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OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 56

METHODS OF STREAM MEASUREMENT

WASHINGTON
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1901

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., July 10, 1901.

SIR: I have the honor to transmit herewith a manuscript describing the methods of stream measurement in use by the Division of Hydrography, and request that it be published in the series of Water-Supply and Irrigation Papers. This material has been compiled from various reports and letters of instruction, and is intended to embody not only a description of the operations but in some cases minute directions which may assist the hydrographers and serve to increase the accuracy of results. It is designed not only to assist and guide the hydrographers employed by the Survey or working in cooperation with it, but also to exhibit as nearly as possible the degree of accuracy of the operations and of the computations of results. It is hoped that hydraulic engineers and others who may be engaged in similar lines of investigation will adopt these methods or so modify their own operations that the results will be comparable with those obtained by this Survey.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

METHODS OF STREAM MEASUREMENT.

INTRODUCTION.

The object of the work herein described is to obtain data bearing upon the water resources of the United States. In undertaking with limited funds an investigation of this character, it is obvious that a plan must be adopted which will yield useful results with moderate outlay. The United States is so vast and offers such diversity of topographic and climatic conditions that measurements of rivers in one section give data of little value concerning those of another section. It is therefore necessary to consider carefully the distribution of field work so as to obtain typical results, and at the same time not to diffuse it so widely as to destroy its effectiveness. The chief object has been to lay out the operations so that there would be obtained results of practical value and of a reasonable degree of accuracy, broadly representative of conditions prevailing throughout the United States, without expending money for the attainment of an unnecessary degree of precision. There is of course room for wide difference of opinion regarding the best way to attain this object. In the practice of the Survey localities have been selected where the results will have a local application to problems of development and at the same time will yield data which can be applied to adjacent areas under similar topographic conditions.

The operations of the branch of the Geological Survey which has to do with hydrography can be divided into three distinct classes: (1) The measurement of surface streams; (2) the survey of sites for and the estimation of capacity and cost of reservoirs; and (3) the study of the quantity and movement of underground waters. The greater part of the funds available, however, is devoted to the measurement of surface streams, for those are of first importance, regarding both the quantity of water obtainable and its industrial application.

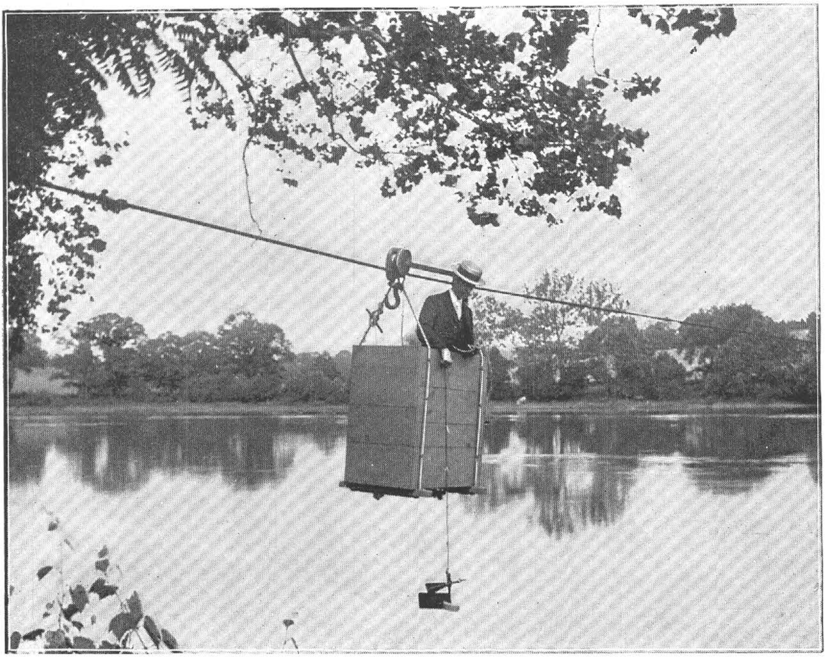
The work of ascertaining the flow of a stream, as developed by the experience of the Division of Hydrography, extending through about thirteen years, consists of (1) observing and recording the daily height of the water, (2) measuring the quantity of flow at different heights, and (3) computing the probable flow at each height or stage of the stream.

The first step is to select a suitable locality for a gaging station. Although apparently simple, this is really a difficult task. Not only must the actual conditions be favorable—the water moving in nearly straight lines over a solid bed and between well-defined banks—but the place must be accessible at moderate cost, and there must be living near a competent person who can be engaged to serve as observer. Usually it is impracticable to hire a man to remain at a locality to observe daily the height of the water and make occasional measurements of the volume. It therefore becomes necessary to locate the station where a person of ordinary intelligence can be employed, at from $2 to $5 a month, to observe and note the height of the stream once or twice a day, and each week send to the Survey a postal card containing a record of these facts. So that in perhaps the majority of cases the station is located not at the most desirable place for obtaining the information desired, but at the best locality where a competent observer can be procured.

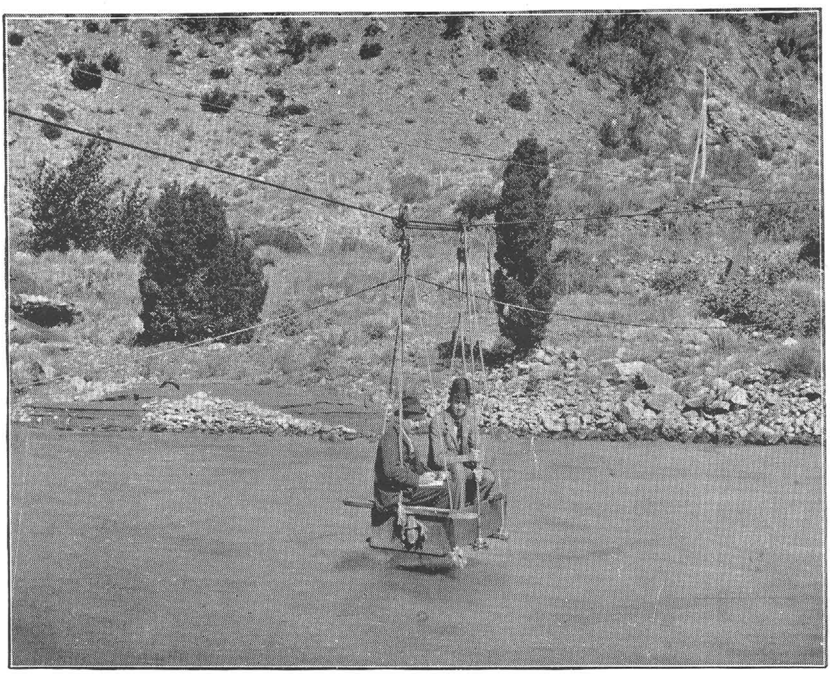
When a suitable location has been found a gage is established, on which the height of the water can easily be read to tenths of a foot. The gage may be either a vertical or an inclined scale, fastened to a pier or attached to supports firmly bedded in the bank. If inclined, it is graduated, after setting, to vertical tenths of a foot, thus affording a magnified reading which is always at the shore line. Sometimes a wire gage is used, a weight being lowered from a bridge or overhanging support, and the distance noted along the horizontal scale. Whatever the device the gage should be referred to permanent bench marks and maintained without alteration.

From time to time the engineers—or hydrographers, as they are termed—visit and inspect the stations and make measurements of the volume of flow by means of a current meter or otherwise. Many forms of current meter are in use. Those preferred have an electric appliance so arranged that every revolution of the wheel causes a click or buzz in a small sounder in the hand or pocket of the hydrographer. Many automatic devices have been tried, but in the long run this form has proved the most satisfactory. In using it, the hydrographer counts and records in a notebook the number of repetitions of the sound during, usually, 50 seconds. The meter is placed in various parts of the cross section by suspending it from a boat or bridge, or, more commonly, from a car in which the hydrographer sits, which is supported by a stout steel cable extending across the stream. (See Pl. I.)

From the occasional measurements of discharge there is constructed, usually by graphic means, a table showing the volume of flow for each tenth of a foot height of the water. From this table the discharge is placed opposite the corresponding gage height for each day, thus giving the fluctuations of the stream, which may be stated in terms of maximum, minimum, and mean for the month, or be shown graphically by diagrams. If the area drained be known, these results can be expressed in units of area and volume, or in depth over the entire catchment basin. The details regarding these measurements and computations are given on the following pages.



A.



B.

CARS USED IN MEASURING VELOCITY OF STREAMS.

A, Shenandoah River near Millville, W. Va.; *B*, Arkansas River at Canyon, Colo.

WEIR MEASUREMENTS.

The flow of water in open channels is controlled by a variety of conditions due to artificial as well as natural features, and no definite rule for gaging can be prescribed which will be applicable to all cases. The methods of operation must therefore be governed largely by local conditions, and should be varied as circumstances require. The accuracy of the results obtained is consequently dependent in no small degree upon the judgment exercised by the hydrographer in dealing with individual cases.

In general, measurements of the volume of flowing water in open channels may be classed under two heads: (1) By means of weirs or dams used as weirs, and (2) by determining the mean velocity and the sectional area for a given cross section. Using the first method, the discharge of the stream is computed by means of an empirical formula, which varies for different types of dams or weirs. On creeks or small rivers it is sometimes practicable to build a timber weir across the channel, causing the total flow of the stream to pass over the sharp edge of the weir crest. Various forms of these weirs are shown in Pls. II and III. By observing the head on the weir computations of the flow can be made. This is probably the most accurate method applicable to small streams. On large rivers, however, the cost of a weir is usually so great as to be prohibitive, so that if there is not a weir or dam already in the stream it is necessary to resort to measurements by floats or current meters, as described further on.

On many rivers of moderate size the conditions are unfavorable for successfully applying either of these methods. For instance, on streams used for manufacturing purposes dams occur at frequent intervals, interrupting the regular flow and in many cases holding back the night flow for use during the following day, so that the discharge during the night may be either nothing or a very small percentage of the day flow. Then, too, the shutting down of the mill wheels for an hour at noon may have a pronounced effect upon the results of float or meter measurements made below the mill. Unfortunately these variations are not always apparent to the hydrographer, and surprise and annoyance are caused by finding that the river height differs by several tenths from the gage as read by the regular observer possibly an hour or two before the hydrographer arrived at the station.

Frequently it is almost impossible to find a section upon a stream used for industrial purposes where the flow is not interrupted by the backwater from dams below. If a station is selected at the time of high water this backing up of the river may not be apparent to the hydrographer, but at the low-water season he may find that the river at the station is merely a placid pond, apparently without current, making measurements impracticable. Examples are Blackstone

River in Massachusetts and Rhode Island and the Sandusky in Ohio. If the fall of a stream is sufficiently rapid a section for meter measurements may be found just below one of the milldams, measurements at such points not being affected by the backwater. They are, however, subject to all of the changes due to gate openings at the mills above.

MILLDAMS AS WEIRS.

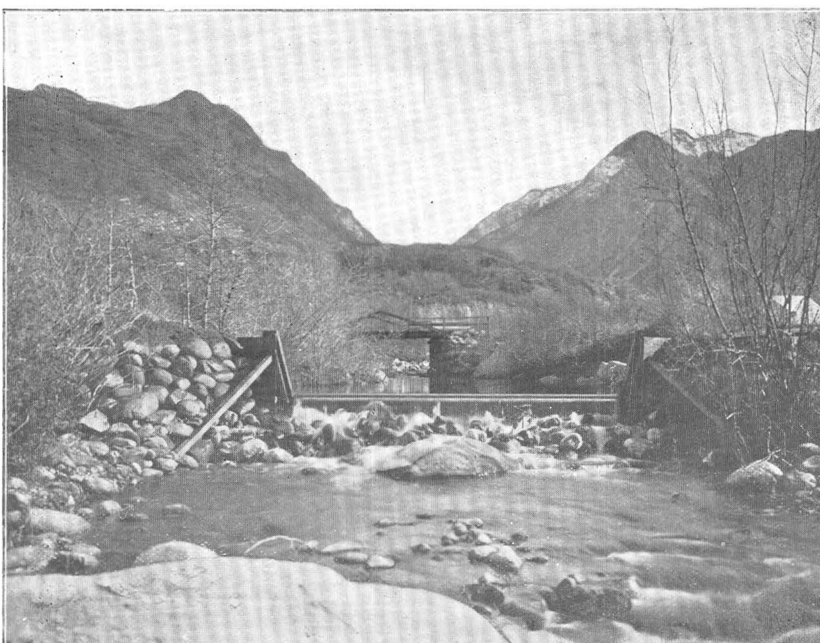
Under the conditions described better results can undoubtedly be obtained if there exists upon the stream a good dam which can be used as a weir. It should have a level, even crest and a constant cross section, with sufficient pondage to reduce the velocity of approach, and it should be free from leakage. Masonry dams are better for this purpose, for they are more likely to be tight and to have an even crest. Timber dams although level when first constructed are likely to settle at various points across the stream, thus producing an uneven crest elevation. There are, however, many good timber dams practically free from leakage and with crests sufficiently uniform for accurate work. Pl. IV shows two dams suitable for use, and Pl. V shows two not suitable for use.

Having selected a dam as the proper site for a station, a careful survey must be made of the crest line and of the upper and lower slopes, so that it can be compared with other dams or with experimental sections for which the coefficients of flow are known. The experiments of James B. Francis, of Fteley and Stearns, and of John R. Freeman, George W. Rafter, and others at Cornell University have given coefficients upon many sections of various forms. It is probable that the dam selected for the station will not be exactly like any of the experimental forms, but it will resemble some of them so closely that coefficients can be selected for the computations.

When the mill gates are open a part of the flow of the stream is diverted from the river through the millrace, the gates, and the tailrace. The amount of the diversion must of course be measured and added to the quantity flowing over the dam in order to determine the total discharge of the stream. In many factories the quantity flowing through the wheels varies from day to day, and also during different hours of the day, so that careful records must be kept of the gate openings in order that proper allowance may be made for these variations. The size and the make of the water wheels must be ascertained and the wheels be used as water meters for the determination of the flow through them. Many of the modern wheels have been carefully rated. Where such ratings have not been made, usually records of wheels of the same type, though possibly of different makes, can be found and the records be compared. Water wheels as meters give fairly accurate records of the discharge.

It will be seen that this method of measuring the flow of streams over dams and through the wheels is somewhat complicated by the

A.



B.

MEASURING WEIRS.

A, Los Angeles River, Cal.; *B*, Cippoletti weir on Little Cottonwood Creek, Utah.

number of records that are taken, which include the height of the water on the crest of the dam, the number and size of the gate openings, the time of starting and stopping the wheels, and all changes of gates; yet in many cases the results obtained will be more accurate than those derived from meter measurements made under unfavorable conditions. A sample of one of the record sheets is given herewith:

Sample of record blank used by United States Geological Survey for recording the flow of streams over dams and through water wheels.

U. S. GEOLOGICAL SURVEY.

Gaging record kept on Schoharie Creek at the Schoharie Falls Dam of Empire State Power Co., Mill Point, N. Y.

For the month ——, 190—. —— ——, *Recorder.*

DAY.	TWO PAIR 40-inch LEFFEL, SAMSON TURBINES.								Crest Gage Above Dam, feet.		Canal Overflow Gage and Waste Gates, feet.		Head Race Gage in Forebay, feet.	Tail-race Gage, feet.
	DAY RUN.				NIGHT RUN.									
	Pair No. 1.		Pair No. 2.		Pair No. 1.		Pair No. 2.							
	Number hours run.	Average Gate Opening.	Number hours run.	Average Gate Opening.	Number hours run.	Average Gate Opening.	Number hours run.	Average Gate Opening.	------- a. m.	------- p. m.	------- a. m.	------- p. m.		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
1														
2														
3														
4														
5														

All gage readings are in feet and decimals. Write each reading plainly in proper column. Put notes as to leakage, ice on dam, waste gate openings, etc., on back of sheet.

[The blank has spaces for 31 days; the above is simply a sample.]

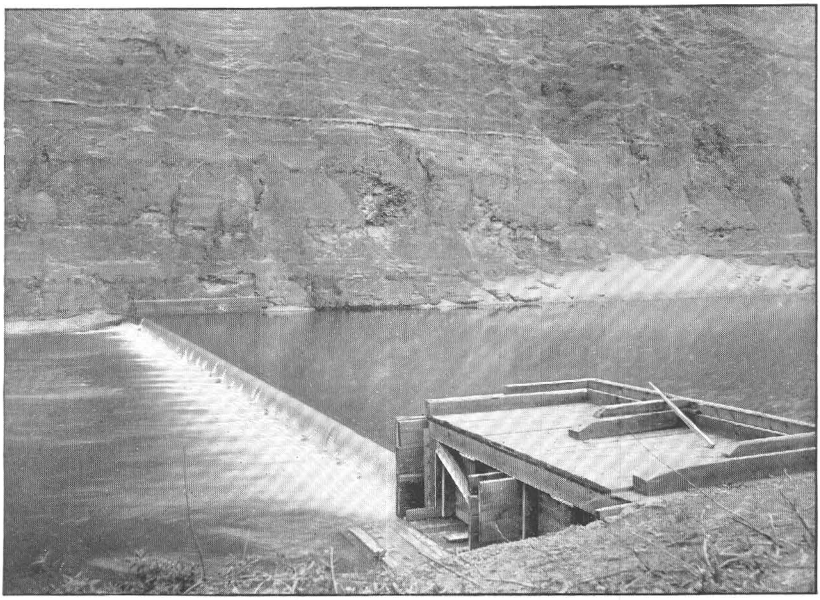
When flashboards are used records must be kept of their height and of the time of placing them, so that a different formula can be used for flow over the flashboards than for that over the broad-crested weir. It is customary to use Francis's formula for sharp-crested weir for computing the flow over the flashboards. Some of the difficulties encountered in measuring the flow of streams by using a dam as a weir are described in the Twenty-first Annual Report, Part IV, page 31.

VELOCITY MEASUREMENTS.

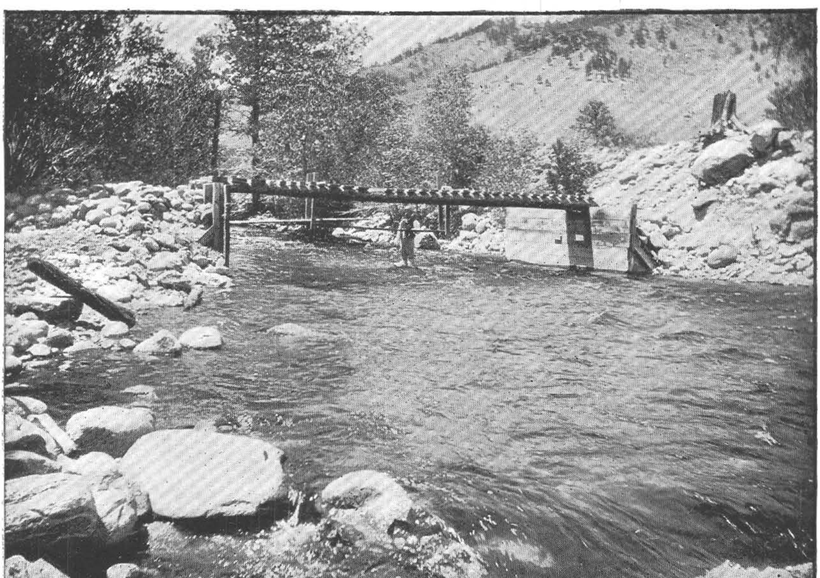
The second method, and the one commonly used for determining the flow of streams, is that in which the area of cross section is multiplied by the velocity per second of the water passing through the section. The units commonly employed are those expressing the area of the cross section in square feet and the mean velocity in that cross section in feet per second. The velocity can be measured by either of the following methods: (1) By means of floats; (2) by means of current meter or other mechanical device.

FLOATS.

This method is employed only when circumstances do not permit the hydrographer to use a current meter. If possible the site should be on a straight reach having a fairly uniform cross section. The flow of the water should be regular, without sudden rapids or stretches of still water, and should exhibit no tendencies to form eddies or cross currents caused by irregularities in the channel or resulting from the effect of a sharp bend above the reach. The course of the floats should have a length of from 100 to 300 feet, and the areas of the cross sections at the upper and lower ends of this course should be carefully determined by soundings. In the case of courses more than 100 feet in length it is desirable that additional cross sections, spaced at equal intervals apart, should be sounded. As a preliminary step a base line should be laid off, by tape, on the bank, as nearly as possible parallel with the stream, and points should be marked opposite the cross sections to be measured. If the stream is not too wide the soundings in a cross section can be taken most conveniently along a tagged rope stretched across the channel at right angles to the base. If the depth does not exceed 4 feet this can be done by wading, the depth being read on a rod graduated to feet and tenths. Should the depth of the channel or the temperature of the water make wading impossible, a boat should be used. On large rivers, where a tag rope can not be employed, the boat from which the soundings are to be made should be located by simple triangulation or stadia. Soundings should be read to tenths of a foot and be taken, preferably, at equal distances apart. In deep rivers a tagged rope or chain with lead weight can be substituted for the rod.



A MEASURING WEIR IN GENESEE RIVER NEAR PORTAGE, N. Y.



B. GAGING STATION ON CLEAR CREEK, WYO.

In reconnaisance work, in which the equipment is as a rule limited by transportation facilities, surface floats consisting of chips will be found most convenient. The use of rod floats, though giving more directly the mean velocity, has many disadvantages and should not be attempted unless time and opportunity permit of obtaining floats of the required lengths. In the simplest case but one man is needed to make the observations. The surface floats should be thrown into the stream a considerable distance above the first cross section. The hydrographer should attempt to start the floats, successively, at different distances from the shore, in order to determine the velocity in different parts of the channel. The time of the passage of each float between the upper and lower cross section should be noted, preferably by a stop watch, and also the position of each float with respect to the tags on the ropes. This will enable the hydrographer to determine whether or not he succeeds in covering the different parts of the stream, and it will serve as an aid in the computation. The observations should be continued until all parts of the stream have been covered.

On wide rivers range poles should be established on opposite shores to mark the upper and lower cross sections. The location of each float as it crosses these imaginary lines can readily be recorded by triangulation. A light traverse plane table will be found especially useful in obtaining a graphic record.

In case rod or tube floats are employed care should be taken to select their lengths to suit the depths of the channel. They should be weighted and adjusted as to depth of immersion so as to move in a vertical position, the bottom clearing the bed of the stream sufficiently to avoid contact with irregularities and the top projecting far enough above the water to be plainly visible. The velocity indicated by a rod or tube float is slightly in excess of the mean velocity of the path traversed, the error being mainly traceable to the distance between the bottom of the float and the bed of the river, the slowest velocities not being taken into account. As a rule the error is small enough to be negligible in this class of work, and the velocities so obtained may be regarded as representing mean velocities.

The method of gaging streams by the aid of floats can be simplified or elaborated according to the nature of the case and the time and facilities at the command of the hydrographer.

In making the computation the area of the cross section is obtained by averaging the areas of all the cross sections measured, provided they are taken at equal distances apart. Care should be exercised to exclude from the computation all areas of still water along the shores. The float measurements should be grouped and reduced to form a set of velocities about equally distributed across the channel, and the mean of this set be taken to represent the mean surface velocity of the stream. The mean velocity for the entire stream may then be assumed to be 0.8 of the former. For the average stream this relation is close enough for all practical purposes, provided the motion of the floats is not affected by wind. For that reason floats should be selected which while being easily discernible do not project unnecessarily above the water.

While this method of gaging does not yield accurate results, it is useful in reconnaissance work. Aside from the uncertainties entering into the observations, the assumptions on which the methods of observation and computation are based introduce additional sources of error, and the method should not be used at regular gaging stations.

CURRENT METERS.

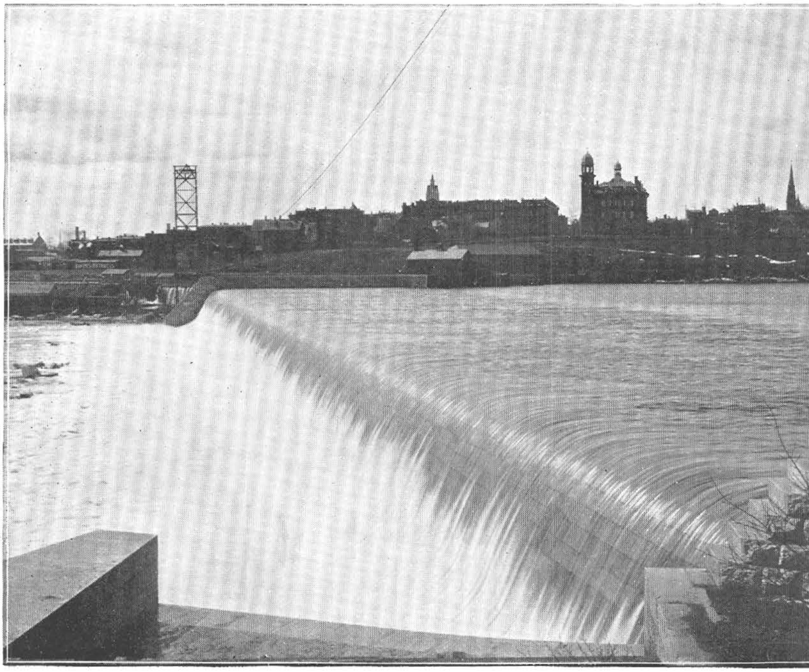
The mean velocity in a vertical can be determined with the current meter in three ways: (1) By making point measurements at a depth corresponding to the approximate position of the thread of mean velocity; (2) by deducing the mean velocity from observations made at other points in the same vertical; and (3) by the integration method.

UNIT MEASUREMENTS.

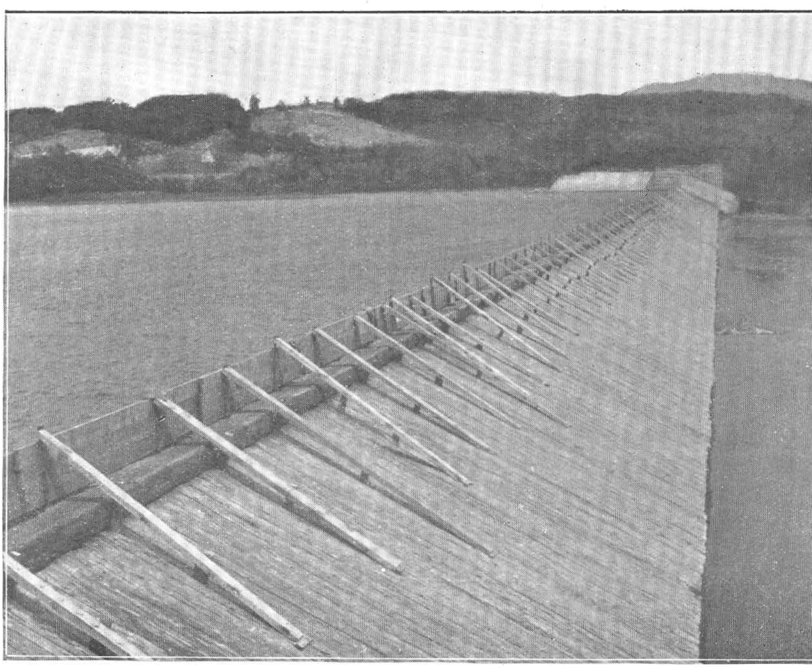
Studies of the vertical velocity curve made on the Mississippi by Humphreys and Abbot, on the Connecticut by T. G. Ellis, on the Merrimac flume by Wheeler and Lynch, on the Potomac by C. C. Babb, and recent experiments by others, notably those at Cornell University by E. C. Murphy, indicate that the position of the thread of mean velocity in a given vertical section occurs at a depth varying from six-tenths to two-thirds of the total depth of the section, measured from the surface down. The values found in the experiments mentioned were as follows:

	Depth.
C. C. Babb	0.58
Humphreys and Abbot	.63
T. G. Ellis	.64
Wheeler and Lynch	.67

The Cornell experiments indicate that measurements made at 0.60 of the depth yield results 4.7 per cent too large, the depth of mean velocity corresponding more nearly with the values obtained by Wheeler and Lynch. In this connection it should be noted that the Cornell experiments, as well as those of Wheeler and Lynch, were made in canals and flumes, the cross sections of which have a greater ratio of depth to width than those of the Mississippi, Connecticut, and Potomac rivers. That this difference in the ratio of depth to width is a factor likely to affect the position of mean velocity will be seen from the following considerations:



A.



B.

DAMS SUITABLE FOR USE IN MEASURING FLOW OF STREAMS

A, Stone dam at Holyoke, Mass., with 2 feet of water on crest; *B*, dam on Hudson River at Mechanicsville, N. Y.

It is a well-established fact that owing to the roughness of the lining of a channel, be the projections ever so minute, particles of water are continually deflected from the sides of the channel, the deflection naturally taking place in the direction of least resistance, i. e., toward the surface and center of the stream. This causes a constant upward flow along the sides of the channel, and a surface flow toward the center, with a tendency to lower the position of the thread of maximum velocity in any given vertical and in the entire stream. This depression of the maximum velocity is known to become more pronounced as the roughness of the lining increases. It also increases with the steepness of the banks and as the ratio of depth to width increases.

In the extreme case of a wide, shallow stream, where the bottom merges imperceptibly into the banks, maximum velocity occurs under normal conditions at or very near the surface of the center of the stream. On the other hand, in a deep, narrow channel, as, for instance, in a flume with vertical sides, maximum velocity occurs a considerable distance below the surface, and, as the Cornell experiments indicate, this depression may amount to as much as one-third, and even two-fifths, of the total depth.

Evidently, in such cases depression of maximum velocity must result in a lowering of the thread of mean velocity, and hydrographers in making unit measurements for mean velocity should therefore bear in mind that while observations at 0.60 depth give fair values for mean velocity in wide, shallow rivers, this ratio should be increased to 0.67 depth in the case of canals and flumes or narrow and deep natural channels.

MULTIPLE MEASUREMENTS.

The following methods are in use: (1) Observations at top and bottom; (2) observations at mid depth; (3) observations of surface velocity; and (4) observations at a series of points in a vertical.

(1) By the first method measurements are made in each vertical as near the bottom as the construction of the meter will permit, also just below the surface. The mean of the results so obtained is taken as the mean velocity. This method should never be used except in streams shallow in comparison with their width. The method assumes that the vertical velocity curve is a straight line, a condition which exists in very few streams. In all streams where the depression of maximum velocity is material the mean velocities obtained by this method are invariably too small.

(2) The second method consists of making measurements at mid depth, and taking about 95 per cent of the result to obtain the mean velocity. This method at best is unsatisfactory, as the velocity at mid depth can not be said to bear a constant relation to the mean velocity.

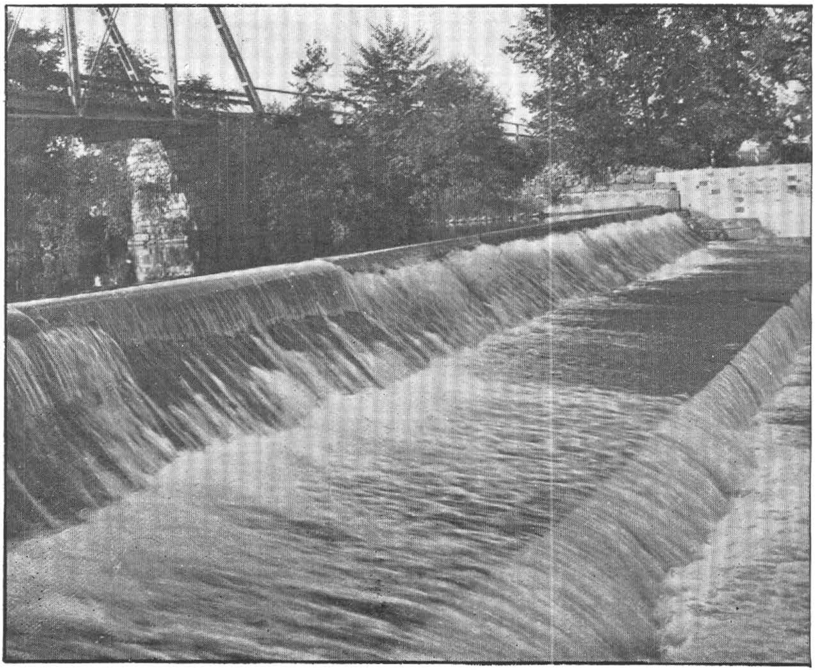
(3) Measurements of surface velocity are frequently the only measurements obtainable, as, for instance, in streams of great velocity during a flood stage, when it becomes impossible to lower the current meter or to maintain its position at a desired depth. In such cases the only course left is to measure surface velocity and deduce the mean velocity from it by multiplying the former by a factor. The error in this method is the assumption that surface velocity, or the velocity indicated by the current meter just below the surface, bears some direct relation to the mean velocity. From the foregoing discussion it will be apparent that the assumption is not correct, and considerable judgment should be exercised in computing the mean velocity. Where from the nature of the conditions it appears that the surface velocity practically represents the maximum velocity, a factor of 0.8 should be taken; while in case the maximum velocity occurs lower down, a factor of 0.9, and even of 1.0, should be used to obtain the mean velocity.

(4) The fourth and most accurate method is to make measurements at regular intervals in a vertical, plotting the velocities so obtained on cross-section paper, and determining the value of the mean velocity by dividing the area inclosed by the curve by the total depth.

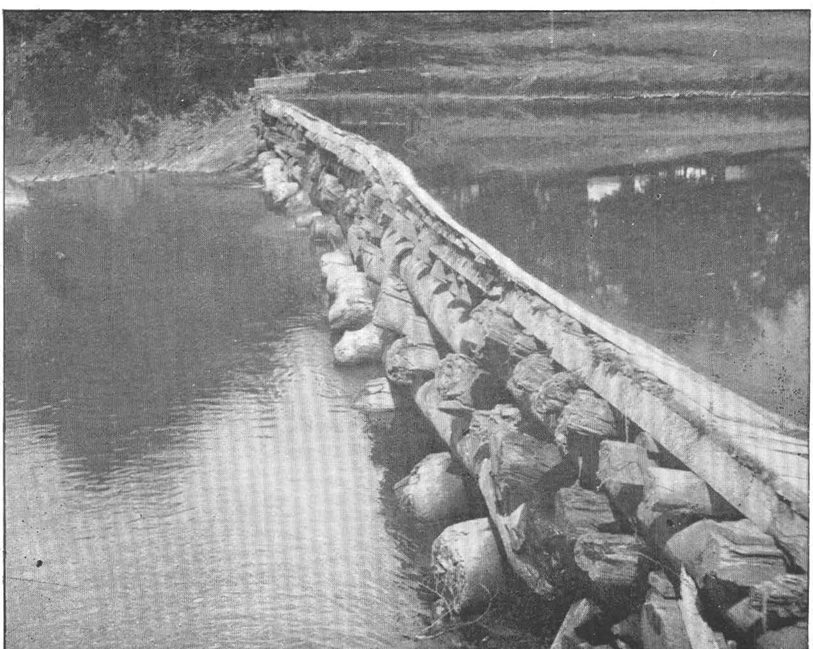
INTEGRATION METHOD.

By moving the current meter uniformly in a vertical from the surface downward until the bottom is reached, then moving it upward, repeating the operation as often as desired, the velocities in the vertical are integrated mechanically, and the mean velocity can be computed by noting the time and the number of up and down movements made. Care should be taken that the motion is uniform and sufficiently slow to prevent the introduction of large errors into the resultant velocities, due to the up or down motion of the meter. Stearns's experiments indicate that in moving the Fteley meter at a velocity not to exceed 5 per cent of the velocity of the current no material errors are introduced. The construction of the meter should always be taken into account in considering or allowing for errors of this kind. Thus in the use of the Fteley meter a too rapid up or down motion causes a decrease in the velocity indicated, while with the Price meter, or, indeed, with any form of meter adjusted to head in the direction of the resultant velocity, the results will be too large. For both kinds of meter, however, the errors, whether negative or positive, will be largest in integrating low velocities.

Aside from the method just described, integration of the entire cross section of a stream can be made by moving the meter obliquely up and down, starting at one bank and proceeding across the stream. This method has a limited application, for in the first place the measurement must be made from a bridge or by wading, and in the second place the time of the up and down motions must be varied pro-



A.



B.

DAMS NOT SUITABLE FOR MEASURING FLOW OF STREAMS.

A, Rome waterworks dam on Mohawk River at Ridge Mills, N. Y.; *B*, dam on Ninemile Creek at Stittville, N. Y.

portionately to the depth, which in an irregular channel requires considerable computation. The method is employed to best advantage on flumes, where the depth is uniform and where a plank can be thrown across at any suitable point to permit the hydrographer to proceed gradually across the channel.

GAGING STATIONS.

In the selection of sites for permanent gaging stations much depends upon the judgment and discretion of the hydrographer. If possible the section selected should be in a straight portion of the channel, where the flow is regular and free from natural or artificial obstruction. Sections near bridges which contain accumulations of brush and snags in which current meters are likely to become entangled should be avoided, also proximity to dams, either above or below the station. It is important that the banks be fairly high and not likely to overflow except at unusually high stages of the river, and that the bed should exhibit no tendencies to shift or be subject to other changes produced by scouring out or filling in of sediment.

A river channel is often obstructed by piers and cofferdams, which set up cross currents and render it impossible to obtain accurate measurements in their vicinity. In such cases other points of measurement must be selected and other means of making them be employed. Where the streams are deep boats are used (Pls. VI, *A*, VII, and VIII) or cables are suspended out of reach of flood water. In some localities boats possess a certain advantage, but where they can not be hired at moderate outlay it has been deemed impracticable to purchase and keep them, for they are likely to be injured or stolen during the intervals between measurements.

It is desirable that the gage be set so that no minus readings will occur—the zero being placed say 1 foot below the lowest known stage; but information on this point obtained from the oldest inhabitants will often be found erroneous or unreliable, and a safe margin should be allowed.

Where possible two or more gages should be established at each station, being connected by level lines, so that the slope of the water surface can be read at various elevations.

It should be borne in mind by the hydrographer in the field that the object is to obtain data of the most value to the public. Work that has only local application or is limited in scope should not be undertaken. In entering upon an investigation, or in preparing a report of the results of the work, full information should be given regarding its purpose, and mention should be made of all facts which in any way affect its value. The simple statement that a certain stream was carrying at a specified time a stated amount of water is in itself important, but its value can be greatly increased by the statement of additional facts, such as, for instance, the reason for making the measurements, the character of the drainage basin above and below the station, and the changes in the behavior of the stream which may have been produced by annual fluctuations in the run-off, by excessive temperatures, by artificial obstructions or diversions of the water, or otherwise. Facts of this character usually are well known to the hydrographer at the time he makes his report, and may appear to him too trivial to mention; but it should be remembered that the figures which he submits will be used again and again by persons who do not understand the local conditions, and for that reason may be misapplied.

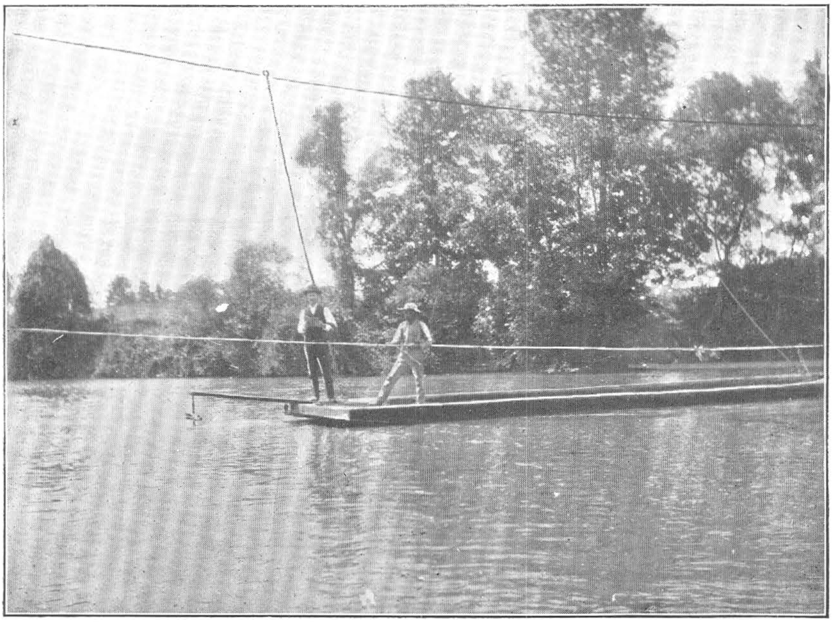
The object of daily observations is to procure material for the computation of discharge. If the conditions at a station are such that the readings can not be made with a reasonable degree of accuracy, the observations should not be continued. The difficulties may arise from several causes—from the irregular, shifting character of the channel, from the impossibility to obtain reliable gage heights and soundings, or from the inability of the resident hydrographer to visit the place at proper times and seasons. It is necessary, therefore, to carefully consider from time to time the advisability of maintaining stations already established, in order that efforts may not be wasted in continuing readings of dubious value.

BRIDGE STATIONS.

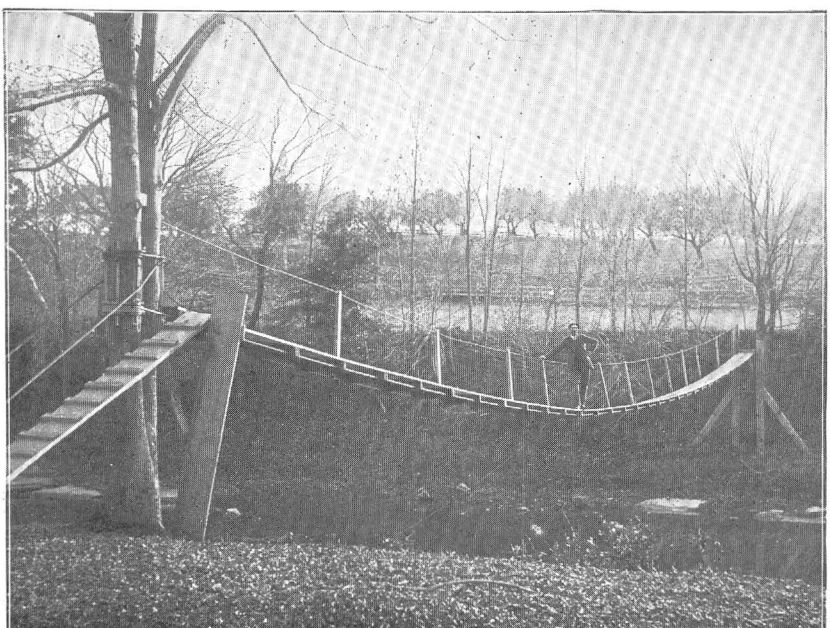
Because of the permanency of their character, the small expense involved, and the great freedom of movement which they permit the hydrographer, bridges are preferred for gaging stations and for the making of discharge measurements. (See Pls. VI, *B*, and VII, *A*.) High trestles and railroad deck bridges should, however, be avoided, for they unnecessarily expose the hydrographer to danger. Covered bridges, unless provided with numerous windows, are not desirable, for they limit the operations. Bridges that are to be used as permanent gaging stations should be marked once for all, either on the guard timber or in some other conspicuous place, with stenciled figures, say 5 or 10 feet apart, indicating sections and points for measurement. In case a stencil is not available nails or tacks can be used to advantage.

CABLE STATIONS.

Frequently it is impossible to establish a permanent gaging station at a bridge. In that case the wire cable of a ferry can be utilized, or, if that is not available, a permanent wire cable can be swung across the river. For spans of average length a galvanized wire cable three-fourths of an inch in diameter is safe. It should be supported on each bank by means of high struts or by passing it through the crotch of a tree. The cable should be run into the ground and anchored securely to a "dead man" buried at least 3 feet below the



A. MEASURING VELOCITY OF WATER FROM FERRYBOAT, TUGALOO RIVER, NEAR FORT MADISON, S. C.



B. SUSPENSION BRIDGE FOR MAKING STREAM MEASUREMENTS, NESHAMINY CREEK, RUSH VALLEY, PA.

surface. In the portion of the cable between the strut and the "dead man" a turn-buckle should be inserted so as to permit tightening the cable when it begins to sag.

A few feet above the cable a wire, provided with tags 5 or 10 feet apart, should be stretched across the stream to serve the same purpose as the stenciled distances on the bridge already referred to. For this purpose the ordinary twisted barbed fence wire has been found very useful, as the tags can be fastened firmly so that they will not slip from side to side, and barbed wire is less likely to be stolen than the ordinary smooth wire. The best tags are made of metal 3 to 4 inches wide, deeply notched so as to indicate at a glance the distance from the initial point. (See Pls. VII, *B*, and VIII.)

A box large enough to hold two men should be constructed and suspended from the cable, by means of cast-iron pulley wheels, in such a manner that it can be run freely in either direction. (See Pls. I, IX, and X, *A*.) An iron or wooden bar lying horizontal and parallel with the cable should connect these pulleys so as to hold them apart. The cable should be high enough above the river so that there will be no danger of the box striking the water during floods.

ROD GAGES.

Well-seasoned timber should be selected for the construction of rod gages, the usual size being 5-inch by 1-inch or 6-inch by 1-inch boards, with at least one face planed. The rods should be graduated to feet and tenths, the graduations being painted in black on white ground, the even-foot marks being conspicuously indicated by painted or brass figures. The datum used is immaterial, provided the zero of the rod is covered by water at even the lowest stages, so as to obviate the use of minus readings. Care should be taken to set the rod vertically. In case the gage is at a bridge station it will generally be found possible to spike it securely to an abutment or pier, where it can easily be read from the shore and not be carried away by ice or floating débris. At cable stations the rod should be spiked to a tree standing in the water, or, if a tree is not available, it can be bolted to a ledge in the stream.

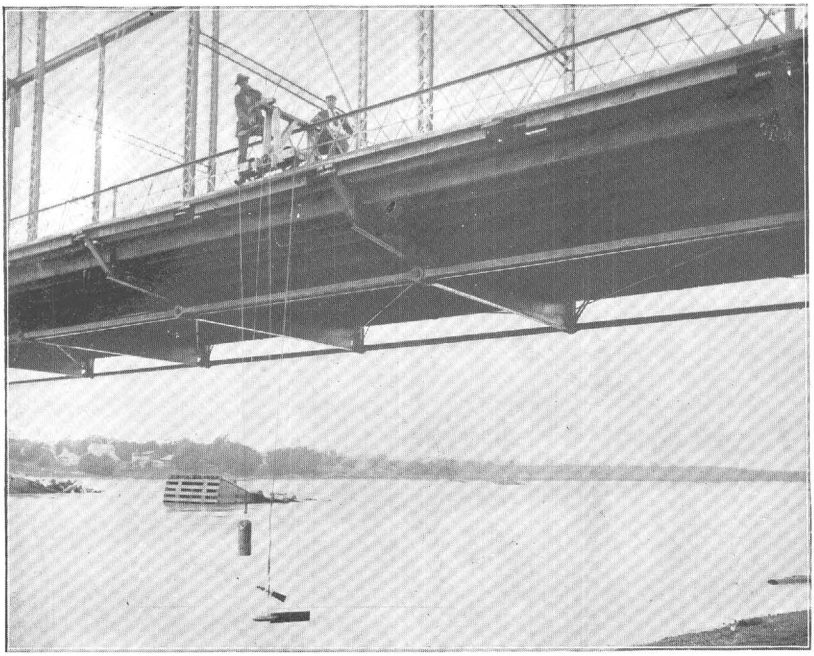
Frequently it will be found best to incline the rod, if it can not be secured in a vertical position without danger of being swept away. An inclined gage should be held in place by long stakes driven into the ground, and no graduations should be marked on it until it has been properly fastened. The slope of the rod should then be accurately determined by the aid of a surveyor's level, and the length of the graduations be computed on the basis that one division on the rod corresponding to 1 foot vertical is equal to the cosecant of the angle of inclination of the rod, in feet. It may be found more convenient to secure the gage rod in position and then graduate it by the use of an engineer's level. To put the graduations on an inclined gage, particularly on that portion extending under water, metal strips will be found most convenient. They can be nailed on without difficulty, and are more permanent than paint.

WIRE GAGES.

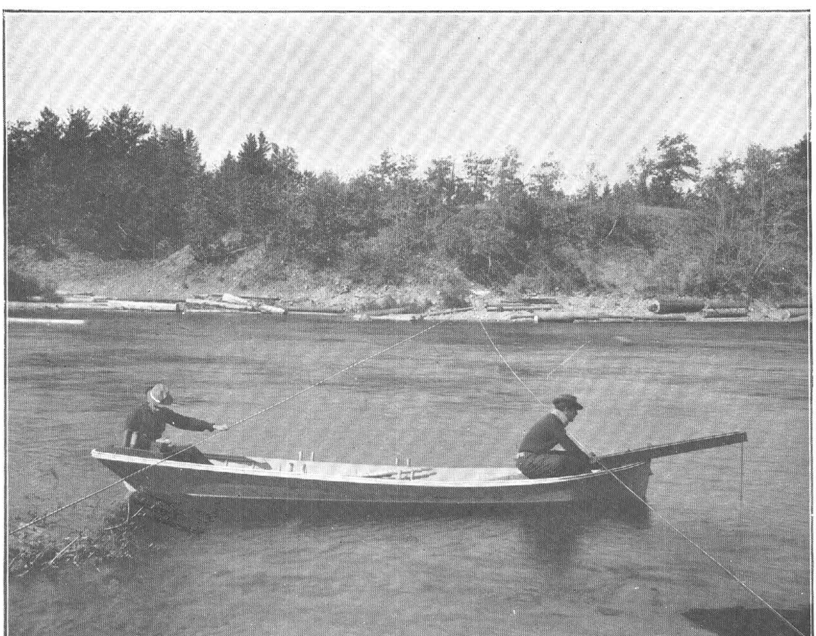
Wire gages will be found useful, especially on high bridges where it is difficult to read with accuracy the water level on a vertical rod gage or where the abutments or banks are not favorable for the erection of any other form of gage. A rod gage graduated to feet and tenths in the manner already described can be utilized for this purpose, being nailed in a horizontal position along the bridge rail or guard timber. The fluctuations of the water level are noted on this gage by lowering a weight attached to a wire or chain provided with a pointer or marker which is made to run along the graduations of the rod. The position of the pointer is read on the rod when the bottom of the weight just touches the surface of the water. The movement of the weight and wire is facilitated by means of a small cast-iron pulley fastened to the side of the bridge. Wire gages can also be used in other places, as illustrated in Pl. X, *B*.

Experience has shown the necessity of frequently testing the wire gages and correcting them to the original length. Great confusion is introduced in computations unless the gages are kept within a tenth of a foot or less of the correct length. When installed the gage should be so arranged and permanent marks be so made that the length of the gage can readily be tested. The description of the method used to accomplish this result should be written plainly, so that it will be understood by all concerned, and sent to the Survey, where copies can afterwards be obtained.

The wire gages should be tested under as nearly as possible the same conditions as those under which the height of the water is measured, that is, with the weight hanging vertically. A substantial mark or stop should be so placed that the upper or lower end of the weight will be brought against it, and a moderate pull given to the wire will remove all kinks or bends. The best weights for these gages are the ordinary ones used for window sashes, weighing from 7 to 10 pounds each. The weight should be attached to a flexible wire or chain. The most satisfactory is probably one of the composition or brass chains used for heavy windows, as that stretches less than a twisted wire. Objection to the chains, however, is found in the fact that in exposed positions they are more likely to be stolen than is the wire. It is preferable to box in the chain or wire by long narrow strips placed horizontally on the bridge. One of these strips can be arranged as a cover, so that access to the wire can be had. This cover can be hinged and held in place by a padlock. With such an arrangement the chain is usually not disturbed.



A MEASURING VELOCITY OF WATER FROM BRIDGE, MISSISSIPPI RIVER AT ANOKA, MINN. (ELLIS METER).



B. MEASURING VELOCITY OF WATER BY MEANS OF BOAT AND CABLE, MISSISSIPPI RIVER ABOVE MOUTH OF CROW WING RIVER, MINNESOTA

Great care should be given to joining the cord or chain and the weight to the handle at the other end so that there can be no slipping. The wire cord should be placed through the eye of the weight, bent back, and carefully wound and tied. In the same way the handle, if used as the index, should be fastened firmly. It is preferable, however, to place the index beyond the handle, and in such a way that, although perfectly firm, it can, if the wire stretches, be moved for the purpose of adjusting. Any adjustment that is made should be reported at once, so that the records can be corrected.

BENCH MARKS.

Wherever it is intended that permanent records shall be kept it is of the greatest importance that the relation between the datum of the gage and one or more fixed points be determined. Such reference marks, generally known as bench marks and indicated by the symbol B.M., may consist of a United States Geological Survey standard bronze or aluminum tablet, or a copper plug set in a drill hole in a rock; or, in case neither of these can be had, a cross cut in a ledge, or the head of a wire nail driven into the root or stem of a tree, will serve the purpose. In every instance it is desirable to have more than one reference mark, in order to insure against removal or accident. A surveyor's level and leveling rod should be used in determining the difference in elevation between some stated foot mark on the rod and the bench marks. In the case of wire gages, aside from the precautions just mentioned the difference of elevation between the water surface and the bench mark should be obtained by leveling and the gage reading for that particular stage be noted, from which data a permanent relation can be deduced, and a gage, if found disturbed, can at any time be verified and reestablished in its former position.

Full descriptions of bench marks should be made and forwarded to the Survey, where they will be kept on file for future reference. Hydrographers are required to test, with the aid of a level, the correctness of each gage at least once a year; oftener if necessary.

STAY LINES AND TROLLEY EQUIPMENT.

When the velocity of the water is considerable—as, for example, more than 5 or 6 feet a second—the sounding line and meter are likely to be swept backward down the stream, so that it is often necessary to provide an additional stay line. This consists of a cable or smooth wire stretched across the stream from 50 to 100 feet above the bridge or cable from which measurements are made. A small twisted wire clothesline or sash cord can be used for the purpose. It should be anchored at both ends and supported in a manner similar to the main cable. On this smooth wire a small pulley is placed, which travels freely from side to side of the river, and from the pulley a small flexible cord leads diagonally downstream. This can be attached to the end of the sounding rod, thus holding it in place; or a fine wire can be similarly fastened near the head of the meter, so that when the instrument is lowered it will be prevented from being carried backward or tilted by the force of the current. Usually the guy line adjusts itself as the hydrographer moves from one side of the stream to the other.

A method of manipulating this stay line from a bridge is shown

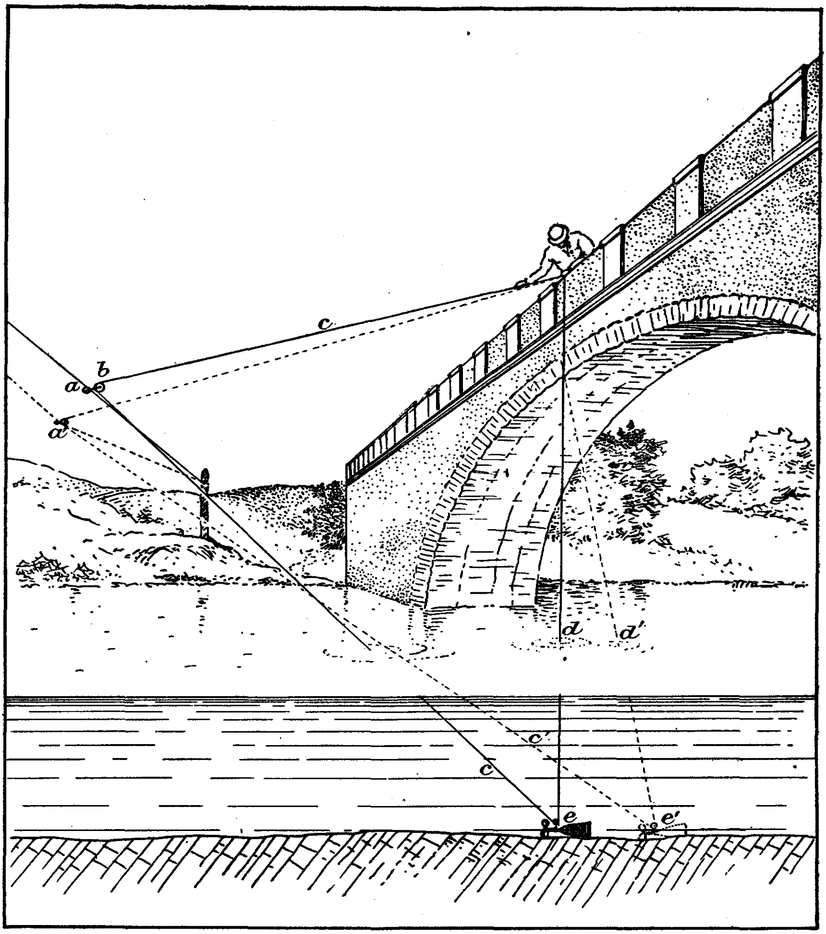


FIG. 1.—Method of manipulating stay line from small cable.

in fig. 1, in which case a small cable or stay wire is stretched across the river above the bridge, and a trolley or double pulley (*a*, *b*) is placed on it. The stay line (*c*) runs from the bridge to the small trolley (*b*) and back (*c*) to the meter (*e*). As the instrument is moved along the bridge the trolley on the cable follows the movement. The meter is raised and lowered by the cord *d*. When the meter is immersed in the swift water it is swept downstream and the cords are

A.

B.

MEASURING VELOCITY OF WATER BY MEANS OF BOAT AND CABLE, MISSISSIPPI RIVER AT ST. PAUL, MINN.

A, Preparing to make meter measurement; *B*, reeling in wire.

MEASURING VELOCITY OF WATER FROM SUSPENDED PLATFORM, RUM RIVER ABOVE MILL POND AT ANOKA, MINN.

stretched to the position a', e', d', but by a slight adjustment the meter can be drawn to the desired spot. Another device is shown in fig. 2.

A further use of stay lines has been successfully tried and adopted on a few streams where the conditions were favorable. It is known as the cable and traveler method, and is described in the Eleventh Annual Report, Part II, page 16. By means of a suitable number of wires and cords it has been found possible to hold the meter at different places

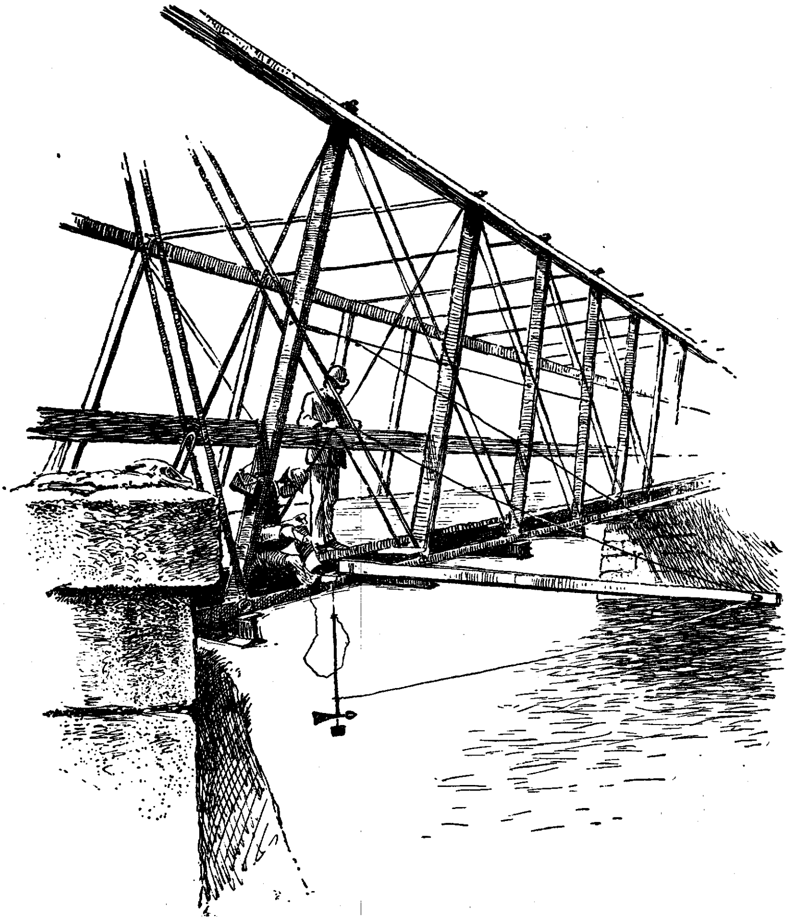


FIG. 2.—Method of attaching stay line to meter by use of pole.

in the stream while the hydrographer remains on the shore. The meter is run out on the main cable by means of halyards, and is lowered and raised by a double incandescent-light cord, or insulated wire, which serves the purpose of conveying the electric current from the battery and instrument on shore to the meter and of acting as a suspending and sounding cord. The stay line just mentioned is fastened to a pulley which travels across the river on a second smaller cable placed above the main cable. The lower end of this stay line holds the meter and prevents it from being swept downstream. By manipulating the various ropes the meter can be held in any position in the cross section, the revolutions being reported by an electric sounder near the observer.

In the same manner soundings can be made quickly and accurately, the rod being held in a vertical position by the stay line, and the depth, if necessary, being read from the amount of movement of the cords on shore, the sounding and insulated circuit cord being graduated to correspond with the marks on the sounding rod.

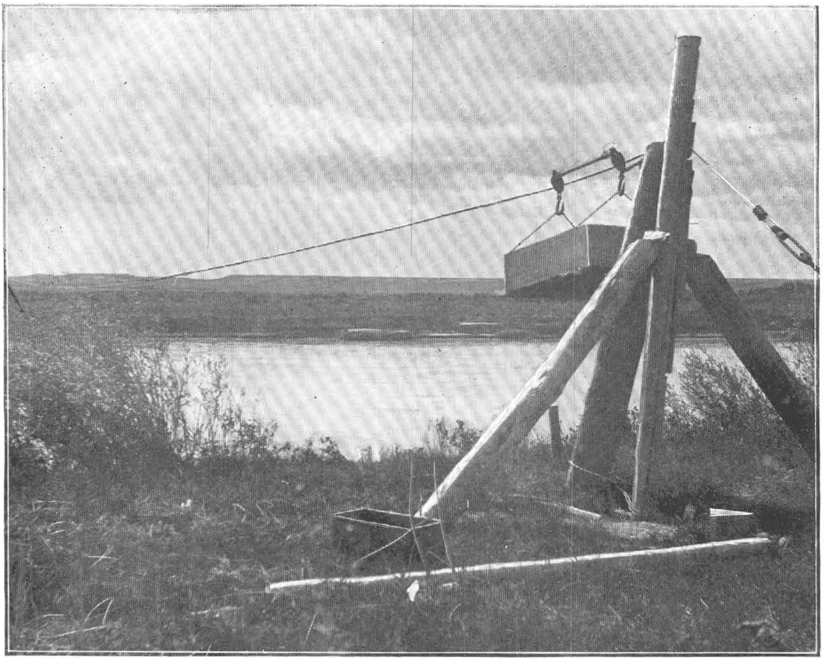
With careful training and experience one man can do all of the work of gaging more easily, it is probable, by this method than by any other. As stations are at present located, however, in most of the basins it is necessary for the hydrographer to have an assistant, and even at stations which can easily be reached by rail it is found economical to employ the resident gage observer, for the few hours consumed in making the measurements, as helper or recorder of notes.

At time of high water it may be difficult to count the revolutions of the meter, owing to the velocity of the current. It may even be impossible to keep the meter in the water, the tendency of the current being to throw it downstream and toward the surface. It is sometimes possible, however, to obtain a count of the revolutions of the meter by means of an electric counter when the speed is several times greater than can be counted by the hydrographer from observation.

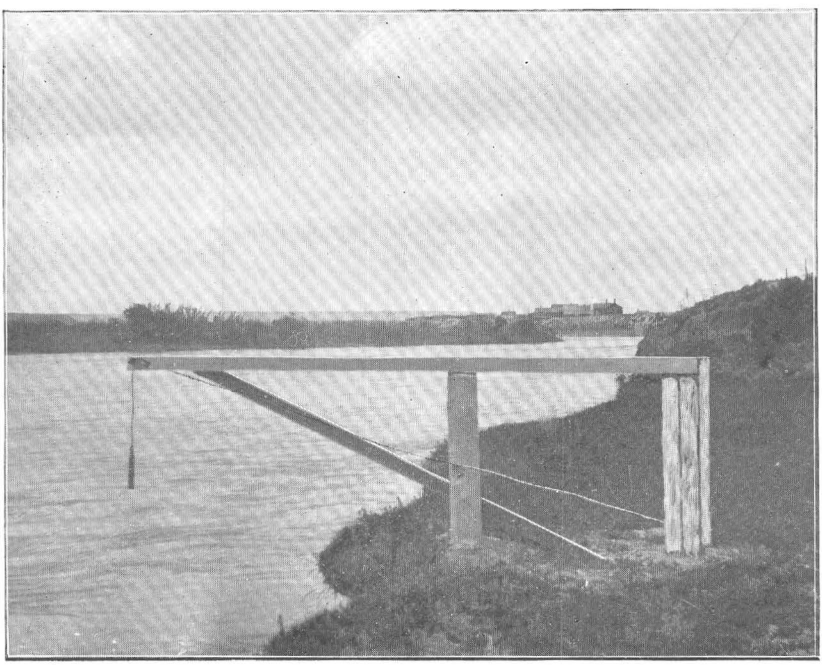
OBSERVERS.

The work of reading gages requires no special educational attainments, the main requisite being faithfulness and regularity in the discharge of the duties assigned. It is generally advantageous to employ persons who from long residence in the locality are familiar with the river and evidence an interest in the matter. The hydrographer should satisfy himself that the observer fully understands his duties, and he should spare no pains to make clear the manner of reading the rod, calling attention particularly to the fact that the graduations are feet subdivided into tenths and not into inches. Instructions should be left with the observer, telling him how to proceed in case of accident to the gage, and to telegraph the fact to the hydrographer in charge of the station. A book (form 9–175) is furnished the observer in which to record each day the stage of the river and the time of the observation. At the end of each week he is required to fill in a mailing card (form 9–176) containing the record for the week, and send it to the hydrographer in charge of the station.

The blanks provided for the use of the observer have space for remarks. This space is intended, as is noted at the bottom of the blank, for the insertion of facts concerning rain, snow, change of weather, and other conditions likely to affect the height of the stream. It is expected that during floods notes will be made of the rate at which the water rises, of the extreme height reached, and of the hour at which the maximum stage occurs. Observers are likely to care-



A.



B.

GAGING APPARATUS IN POSITION, BLACK FORK OF GREEN RIVER NEAR GRANGER, WYO.

A, Cable and car; *B*, wire gage.

lessly omit memorandums of this character, and their attention should be called to the matter from time to time, for it is essential that these minor details be noted, in order that the changes in the height of the stream may be interpreted correctly.

In case of a sudden rise of the stream frequent readings should be made, and at the time the observer is hired he should be instructed when and how often to make extra readings; otherwise in "flashy" streams a flood may pass between two observations without being noted. When practicable the resident hydrographer should arrange for the observer to telegraph him when an unusually high stage seems imminent, so that high-water measurements can be made.

The remuneration paid to observers varies from \$2 to \$5 a month, according to the distance they live from the place of observation and the extent of their duties.

The principal work of the hydrographer is the measurement of the streams at the stations in the district assigned to him, but his supervision of the stations should be such that he will know that the local observers are careful and accurate in their readings and reports. At the time a station is established the reasons controlling the selection of that particular locality should be carefully recorded, and after the work is begun vigilance should be exercised to see that the records of the gage heights and the discharge measurements made can by proper interpretation be converted into quantities of discharge. The observer should be required to fill in the blanks fully and carefully, for these original records are preserved in the files of the Survey. Carelessness in forming the figures or in omitting the dates or other details should be promptly checked, and reports of that character should be copied at once and returned to the observer with the request that the details lacking be supplied.

One of the greatest difficulties in the work as now conducted is to obtain accurate and reliable reports from the observers, who are not at all times alive to the importance of accuracy. For this reason the readings of the observers should be verified occasionally, and if there is a well-founded suspicion that at any time heights are reported which are not actually observed, the observer should be reprimanded and if necessary the station be discontinued. It is better to discontinue a station than to have records that are open to suspicion. In a case where it is impracticable for the observer to make regular readings the fact should be noted in the report, in the "Remarks" column, and he should have impressed upon him the fact that it is better to report that observation was not made than to attempt to fill in the blank by guessing at the gage height. The observer should also be carefully instructed regarding the best method of making the readings, and he should be cautioned against reading at too great a distance a vertical gage on a pier from a position on the bridge at which estimates can not be made nearer than two or three tenths.

CARE OF INSTRUMENTS.

Hydrographers are responsible for the care of current meters and other instruments of the public property intrusted to them, and are required to account at stated times for all such property in their keeping. Since the accuracy of stream gagings depends largely upon the correct working of the current meter, great care should be exercised in handling these instruments and in keeping them properly adjusted. Inaccurate work and poor results can be traced directly to neglect in caring for instruments.

The following description and suggestions regarding the use and care of the small Price electric current meter (see Pl. XI) are intended for the guidance of hydrographers in the field.

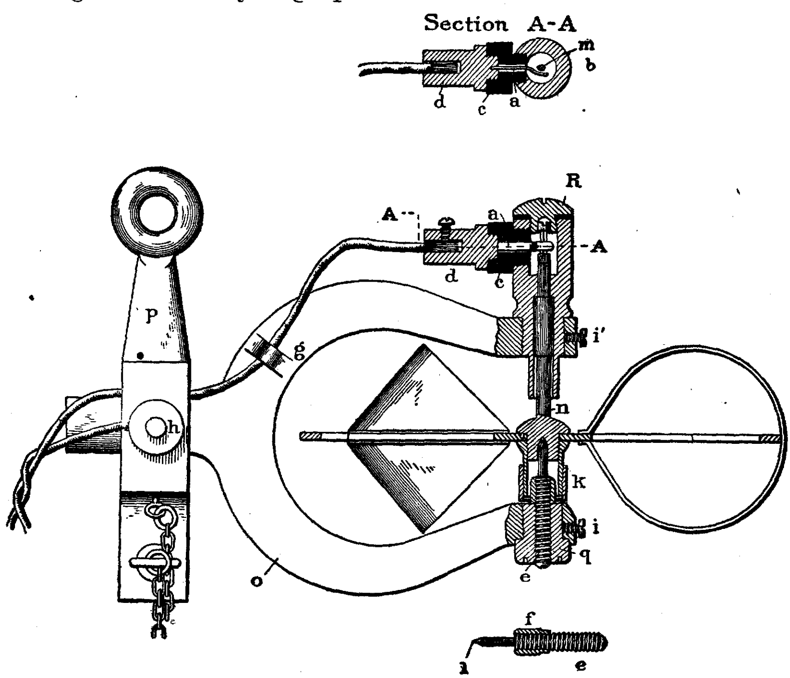
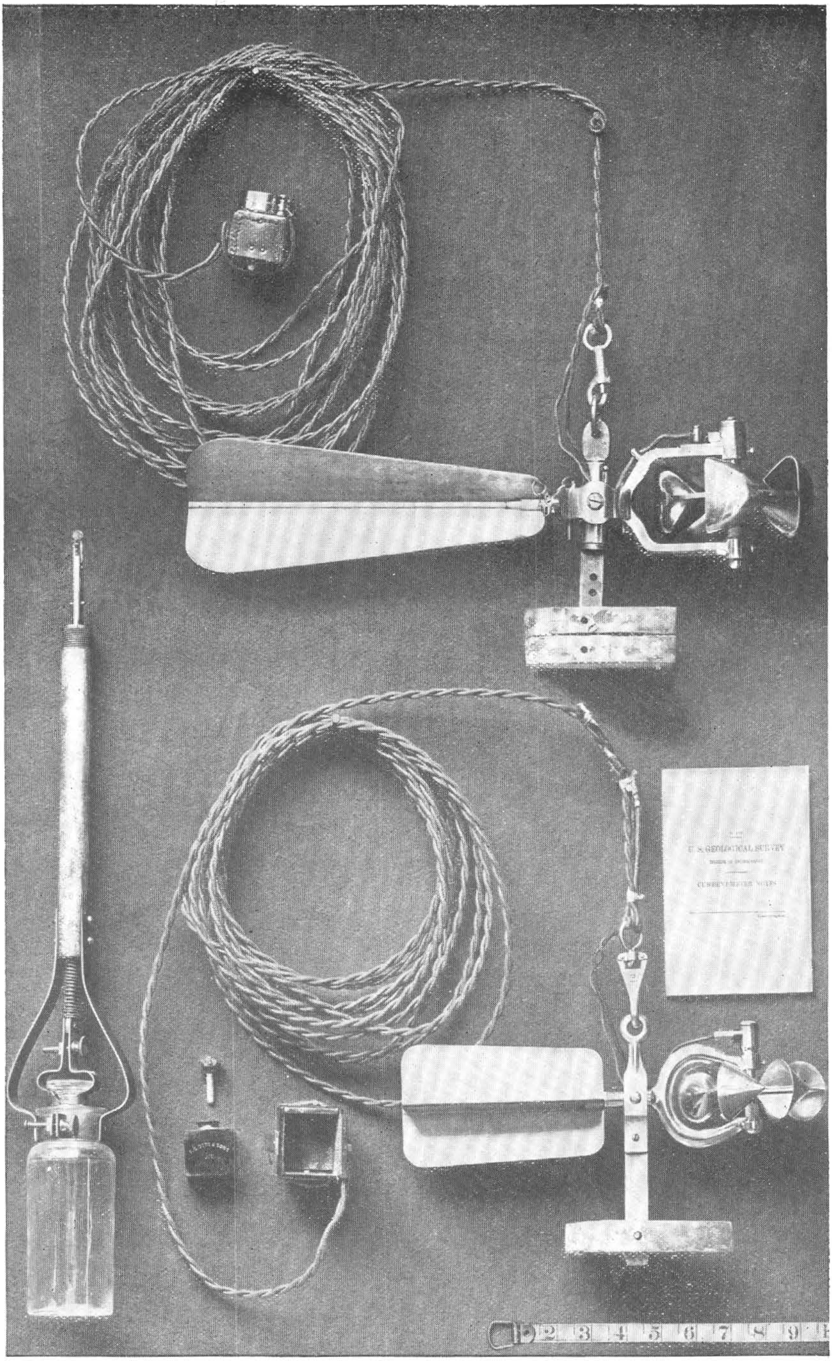


FIG. 3.—Cross section of small Price electric current meter, showing details.

When in use the meter is suspended by a double conductor cable of No. 14 or No. 16 flexible copper wire, heavily insulated. Wire of that size is of sufficient strength to hold the meter and weights, and it obviates the necessity of additional rope for suspending the equipment. The cable is attached to the meter with a spring snap hooked into the circular end of the trunnion *p*, fig. 3. The heavy copper wires are connected with the meter binding posts *h* and *d*, fig. 3, with smaller and more flexible wires. The wire connected with the binding post *d* should be threaded through the metal loops on the yoke *o*, within the trunnion frame and at *g*. It is desirable that these wires should be flexible and loose to allow the meter to swing free in the vertical plane when it is in use.



PRICE ELECTRIC CURRENT METERS, WITH BUZZERS.

Lead weights (*a*, fig. 4) are attached to the lower end of the trunnion by means of a detachable weight stem (*b*, fig. 4), to hold the meter steady in moving water—the higher the velocity of the stream the greater the weight.

The weight vane (*c*, fig. 4) should be attached to the weights at all times when the meter is used suspended from a cable. When gaging small or shallow streams it may be necessary to make the observations by wading. Under such circumstances it will be more convenient to dispense with the lead weights and attach the meter to a light rod or pole. If desired a brass standard can be supplied for attaching the meter to the pole.

The meter is supported in a trunnion or hanger (*p*, fig. 3), and is free to swing in a vertical plane. One revolution of the wheel or cups is indicated by a buzz of the electric buzzer—the observer being required to count the number for a certain interval of time, preferably 50 seconds, as the computations can more easily be made from that number. A second observation of the same length of time should immediately follow the first observation, in order to verify the count.

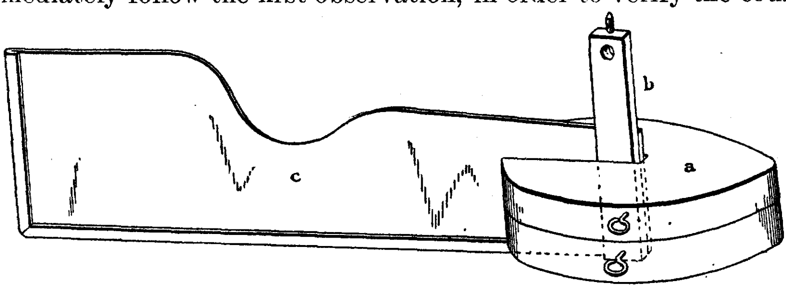


FIG. 4.—Weights and weight vane of small Price electric current meter.

The vertical axis (*n*, fig. 3) bearing the cups of the current meter, and hereinafter referred to as the cup shaft, terminates at the lower end in an inverted cone, which bears or turns on the cone-shaped point of *e*, fig. 3. The part marked *l*, fig. 3, will be referred to as the point bearing. This is the most delicate part of the meter, and should be given the greatest care, as it is made of highly tempered steel and is liable to be fractured or broken. To protect this sharp point bearing during shipping or carrying the meter, a milled sleeve (*k*, fig. 3) is provided. This sleeve is threaded on the inside, and screws up or down on the screw thread on the extension of the lower end of the cup shaft shown in fig. 3. When the meter is not actually in use, and before putting it into the wooden case after using, see that the milled sleeve *k* is screwed down until it bears on the top of *q* and raises the cups and cup shaft off of the point bearing, thus protecting it from possible injury. It is not necessary to screw this sleeve down very tight, and if it is screwed down tight the shoulder of the journal on the upper end of the cup shaft will be thrust hard against the end of its bearing and perhaps be injured.

When preparing to make a measurement with the meter the milled sleeve should be screwed up on the cup shaft as far as it will go, so as to be absolutely certain that the cups are turning on the point bearing and are working with the least possible friction. This sleeve is milled for adjustment with the fingers and not with a wrench or pliers.

If it becomes necessary, on account of injury, to replace the point bearing, an extra one will be found in the meter case. To replace the bearing slacken the screw *i*, fig. 3; with the small spanner wrench provided with the meter remove the large nut *q*, with the point bearing locked in it. After its removal hold the head of nut *q* firmly with a small wrench or pair of pliers, slip the small spanner wrench over the flat sides of the nut *f*, and loosen it. Remove the nut *f* with the fingers, and with a small screw-driver take out the damaged point bearing from the large nut *q*. Replace the large nut *q*, and with the spanner wrench screw it firmly into the yoke *o*. Remove the lock nut from the new point bearing to be inserted, and with a screw-driver send the latter through the large nut *q*. Great care should be exercised in making this most important adjustment of the current meter. A slight amount of play or movement of the cups up and down must be allowed, so that they will revolve freely and without friction. When the point is almost up turn it a part of a revolution at a time, with the screw-driver, until the proper adjustment is obtained. After the adjustment has been made a full turn of the point bearing in the nut *q* would crush the sharp point of the bearing *e* into the inverted cone of the cup shaft and break the point. After the point has been satisfactorily adjusted remove the nut *q*, with the point in it, put the lock nut on the point, and draw it down on the face of the large nut, taking care while turning it not to allow the point to turn in the large nut and thus disturb the adjustment. Should the adjustment of the meter be too tight the results obtained from its use will be erroneous. An examination of the meter when received from the Survey will give an idea of the proper adjustment. Do not disturb the adjustment of the meter unless it is necessary to put in a new point bearing.

Section *A–A*, fig. 3, shows the construction of the binding post and contact spring of the meter. A flexible, well-insulated copper wire (No. 20, or smaller) is drawn through the metal loop *g* of the yoke *o*; the end of the wire free from the insulation is thrust into the metal binding post *d* and secured by the small set screw. This metal binding post terminates in a slender platinum spring (*a*), which extends through the hard rubber nipple *c* into the contact chamber, to *m*. The top or upper end of the cup shaft terminates in the contact chamber with an oval-shaped eccentric (*m*), which makes a contact with the spring *a* at each revolution of the meter cups. This contact can be prolonged or shortened by bending the point of the contact spring in the contact chamber in the desired direction. The oval-shaped eccentric end of the cup shaft is detachable, and can be removed by taking off the cap *R*, holding the cups firmly, and applying a screw-driver to the small slotted head.

The insulating nipple *c* is made of hard rubber, and is likely to break if the binding post *d* receives a sharp blow. An extra insulating nipple will be found in a small tin case in the meter box. Before removing or replacing the binding post *d*, take out the eccentric-shaped top of the cup shaft. If this is neglected the contact spring will be destroyed by the turning of the binding post.

In charging the battery cell used with the electric buzzer furnished with the current meter, one-half teaspoonful of bisulphate of mercury is sufficient. Fill the cell with water and insert the zinc pole with the rubber stopper attached. When putting the battery cell in the leather case be sure that the small platinum point on the lower end of the cell and the screw head of the rubber stopper make perfect contact with the copper plates. If the buzzer makes but a faint clicking sound instead of a buzz, remove the metal cap covering the buzzer, and with a knife blade adjust the small upright brass point, by bending until the armature produces the desired sound. Never allow the liquid to remain in the battery cell over night, as it will generate gas and produce pressure sufficient to cause the cell to leak at the rubber stopper, and the solution escaping will destroy the leather of the case and the brass parts of the buzzer.

Care should be exercised in the use and handling of the meter that it does not get a fall or hard knock, thus injuring the cups or cup shaft. An injury to either will change the rating of the meter, and it should be immediately returned to the Survey for repairs. When using the meter in streams containing grass or moss, examine the instrument frequently to see that nothing has lodged or wrapped around the cup shaft *n*.

When preparing to make a discharge measurement charge the battery cell of the buzzer; remove the meter from the case; take out the weights, weight stem, and vane, combine them as in fig. 4, and attach them to the meter with the spring pin provided; turn up the milled sleeve *k;* and turn the cups to see that they revolve freely and that the buzzer responds to each revolution.

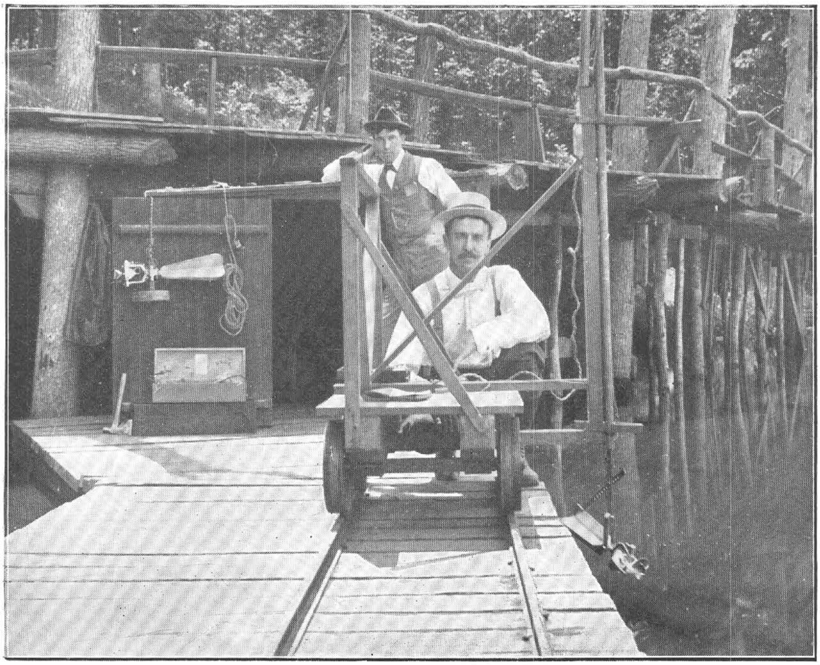
After making a discharge measurement, or at the close of a day's work with the meter, unscrew the large nut *q*, with the point bearing in it, and examine the point carefully to detect injury. With a piece of soft cloth remove the water in the opening at the lower end of the cup shaft, oil generously, and replace the bearing. Then remove the screw cap *R*, turn the meter over to allow the water to run out of the contact chamber, put in a plentiful supply of oil, and replace the cap; this protects the top or journal bearing of the cup shaft from rusting. After this has been done turn down the milled sleeve *k*, to protect the point bearing while carrying the meter, remove the battery cell, empty out the liquid, wash the cell with water, and pack the meter carefully in the case, when it will be ready for future use.

METHODS OF RATING METERS.

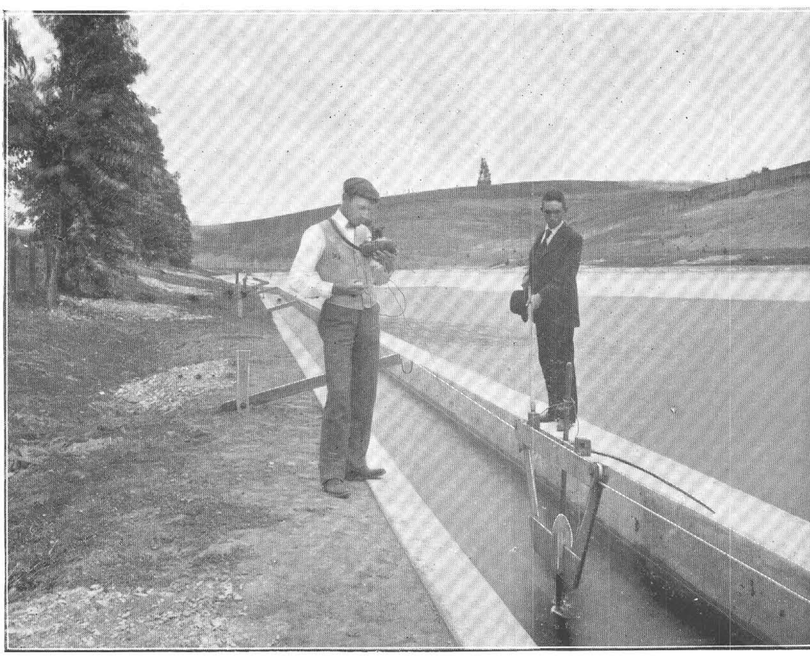
Each current meter when received from the factory, and subsequently when repaired, is rated by running it through still water, the assumption being that the same relation will hold between the turns of the instrument when running through still water as when held in one position in flowing water. This relation is obtained by fastening the meter in a position comparable to that in which it will be held when in use in the stream. That is to say, if the meter is to be used fastened rigidly to a rod, it is rated in that manner; if, on the other hand, it is to be used on the end of a flexible cord the rating is accomplished under those conditions.

Two devices for rating meters are shown in Pl. XII. The upper illustration is of the equipment used by the Survey at its rating station at Chevy Chase, a suburb of Washington, D. C., the lower picture is of the device employed at Los Angeles, Cal. The apparatus used at Chevy Chase consists of a platform, about 200 feet in length, built along the edge of a small, deep pond the waters of which are practically stagnant. On the outer edge of this platform are small iron rails, on which is placed an ordinary mine car or truck, with outrigger so that the meter can be held vertically over the water and immersed to the desired depth. On the platform a measured course of 100 feet is laid off, and the car is pushed by hand, care being taken to pass over every 10 or 20 feet in a uniform number of seconds, so that the same velocity can be maintained from start to finish. In the view a meter is shown suspended from the car on the right-hand side, and another meter is shown in the background against the door of the house in which the car and smaller tools are stored.

The device used at Los Angeles, Cal., consists of a cement-lined trough along the edge of the reservoir. Above this is stretched an iron cable, suitably supported, on which is a trolley with two wheels, by means of which the meter is supported beneath the surface of the water. The meter is propelled through the water over a measured course, usually 100 feet, for 20 or more times in succession, the speed varying from less than 0.5 foot per second to 6 or 8 feet per second, or even more, the number of revolutions per hundred feet and the number of seconds being noted. Thus there is obtained the feet per second and the revolutions per second at different speeds. When these data are plotted upon cross-section paper it will be found that for higher velocities the points lie in a nearly straight line, but for lower velocities there is a tendency for the revolutions per second to decrease, owing to the slight friction in the instrument. A broken or somewhat curved line is therefore sketched for the lower velocities, and from this curve values are taken to make the arbitrary table of the relation between the revolutions of the meter per second and the speed of the water. This table is found to be fairly constant until the meter becomes injured or the friction notably increases by the wearing away of the more delicate points of the bearings.



A.



B.

APPARATUS FOR RATING METERS.

A, At Chevy Chase, Md; *B*, at Los Angeles, Cal.

In using current meters, especially those suspended from a cord or line, it frequently happens that in swift water the instrument is swept backward and tipped at an angle from the horizontal, either momentarily or for a considerable period of time. In order to obtain data concerning the reliability of results under such conditions a series of tests was made at the Chevy Chase rating station. A small Price current meter was used, being held rigidly at various angles as measured from a horizontal line. The results are given in the Nineteenth Annual Report, Part IV, page 27.

At an angle of 5 degrees, with a velocity below 4 feet per second, the meter apparently revolves a trifle faster than when it is horizontal. In other words, at moderate speeds and at low inclination the meter may indicate a slightly higher velocity than actually exists. At high speeds, however, and at a high inclination, the reverse is true, as the meter turns more slowly than when held perfectly parallel to the current. When depressed beyond 25 degrees the resistance to the current approaches that offered by the tail, and the meter swings about in a position nearly at right angles to the current, causing the head to approach the normal or zero angle.

NOTES AND COMPUTATIONS.

The ordinary method of computing discharge from the observations is indicated by a small field notebook (form 9–198) ruled for the purpose. The velocity at each element of the section of the stream is ascertained by observations at various depths, as previously described. The area of each element or fraction of the section is obtained by multiplying the width by the mean depth. The discharge is the product of the velocity by the area, and the discharge of the whole section is the sum of these products. This has been found to be, under usual circumstances, the most convenient method of computation. It is desirable that soundings in the cross sections be made at regular intervals and at the same points in the stream. In this way changes in the river bed will be noted, and if the gage is broken or displaced the soundings will often furnish data for an approximate computation of the mean depth for resetting the gage.

Referring to the notebook (form 9–198), at the top of the page are spaces for recording the date, the name of the hydrographer, the number of the meter, the locality, the height of the water at the time of beginning and ending the measurements, also the average height, and whether the river was rising, falling, or stationary. On the opposite page is space for inserting the results, i. e., the total area, the mean velocity, and the total discharge in cubic feet per second. On the extreme left are double columns for recording the soundings, the first column being for the distance from the initial point and the second column for the depth at that particular place. The following table shows the method of recording and computing discharge measurements in the notebook (form 9–198):

Sample page from notebook, showing method of

Gaging made (January 26, 1898), by (E. G. Paul and G. H. Matthes). Meter No. (95). Gage height: beginning (7.5) ft., ending (7.6) ft.; mean (7.55) ft. River rising, falling, stationary.

Soundings.		Observations.						
Distance from initial point.	Depth.	Depth of observation.	Time, in seconds.	Register reading. Begin.	Register reading. End.	Register reading. Diff.[1]	Revolutions per second.	Velocity per second.
60	4.8							
65	5.3							
70	5.2	$\frac{3}{5}$	50 "			33 33	0.66	1.60
75	5.3							
80	5.2	"	" "			48 49	0.97	2.35
85	5.							
90	5.4	"	" "			64 64	1.28	3.09
95	5.3							
100	5.3	"	" "			77 77	1.54	3.72
105	5.2							
110	5.4	"	" "			81 81	1.62	3.91
115	5.5							
120	5.8	"	" "			98 96	1.94	4.68
125	5.7							
130	6.3	"	" "			36 36	0.72	1.75
135	6.7							
140	6.4							
173	1.7							
185	2.4							
190	3.9	"	" "			88 89	1.77	4.27
195	4.7							
200	4.8	"	" "			85 85	1.70	4.10
205	5.3							
210	5.1	"	" "			80 79	1.59	3.84
215	5.0							
220	4.9	"	" "			68 67	1.35	3.26
225	4.5							
230	4.3	"	" "			62 62	1.24	3.00
235	4.0							
240	4.0	"	" "			50 50	1.00	2.42
245	4.1							
250	3.8	"	" "			23 23	0.46	1.12
255	3.3							
260	3.0	"	" "			3½ 3½	0.07	0.19
270	1.2							
Total								

[1] The figures in this column are the number of revolutions of the meter in 50 seconds, a recorder not being used.

recording and computing discharge measurements.

At station (Frederick, Md.), on (Monocacy) River. Total area (808) sq. feet. Mean velocity (2.90 feet). Discharge (2,342) second-feet.

Section.			Discharge of section.	Remarks.
Width.	Mean depth.	Area.		
				Edge of still water.
15	5.15	77.3	123.7	
10	5.20	52.0	122.2	
10	5.30	53.0	163.7	
10	5.27	52.7	196.0	
10	5.37	53.7	210.0	
10	5.70	57.0	266.7	
15	6.35	95.2	166.6	
				Edge of still water.
				Edge of second channel.
22	2.81	61.8	263.8	
10	4.90	49.0	200.9	
10	5.13	51.3	197.0	
10	4.82	48.2	157.1	
10	4.27	42.7	128.1	
10	4.03	40.3	97.5	
10	3.75	37.5	42.0	
15	2.45	36.7	7.0	
				Edge of still water.
177		808.4	2,342.3	

At all river stations, besides the bench marks for the zero of the gage rod, there should be chosen an initial point at which to begin all soundings. This initial point may be some permanent object on the bank, the end of a bridge, or the edge of a pier. A bench mark should be permanent, easily identified, and in such position that it will always be a short distance beyond the high-water mark. Starting from this initial point the soundings are usually made every 10 or 20 feet, or, in the case of very small streams, at intervals of 5 feet.

The first sounding should be at the edge of the water, and its distance from the initial point should be recorded in the notebook, the sounding being registered as zero. The last sounding should be at the farther edge of the water, and should be noted as so many feet from the initial point and as zero in depth. If intermediate islands or bars project above water the fact should be recorded in the notebook, also the distance of both margins from the initial point. This greatly simplifies the comparison of subsequent changes of depth.

To the right of the columns for soundings are spaces for the observations, including depth of observation, or number of feet and tenths below the surface of the water at which the meter is read, and the number of seconds, usually 50 or 100, during which the revolutions of the meter are noted. To the right of these are three columns for use in case a recording register is used with the meter. The first of these is for the register reading at the beginning of the observation, the second is for the reading at the end of the number of seconds (50, 100, or more) during which the revolutions are counted, and the third is for the difference between these two readings. In cases where the revolutions of an electric meter are counted by listening to the sounder, as in the sample computation on pages 36 and 37, the third column only is used. It is customary to make two observations of 50 seconds each at a point, and if these do not agree to make a third, and a fourth if necessary, continuing until it is ascertained whether there may have been any accidental irregularity in the behavior of the instrument. If these observations appear to have equal value the average of all is taken; if one or more are of doubtful value the doubtful ones are rejected.

The number of revolutions of the meter as recorded in the column of differences divided by the number of seconds gives the revolutions per second to be inserted in the column headed thus. Where two observations of 50 seconds each have been made it is necessary merely to add the revolutions and point off two places.

The observations for velocity per second are usually taken not only at intervals across the stream but also at the top and near the bottom at each locality and at intermediate points. Where the stream is shallow it has been found that the average of the observations taken slightly below the surface and above the bottom at a distance where the meter runs freely, represents very closely the mean velocity of the section. In deeper streams the mean velocity of the vertical section can be obtained by observations at a large number of points, or by assuming that the measurement obtained at a distance below the surface of three-fifths of the depth is the mean velocity, as more fully described on pages 18 and 19. Taking, therefore, the average of the velocities in the vertical plane as obtained in either way, it is assumed to represent the average velocity for a portion of the river on both sides of the plane, which is taken parallel to the course of the stream and as extending halfway to the points of observation on each side. If these points of observation are 10 feet apart the width of the section is taken as 10 feet and is entered in the proper column.

In the case of a broad, smooth channel the mean depth of the section is taken as the depth of water at the place where the meter is run, or as an average obtained by adding the depth of water on each side halfway to the next point of observation, adding to this twice the depth where the meter is run, and dividing the whole by four. This mean depth, in feet, multiplied by the width, in feet, gives the area of the section, in square feet. This area multiplied by the velocity per second, as given in the column headed thus, gives the discharge, in cubic feet per second, or second-feet, to be inserted in the column thus designated. The sum of the discharges of the various sections is the total discharge of the river. This is inserted at the top of the page. The sum of the individual areas is the total area, in square feet, to be inserted also at the top of the page. The mean velocity of the whole stream is the discharge, in cubic feet per second, divided by the total area thus obtained, but it is not the average of the velocities per second as measured by the current meter.

In the sections of the river adjacent to the shore special care must be taken in the computations, as the current is often so sluggish that the meter will barely revolve, and at times reverse currents creep up along the bank. Allowance must be made for all of these factors, also for still or dead water. In computing the average depth of the triangular sections at each end the depth at the shore is taken as zero, this being added to the other depths and the total divided by four, as in the case just described. Where the current is running diagonally to the channel of the stream, allowance for that must be made in the width of each section. The notebook is provided with space, under the head of "Remarks," for these details and for comments upon the accuracy of the measurement.

In making the computations in the notebook it is undesirable to carry them out to a degree of refinement not warranted by the original observations; that is to say, if the meter reading is only to whole numbers it is a waste of time to make computations to more than one point of decimals, or, in fact, to employ decimals at all except as a safeguard against errors creeping into the last figure of the results.

The hydrographer should occasionally look over the measurements made during the year and determine whether or not a sufficient number have been made for the construction of a rating curve for each station. If either high-water or low-water measurements are lacking a special effort should be made to reach the station during that stage of the stream, so that doubtful parts of the rating curve can be accurately constructed. One of the chief difficulties encountered in working up the field notes is that a number of measurements will be made at the ordinary flow of the stream and none during high-water and low-water stages.

It is very important that hydrographers carefully check and revise all records before they are sent to the Survey; but if mistakes are found after the records have been sent to Washington a detailed description of them should at once be prepared and forwarded, so that the records on the books of the Survey will be accurate and complete. Occasionally annoyance is caused by carelessness in this matter, and after computations of the discharge of a stream are worked up at the Survey notification is received of errors in the gage readings, or of the displacement of the gage, which vitiates the records on file.

REPORTS OF DISCHARGE MEASUREMENTS.

The field notebooks (form 9–198) referred to are to be retained by the hydrographer as long as required and ultimately forwarded to the Survey for preservation with other original records. In order to report the results as soon as possible, however, a blank (form 9–197) has been provided which gives space for the date, the locality, the name of the hydrographer and his assistant, and for a memorandum concerning the number and page of the notebook on which the computations are made. Under the head "Description of river stations" is space for a description of the location of the station, the date when originally established, the name and address of the observer and his pay, occupation, and the distance which he is required to travel in order to make readings, also the time of day at which the readings usually are made. A line is also added on which to record the fact whether the observer is reliable and is taking a proper interest in the results of his work, and space is provided for memoranda concerning the equipment and the condition of any Survey property at the station. Attention is also called to the condition of the gage, and descriptive words are inserted in order that by striking out those not applicable the words remaining will indicate whether the gage is in good order or needs attention. Space is also left for comments on the bench marks, whether the initial point for sounding is on the right or left bank, whether the channel both above and below the station is straight or curved, the water swift or sluggish; also for the height of the banks, whether high or low, the character of the bed of the stream, and similar details. Any changes in the channel shown by soundings should also be noted.

Where possible two or more gages are established at each station, being connected by level lines, so that the slope of the water surface can be read at various elevations. Assuming a value of n for Kutter's formula of discharge, it is possible to estimate the discharge by computation based upon the slope. This should be done and the product be compared with the measured result, in order that the hydrographer may obtain data regarding the application of such formulæ and the value of the constant (n) to be applied in each case.

The results of the measurement itself are to be given on the lower part of the blank, the first item being the height of water and its condition, whether rising, falling, or stationary, the inapplicable words being stricken out for the latter purpose. The total width of the channels and their number should also be given. Space is provided for an abstract of the field notes, giving, for important points, the distance from the initial point, the depth, and the mean velocity. This is for the purpose of showing concisely the character of the stream. It is not intended to insert fully all of the observations, but simply selected ones which will bring out essential facts most clearly. The make and number of the current meter used should also be given, or if measurements are made by means of floats or over a weir the fact should be stated. The velocity and direction of the wind should also be recorded, as they have considerable influence upon the behavior of the stream. In some cases, especially in extremely hot or cold climates, it is also desirable to have the temperature of the water and the air. A line is also provided on which the hydrographer should note any possible cause of error; and, finally, space is provided for a statement of the mean, minimum, and maximum velocities, the total area of the section in square feet, and the total discharge in second-feet. On the back of the sheet a sketch should be made showing the position of the gage, the bridge, or cable from which measurements are made, the bench marks, the initial point of sounding, etc. Where a number of measurements are made in succession at one point, it is of course unnecessary to fill in all of the details each time; but in cases where the hydrographer visits a station at long intervals, and after changes due to floods have taken place, all of the facts should be carefully noted, in order to show the extent of the changes and to indicate clearly that certain details are unchanged.

In reporting measurements of discharge it is not desirable, except in cases of exceedingly small amounts of water, to give the results to decimals of a second-foot, for a false idea might be given regarding the accuracy of the measurements. Velocities should be given in feet and hundredths of a foot per second, and, for uniformity, the height of water on the gage in feet and hundredths of a foot. In statements of this kind attention should be paid to the accuracy of the data. The field work should be conducted with the greatest care, but, on the other hand, the computations made in the office should not be carried out to a degree of refinement inconsistent with the original work.

In work of this character accuracy has been and always will be a subject for debate. At the outset it should be recognized that in the measurement of flowing water either above or under ground the precision of ordinary engineering operations is not attainable, because the quantities to be measured are not fixed, but fluctuate to a notable extent even during the process of measurement. We can ascertain the width of a river by fixing arbitrarily two points which shall represent the sides, but here an assumption comes in as to what shall be considered the sides, and usually there is a latitude of several feet. We can measure the depth if we assume some fixed object as representing the bottom. But for the top surface, even when artificially stilled, there is usually a pulsation ranging from 30 to 50 seconds or more and giving a vertical oscillation through several hundredths of an inch, so that judgment must be exercised in that also. When we come to the velocity, we have the widest possible range, not only in different parts of the cross section but at the same point during successive moments, and in determining that also judgment must be exercised. In other words, at every step of the operation of measuring a stream certain assumptions, which may affect the total by from 2 to 5 per cent, must be made.

Engineers, and especially office men, who spend most of their lives compiling and digesting figures, are likely to lose sight of these primary assumptions, and in their desire for accuracy of computation to express results in decimal figures, which, if we pause to consider the primary assumptions, is generally, except in the case of very small streams, not only ludicrous but misleading. In all questions of original investigation, like that of the water resources of the country, this element of primary assumption must constantly be borne in mind in considering the plan of work and the results attained. In the practical application of the figures of flow of water above or under ground the tacit assumption is that the results obtained at one time will again prevail. If, for example, the midsummer measurements gave a stream discharge of 100 cubic feet per second, engineers and others concerned will quote this figure and use it in their estimates, although, if they stop to think, they will admit that the stream may never again discharge an equal volume, but that the low water in other years or for an average of years may be greater or less than this one measurement indicates. Yet there are those who will recompute the data and take great satisfaction in expressing the measurement as 99.63 cubic feet per second, when they should know not only that there is an error of plus or minus 2 per cent in the result, but that the stream may next year discharge half or twice as much at the same season.

FLOOD ESTIMATES.

At the highest floods, when it is impossible to use a current meter, it is desirable to make an approximate estimate of the flow. This can be done by noting the speed of floating driftwood and other débris on the water surface—by placing a certain base line on the shore parallel to the current, and noting the time that it takes the drift to pass over a certain distance. It will generally be found that the velocity at the center of the stream is greater than toward the edges, and it is well to make estimates of the surface velocity at various points across the stream. From these velocities and a rough estimate of the areas controlled by the various velocities an approximate estimate of discharge can be made. Notes should accompany such estimations describing just how they were obtained, so that a false idea of the accuracy of the measurement will not be conveyed. Records of this kind are often of the greatest value to engineers and investors, in cases where it is not important to know within 10 or even 20 per cent the maximum discharge of a stream, but where it is important to know its discharge within 30 or 40 per cent. Many cases are on record where, without any data upon which to base an estimate, assumptions of the maximum discharge of streams have been made which afterwards were found to be in error by 200 or 300 per cent.

If it is impracticable to make even a rough estimate of the flow of a stream at its maximum discharge, the hydrographer should at least note on the bank, bridge pier, or other permanent landmark the greatest height to which the water rises. It is also desirable to note the rapidity with which it rises and falls, and other natural phenomena.

RATING TABLES.

The immediate object of measurements made at a river station is the construction of a rating table, or series of tables, which shall show the relation for a given length of time between the height of water and the quantity flowing in the stream. In order to prepare such a table it is of course necessary to obtain the discharge at various stages of the stream, covering the ordinary range of fluctuation. This is a comparatively easy task if the channel does not change. The simplest method of procedure in constructing a rating table is to plot upon rectangularly ruled paper each point representing the gage height and the discharge for a given measurement, the vertical distance from the bottom line being taken to represent the height of water at the given measurement and the distance from left to right the quantity of discharge in cubic feet per second. For convenience, the measurements of discharge should be numbered consecutively from 1, the earliest, the numbers being placed opposite the points upon the rectangularly ruled paper. If there are a half dozen or more of these points well distributed according to height of water, it will usually be found that they lie approximately in the path of a parabolic curve. This curve can be sketched through or near the points, the hydrographer, from his intimate knowledge, giving greater weight to some points than to others. This curve shows the relation of gage height to discharge for the particular times under consideration. The rating table is the numerical expression for the curve described. The next step is to read off the figures from the drawing, starting with the lowest value in the lower left-hand corner. The lowest horizontal line representing a tenth of a foot is followed from left to right until it intersects the curve, and the value represented by this distance is set opposite the tenth of foot taken. The line representing the next higher tenth of a foot is then followed out, and its length from the margin at the left to the curve at the right is also obtained, and so on, setting opposite each tenth of a foot the corresponding value of discharge. When the table has been prepared in this way it will be found that there is an increasing value for the discharge, and that the difference between the values is also constantly increasing. Owing, however, to the small scale upon which such a sketch necessarily is made, the figures read off from the drawing do not always have this constantly increasing value, some being proportionally too large and others too small. In order, therefore, to smooth out the curve, it is convenient to set off between the lines of the rating table the differences in quantity of discharge, making a third column. Upon running the eye down this column several points are quickly detected where the differences are not regular. Considering these, it will be seen that a slight adjustment of the differences and the addition or subtraction of a small amount from the figures of discharge will smooth out these irregularities. This adjustment should be made, and as a check upon the accuracy of the work the resulting figures, after the rating table has been smoothed out, should be plotted upon the original drawing to determine, by inspection, that the rating table as finally adjusted is accordant with the observations. This method of graphic construction avoids difficulties and liability to error in the use of the higher mathematics, and its accuracy is well within that of the original data.

The length of time during which a rating table can safely be applied to the observations should be determined by the hydrographer and noted upon it, in order that it may not be used beyond proper limitations. Where the channel is constantly shifting a table can not be used for many weeks or months unless it be referred to the readings of heights as interpreted by the occasional soundings.

TABLES FOR COMPUTING RESULTS FOR PUBLICATION.

The unit employed in the measurement of streams is the cubic foot per second. This is described in the Eleventh Annual Report, Part II, Irrigation, pages 2 to 5; also in the Fourteenth Annual Report, Part

II, pages 100 and 101. From this fundamental unit others have been derived, and the results of the investigation are shown in these for convenience of comparison. The tables formerly published give the maximum, minimum, and mean discharge, in second-feet, for each month. They also usually give the total discharge for the month, in acre-feet, and the run-off in two terms, viz, the depth in inches and the rate of flow in second-feet per square mile. The acre-foot of water is a quantity equivalent to an area of 1 acre covered 1 foot in depth, or 43,560 cubic feet.

Table for converting second-feet into acre-feet per day.

Days.	Second-feet.								
	1	2	3	4	5	6	7	8	9
	Acre-ft.	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*
1	1.98	3.97	5.95	7.93	9.92	11.90	13.88	15.87	17.85
2	3.97	7.93	11.90	15.87	19.83	23.80	27.77	31.74	35.70
3	5.95	11.90	17.85	23.80	29.75	35.70	41.65	47.60	53.55
4	7.93	15.87	23.80	31.74	39.67	47.60	55.54	63.47	71.40
5	9.92	19.83	29.75	39.67	49.59	59.50	69.42	79.34	89.26
6	11.90	23.80	35.70	47.60	59.50	71.40	83.31	95.21	107.11
7	13.88	27.77	41.65	55.54	69.42	83.31	97.19	111.07	124.96
8	15.87	31.74	47.60	63.47	79.34	95.21	111.07	126.94	142.81
9	17.85	35.70	53.55	71.40	89.26	107.11	124.96	142.81	160.66
10	19.83	39.67	59.50	79.34	99.17	119.01	138.84	158.68	178.51
11	21.82	43.64	65.45	87.27	109.09	130.91	152.73	174.55	196.36
12	23.80	47.60	71.40	95.21	119.01	142.81	166.61	190.41	214.21
13	25.79	51.57	77.35	103.14	128.93	154.71	180.50	206.28	232.07
14	27.77	55.54	83.31	111.07	138.84	166.61	194.38	222.15	249.92
15	29.75	59.50	89.26	119.01	148.76	178.51	208.26	238.02	267.77
16	31.74	63.47	95.21	126.94	158.68	190.41	222.15	253.88	285.62
17	33.72	67.44	101.16	134.88	168.59	202.31	236.03	269.75	303.47
18	35.70	71.40	107.11	142.81	178.51	214.21	249.92	285.62	321.32
19	37.69	75.37	113.06	150.74	188.43	226.12	263.80	301.49	339.17
20	39.67	79.34	119.01	158.68	198.35	238.02	277.69	317.36	357.02
21	41.65	83.31	124.96	166.61	208.26	249.92	291.57	333.22	374.88
22	43.64	87.27	130.91	174.55	218.18	261.82	305.45	349.09	392.73
23	45.62	91.24	136.86	182.48	228.10	273.72	319.34	364.96	410.58
24	47.60	95.21	142.81	190.41	238.02	285.62	333.22	380.82	428.43
25	49.59	99.17	148.76	198.35	247.93	297.52	347.11	396.69	446.28
26	51.57	103.14	154.71	206.28	257.85	309.42	360.99	412.56	464.13
27	53.55	107.11	160.66	214.21	267.77	321.32	374.88	428.43	481.98
28	55.54	111.07	166.61	222.15	277.69	333.22	388.76	444.30	499.83
29	57.52	115.04	172.56	230.08	287.60	345.12	402.64	460.17	517.68
30	59.50	119.01	178.51	238.02	297.52	357.02	416.53	476.03	535.54
31	61.49	122.98	184.46	245.95	307.44	368.93	430.41	491.90	553.39

As the months are of varying length it is necessary to use three or four factors to convert the average discharge for the month in second-feet into the total in acre-feet. One second-foot flowing for twenty-four hours is equivalent to 86,400 cubic feet. Since there are 43,560 square feet in an acre there will be the same number of cubic feet in an acre-foot. Dividing, it is found that 1 second-foot for twenty-four hours very nearly equals 2 acre-feet, or, in exact figures, 1.983471 acre-feet. This multiplied by the number of days in the month will give the total monthly discharge in acre-feet. This quantity, therefore, must be multiplied by 28 for the month of February, or 29 for that month in leap year, and by 30 or 31 for the other months.

For the month of February when it has 28 days the factor to be used is 55.537188. For convenience in computation this factor multiplied from 1 to 9 is given on the following page:

1	55.53719
2	111.07436
3	166.61154
4	222.14872
5	277.68590
6	333.22308
7	388.76026
8	444.29744
9	499.83462

When February has 29 days the factor to be used is 57.520659. This when multiplied from 1 to 9 is as follows:

1	57.52066
2	115.04132
3	172.56198
4	230.08264
5	287.60330
6	345.12396
7	402.64462
8	460.16528
9	517.68594

Table for converting second-feet into acre-feet per month.

Second-feet.	Acre-feet per 30 days.	Acre-feet per 31 days.	Second-feet.	Acre-feet per 30 days.	Acre-feet per 31 days.
1	59.504	61.488	51	3,034.711	3,135.868
2	119.008	122.975	52	3,094.215	3,197.355
3	178.512	184.463	53	3,153.719	3,258.843
4	238.017	245.950	54	3,213.223	3,320.330
5	297.521	307.438	55	3,272.727	3,381.818
6	357.025	368.926	56	3,332.231	3,443.306
7	416.529	430.413	57	3,391.735	3,504.793
8	476.033	491.901	58	3,451.240	3,566.281
9	535.537	553.388	59	3,510.744	3,627.768
10	595.041	614.876	60	3,570.248	3,689.256
11	654.545	676.364	61	3,629.752	3,750.744
12	714.050	737.851	62	3,689.256	3,812.231
13	773.554	799.339	63	3,748.760	3,873.719
14	833.058	860.826	64	3,808.264	3,935.206
15	892.562	922.314	65	3,867.768	3,996.694
16	952.066	983.802	66	3,927.273	4,058.182
17	1,011.570	1,045.289	67	3,986.777	4,119.669
18	1,071.074	1,106.777	68	4,046.281	4,181.157
19	1,130.578	1,168.264	69	4,105.785	4,242.644
20	1,190.083	1,229.752	70	4,165.289	4,304.132
21	1,249.587	1,291.240	71	4,224.793	4,365.620
22	1,309.091	1,352.727	72	4,284.297	4,427.107
23	1,368.595	1,414.215	73	4,343.801	4,488.595
24	1,428.099	1,475.702	74	4,403.306	4,550.082
25	1,487.603	1,537.190	75	4,462.810	4,611.570
26	1,547.107	1,598.678	76	4,522.314	4,673.058
27	1,606.612	1,660.165	77	4,581.818	4,734.545
28	1,666.116	1,721.653	78	4,641.322	4,796.033
29	1,725.620	1,783.140	79	4,700.826	4,857.520
30	1,785.124	1,844.628	80	4,760.330	4,919.008
31	1,844.628	1,906.116	81	4,819.835	4,980.496
32	1,904.132	1,967.603	82	4,879.339	5,041.983
33	1,963.636	2,029.091	83	4,938.843	5,103.471
34	2,023.140	2,090.578	84	4,998.347	5,164.958
35	2,082.645	2,152.066	85	5,057.851	5,226.446
36	2,142.149	2,213.554	86	5,117.355	5,287.934
37	2,201.653	2,275.041	87	5,176.859	5,349.421
38	2,261.157	2,336.529	88	5,236.363	5,410.909
39	2,320.661	2,398.016	89	5,295.868	5,472.396
40	2,380.165	2,459.504	90	5,355.372	5,533.884
41	2,439.669	2,520.992	91	5,414.876	5,595.372
42	2,499.173	2,582.479	92	5,474.380	5,656.859
43	2,558.678	2,643.967	93	5,533.884	5,718.347
44	2,618.182	2,705.454	94	5,593.388	5,779.834
45	2,677.686	2,766.942	95	5,652.892	5,841.322
46	2,737.190	2,828.430	96	5,712.396	5,902.810
47	2,796.694	2,889.917	97	5,771.901	5,964.297
48	2,856.198	2,951.405	98	5,831.405	6,025.785
49	2,915.702	3,012.892	99	5,890.909	6,087.272
50	2,975.207	3,074.380	100	5,950.413	6,148.760

For the months containing 30 days, viz, April, June, September, and November, the factor to be used is 59.5041300. This when multiplied by the unit figures is as follows:

1	59.50413
2	119.00826
3	178.51239
4	238.01652
5	297.52065
6	357.02478
7	416.52891
8	476.03304
9	535.53717

For the months containing 31 days, viz, January, March, May, July, August, October, and December, the factor to be used is 61.4876010. This when multiplied by the unit figures is as follows:

1	61.48760
2	122.97520
3	184.46280
4	245.95040
5	307.43800
6	368.92560
7	430.41320
8	491.90080
9	553.38841

The run-off per square mile is obtained by simply dividing the average for the month by the total number of square miles in the drainage basin, which is usually ascertained by planimeter measurements from the best map available. Being a rate of flow it is independent of time, and therefore the number of days in each month does not enter into the ratio.

The depth of run-off over the drainage basin is usually computed in inches for convenience of comparison with the depth of rainfall, which is almost invariably given in that unit. This depth can most conveniently be computed from the run-off per square mile by computation based upon the number of days in each month and the relation between the rate of flow and the depth in inches for this quantity were it held during the given number of days. One second-foot for twenty-four hours is equivalent to 86,400 cubic feet in one day. In other words, 1 cubic foot per second run-off from 1 square mile would, if held upon this area, cover it to a depth represented by dividing 86,400 by the number of square feet in a mile, 27,878,400, or 5,280 squared. Completing this division, it is found that 1 second-foot for one day is equivalent to a body of water covering 1 square mile 0.003099173 feet, or 0.037190076 inch. Multiplying this by the number of days in a month gives the following factors:

28 days	1.041322128
29 days	1.078512204
30 days	1.115702280
31 days	1.152892356

Table for converting second-feet per square mile into depth in inches per month.

Second-feet per square mile.	28 days.	29 days.	30 days.	31 days.
	Inches.	*Inches.*	*Inches.*	*Inches.*
1	1.041	1.079	1.116	1.153
2	2.083	2.157	2.231	2.306
3	3.124	3.236	3.347	3.459
4	4.165	4.314	4.463	4.612
5	5.207	5.393	5.579	5.764
6	6.248	6.471	6.694	6.917
7	7.289	7.550	7.810	8.070
8	8.331	8.628	8.926	9.223
9	9.372	9.707	10.041	10.376
10	10.413	10.785	11.157	11.529

Table for converting run-off in second-feet per square mile into depth in inches per month of 30 and 31 days.

Second-feet per square mile.	30 days.	31 days.	Second-feet per square mile.	30 days.	31 days.	Second-feet per square mile.	30 days.	31 days.	Second-feet per square mile.	30 days.	31 days.
	Inch.	*Inch.*		*Inch.*	*Inch.*		*Inch.*	*Inch.*		*Inch.*	*Inch.*
0.01	0.01	0.01	.60	.67	.69	1.19	1.33	1.37	1.78	1.99	2.05
.02	.02	.02	.61	.68	.70	1.20	1.34	1.38	1.79	2.00	2.06
.03	.03	.03	.62	.69	.71	1.21	1.35	1.39	1.80	2.01	2.08
.04	.04	.04	.63	.70	.72	1.22	1.36	1.41	1.81	2.02	2.09
.05	.06	.06	.64	.71	.74	1.23	1.37	1.42	1.82	2.03	2.10
.06	.07	.07	.65	.72	.75	1.24	1.38	1.43	1.83	2.04	2.11
.07	.08	.08	.66	.73	.76	1.25	1.39	1.44	1.84	2.05	2.12
.08	.09	.09	.67	.74	.77	1.26	1.41	1.45	1.85	2.06	2.13
.09	.10	.10	.68	.75	.78	1.27	1.42	1.46	1.86	2.08	2.14
.10	.11	.12	.69	.77	.79	1.28	1.43	1.48	1.87	2.09	2.16
.11	.12	.13	.70	.78	.81	1.29	1.44	1.49	1.88	2.10	2.17
.12	.13	.14	.71	.79	.82	1.30	1.45	1.50	1.89	2.11	2.18
.13	.14	.15	.72	.80	.83	1.31	1.46	1.51	1.90	2.12	2.19
.14	.16	.16	.73	.81	.84	1.32	1.47	1.52	1.91	2.13	2.20
.15	.17	.17	.74	.82	.85	1.33	1.48	1.53	1.92	2.14	2.21
.16	.18	.18	.75	.83	.86	1.34	1.50	1.54	1.93	2.15	2.22
.17	.19	.20	.76	.84	.87	1.35	1.51	1.56	1.94	2.16	2.24
.18	.20	.21	.77	.85	.89	1.36	1.52	1.57	1.95	2.18	2.25
.19	.21	.22	.78	.87	.90	1.37	1.53	1.58	1.96	2.19	2.26
.20	.22	.23	.79	.88	.91	1.38	1.54	1.59	1.97	2.20	2.27
.21	.23	.24	.80	.89	.92	1.39	1.55	1.60	1.98	2.21	2.28
.22	.24	.25	.81	.90	.93	1.40	1.56	1.61	1.99	2.22	2.29
.23	.26	.26	.82	.91	.94	1.41	1.57	1.63	2.00	2.23	2.31
.24	.27	.28	.83	.92	.95	1.42	1.58	1.64	2.01	2.24	2.32
.25	.28	.29	.84	.93	.97	1.43	1.60	1.65	2.02	2.25	2.33
.26	.29	.30	.85	.94	.98	1.44	1.61	1.66	2.03	2.26	2.34
.27	.30	.31	.86	.95	.99	1.45	1.62	1.67	2.04	2.28	2.35
.28	.31	.32	.87	.97	1.00	1.46	1.63	1.68	2.05	2.29	2.36
.29	.32	.33	.88	.98	1.01	1.47	1.64	1.69	2.06	2.30	2.37
.30	.33	.35	.89	.99	1.02	1.48	1.65	1.71	2.07	2.31	2.39
.31	.35	.36	.90	1.00	1.04	1.49	1.66	1.72	2.08	2.32	2.40
.32	.36	.37	.91	1.01	1.05	1.50	1.67	1.73	2.09	2.33	2.41
.33	.37	.38	.92	1.02	1.06	1.51	1.68	1.74	2.10	2.34	2.42
.34	.38	.39	.93	1.03	1.07	1.52	1.70	1.75	2.11	2.35	2.43
.35	.39	.40	.94	1.04	1.08	1.53	1.71	1.76	2.12	2.37	2.44
.36	.40	.41	.95	1.05	1.09	1.54	1.72	1.78	2.13	2.38	2.46
.37	.41	.43	.96	1.07	1.10	1.55	1.73	1.79	2.14	2.39	2.47
.38	.43	.44	.97	1.08	1.12	1.56	1.74	1.80	2.15	2.40	2.48
.39	.44	.45	.98	1.09	1.13	1.57	1.75	1.81	2.16	2.41	2.49
.40	.45	.46	.99	1.10	1.14	1.58	1.76	1.82	2.17	2.42	2.50
.41	.46	.47	1.00	1.11	1.15	1.59	1.77	1.83	2.18	2.43	2.51
.42	.47	.48	1.01	1.13	1.16	1.60	1.79	1.84	2.19	2.44	2.52
.43	.48	.49	1.02	1.14	1.18	1.61	1.80	1.86	2.20	2.45	2.54
.44	.49	.51	1.03	1.15	1.19	1.62	1.81	1.87	2.21	2.47	2.55
.45	.50	.52	1.04	1.16	1.20	1.63	1.82	1.88	2.22	2.48	2.56
.46	.52	.53	1.05	1.17	1.21	1.64	1.83	1.89	2.23	2.49	2.57
.47	.53	.54	1.06	1.18	1.22	1.65	1.84	1.90	2.24	2.50	2.58
.48	.54	.55	1.07	1.19	1.23	1.66	1.85	1.91	2.25	2.51	2.59
.49	.55	.56	1.08	1.20	1.25	1.67	1.86	1.93	2.26	2.52	2.61
.50	.56	.58	1.09	1.22	1.26	1.68	1.87	1.94	2.27	2.53	2.62
.51	.57	.59	1.10	1.23	1.27	1.69	1.89	1.95	2.28	2.54	2.63
.52	.58	.60	1.11	1.24	1.28	1.70	1.90	1.96	2.29	2.55	2.64
.53	.59	.61	1.12	1.25	1.29	1.71	1.91	1.97	2.30	2.57	2.65
.54	.60	.62	1.13	1.26	1.30	1.72	1.92	1.98	2.31	2.58	2.66
.55	.61	.63	1.14	1.27	1.31	1.73	1.93	1.99	2.32	2.59	2.69
.56	.62	.64	1.15	1.28	1.33	1.74	1.94	2.01	2.33	2.60	2.67
.57	.63	.66	1.16	1.29	1.34	1.75	1.95	2.02	2.34	2.61	2.70
.58	.64	.67	1.17	1.31	1.35	1.76	1.96	2.03	2.35	2.62	2.71
.59	.65	.68	1.18	1.32	1.36	1.77	1.97	2.04	2.36	2.63	2.72

Table for converting run-off in second-feet per square mile, etc.—Continued.

Second-feet per square mile.	30 days.	31 days.	Second-feet per square mile.	30 days.	31 days.	Second-feet per square mile.	30 days.	31 days.	Second-feet per square mile.	30 days.	31 days.
	Inch.	*Inch.*		*Inch.*	*Inch.*		*Inch.*	*Inch.*		*Inch.*	*Inch.*
2.37	2.64	2.73	2.78	3.10	3.21	3.19	3.56	3.60	3.60	4.02	4.15
2.38	2.66	2.74	2.79	3.11	3.22	3.20	3.57	3.68	3.61	4.03	4.16
2.39	2.67	2.76	2.80	3.12	3.23	3.21	3.58	3.79	3.62	4.04	4.17
2.40	2.68	2.77	2.81	3.14	3.24	3.22	3.59	3.71	3.63	4.05	4.18
2.41	2.69	2.78	2.82	3.15	3.25	3.23	3.60	3.72	3.64	4.06	4.20
2.42	2.70	2.79	2.83	3.16	3.26	3.24	3.61	3.74	3.65	4.07	4.21
2.43	2.71	2.80	2.84	3.17	3.27	3.25	3.63	3.75	3.66	4.08	4.22
2.44	2.72	2.81	2.85	3.18	3.29	3.26	3.64	3.76	3.67	4.09	4.23
2.45	2.73	2.82	2.86	3.19	3.30	3.27	3.65	3.77	3.68	4.11	4.24
2.46	2.74	2.84	2.87	3.20	3.31	3.28	3.66	3.78	3.69	4.12	4.25
2.47	2.76	2.85	2.88	3.21	3.32	3.29	3.67	3.79	3.70	4.13	4.27
2.48	2.77	2.86	2.89	3.22	3.33	3.30	3.68	3.80	3.71	4.14	4.28
2.49	2.78	2.87	2.90	3.24	3.34	3.31	3.69	3.82	3.72	4.15	4.29
2.50	2.79	2.88	2.91	3.25	3.35	3.32	3.70	3.83	3.73	4.16	4.30
2.51	2.80	2.89	2.92	3.26	3.37	3.33	3.71	3.84	3.74	4.17	4.31
2.52	2.81	2.91	2.93	3.27	3.38	3.34	3.73	3.85	3.75	4.18	4.32
2.53	2.82	2.92	2.94	3.28	3.39	3.35	3.74	3.86	3.76	4.20	4.33
2.54	2.83	2.93	2.95	3.29	3.40	3.36	3.75	3.87	3.77	4.21	4.35
2.55	2.85	2.94	2.96	3.30	3.41	3.37	3.76	3.89	3.78	4.22	4.36
2.56	2.86	2.95	2.97	3.31	3.42	3.38	3.77	3.90	3.79	4.23	4.37
2.57	2.87	2.96	2.98	3.32	3.44	3.39	3.78	3.91	3.80	4.24	4.38
2.58	2.88	2.97	2.99	3.34	3.45	3.40	3.79	3.92	3.81	4.25	4.39
2.59	2.89	2.99	3.00	3.35	3.46	3.41	3.80	3.93	3.82	4.26	4.40
2.60	2.90	3.00	3.01	3.36	3.47	3.42	3.82	3.94	3.83	4.27	4.42
2.61	2.91	3.01	3.02	3.37	3.48	3.43	3.83	3.95	3.84	4.28	4.43
2.62	2.92	3.02	3.03	3.38	3.49	3.44	3.84	3.97	3.85	4.30	4.44
2.63	2.93	3.03	3.04	3.39	3.50	3.45	3.85	3.98	3.86	4.31	4.45
2.64	2.95	3.04	3.05	3.40	3.52	3.46	3.86	3.99	3.87	4.32	4.46
2.65	2.96	3.06	3.06	3.41	3.53	3.47	3.87	4.00	3.88	4.33	4.47
2.66	2.97	3.07	3.07	3.43	3.54	3.48	3.88	4.01	3.89	4.34	4.48
2.67	2.98	3.08	3.08	3.44	3.55	3.49	3.89	4.02	3.90	4.35	4.50
2.68	2.99	3.09	3.09	3.45	3.56	3.50	3.90	4.04	3.91	4.36	4.51
2.69	3.00	3.10	3.10	3.46	3.57	3.51	3.92	4.05	3.92	4.37	4.52
2.70	3.01	3.11	3.11	3.47	3.59	3.52	3.93	4.06	3.93	4.38	4.53
2.71	3.02	3.12	3.12	3.48	3.60	3.53	3.94	4.07	3.94	4.40	4.54
2.72	3.03	3.14	3.13	3.49	3.61	3.54	3.95	4.08	3.95	4.41	4.55
2.73	3.05	3.15	3.14	3.50	3.62	3.55	3.96	4.09	3.96	4.42	4.57
2.74	3.06	3.16	3.15	3.51	3.63	3.56	3.97	4.10	3.97	4.43	4.58
2.75	3.07	3.17	3.16	3.53	3.64	3.57	3.98	4.12	3.98	4.44	4.59
2.76	3.08	3.18	3.17	3.54	3.65	3.58	3.99	4.13	3.99	4.45	4.60
2.77	3.09	3.19	3.18	3.55	3.67	3.59	4.01	4.14	4.00	4.46	4.61

INSTRUCTIONS TO COMPUTERS.

GAGE HEIGHTS.

A careful inspection of tabulated gage heights frequently will reveal errors made in reading the rod or subsequently introduced by transcribing, which on the face of them are incongruities or physical impossibilities. For example, take the accompanying table of the low-water flow of Coosa River at Rome, Ga., during part of the month of October, 1899. An inspection will reveal at once that the gage height for October 11 is to be viewed with suspicion. Although a sudden rise of 1.30 feet in twenty-four hours might be expected, at this low stage of the river a drop of 1 foot in the next twenty-four hours would be a very improbable occurrence. Upon looking up the original record it will be found that the correct gage height for that day is 1 foot.

October, 1899.	
1	0.40
2	.30
3	.30
4	.30
5	.30
6	50
7	.70
8	.70
9	.80
10	.60
11	1.90
12	.90
13	.70
14	.70
15	.60
16	.60

In working up gage heights and records of discharge measurements computers should always be on their guard for errors of this nature, although the data bear check marks or initials indicating revision. In cases of this kind the stage and locality of the river should be taken into account, for a fluctuation similar to that just illustrated would be quite characteristic of the river at a higher stage, say during the spring-flood season; or, again, it would be entirely compatible with the erratic behavior of streams in the arid regions, as, for instance, Queen Creek, Ariz., at any season of the year. Many errors in gage reading are due to observers mistaking feet for tenths or tenths for hundredths. A careful scrutiny of the general behavior of the stream and the exercise of a little judgment will often be found fruitful in determining the true relations.

RATING TABLES.

Rating tables should be made in all respects complete. They should contain the discharges for the lowest as well as for the highest gage heights occurring during the period to which they are applicable. If the gage at a station has been read to tenths of a foot only, the discharge in the rating table should be given for every tenth, and where gage readings are carried out to hundredths of a foot the rating table should give values for each half tenth. In applying rating tables of the latter class the gage readings are mentally reduced to the nearest half tenths and the corresponding discharge values are taken from the rating table. This applies to all rivers and creeks, with the exception of small streams and canals the observations on which have been made with special care, in which cases the rating tables should be constructed to furnish values for single hundredths.

In constructing rating tables great stress is laid on the necessity of avoiding the occurrence of negative second differences. The increments of the differences between the discharges of successive increasing gage heights may vary from a given quantity down to zero, as in the case of a rating curve changing into a straight line, but in no instance should the values of these increments or second differences become negative, implying the occurrence of a reverse curve in any portion of a rating curve. Although theoretically not impossible, the occurrence of a reverse curve is only admissible under certain peculiar local conditions existing in the stream channel at or near the gaging station, conditions which are generally avoided in establishing stations.

AVERAGES, RUN-OFFS, ETC.

Great care should be exercised in obtaining the mean monthly flow in second-feet to divide the total for a month by *the actual number of days recorded in that month*, i. e., not necessarily by the total number of days in the month, 28, 29, 30, or 31, as the case may be, but by the number of days for which the gage heights are given. Omissions in gage readings, due to a variety of causes, give rise to frequent gaps in the records, and these should not escape the attention of the computer. From the monthly means or averages so obtained are computed the run-off per square mile, the run-off, in inches, on the watershed, and the total number of acre-feet for the month. In case of fractional months or incomplete records the monthly average should be treated as the average for a full month whenever the character of the partial record is such as fairly to represent the flow of the river during the entire month.

Thus an incomplete record of flow for a month during the low-water season may in most cases, without appreciable error, be given the weight of a full record, and the average run-offs and acre-feet be treated accordingly. On the other hand, a gap of six days in the record for a high-water month may frequently mean the omission of a large flood, perhaps too large to be measured and recorded, and the amount of water discharged during those six days may have equaled the total discharge of the river for the remainder of the month. Considering the mean of such a record as the mean for the entire month would evidently introduce here an error of 100 per cent. In such a case the proper method of procedure is to compute the run-offs and acre-feet for the exact number of days recorded, and insert a footnote stating the number of days that they represent.

Again, four or five readings taken at intervals during a winter month, when the river is partly frozen and its flow practically devoid of material fluctuations, will be ample upon which to base general figures of run-offs and acre-feet. The mean in such a case, however, will not be the arithmetical mean of the four or five records available, but an approximation, in round numbers, to that arithmetical mean. Such a figure should always be accompanied by a footnote stating that it is approximate.

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