | 101 | 99.6 | 97.7 | 95.8 |
| 5 | 0 | 292 | 292 | 292 | 292 | 291 | 291 | 290 | 290 | 289 | 288 |
| | 10 | 288 | 287 | 286 | 284 | 283 | 282 | 281 | 279 | 278 | 276 |
| | 20 | 274 | 273 | 271 | 269 | 267 | 265 | 262 | 260 | 258 | 255 |
| | 30 | 253 | 250 | 248 | 245 | 242 | 239 | 236 | 233 | 230 | 227 |
| | 40 | 224 | 220 | 217 | 214 | 210 | 206 | 203 | 199 | 195 | 192 |

SIN of ANGLE $\alpha$

| Angle $\alpha$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .000 | .017 | .035 | .052 | .070 | .087 | .105 | .122 | .139 | .156 |
| 10 | .174 | .191 | .208 | .225 | .242 | .259 | .276 | .292 | .309 | .326 |
| 20 | .342 | .358 | .375 | .391 | .407 | .423 | .438 | .454 | .469 | .485 |
| 30 | .500 | .515 | .530 | .545 | .559 | .574 | .588 | .602 | .616 | .629 |
| 40 | .643 | .656 | .669 | .682 | .695 | .707 | .719 | .731 | .743 | .755 |
| 50 | .766 | .777 | .788 | .799 | .809 | .819 | .829 | .839 | .848 | .857 |

Figure 6.—Sample tables of meter rating, $L_b$, and sine $\alpha$.

to 16 hours. A marginal reading, with needle deflection just to the test mark, indicates approximately 4–8 hours of useful battery operation remaining. A reading below the mark serves as a warning that a battery charge is needed.

## Battery charger

The battery charger serves as a dual unit for charging either one of the two battery supply packs located within the rate indicator and counter unit. Its charge plug is inserted into the charge receptacle located on the panel of the rate indicator and counter. The other plug should be connected to a 115-volt, 60-cycle line power supply. Early models of this unit provide two panel meters which indicate the rate at which the batteries are being charged, the left panel meter for the 3.6-volt supply pack and the right panel meter for the 12-volt supply pack. With controls turned fully counterclockwise, the unit is off. As the controls are rotated clockwise, readings will appear on the meters, indicating the charge rate. An indication of "1" on the panel would be a good slow-charging rate, useful for applying a charge over a weekend. To avoid possible overheating of the batteries, it is advisable that a charge rate of "4" not be exceeded. Later models now provide two three-position switches ("Lo," "Off," and "Hi") in place of the original panels and their numbered control dials. The "Lo" and "Hi" switch positions correspond to charge rates of approximately "1" and "3½," respectively, on the control dials of the older models. With proper care the batteries should provide many years of service.

## Sonic sounder

A portable sonic sounder (fig. 7) is used to provide a continuous strip-chart record of the depth of the stream; that is, a profile of the cross section between the two floats. Its transducer releases bursts of ultrasonic energy at fixed intervals. The instrument measures the time required for these pulses of energy to travel to the streambed, to be reflected, and to return to the transducer. With a known propagation velocity of sound in water, the sounder computes and records the depth. Accuracy of the recording depth sounder is approximately ±0.5 foot. The sounder used in this application is a commercially available model with a minor modification for automatically marking the chart at each observation point by an electrical pulse from the meter electronics.

The four operating controls are located on the top of the recorder case, beneath the carrying handle (fig. 7). The control on the left is a four-position switch that is used to select the appropriate depth range for the measurement. The four depth-range choices available are 0–60, 60–120, 120–180, and 180–240 feet. Detailed instructions for operating the range switch and the other three controls are given in the section "Selection of instrument settings."

The sounder unit opens from both the front and back. The front cover protects the recording mechanism against any spray, yet allows easy access for changing chart paper and stylus belts and for making occasional adjustments. The maintenance instructions provided in the instruction manual accompanying the sounder unit should be referred to when replacing the stylus and belt assembly.

Inside the back cover are usually stored the transducer and six tubular mounting sections as well as a battery cable and clips. These tubular sections should not normally be required for this particular application because of other special arrangements provided for mounting and supporting the transducer. (See "Mounting of the equipment.") Once the transducer is attached to its support arm on the aluminum bearing tube which houses the assembly, it is desirable to leave it and the support both mounted after completing the measurement. If this is done, then they and the assembly can be removed from the boat and stored as a single unit.

The battery and transducer cables of the sonic sounder are provided with plug-in connectors for insertion in the marked receptacles at the back of the dividing plate. When the unit is operated with the case completely closed, these cables are fed through the holes provided near the hinge. A standard 6- or 12-volt (depending on the sounder model) lead-acid storage battery is used as a power supply. This type of battery is needed because of heavy power consumption by the unit.

One minor modification to the sonic sounder is the installation of a receptacle on its front

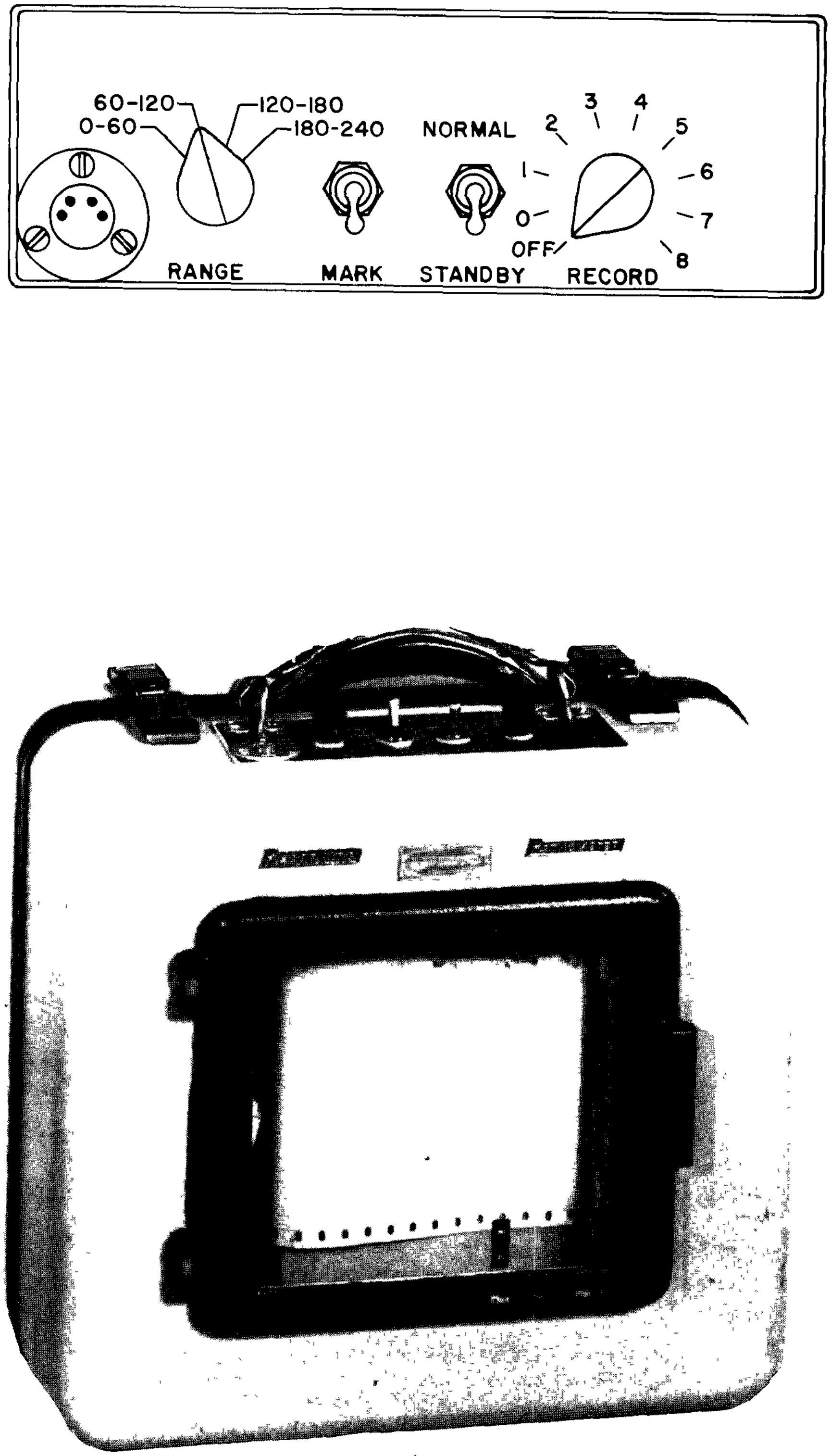



Figure 7.—Sonic sounder and control panel.

panel into which is plugged the relay cable from the rate indicator and counter. The purpose of this relay connection is to transmit the electrical pulses from the counter unit which will automatically trigger the vertical-line markings on the sounder chart. This provision for automatically marking the sounder chart at regular intervals of distance traveled eliminates the need for the manually operated "MARK" switch, except in the event that the relay cable is damaged or missing. Then, as an expedient measure, the chart is marked at each observation point by manually pulling the switch at each tone signal sounded by the counter unit.

There are three paper-feed speeds provided with the unit. The small lever in the lower left-hand corner of the recorder chassis is the control. The set of speeds available will vary according to the model. Some models provide choices of 12, 30, and 60 inches per hour and others 36, 90, and 180 inches per hour. A chart speed which results in approximately 0.25 of an inch spacing between the vertical-line markings that are set on the chart during the measurement is suitable. Spacing wider than this needlessly wastes chart paper, whereas much narrower spacing results in poor resolution of the streambed trace. Narrow spacing also provides difficulty in determining what fractional part of a full spacing should be assigned to the final width increment. Spacing width is dependent upon the range setting on the counter unit, the current-meter velocity, and the chart speed. Table 1, computed for a current-meter velocity of 5 fps (feet per second), shows an example of typical spacing distances expected for various combinations of chart speed and range distance.

Table 1.—Spacing of vertical-line markings, in inches, on the sonic-sounder chart for various combinations of chart speed and range distance

| Chart speed (inches per hour) | Range distance (feet) | | | | |
|---|---|---|---|---|---|
| | 18.75 | 37.5 | 75 | 150 | 300 |
| 36 | 0.04 | 0.08 | 0.16 | 0.32 | 0.64 |
| 90 | .10 | .20 | .40 | .80 | 1.6 |
| 180 | .20 | .40 | .80 | 1.6 | 3.2 |

## Boat

Any easily maneuverable small boat which is sufficiently stable for the stream on which it is to be used is adequate for a moving-boat measurement. A photograph of a boat with the vane assembly mounted is shown in figure 8.

### Preparation of the boat

A 12- by 12- by ¼-inch steel plate should be attached so that it is centered on the bow of the boat, perpendicular to the centerline of the boat, and as nearly vertical as possible. This plate must be securely anchored because at high velocities great force will be exerted on it. It may be necessary, depending on the style of boat being used, to erect handrails on the forward part of the boat similar to those shown in figure 3. This is for the safety of the angle reader who must stand in the bow.

### Mounting of the equipment

The 12- by 12-inch aluminum plate on the vane assembly is attached to the 12- by 12-inch steel plate on the bow of the boat. It is necessary to clamp these two plates together and drill four holes for accepting bolts to permanently fasten the plates together. The general location of the bolt holes should be near the four corners, but exact placement is not critical.

The two cap screws in the depth adjustment clamp that hold the aluminum bearing tube of the assembly (fig. 9) can be loosened so that the tube may be either raised or lowered in order to position the meter at the desired depth. This depth should preferably be at least 3 feet to avoid the effect of surface disturbances and not greater than 4 feet to avoid the danger of too great a torque being exerted at high velocities. Caution should be exercised to avoid high boat speeds, for the drag on the vane assembly is proportional to the square of the velocity of the water past the vane and therefore increases very rapidly with speed.

The sonic-sounder transducer is mounted on a support arm at a depth of either 2 or 3 feet. It can be positioned by loosening the two cap screws that secure the support arm to the aluminum bearing tube of the vane assembly

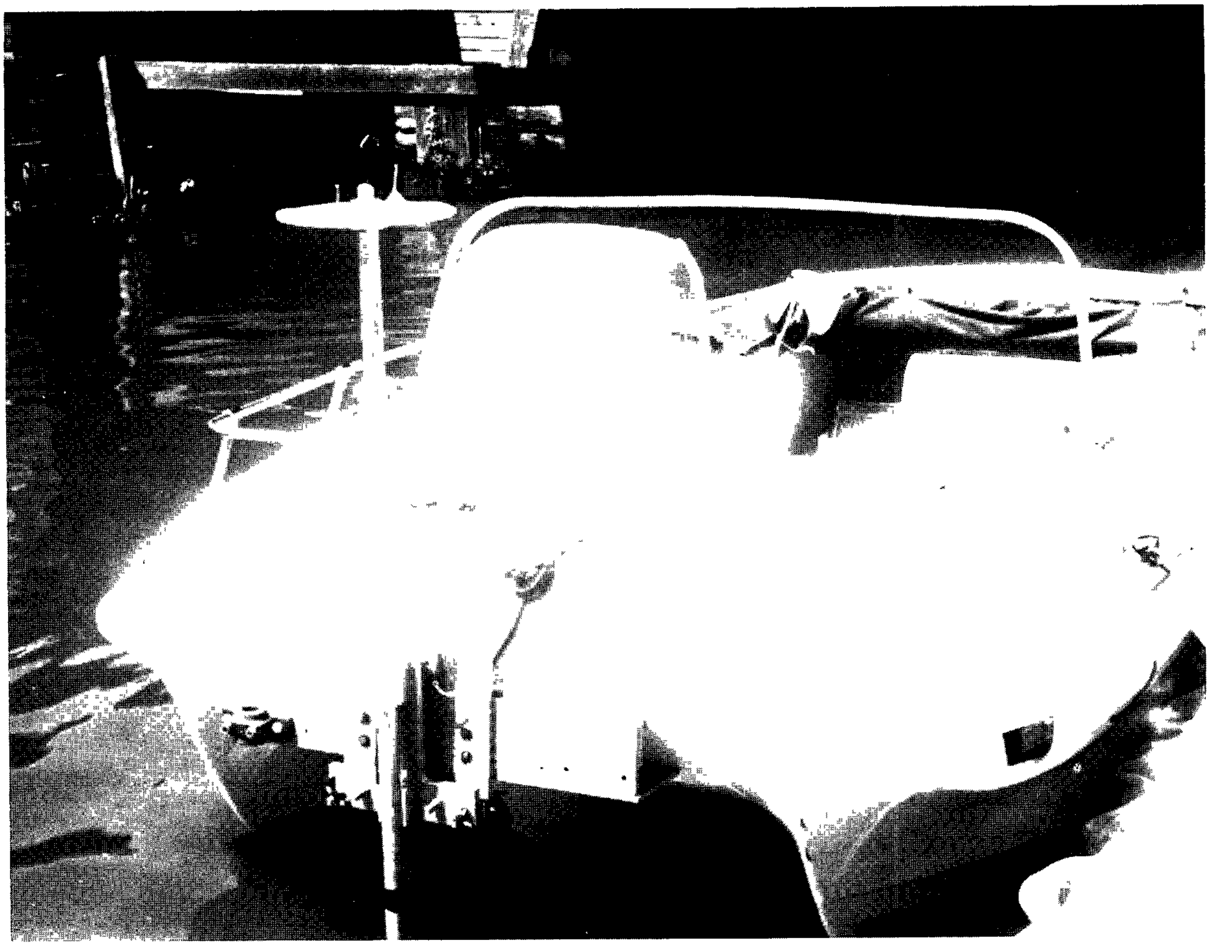


Figure 8.—Boat and mounted vane assembly.

and then moving the arm either up or down to the desired depth.

Because the vane assembly is mounted perpendicular to the centerline of the boat, it will change slightly from its original vertical position because of the raising of the bow of the boat during the moving-boat measurement. To offset this change and thus allow for vertical positioning of the assembly during normal boat operation, the mounting assembly provides for a compensating angle adjustment to be accomplished through the use of two adjusting bolts and a pivot plate (fig. 9). By screwing these bolts either inward or outward, the lower part of the assembly can be pivoted toward or away from the boat. If the adjusting bolts are touching the aluminum plate when the assembly is in a vertical position, they must be screwed away from the plate so that the lower part of the assembly can then be pivoted toward it and secured in position by use of two clamping bolts. The degree of adjustment would depend upon the operating velocity of the boat during the measurement.

### Removal of the equipment

After the measurements are completed, the vane assembly can be removed while leaving the aluminum plate bolted to the steel plate on the bow of the boat. This is accomplished by first loosening the wing nuts on the two clamping bolts of the plate and then removing the clip and sliding out the pivot pin that secures the assembly to the aluminum plate (fig. 9). Prior to removal of the vane assembly, the meter and the transducer cables should be disconnected from the rate indicator and the sonic sounder, respectively.

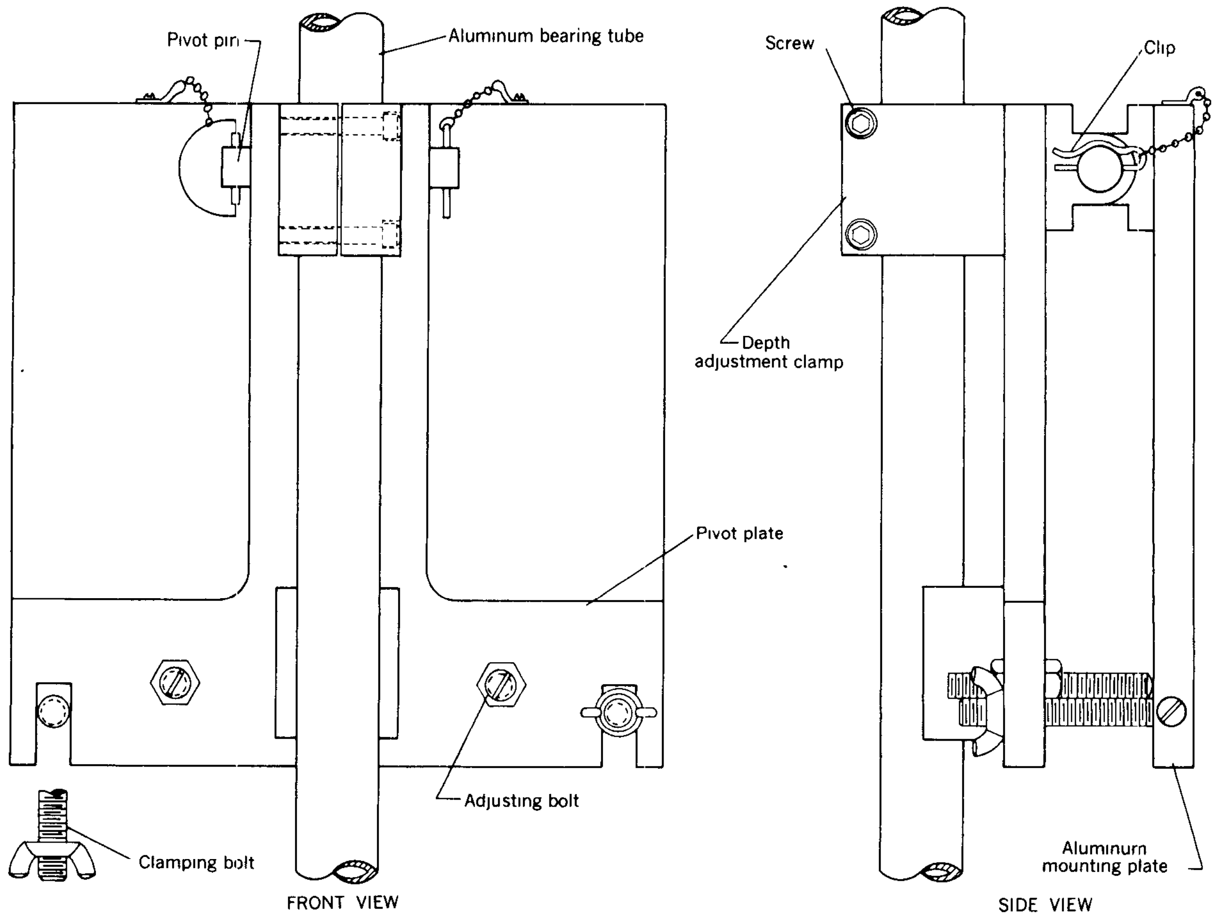



Figure 9.—Vane-mounting assembly.

# Measurement Procedures

Procedures for a moving-boat measurement include selection and preparation of a suitable measuring site, preparation and assembly of the equipment used for the measurement, and a selection of settings for the instruments used to collect the data.

## Selection and preparation of the site

Some preparation is required at the site prior to starting a series of moving-boat measurements. First, a path for the boat to travel is selected, which is as nearly perpendicular to the flow direction as possible. Then, two clearly visible range markers are placed on each bank in line with this path. The color of these markers should contrast sharply with the background. Spacing between the markers is dependent upon the length of the path, the longer paths requiring greater spacing. Approximately 100 feet of spacing is needed for each 1,000 feet of path length. Next, anchored floats are placed in the stream 40–50 feet from each shore along the selected path (fig. 1). In making a traverse, this distance is needed for maneuvering the boat when entering or leaving the path. The floats should be placed so that the depth of water in their vicinity is always greater than 3–4 feet (vane depth). Large plastic bleach containers are suitable for use as floats; styrofoam cubes can also be used. It is preferable not to place them directly in the boat path but rather 10–20 feet upstream. Their purpose is to mark the beginning and ending points of the boat measurement, and by offsetting them upstream they can serve that purpose without being in the way as the boat approaches along the selected path. Finally, the width of the stream is measured by triangulation, stadia, or other methods, and the exact locations of the floats are determined. Because the floats are close to the bank, a tape measure can be used to determine the distance from the edge of water to each float. These distances should be recorded in the spaces provided on the front page of the discharge measurement notes for they will be used in the computation of the measurement.

If a station is to serve as a site for moving-boat discharge measurements on a continuing basis, it will probably be desirable to construct permanent range markers. Such markers would serve two useful purposes. First, determination of stream width would become a relatively simple procedure because of the availability of the constant distance between the markers once this distance has been established. A tape measure could be used to obtain the horizontal distance from the nearest marker to the water's edge on both banks. Subtracting these two distances from the established distance between the markers would provide the width of the stream. A second advantage would be that if the need arose, the markers could serve as permanent initial points from which cross-section profiles of the measuring section could be constructed.

## Preparation of the equipment

The special equipment and instruments necessary for a moving-boat measurement have been described in some detail under "Equipment." The purpose of this section is to summarize for the convenience of the boat crew the steps involved in the assembly of the equipment and in the selection of the instrument settings.

### Assembly of the equipment

The steps listed below should be observed in the assembly of equipment:

1. Permanently mount a steel plate to the bow of the boat (see "Preparation of the boat") and then attach the aluminum plate of the vane assembly to it. (See "Mounting of equipment.") Both of these steps are "one time" operations that should be completed in advance of the trip.
2. Attach the sonic-sounder transducer to its support arm on the vane assembly (fig. 3).
3. Mount the current meter to the leading edge of the vane (fig. 3).
4. Use the pivot pin and clip and the two clamping bolts of the aluminum plate to secure the vane assembly to the plate (fig. 9).
5. Position the current meter at the desired depth (3–4 ft). This is done by loosening the two cap screws in the depth adjustment clamp and then raising or lowering the aluminum bearing tube to the proper position before retightening the screws. Measure the meter depth and record it in the measurement notes once positioning is completed.
6. Route the current-meter cable up the vane assembly and plug it into the marked receptacle on the rate indicator and counter unit. To prevent entanglement, the cable should be taped to the aluminum bearing tube in several places. It is necessary to provide some slack in the cable at its lower end to allow for the movement of the meter as the vane rotates during the measurement.
7. Position the sonic-sounder transducer at a depth of 2 or 3 feet. This is accomplished by loosening the two cap screws that secure the support arm to the aluminum tube and then sliding the arm either up or down the tube to the proper position before tightening the screws. Measure the transducer depth and record it in the measurement notes at this time.
8. Route the transducer cable up the vane assembly, securing it by tape to the aluminum bearing tube; feed it through the hole provided near the hinge of the sonic-sounder case; and then plug it into the marked receptacle at the back of the dividing plate.
9. Insert the battery cable of the sonic sounder into the marked receptacle at the back of the dividing plate of the unit. It can be fed through one of the holes provided near the hinge. A standard 6- or 12-volt (depending on the sonic-sounder model) storage battery should be used as a power supply.

10. Plug the relay cable from the counter unit to the sonic sounder into the marked receptacle on the front of each unit.
11. Use the two adjusting screws (fig. 9) to provide for the compensating angle adjustment of the vane assembly as described in "Mounting of equipment."

### Selection of the instrument settings

The notekeeper is responsible for the functioning of the rate indicator and counter and the recording-depth sounder. To assure proper operation of the equipment, it is necessary that he make several preliminary instrument settings for each unit prior to the measurement. The following is a list of the steps involved in obtaining these settings:

Sonic sounder:

1. Check to see that the pulleys turn smoothly and that the stylus enters the track easily.
2. Set the operation switch to "STAND BY" position.
3. Turn the unit on by rotating the "RECORD" switch clockwise to some low-numbered position and wait a few minutes for the tubes to warm up.
4. Set the depth-range selection at phase 1 (0–60 ft) and advance the gain control to obtain the "zero mark" near the top of the sounder chart.
5. Set the "zero mark" on the zero line of the recorder paper through use of the zero adjustment screw located behind the top pulley.
6. Continue to advance the gain until the "echo mark" appears somewhere below the "zero mark." If no echo appears when the gain is opened, switch the range control to the next phase (60–120 ft) and so on until the bottom is found.
7. Determine the optimum chart speed through use of table 1; then use the small lever in the lower left-hand corner of the recorder chassis to make this selection.
8. Change the operating switch from "STAND BY" to "NORMAL" position several minutes before the measurement begins. This will start the chart recording and provide an opportunity for a final check of instrument operation before the measurement begins.

Rate indicator and counter:

1. Select the desired scale for the rate-indicator meter located on the panel.
2. Check both battery packs with the battery test switch. This final check should have been preceded by a test several days before the measurement date in order to provide time to charge the batteries if needed.
3. Set the rate-indicator switch to "ON" position.
4. Set the marker switch to "ON" position. (The actual marking will not begin until the "START" button is depressed.)
5. Select a range setting that will provide between 30–40 observation points. Because of the scale settings available, this may not always be possible, in which case choose that compromise setting which will come the closest to meeting this provision.

After all the control settings are completed, the instruments are ready for use. The "START" and "STOP" buttons on the panel of the counter unit are used to begin and end instrument operation at the precise moments the bow of the boat reaches the first and second floats, respectively. The operation of these button controls in regard to the starting and stopping procedure is described in the following section, "Functions of the crew members."

## Functions of the Crew Members

Three crew members are necessary for making a moving-boat discharge measurement. They include a boat operator, an angle observer, and a notekeeper. Before crew members begin making discharge measurements by the moving-boat method, it is important that they develop a high degree of proficiency in all phases of the technique. This can be done by making practice measurements at a site where the discharge is known and then comparing the moving-boat discharge with the rated discharge. If there is no suitable site available for this purpose, then the boat crew should make a series of moving-boat measurements at a single location and compare results for repeatability.

## Boat operator

Before the measurement begins, the boat operator should become thoroughly familiar with the sampling site. In tidal streams the operator should be familiar with conditions during all phases of the tidal cycle. This will help him avoid running the boat aground in shallow depths and damaging the submerged equipment. While maneuvering the boat, it is necessary to avoid sudden sharp turns that might result in damage to the meter cable by causing it to be wrapped around the vane assembly.

The operator should select an approach path for the boat that will allow it to be properly maneuvered into position prior to passing the first float. The path should begin from a downstream position as close to the riverbank as depth considerations permit. From such a starting point the boat can be accelerated to near its normal operating speed and the turn into the measuring section can be completed before the measurement begins. By attaining both the proper speed and alinement prior to reaching the float, the instrument readings will have time to stabilize before the initial sample is taken.

During a traverse the only function of the boat operator is to pilot the boat. He maintains course by "crabbing" into the direction of flow sufficiently to remain on line throughout the run. As stream velocities vary in the cross section, he should rely more upon steering adjustments to keep the proper alinement than upon acceleration or deceleration of the boat. Alinement is determined by sighting on the shore which is being approached. Much of the accuracy of the measurement depends on the skill of the boat operator in maintaining a true course with the boat.

Because the stream velocity is calculated as a sine function of angle alpha (see "Theory of the moving-boat measurement"), small angles should be avoided whenever possible. It is desirable to maintain angle alpha at approximately 45°. The reason for this is that an error of several degrees in reading angle alpha would be more significant at the lower angle readings than the same error at high angle readings. In order to maintain an angle of 45°, the velocity of the boat must be equal to that of the stream. This can be done if the stream velocity is above 2.5 fps; however, control of the boat is difficult to maintain below this velocity. For example, in tidal streams the velocity magnitude will often vary from 0 to several feet per second; therefore, it is not always possible to maintain an angle as large as 45°, and the measurement must be made using smaller angles.

## Angle observer

A second man alines the dial of the vane indicator through its sighting device and, upon the audible signal from the pulse counter, reads the angle formed by the vane with respect to the true course. He reports the angle to the notekeeper who then records it. If the boat has strayed from the true path, the angle reader should sight parallel to the cross-section markers rather than at the markers themselves.

## Notekeeper

The notekeeper has several functions to perform. Prior to the measurement it is his responsibility to see that all preparation of equipment as it pertains to the rate indicator and counter and the sonic sounder is completed satisfactorily. This includes not only equipment assembly but also selection of appropriate instrument settings.

The accuracy of the sonic sounder is dependent upon the velocity of sound in water which varies slightly with temperature, dissolved solids, and other variables. Thus the sounder's output should be compared to a known depth. Any significant error detected in the comparison can be expressed as a percentage of the known depth, and this percentage would be applicable to all depths determined by the sonic sounder. Consequently, this percentage correction should be applied to the total area and total discharge.

A check to determine that the current meter and rate indicator are functioning properly is also desirable. Such a check can be made by comparing the indicated velocity to a velocity determined by the Price current meter. This test is intended to determine proper operation only and is not intended for calibration purposes.

It is the notekeeper's responsibility to operate the controls provided on the equipment for starting and stopping the counter. It is important to the accuracy of the measurement that this unit promptly begin and end its operation at the first and second floats, respectively. This is accomplished by operating the "START" and "STOP" buttons on the panel of the counter in the following manner:

1. Approximately 1 second before the boat reaches the first float, the "START" button is depressed; it is released at the moment of passing. This marks the sounder chart, resets the counter, and starts it.

   Marking of the sounder chart and sounding of the beeper (tone signal) will be automatic during the measurement. This marking and sounding will occur at regular intervals as determined by the setting of the range switch on the panel of the counter unit.
2. At the moment the bow of the boat reaches the second float, the "STOP" button is depressed for 1 second and then released. This marks the sounder chart, signifying the end of the measurement, and stops the counter.

During the measurement, the notekeeper records the angle reading at each signal as it is called out by the angle reader. He also reads and records the instantaneous "velocity" from the rate indicator meter at the same time. Readings are taken at all observation points as defined by the tone signals, including the two float positions.

If the time between consecutive measurements is short, it is desirable to leave the operating switch of the sonic sounder on the "NORMAL" position until the measurement series is concluded. In this way the chart continues to advance between measurements, but there are no vertical line markings. This absence of vertical lines provides a gap on the chart that clearly sets off one measurement from another.

## Computation of the Measurement

Streamflow, or discharge, is the volume rate of flow of water. The dimensions are usually expressed in cubic feet per second. A measurement is the summation of the products of the partial areas of the stream cross section multiplied by their respective average velocities. It can be represented by the formula

$$Q = \Sigma(a\,V), \tag{6}$$

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

The moving-boat measurement is similar to the standard current-meter measurement in that it utilizes the midsection method of computing cross-section area for discharge measurements. This method assumes that the velocity sampled at each location represents the mean velocity in a partial rectangular area. The area extends laterally from half the distance from the preceding meter location to half the distance to the next and vertically from the water surface to the sounded depth.

### Method of computation

In figure 10 a definition sketch of the midsection method of computing cross-section area for discharge measurements has been superimposed over a facsimile of a cross-section profile from a sonic-sounder chart. The cross-section is defined by depths at locations, 1, 2, 3, 4, . . . $n$; except for the two edge-of-water positions, each location would be automatically marked on the sounder chart at the time the measurement readings were made. The markings appear as parallel vertical lines, extending the width of the chart.

The partial discharge in a moving-boat measurement is computed for any partial section at location $x$ as

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

$$= V_x\left[\frac{b_{(x+1)} - b_{(x-1)}}{2}\right] d_x, \tag{7}$$

where

$q_x$=unadjusted discharge through partial section $x$,

$V_x$=sampled velocity at location $x$,

$b_x$=distance from initial point (marker) to location $x$,

$b_{(x-1)}$=distance from initial point to preceding location,

$b_{(x+1)}$=distance from initial point to next location, and

$d_x$=depth of water at location $x$.

Thus, for example, the unadjusted discharge through partial section 4 (heavily outlined) is

$$q_4 = V_4\left[\frac{b_5 - b_3}{2}\right]d_4. \qquad (8)$$

At the end subsections, the "preceding location" at the beginning of the section is considered coincident with location 1; the "next

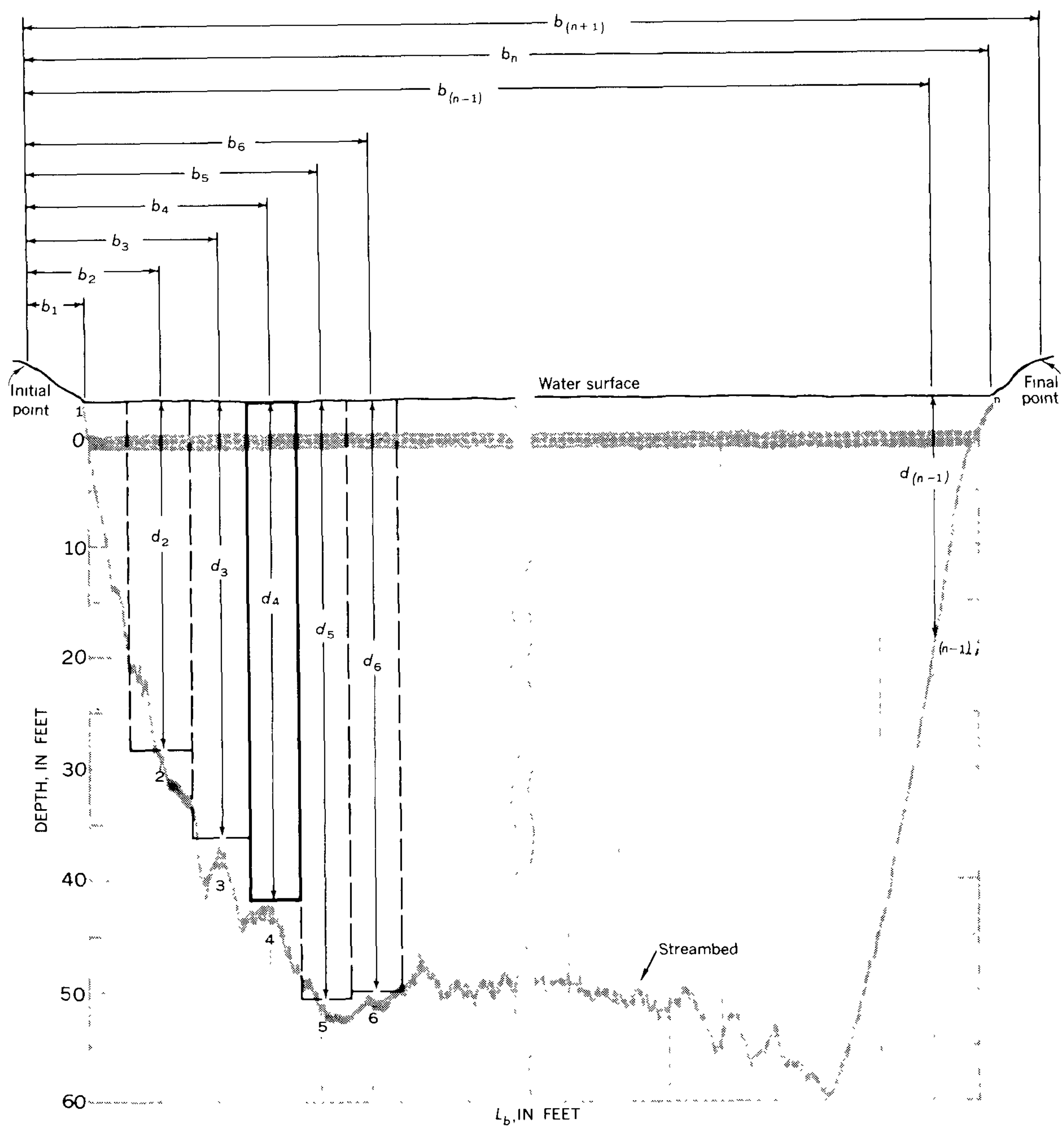



Figure 10.—Definition sketch of midsection method of computation superimposed over a facsimile of a sonic-sounder chart.

location" at the end of the section is considered coincident with location $n$. Thus,

$$q_1=V_1\left[\frac{b_2-b_1}{2}\right]d_1 \qquad (9)$$

and

$$q_n=V_n\left[\frac{b_n-b_{(n-1)}}{2}\right]d_n. \qquad (10)$$

For the example shown in figure 10, $q_1$ and $q_n$ are both zero because the depths at location 1 and $n$ are zero.

The summation of the discharge of the partial sections, $q_1, q_2, q_3, \ldots q_n$, is the total unadjusted discharge of the stream. A step-by-step outline of the computation procedure, which refers to the example of the measurement notes shown in figure 11 is given as a guide to the computer.

1. The data in the first column are the angle readings recorded by the notekeeper during the measurement. Because these readings begin and end at the float positions (there are no edge-of-water readings), they represent the values observed at locations 2, 3, 4, . . . ($n$–1).
2. Each value in column 2 represents an incremental distance the boat has traveled along the cross-section path between two consecutive observation points. With $a_x$ representing the angle reading at location $x$, then $L_{b_x}$ is the incremental distance the boat has traveled along the true course, extending from the previous observation point, $x$–1 to the location $x$ where the reading was taken.

The values in this column can be read directly from a table (fig. 6) by using the angle values recorded in column 1 and the range number as determined by the range selection on the counter unit. Two exceptions are the first and last values in the column, representing the distance to each float from its nearest edge of water. These values are determined by direct measurement prior to the actual run. This is necessary because the actual boat run does not begin and end at the edge-of-water positions and thus is not set up to measure these distances. Therefore, the beginning angle reading, $a_2$, at the first float, is not used for obtaining distance from the edge of water to that float. It should also be noted that $L_{b_3}$ is always recorded as one-half of the value found in the table. This is necessary because the counter unit has been programed to signal at a "half-count" on its first count routine. All remaining values can be recorded directly from the table of $L_b$ values, without any changes, with the possible exception of the one determined from the last angle reading which was made at the second float. This angle reading may or may not have been made at the end of a full count by the counter unit. In the sample measurement the value recorded was three-fourths of that in the table because the sounder chart distance between the last two vertical markings was approximately three-fourths of the normal spacing.

3. Each value recorded in column 3 represents the distance from the initial point (marker) to the observation point where the data were collected. The data in column 2, together with the "Distance to float" and the "Distance to marker" values recorded on the front sheet of the discharge measurement notes (fig. 11) are used to obtain these cumulative distances. For a moving-boat measurement, these distances are defined as follows:

   $b_1$ = distance from initial point (marker) to edge of water,

   $b_2=b_1$ + measured distance to float from edge of water,

   $b_3=b_2+L_{b_3}$

   $b_4=b_3+L_{b_4}$,

   . . . . . . . . . . ,

   $b_{(n-1)}=b_{(n-2)}+L_{b_{(n-1)}}$

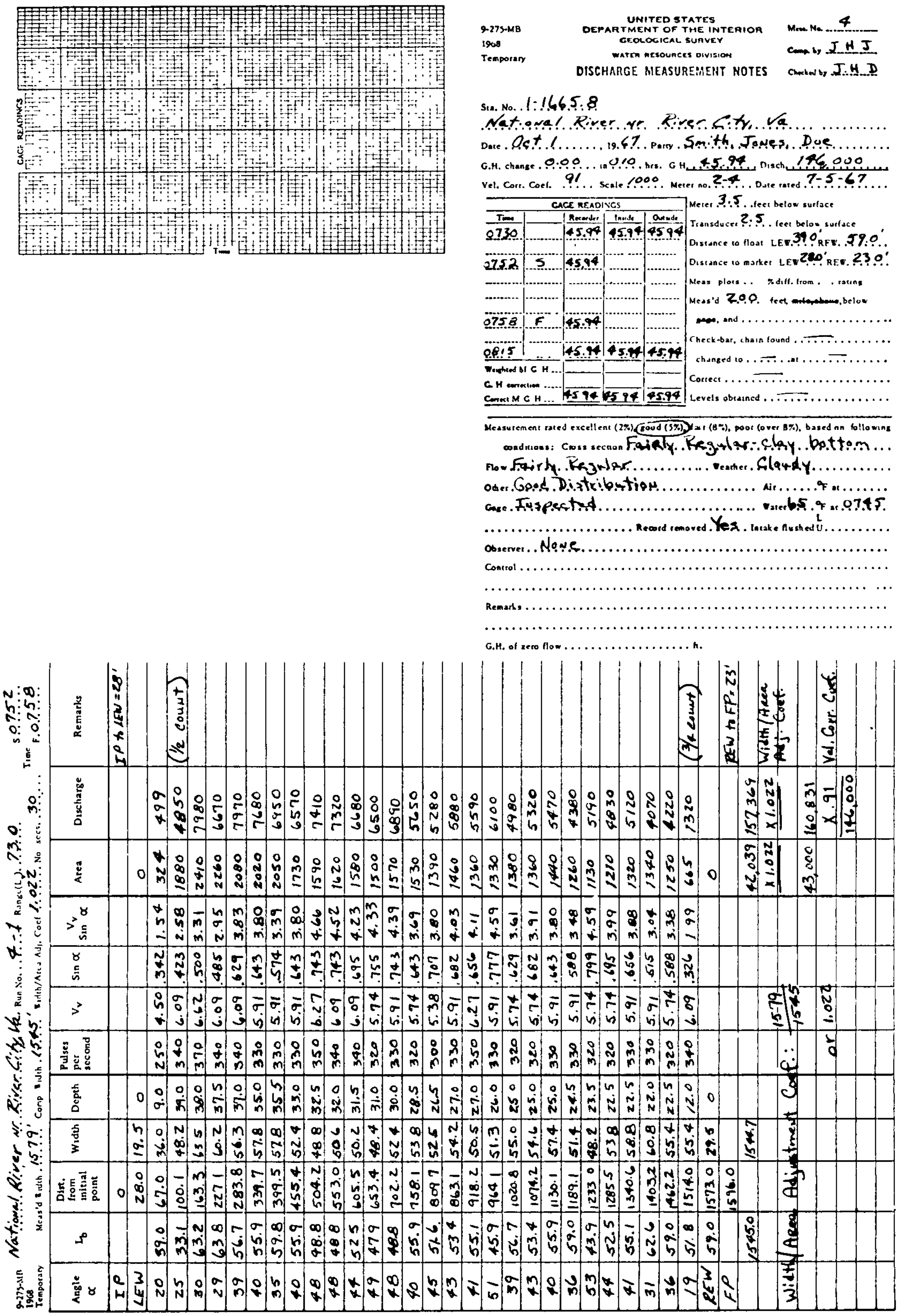
   $b_n=b_{(n-1)}$ + measured distance from float to edge of water,

   $b_{(n+1)}=b_n$ + distance to final point (marker).

4. Each of the subsection widths in column 4 represents the distance that extends laterally from half the distance from the preceding meter location, ($x-1$), to half the distance to the next, ($x+1$). For example, the width of subsection $x$ equals

$$\frac{b_{(x+1)}-b_{(x-1)}}{2}.$$

5. Each of the values in column 5 represents the stream depth at a sampling point in the cross section. These values are obtained by adding the transducer depth to each of the depth readings recorded on the sounder chart at the sampling locations.



9-275-MB
1968
Temporary

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION
DISCHARGE MEASUREMENT NOTES

Meas. No. 4
Comp. by J H J
Checked by J. H. D

Sta. No. 1-1665.8
National River nr. River City, Va.
Date Oct. 1, 1967 Party Smith, Jones, Doe
G.H. change 0.00 in 0.10 hrs. G.H. 45.94 Disch. 146,000
Vel. Corr. Coef. .91 Scale 1000 Meter no. 2-4 Date rated 7-5-67

| GAGE READINGS | | | | |
|---|---|---|---|---|
| Time | | Recorder | Inside | Outside |
| 0730 | | 45.94 | 45.94 | 45.94 |
| 0752 | S | 45.94 | | |
| 0758 | F | 45.94 | | |
| 0815 | | 45.94 | 45.94 | 45.94 |
| Weighted M G H | | | | |
| G H correction | | | | |
| Correct M G H | | 45.94 | 45.94 | 45.94 |

Meter 3.5 feet below surface
Transducer 2.5 feet below surface
Distance to float LEW 39.0' REW 59.0'
Distance to marker LEW 28.0' REW 23.0'
Meas plots ... % diff. from ... rating
Meas'd 2.0.0 feet ~~microphone~~, below gage, and ...
Check-bar, chain found ...
changed to ... at ...
Correct ...
Levels obtained ...

Measurement rated excellent (2%), good (5%) [circled], fair (8%), poor (over 8%), based on following conditions: Cross section Fairly Regular, clay bottom
Flow Fairly Regular Weather Cloudy
Other Good Distribution Air ... °F at ...
Gage Inspected Water 65 °F at 0745
Record removed Yes Intake flushed
Observer None
Control
Remarks
G.H. of zero flow ... ft.

9-275-MB
1968
Temporary

National River nr. River City, Va. Run No. 4-1 Range (L) 73.0 No. secs. 30 Time S 0752 F 0758
Meas'd width 1545' Comp width 1579' Width/Area Adj. Coef 1.022

| Angle α | $L_b$ | Dist. from initial point | Width | Depth | Pulses per second | $V_v$ | Sin α | $V_v$ Sin α | Area | Discharge | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| IP | | 0 | | | | | | | | | IP to LEW = 28' |
| LEW | | 28.0 | 19.5 | 0 | | | | | 0 | | |
| 20 | 59.0 | 67.0 | 36.0 | 9.0 | 250 | 4.50 | .342 | 1.54 | 324 | 499 | |
| 25 | 33.1 | 100.1 | 48.2 | 39.0 | 340 | 6.09 | .423 | 2.58 | 1880 | 4850 | (1/2 count) |
| 30 | 63.2 | 163.3 | 63.5 | 38.0 | 370 | 6.62 | .500 | 3.31 | 2410 | 7980 | |
| 29 | 63.8 | 227.1 | 60.2 | 37.5 | 340 | 6.09 | .485 | 2.95 | 2260 | 6670 | |
| 39 | 56.7 | 283.8 | 56.3 | 37.0 | 340 | 6.09 | .629 | 3.83 | 2080 | 7970 | |
| 40 | 55.9 | 339.7 | 57.8 | 35.0 | 330 | 5.91 | .643 | 3.80 | 2020 | 7680 | |
| 35 | 59.8 | 399.5 | 57.8 | 35.5 | 330 | 5.91 | .574 | 3.39 | 2050 | 6950 | |
| 40 | 55.9 | 455.4 | 52.4 | 33.0 | 330 | 5.91 | .643 | 3.80 | 1730 | 6570 | |
| 48 | 48.8 | 504.2 | 48.8 | 32.5 | 350 | 6.27 | .743 | 4.66 | 1590 | 7410 | |
| 48 | 48.8 | 553.0 | 50.6 | 32.0 | 340 | 6.09 | .743 | 4.52 | 1620 | 7320 | |
| 44 | 52.5 | 605.5 | 50.2 | 31.5 | 340 | 6.09 | .695 | 4.23 | 1580 | 6680 | |
| 49 | 47.9 | 653.4 | 48.4 | 31.0 | 320 | 5.74 | .755 | 4.33 | 1500 | 6500 | |
| 48 | 48.8 | 702.2 | 52.4 | 30.0 | 330 | 5.91 | .743 | 4.39 | 1570 | 6890 | |
| 40 | 55.9 | 758.1 | 53.8 | 28.5 | 320 | 5.74 | .643 | 3.69 | 1530 | 5650 | |
| 45 | 51.6 | 809.7 | 52.5 | 26.5 | 300 | 5.38 | .707 | 3.80 | 1390 | 5280 | |
| 43 | 53.4 | 863.1 | 54.2 | 27.0 | 330 | 5.91 | .682 | 4.03 | 1460 | 5880 | |
| 41 | 55.1 | 918.2 | 50.5 | 27.0 | 350 | 6.27 | .656 | 4.11 | 1360 | 5590 | |
| 51 | 45.9 | 964.1 | 51.3 | 26.0 | 330 | 5.91 | .777 | 4.59 | 1330 | 6100 | |
| 39 | 56.7 | 1020.8 | 55.0 | 25.0 | 320 | 5.74 | .629 | 3.61 | 1380 | 4980 | |
| 43 | 53.4 | 1074.2 | 54.6 | 25.0 | 320 | 5.74 | .682 | 3.91 | 1360 | 5320 | |
| 40 | 55.9 | 1130.1 | 57.4 | 25.0 | 330 | 5.91 | .643 | 3.80 | 1440 | 5470 | |
| 36 | 59.0 | 1189.1 | 51.4 | 24.5 | 330 | 5.91 | .588 | 3.48 | 1260 | 4380 | |
| 53 | 43.9 | 1233.0 | 48.2 | 23.5 | 320 | 5.74 | .799 | 4.59 | 1130 | 5190 | |
| 44 | 52.5 | 1285.5 | 53.8 | 22.5 | 320 | 5.74 | .695 | 3.99 | 1210 | 4830 | |
| 41 | 55.1 | 1340.6 | 58.8 | 22.5 | 330 | 5.91 | .656 | 3.88 | 1320 | 5120 | |
| 31 | 62.6 | 1403.2 | 60.8 | 22.0 | 330 | 5.91 | .515 | 3.04 | 1340 | 4070 | |
| 36 | 59.0 | 1462.2 | 55.4 | 22.5 | 320 | 5.74 | .588 | 3.38 | 1250 | 4220 | |
| 19 | 51.8 | 1514.0 | 55.4 | 12.0 | 340 | 6.09 | .326 | 1.99 | 665 | 1320 | (3/4 count) |
| REW | 59.0 | 1573.0 | 29.5 | 0 | | | | | 0 | | REW to FP, 23' |
| FP | | 1596.0 | 1544.7 | | | | | | 42,039 | 157,369 | |
| Width/Area Adjustment Coef. | 1545.0 | | | | Coef.: 1579/1545 | | | | × 1.022 | × 1.022 | Width/Area Adj. Coef. |
| | | | | | or 1.022 | | | | 43,000 | 160,831 | |
| | | | | | | | | | | × .91 | Vel. Corr. Coef. |
| | | | | | | | | | | 146,000 | |

Figure 11.—Sample of computation notes of a moving-boat measurement.

6. The data in column 6 are the pulses-per-second readings recorded by the note-keeper during the measurement.
7. The values recorded in column 7 represent the instantaneous velocity of the water past the vane at each observation point. They are read directly from the meter-rating table (fig. 6), using the pulses-per-second values of column 6.
8. The data in column 8 are the sine function values of the angle readings in column 1. These values may be obtained from the sine table in figure 6, using the angle readings of the first column.
9. Each of the values in column 9 represents the stream velocity normal to the cross section at that particular sampling point. To obtain these values, it is necessary to multiply each $V_V$ value in column 7 by the corresponding sin $\alpha$ value in column 8.
10. The values in column 10 represent the individual partial cross-section areas for the measurement. They are obtained by multiplying the widths of column 4 by their corresponding depths in column 5. The incremental areas are then summed to provide the total unadjusted area for the measurement.
11. Each quantity in column 11 represents the unadjusted discharge through one of the subsections of the discharge measurement. These values are summed to provide the total unadjusted discharge of the measurement.
12. This column is used for recording any descriptive remarks pertaining to the measurement.

## Correction for width

As previously shown, the relationship expressed by the equation $L_b \approx L_V \cos \alpha$ is used to obtain the incremental widths across the stream. This equation is based on the assumption that a right-triangle relationship exists among the velocity vectors involved. If the flow is not normal to the cross section, this situation does not exist and the use of the equation can result in a computed width that is too large or too small (fig. 12), depending on whether the vector quantity representing the oblique flow has a horizontal component that is opposed to or in the direction of that of the boat. Thus in figure 12, the computed width would be $AB'$ of the right triangle $AB'C$ rather than the true width $AB$ of oblique triangle $ABC$. Here the computed width is too large, whereas the computed width $DE'$ of right triangle $DE'F$ is less than the actual width $DE$ of oblique triangle $DEF$.

Ideally the correction for error in the computed width would be applied to that particular increment in the cross section where the error occurred. However, in practice only the overall width is directly measured and thus is available for comparison with the computed quantities. Therefore, if the sum of the computed incremental widths does not equal the measured width of the cross section, correction is made by adjusting each increment proportionately.

The moving-boat method uses the relationship between the measured and computed widths of the cross section to determine a width–area adjustment factor. To obtain this coefficient, the measured width of the cross section is divided by its computed width, that is

$$k_B=\frac{B_m}{B_c}, \tag{11}$$

where

$k_B$=width-area adjustment factor,

$B_m$=measured width of cross section, and

$B_c$=computed width of cross section.

The coefficient is then used to adjust both total area and total discharge of the measurement as if the width error had been evenly distributed on a percentage basis across each width increment of the cross section.

See "Computation notes" (fig. 11), for an example of an application of a width–area adjustment coefficient.

## Mean-in-vertical velocity adjustment

During a moving-boat discharge measurement, the current meter is set at a predetermined, fixed depth of from 3 to 4 feet below the water surface; thus, this technique uses the subsurface method of measuring velocity as discussed by Corbett and others (1945, p. 41–42). Measurement is computed by using constant-depth subsurface velocity observations without adjustment coefficients as though each

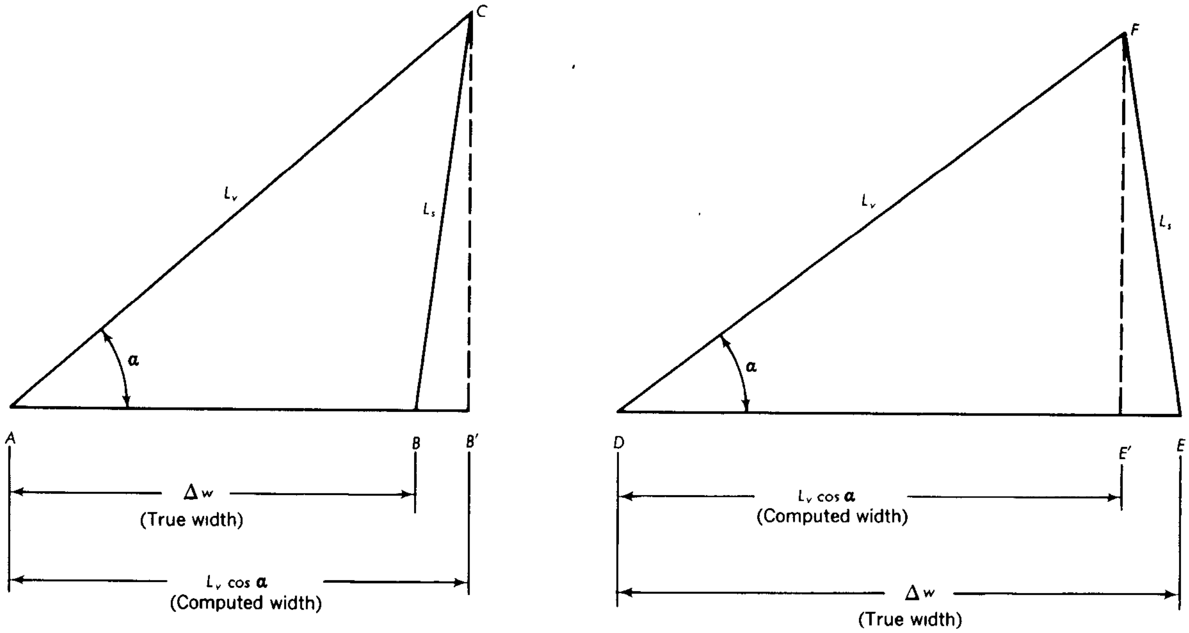



Figure 12.—Comparison of actual and computed values of incremental widths.

were a mean in the vertical. In using this method, each measured velocity should ideally be multiplied by a coefficient to adjust it to the mean velocity in its vertical. However, it is assumed that in the larger streams where the moving-boat technique would be applicable, these coefficeints would be fairly uniform across a section. This uniformity would permit the use of an average cross-section coefficient to be applied to the total discharge. Information obtained from several vertical-velocity curves, well distributed across the measuring site, would be needed to determine a representative coefficient for the total cross section.

### Determination of vertical-velocity coefficient

Vertical-velocity curves are constructed by plotting observed velocities against depth. The vertical-velocity curve method calls for a series of velocity observations (by conventional methods) at points well distributed between the water surface and the streambed. Normally these points are chosen at 0.1-depth increments between 0.1 and 0.9 of the depth. Observation should also be made at least 0.5 foot from the water surface and 0.5 foot from the streambed; for this particular application, a velocity reading should be made at the moving-boat sampling depth of from 3 to 4 feet below the water surface. Once the velocity curve has been constructed, the mean velocity for the vertical can be obtained by measuring the area between the curve and the ordinate axis with a planimeter, or by other means, and then dividing this area by the length of the ordinate axis.

To obtain a velocity correction coefficient at location $x$ in the cross section, the mean velocity in the vertical is divided by the observed velocity at the measured depth; that is,

$$k_V = \frac{\overline{V}}{V}, \qquad (12)$$

where

$k_V$=mean-in-vertical velocity adjustment factor,
$\overline{V}$=mean velocity in the vertical, and
$V$=observed velocity (3- or 4-foot depth).

In order to arrive at a representative average coefficient, there should be at least several strategically placed verticals, representing a major part of the flow, where coefficients are determined. Once an average coefficient has been determined, it should not be necessary to redetermine it each time when making future discharge measurements at the same site. However, it would be necessary to test its validity at several widely varying stages, and, in estuaries, at widely different parts of the tidal cycle.

Investigations on the Mississippi River at both Vicksburg and St. Louis, on the Hudson River at Poughkeepsie, and on the Delaware River at Delaware Memorial Bridge, all indicated coefficients that lie in the narrow range of 0.90 to 0.92 for adjusting the subsurface velocity to the mean. Carter and Anderson (1963) present a table of velocity ratios and standard deviations for various relative depths. This table indicates that for streams 10 feet in depth and deeper, the average coefficient would be approximately 0.90 to adjust the velocity obtained at 4 feet below the surface to the mean velocity. The sample from which the data in this table were obtained represents 100 stream sites with from 25 to 30 verticals taken at each site.

### Application of adjustment

The mean-in-vertical velocity adjustment is made immediately after the width-area adjustment has been applied. For this adjustment the total discharge, as determined from use of subsurface velocity readings, is multiplied by a representative velocity-correction factor for the cross section. The product is the discharge for the measurement. (See fig. 11.)

## Selected References

Buchanan, T. J., and Somers, W. P., 1968, Discharge measurements at gaging stations: U.S. Geol. Survey Techniques, Water Resources Inv., book 3, chap. A8. (In press.)

Carter, R. W., and Anderson, I. E., 1963, Accuracy of current-meter measurements: Am. Soc. Civil Engineers Jour., v. 89, no. HY4, p. 105–115.

Smoot, G. F., and others, 1967, A technique for rapid measurement of flows in large streams: U.S. Geol. Survey open-file report, 12 p.

Corbett, D. M., and others, 1945, Stream-gaging procedure: U.S. Geol. Survey Water-Supply Paper 888, 245 p.

☆ U.S. Government Printing Office: 1977—240-961/119