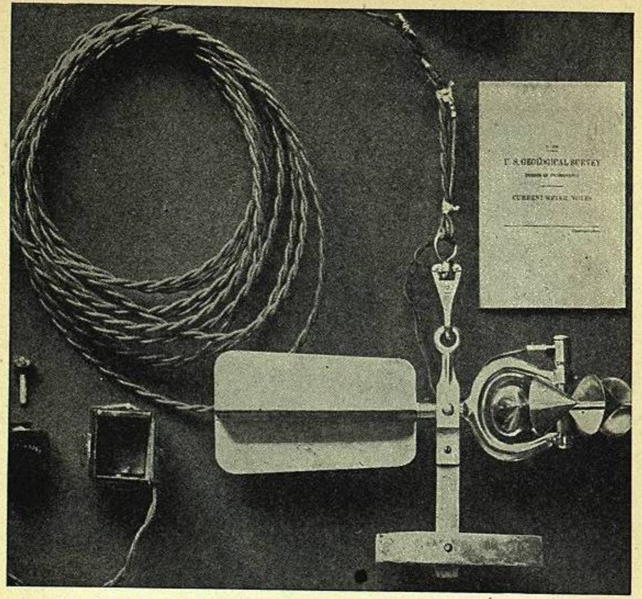
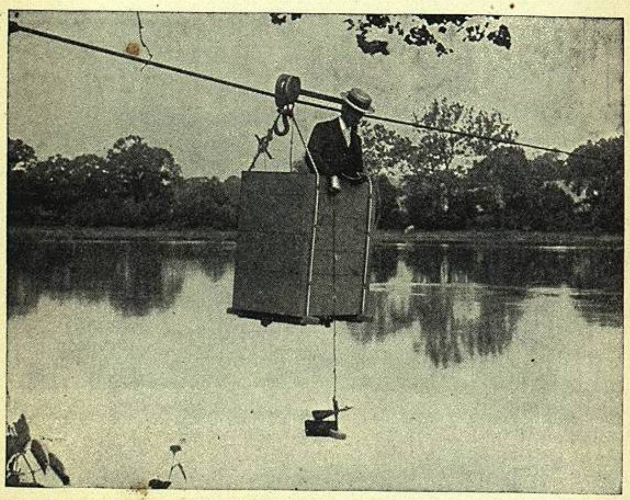
and caused to revolve by the stream, the speed of revolution being dependent upon the speed of the water. This rate of revolution may be noted in a number of ways, either by means of small wheels connected with a dial, or by a device making a rap or click, or by some form of electric "make and break." The latter is the preferred form, since the meter can then be used in a great variety of ways and at a considerable distance from the operator.

The accompanying view (Pl. X, *A*) is of an electric current meter, one which may be considered as illustrative of many different forms. On the extreme right is shown a series of conical cups arranged on the periphery of a wheel in such a way that the water striking the open face of the cups causes them to revolve. Each revolution "makes and breaks" the electric current passing through the spindle or bearing of the wheel. This electric impulse is transmitted through a double insulated conducting cord, the battery supplying the impulse being connected at the far end of this cord. In the view the battery box is open, and the small bisulphate of mercury cell is shown taken out of the box and with the zinc pole removed.

Behind or at the left of the revolving wheel or head of the meter is seen the device for supporting it with a lead weight below, and beyond this the tail of the meter, consisting of two sheets of metal at right angles to each other, intended to hold the



A. ELECTRIC CURRENT METER, CONDUCTING CORD, AND BATTERY.



B. METHOD OF USING ELECTRIC CURRENT METER FROM SUSPENDED CAR.

head of the meter horizontally in the flowing water. When the meter is lowered into the stream by means of the conducting cord, the head begins to revolve, and each revolution opens and closes the electric circuit, this fact being made known by a little buzzer or sounder about the size of a watch attached to the back of the battery box. The engineer or hydrographer using the instrument can put this battery box, with sounder attached, in his pocket, and can hear the click, click, click, as the meter wheel revolves under the water. By holding his watch in his hand and noting the number of clicks during, say, 50 seconds, he can readily obtain the number of revolutions per second. For example, if he counts 100 clicks in 50 seconds, the meter head is obviously revolving at the rate of two per second. Referring to the table constructed for the purpose, he notes that two revolutions per second are equivalent to a speed of 5 feet per second, and thus he obtains at once the speed of the water at the particular point where the meter is placed.

In using a current meter the chief operation consists of placing the meter at a sufficient number of points across the stream, and from the surface to the bottom, so as to obtain a full knowledge of the rate of flow of each portion of the current. In rivers and creeks of ordinary size it is usually sufficient to make observations at intervals of, say, 10 or 20 feet horizontally, so that there will be from eight to sixteen localities of measurement across the stream. The velocity is usually found to vary but little from one of these localities to another, unless there are obstructions, such as large rocks or snags. In deep streams it is necessary at each of these localities across the section to observe the velocity just below the surface and at intervals of from 2 to 5 feet to the bottom. In very shallow streams usually only a single measurement at each point across the stream can be made, as the meter requires some space in order to be submerged and not strike the stones on the bottom.

When these observations have been made at evenly distributed points in the vertical, the average of them may be taken as the velocity at this locality, or the figures can be plotted graphically and the average velocity obtained by measurement of the drawings. If the localities of measurement of speed are taken at intervals of, say, 10 or 20 feet across the river, the average depth of each of these portions of the stream should be multiplied into the width and into the average velocity; the flow of each portion of the stream being thus separately ascertained, the total will give the complete discharge.

In order to use the current meter successfully, it is necessary to be able to reach all parts of the cross-section. This can be done by a plank laid across a narrow brook, or by a bridge, if favorably located, across the larger stream. Where there are

no bridges, boats are occasionally used, although in flood times these are often dangerous. A device which is largely used consists of a stout iron or steel cable stretched across the stream at a convenient place and suspended from this a box, or car (Pl. X, *B*), large enough for the hydrographer to sit or stand in while using the meter. In this box, out of the reach of the floods, the hydrographer can propel himself from side to side and can lower his meter to any desired depth beneath the surface.

The accompanying illustration (Fig. 19) has been prepared to illustrate the operations of measurement of velocity by this method. The drawing represents a river flowing toward the reader, and ending abruptly, as though cut off to give a section showing the surface and bottom of the stream. Across the river at this point is stretched a steel cable suspended from posts, each end of the cable being carried over the top of the post and continued to an anchorage buried deeply in the soil. The cable is drawn tight by means of a turnbuckle between the anchorage and the supporting post. On this cable a small car is hung by means of two pulleys, which allow easy motion forward and back. Beside the cable, or immediately above it, is a small wire carrying at intervals of ten feet a series of tags marked ten, twenty, thirty, etc.; these serve to give the distance from some fixed point on the shore. On the left side of the view on the bank of the river, is shown a stick of timber inclined at about the slope of the shore. This has been marked to vertical feet and tenths, and is the gage upon which record of the daily height of water is kept.

The curved, dotted lines of the figure are intended to show points of equal velocity; the points forming an oval-shaped figure in the centre of a section of the stream are those having the same speed, this being greater than that shown by the

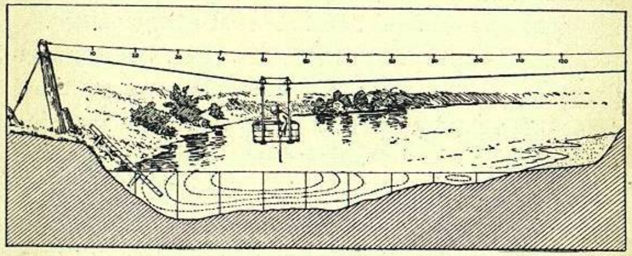
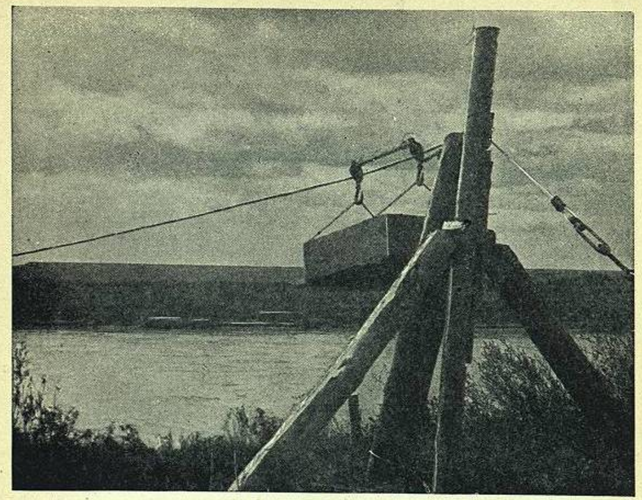


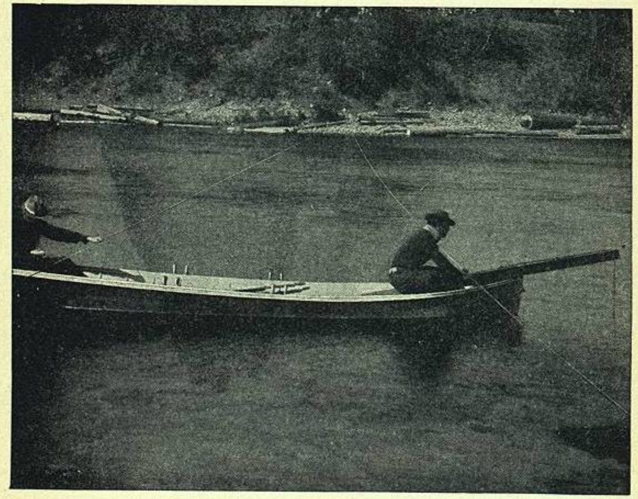
FIG. 19. — Method of measuring a river from a car suspended from a steel cable.

curved line which surrounds it; and this in turn having greater speed than the points lying outside of it, and so on, the speed of the water decreasing from a point beneath the centre out toward the banks. The bottom being irregular, there is shown on the right-hand side a portion of the stream where the velocity increases somewhat and again diminishes toward the shore.

The vertical lines on the section divide the river into compartments ten feet in width, these being located by means of the tagged wire. The depth



A. SUPPORTS FOR SUSPENDED CAR.



B. METHOD OF USING METER FROM BOAT.

of each of these compartments is ascertained by sounding, by means of a cord and weight, or by a stick or pole. The velocity is also measured near the centre, this being taken as the average for the whole compartment. The velocity thus obtained by means of the current meter and computed in feet per second is multiplied by the average depth of the compartment and by its width, the result being the discharge in cubic feet per second. The sum of all the measurements gives the total flow of the stream.

The methods of using the meter, or rather places at which it is held in the cross-section, vary somewhat according to the nature of the stream to be measured. In an artificial channel of regular size, particularly in a wooden or masonry flume or conduit with flat bottom and straight sides, there is usually less variation in the velocity of different portions of the section. Thus, the number of observations with the meter may frequently be reduced without decreasing the accuracy of the work. In the accompanying figure (20) is shown the cross-section of a wooden flume, this being considered as divided into four portions or compartments. In that on the left-hand side, numbered 1, dotted lines and arrows have been drawn to indicate one of the methods of using a current meter. Starting at the top, the meter is lowered slowly along the side of the flume to the bottom, then carried diagonally upward to the top, then vertically downward to the bottom and diagonally across to the point of beginning. The instrument is moved with a slow, steady motion. The number of seconds required to complete this circuit is usually from fifty to seventy-five, record of these being kept by a stop-watch, and the number of revolutions of the meter being counted. This process and its modifications are sometimes known as measurement by integration, it being assumed that the average velocity of the water is obtained by the meter as it is moved from place to place.

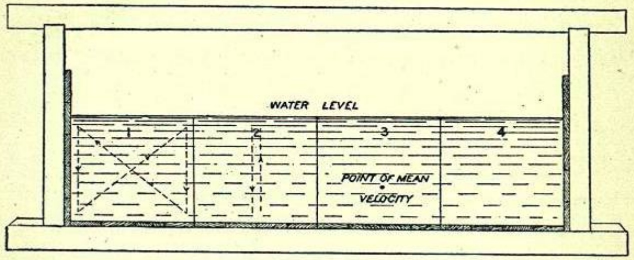


FIG. 20.—Section of flume illustrating methods of measurement.

In the division numbered 2 the course of the meter is indicated as being moved slowly from the top to the bottom, thus integrating the velocity through the centre of the section, it being considered that at a distance from the side of the flume a fairly uniform motion of the water takes place. A third method of obtaining the velocity is that shown in the division marked 3, where the meter is held steadily for fifty or one hundred seconds

at the point of mean velocity, this being approximately three-fifths of the depth below the surface. The speed at this point has been found by experiment to be usually equal to the average for the entire division or compartment.

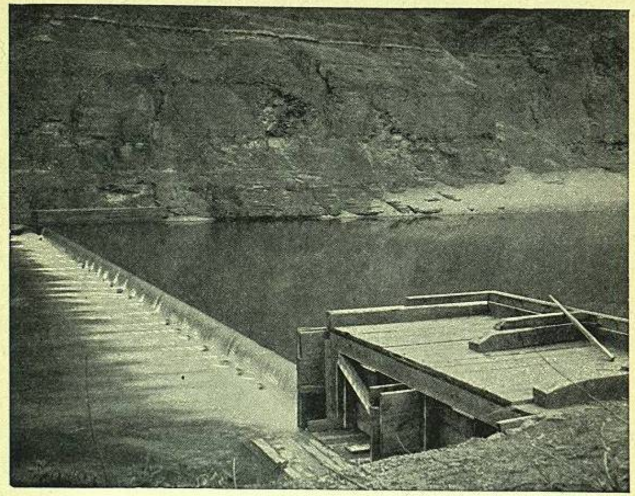
It is usually preferable in streams with rough sides and bottom to make observations of velocity at various points across the section and near the top and bottom, as it is not safe to rely upon the water following any arbitrary rule deduced from other streams. There are occasionally pools of stagnant water near the edges or in deep holes, and these can be discovered only by a well-distributed series of velocity measurements at definite points.

Weirs.

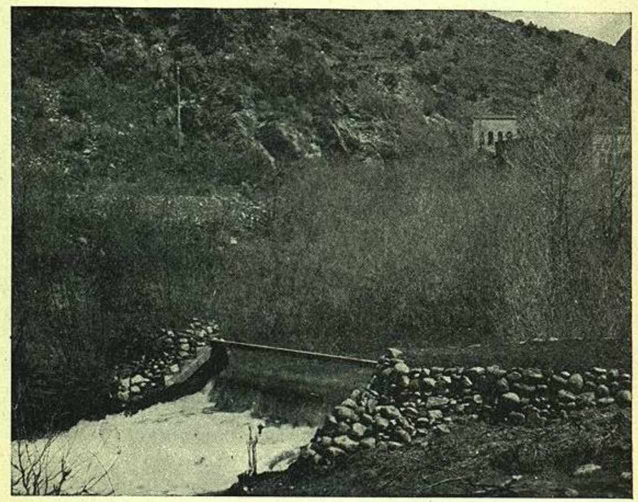
The methods above described are what may be termed direct forms of measurement, since they involve ascertaining the simple elements of width, depth, and velocity. There are, however, other methods which arrive at the total flow by the application of principles and formulæ derived from experiments. In these methods the velocity of water is estimated as it passes over or through some regularly formed channel or aperture; for example, over the crest of a dam or through openings cut in it. A dam, whether in a large or small stream, so constructed that the water passes over it or through a regular section, usually with decided fall, is termed a weir. The weir may be totally submerged or its sides or ends may project above the water, narrowing the channel. The term is applied, on the one extreme, to the great masonry structures built across large rivers for the purpose of regulating the channel, and on the other extreme, to a board placed across a small brook or ditch, with a notch or opening cut in it, to permit the regular flow of water for the purpose of measurement.

Elaborate and careful experiments have been made with weirs of various forms and dimensions, to determine the rule or law of velocity of the water flowing through openings of given size and shape. From the facts thus obtained formulæ have been derived which are applied to streams of considerable size, as well as those comparable to the ones upon which the experiments were tried. The accompanying illustrations show two classes of weirs. The first (Pl. XII, *A*) is across Genesee River, New York, taking the full flow of that stream in high and low water. The second (Pl. XII, *B*) is on Cottonwood Creek, in Utah.

The essentials of a weir are that the water shall be partially stilled and flow gently with uniform current toward the edge. Above this edge there should be deep water, so that the currents may approach without disturbance. On the lower side there should also be a free fall. There are a number of technical requirements to be observed according to the formula to be applied; that is to say,



A. WEIR ON GENESEE RIVER, NEW YORK.



B. WEIR ON COTTONWOOD CREEK, UTAH.

for a sharp-crested or flat-crested weir, or for one with end contractions, certain precautions are to be observed. In order to secure accuracy, attention must be given to all of these details, that they may conform to the conditions of the original experiments from which the rules were derived.

The accompanying figure (21) shows a small weir placed in a running stream, ponding water somewhat by contracting the channel.

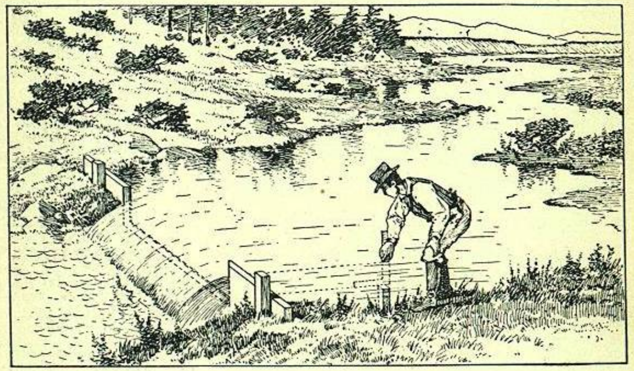


FIG. 21.—Ordinary weir in a small stream.

As the water approaches the sharp edge over which it falls the stream contracts, so that to ascertain the exact height of the water above the horizontal crest over which it falls it is necessary to drive down a peg three or four feet back from the crest to the exact level with the edge of the weir, and to measure from this peg up to the water surface. This gives the height of the water on the weir; the depth of water above the weir should be at least twice this height. The weir should be placed at right angles to the current of the stream, and the water should be brought as nearly as possible to rest, passing with free fall over the crest, and with a width at least three times the depth. By carefully observing certain precautions, and applying suitable formulæ or rules derived from experiment, it is possible to ascertain the flow of a stream with an error of only 1 or 2 per cent. Computations of discharge can be avoided by using tables prepared for weirs of different size and form, a number of these having been printed as standard books of reference for the use of engineers.

Many of the more important rivers of the United States are used, in part at least, for water power, and dams have been built across them, raising the water and ponding it for many miles. Occasionally the dam of one water power is placed near the upper end of the slack water caused by the dam below, and thus the free flow of the river is impeded and artificial conditions are created, so that ordinary current meter or float measurements are impossible. In such cases the discharge of the stream can be ascertained only by using the dam as a measuring weir and by various indirect methods. It is necessary to know the amount which passes through the water wheels, out of the waste ways, as well as that flowing over the crest of the dam

in times of flood. To do this requires a large number of observations. The amount of water used by each wheel must be known, and the number of hours during which the wheel is operated each day, the wheel being considered as a water meter. The sum of the quantities used by the wheels can thus be obtained, and to this must be added the amount flowing over or through the dam. Each of the openings must be measured, and the amount which escapes over the top computed by considering the dam as a weir. The matter is further complicated by the fact that many mill dams, especially those built of logs or timber, are full of small leaks, permitting a quantity of water to pass through or beneath them, the amount of which can only be roughly approximated or guessed. It is possible, however, by these somewhat roundabout methods to obtain a very fair estimate of the discharge of a river, — one which is of value in all practical considerations.