Unfinished Paper

by P.L.

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Water from the standpoint of man's existence, in supplying his immediate bodily needs and its use in providing food, marks this essential element a thing of prime importance. When considering this element, a commodity it is necessary for many reasons to provide means for its measurement both from the standpoint of practical application as well as that of scientific consideration.

The measurement of water may be assumed to be of two general conditions, namely, static, as water in a basin or reservoir, and mobile, as water flowing in a channel or closed conduit. For the former condition the units of measure are cubic feet or meters, gallons or litres, acre-feet or units of million gallons or cubic feet; while for the latter such units imply motion or velocity and the element of time is involved, and one cubic foot or meter per second, gallons per minute or clay, million gallons per day or acre-feet per day or other cubical units moving over a definite period of time. Customs appear
It has been established that in irrigation, the capacity of storage reservoirs is usually in acre-feet or units of one million cubic feet, while for municipal supplies, such ratings are in either acre-feet or gallons.

This paper is intended to discuss the subject of measuring flowing water and will not touch upon the methods of survey and computations dealing with capacities and volumes.

The determination of the quantity of flow involves but two principal factors, namely, velocity or rate of movement and the cross section of the fluid prism. The velocity of the stream, when moving directly under the influence of gravity, is dependent upon the gravitational constant *g* and the slope or head through which the stream moves, and is expressed as $v = \sqrt{2gh}$, which is one of the fundamental hydraulic equations used by the scientist and engineer. The area of the fluid prism being square units and may be of any shape. However, in this respect
It is usual to have the section one of geometrical design as a convenience in calculating more accurately the true value of the cross section. Since the discharge is a rate per unit of time, usually seconds, it is quite obvious that the product of the velocity and the area, when taken as functions of identifiable linear units, will result in cubic units as the rate of flow. This relation is also one of the fundamental hydraulic equations and is expressed simply as \( Q = a \cdot v \). These two brief and simple equations constitute the basis upon which theory and practice are founded in the science of measuring the rate of discharge of moving media.

In the application of these basic principles, the scientist and engineer strive for simplicity in the creation of devices suited to meet certain conditions. Since this group is interested in the subject of water we will keep in mind that references to discharges are to be related to this common thing which, at times
gives us much concern. Measurement of flowing water can be made simple under certain conditions while in other cases quite complex when involving corrections, modifications and extensions to known basic relations.

Roman history dating back to the period of the beginning of the present era brings to light that men concerned with water had conceptions of gaging the flow of a stream but it appears that these early investigators thought of area only and gave no consideration to the rate of movement or velocity. It may well be since at that time there was no practical means of measuring time these men dismissed the element of rate or period of duration and thus simplified their work to that of square units of flow. It may or may not be of interest to you to know that even to day it is found among the laymen concerned with irrigation supplies that the area through which the water passes suffices in meeting the needs of the problem of distribution.
Over the years men have conceived and developed many devices expressly for the purpose of measuring the rate of discharge of a stream of water. As to methods these might be classified as way of measuring velocity such as by means of current meters, Pitot tubes of various designs, coloring salt solutions, resistant meters, gradient of channel involving coefficients of roughness, horizontal or vertical trajectory of jet, applications of the principles of impact or momentum and other means whereby the rate of flow or velocity can be determined. The displacement or volumetric method is merely the filling of a known volume by admitting the whole stream for a definite period of time. In small streams the flow for a period of time is caught in a container and the volume determined by weight. The displacement and weighing methods are only applicable for the measurement of small flows and are best suited for laboratory practice.
One of the simplest devices for gauging stream flow is to pass the water through an opening which is assumed to be an orifice. Such an opening may be either circular, rectangular, or of other regular form of known area. The rate of flow is calculated according to the formula

$$Q = C a \sqrt{Zg \cdot h}$$

In practice it is possible to determine within close limits the values of the area "a" and the effective head "h" but experience indicates that the value of the coefficient "C" may vary between rather wide limits. For perfect entrance conditions and the elimination of resistance, this coefficient approaches unity and when the entrance is poor and other conditions interfere, this value may be \(\frac{1}{2}\) or less. The general practice is to assume this coefficient to be 0.6. The pressure head when the orifice is not submerged, is reckoned vertically from the center of gravity of the opening to the water surface on the pressure side. The effective pressure head...
where a difference in head is involved, because of submergence, may be determined from any datum. The use of the orifice is confined mostly for the measurement of moderate to small flows and under certain conditions of operation is found to be a practical measuring device.

A weir, as is understood in our country, is a notch of definite shape and dimension through which a stream may be passed and measured in cubic units of flow. The notch may be rectangular, trapezoidal, triangular or circular in form or of special design where the sides may be a part of an ellipse, parabola or hyperbola tangent to a level crest of definite length or spring from a common point with a zero crest length. Such forms of weirs may have special use and are impractical because of the difficulty in construction. The most common and practical weir notch is known as the rectangular type where the
Another practical application of the orifice is found in the device generally known as the module. This is essentially a means of measuring water in units of Miner's inches and has been used in the placer mining industry and also in irrigation practice. This device consists of a short flume, usually of wood construction, about 10 feet long, 2 feet wide and 2 feet deep. Horizontally along one side is a slot 1 inch high and several inches long provided with a movable strip such that by sliding this piece laterally the opening may be adjusted to any convenient length. The center of this slot is, let us say, 5 inches vertically below the level top edge of the structure. In operation the movable strip is adjusted to such a position that the spill over the side of the flume is 1/2 inch deep and for this condition the length of the orifice in inches is equivalent to the discharge in Miner's inches.
crest is set level and the sides vertical. The trapezoidal or Cippoliti notch has gained favor principally because of the simplified mathematical formulas used in computing the rate of flow. Laboratory tests show that if these types of weir notches are both of equal accuracy, the triangular notch weir has a zero crest length with the sides inclined outward at equal angles from the vertical. The usual form is where the angle of intersection of the two sides is one of 90 degrees. This weir notch is of practical design because of its ability to measure small as well as relatively large flows accurately. The circular weir is one having a curved crest when viewed in elevation and is limited in its practical application. There are certain limitations in the use of weirs, such as the effect of velocity of approach, limiting minimum heads to avoid adherence of the nappe, aeration of the nappe, tolerance of submergence and
others factors such as the degree of off-level of the crest sides not plumb and the rounding of the crest where the law of discharge is applicable to a sharp edge. Weirs of the types mentioned are mostly used for measuring small to moderate sized flows in the laboratory. The use of the weir in the field for irrigation practices has been found generally to be impractical. The many weir discharge formulae are here omitted. Any standard reference on hydraulics may be consulted for review of the different expressions covering this point. In passing it may be pointed out that to secure an accuracy of 1/2 percent in the measurement of flow over a standard sharp crested weir not the velocity of approach must be not greater than 0.5 feet per second; the bottom contraction 2H and the side contractions 3H or bottom contraction 3H and the sides at 2H.

There are of course other types of weirs such as those having broad crests
of different shapes and patterns used primarily in gauging large flows of several hundred second feet or more. There is one special type of weir that may be of interest, proposed by the late Clemens Herschel and tested at the hydraulic laboratory at Fort Collins. This device consisted of a tubular crest 2 feet long, side walls vertical and parallel, with 45 degree slopes extending downward both upstream and downstream from the crest. As implied the crest is hollow. Just downstream from the top of this level crest were four 1/4-inch holes equally spaced through into the tubular cavity within. This inside space being about 3 inches in diameter and the radius of the face of the crest being about 1 foot. The usual weir formula enters the head as a value of the \( \frac{3}{2} \) power, showing a relation of discharge to head to be a smooth regular curve of higher order. For the Herschel hollow crest weir, with the difference in head between the stage of
flow up stream and the pressure head observed inside the tube as a function of the discharge it is found that the relation between discharge and this difference in head is a straight line or as may be expressed by the equation \[ Q = 5.5 \Delta P \]. The fact that the law of discharge is of such a simple relation is of no particular significance.
The rating flume, as commonly found in irrigation practice, is a simple structure built in a channel where the floor of the flume is level and on grade and may have either vertical walls or so constructed that the side walls are inclined to agree with the side slopes of the channel. A calibration of the flume is made by means of current meter gaging of the discharge for various depths of flow and a simple curve prepared to show the relation of depth to flow. Experience with this type of measuring device in the field, especially in irrigation canals and ditches, has shown in some instances a marked instability in the relation of depth of flow to the rate of discharge. Such variation in the rating is caused by filling in and scouring out of the bed of the channel, checks and temporary checks placed in the channel downstream as a means of elevating the water surface to accommodate high delivering encroachment along the banks of the canal or ditch by heavy growth of grass or willows and
aquatic growth in the channel itself. These variable effects in causing resistance to flow or change of the conditions under which the original calibration was made result in deviations from the standard rating curve. Growth of moss in the channel during the summer months has been found to cause deviations in the indicated discharge in amounts approximating 75 percent
Improved Water Measuring Devices and Methods

By R. L. Parshall

(This paper is intended as a radio talk to be given in a series of papers on irrigation subjects. Western Farm and Home Hour, K.G.O., San Francisco.)

Water, a necessary requirement for the existence of man, not only for his immediate bodily needs but also its use to provide food, marks this essential and required element a thing of prime importance. This natural element is spread over the earth's surface in lavish proportions, but in certain land areas the precipitation is limited and thus the surface water supplies are not overly abundant. The right in the enjoyment of this essential natural asset in its utilization in serving mankind; such as quenching his thirst, growing his crops, and turning the wheels of his work shop, are recognized by law in the order of importance as to its use.

The apportionment of a common water supply between varied and numerous users is legally based on decreed rights which very definitely specify rate of diversion or some unit of volume as the measure of the amount of water to be withdrawn from this common source of supply. In compliance with the law which permits the use of water by
these varied interests, units of measure have been established which are mutually agreeable to all concerned. Water at rest, as confined in a basin or reservoir, may be determined volumetrically in units of gallons, cubic feet, cubic meters, or acre-feet, while for flowing water the element of time or period of flow is considered which introduces the factor of rate, speed, velocity or movement. The unit of flow may be gallons per minute, cubic feet per second, (Sometimes stated as second-feet), cubic meter per second, acre-feet per day, or other cubic units as the rate of discharge during a definite period of time usually taken as one second or one minute. Throughout the western states during the gold rush days another unit of measuring water was recognized in relation to the placer mining industry and is known as the Miner's Inch. This unit of flow is the exception in that the element of time is not considered and is simply expressed as the amount of water issuing from a square orifice, 1 inch high and 1 inch wide, cut through a vertical smooth plate where the surface of the water is at a definite distance in inches, above the center of this opening. This unit of measure is different in some of the western states because the pressure head being taken at different depths. Fifty miner's inches equal a flow of one cubic foot per second in southern California,
Idaho, Kansas, New Mexico, North Dakota, South Dakota, Utah, and Nebraska; 40 in central California, Arizona, Montana and Oregon, while for Colorado, 38.4 such inches equals one second-foot.

Over the past twenty years the Division of Irrigation of the Bureau of Agricultural Engineering, in cooperation with the Colorado Agricultural Experiment Station at Fort Collins, has been concerned with the development of practical water measuring devices primarily for use in connection with irrigation practice. The rate of discharge of a stream of water in cubic feet per second may be determined in various ways, such as finding the cross-sectional area of the water prism of a channel in square feet and multiplying this by the mean velocity or speed of the current in feet per second; or by passing the stream through an opening of known area and then finding the effective pressure head in feet which causes the water to flow; or by passing the stream over a notch of known dimensions; or simply directing the stream into a basin and noting the time necessary to accumulate a known volume. The limitations imposed under practical field conditions usually dictates the selection of the type of measuring device best suited. The problem also involves the size of stream to be measured as well as to what degree of accuracy is required when considering the value of the water.
A measuring device may be quite accurate under laboratory conditions but because of uncontrollable factors arising in the field, such a device might prove to be wholly unsuited when thus operated under a practical field setting. A wide range of flow is encountered by the engineer in dealing with the problem of measuring water. He may be called upon to devise means of measuring and recording a flow of a few thousandths of a cubic foot per second or the discharge of a river when carrying more than one million second-feet. These extremes are special cases and ordinarily the problem is confined to reasonable limits.

From the standpoint of irrigation practice, two phases of the measuring problem are to be considered; first, the measurement of the diversion from the source of supply and second, the parcelling out of the water to the individual user. To meet these varied requirements as to the amount of water and conditions under which measurements are to be made, various practical measuring devices have been developed in the hydraulic laboratories at Fort Collins. Weirs of different types have been investigated and were proposed as a means of meeting in a practical manner, the measurement of small farm deliveries. When operating under standard conditions the sharp-crested weir is regarded
as an accurate measuring device. It is found frequently in the field, however, that the weir pool just up stream from the weir bulkhead will fill with sand and silt and thus alter the velocity of approach of the stream which in turn affects the accuracy of measurement. Encroachment of the banks of the channel due to growth of grass, weeds, willows or aquatic plants also interferes with the measurement. Should the channel downstream from the weir become foul due to deposits of sand or silt or plants of various kinds grow in the channel, these have the effect of retarding the flow and may cause the water surface to rise up to or beyond the elevation of the crest of the weir and thus a submerged flow condition is created which complicates the determination of the true discharge. Orifices and headgates have been studied with the view of developing these into practical measuring devices. Progress is being made in this direction.

In 1915, at the suggestion of Mr. V. M. Cone, a scheme of measuring flowing water through a constricted throat was tested in the laboratory and found to possess merit. This device, in plan, has a converging and a diverging section. Certain hydraulic relations exists as the stream passes from the converging to the diverging parts of the device, and by experimentation the law of the rate of flow has been determined where the discharge in cubic feet per
second is a function of the width of the throat and depths of water at certain points. This original device was called the Venturi flume. Later certain alterations in plan and dimensions were found desirable through further laboratory studies, and this modified device was called the improved Venturi flume. At the present time this improved type of measuring device is known as the Parshall measuring flume. For the past 10 years this flume has been growing in popularity, not only throughout the irrigated west but has been found useful in many foreign lands such as South Africa, Argentine Republic, Peru, Canada and Australia. Many of these are now in use where irrigation water is measured on the sugar plantations in the Hawaiian Islands. Recent information has been received stating that in Peru one irrigation project is now using 800 of these measuring flumes. In Colorado, over the past few years these flumes have been installed in large numbers for measuring flows in canals up to nearly 2000 second-feet and delivery of water to the farmer in flows of as little as 1/10 second-feet. Along the Arkansas, South Platte and Big Thompson rivers in Colorado, practically every ditch and canal diversion from these streams is measured through this type of measuring device. Water delivered to the farmer from the Fort Lyon Canal, the largest irrigation system in the state, serving about 100,000 acres of land in the Arkansas Valley, is
measured through these flumes. The Twin Lakes Reservoir and Canal Company, which irrigates more than 50,000 acres of land in the Arkansas Valley, measures about 95 percent of all farm deliveries by use of this flume. For the Parshall measuring flumes of large size as used in canals, a special recording and indicating instrument has been designed, built and placed in use on a number of these large installations. This instrument records graphically the two effective pressure heads and at the same time indicates in a practical way the rate of discharge in cubic feet per second. Other uses have been found for this flume in connection with sewage disposal and industrially in the paper mills of Canada.

The design of this measuring flume is such as to prevent silting within the structure under ordinary operating conditions, and it will, withstand a relatively high degree of submergence before it becomes necessary to apply a correction to the rate of flow as indicated by the discharge table.

At the present time studies are being carried on by the Bureau of Agricultural Engineering in cooperation with the Colorado Agricultural Experiment Station at Fort Collins in the development of a new type of measuring device. This scheme of measuring flowing water is intended to meet conditions of flow in small ditches or laterals of flat grade.
In many cases the farmer's irrigation lateral is established on a slight grade in order to serve the maximum area of his farm, and by so doing the loss of head available to perfect a measurement of the flow is limited. The principle of operation of this new device, called the adjustable tube orifice meter, is that of the submerged orifice. The device is simple, has an accuracy well within practical limits and no diagrams, curves or discharge tables are necessary for reference in determining the rate of flow. This measuring device as now developed, ranges in size from 1 to 4 feet and for capacities of flow ranging from less than 0.2 second-feet to more than 20 second-feet. The movable part of this meter consists of a vertical slide gate having a horizontal shelf at the bottom edge that extends 1 foot down stream. Fixed to this gate, at a convenient place, is a graduated scale, and for any opening a fixed index pointer shows the value of the reading on this scale. There are two small stilling wells attached to the gate in which the effective pressure head is conveniently observed by means of a "U" bar and square root scale. The scale reading on the gate when multiplied by the square root of the effective head gives the rate of discharge through the meter in cubic feet per second. Laboratory tests indicate that reliable measurements of the flow can be made where the loss in head through the meter may be as little as 1/2 inch.
"Kiln dried samples are subject to 2% error above or below the actual amount. This is from 7 to 30% of the actual amount of water in the soil, so that a single observation is not correct or accurate to within 1% on the average of the actual amount of water in the soil."

It has been found by Whitney and Gardner that the electrical resistance is very nearly inversely proportional to the square of the water content of the soil, expressed in percentage of the dry weight.

Hemistically-seal tubes containing a salt solution with platinum electrodes sealed in ends of tube. This is used in determining the temperature..."
by previously calibrating it. This tube is placed upon a wooden block which also carries two carbon electrodes about \( \frac{3}{8}'' \times \frac{3}{16}'' \) in section. These two carbon strips are placed about \( \frac{1}{2}'' \) apart. The resistance of the moist soil contained between these carbons is supposed to be proportional to the amount of moisture.

Footnotes in many were marked and inserted in the body of the text.

Soil samples heated to \( 105^\circ \text{C} \) to \( 110^\circ \text{C} \)

Cipolletti

Average slip of centrifugal pump about \( 15\% \)

Water at a temperature of \( 45^\circ \text{C} \) flows 2.5 times as fast under otherwise like conditions as water at \( 5^\circ \text{C} \).
If a certain soil is capable of retaining a certain amount of moisture irrespective of the amount of water applied, then why is it that the yield of alfalfa increases with the amount of water applied?

Find out about computing machines

Began on percolation
Jan 18, 1917

New current meter being constructed by Buff.

In case of silty or clouded streams & direction, meter may be useful in determining the current beneath the surface.

What about commercial HNO₃ being added in small quantities to irrigation water.
Lysimeter—an instrument for measuring the amount of percolation through soils.

Current Metres Eng News Jan 10-75

The distribution of water in soils with special reference to:
- a. Uniformity of distribution
- b. Amount of water retained in each foot within the root zone.
- c. Amount of water passing into the subsoil beyond the root zone.
- d. Relation between the foregoing factors and
  - 1. The amount of water applied per irrigation
  - 2. The period between irrigations
  - 3. The methods employed
  - 4. The ditch regulations.

The Monroe Calculating M. C.
722 13th St. Wash D.C.

Power cost per acre inch.
Experiments in the use of current meters in irrigation canals.

In preparing diagrams for cuts it may sometimes be useful to alter existing cuts by adding or taking away certain details - make such corrections and then have a tracing made and enlarged. From the enlargement make a tracing and reduce back to the proper size.

Current Meter References

U.S. D.A. - Bul 104
Am Soc. of C.E. Box Aug '09
See discussion Oct '09
Eng News Jan 9-1913
West. St. & Cir No 24 1913
Eng Record Nov 16-1917

Thalweg Thalweg (väl' tak')
The continuous lowest portion of a valley either above or below ground.
Could a hygrometric hero construct
that varying weights of a certain
substance would indicate the
degree of moisture—

Current meter page 31 O.E.S.
Bul N°104

Perculation References
Yearbook '98 p. 399-404
Bureau of Soils N° 52