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Director

Farm Water Measurement

By

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Summary

CORRECT measurement of water is necessary for good farm management.

Farm-made measuring devices are satisfactory when properly made, installed, and operated.

The irrigating farmer is competent to make his own water measurements.

Combined regulating and measuring devices are of special design and are not treated in this Circular.

Weirs are simple, accurate, durable, and require but one reading of head *(H)* but need excess fall in the ditch for free-flow measurements.

Submerged orifices do not require a large fall for operation but require two readings to determine head *(h)*. They are clogged easily by weeds and trash, and have a small range.

The Parshall measuring flume combines the advantages of the weir and the orifice.

Definitions of terms used will be found in Appendix III.

Farm Water Measurement

By

MARK R. KULP*

WATER is the most valuable asset of irrigated agriculture and its intelligent and economical application depends largely upon a knowledge of the amount used. An estimate or guess is not accurate enough for good irrigation practice. Refined laboratory methods of measuring water are not practical on the farm and they are not necessary, for the irrigating farmer can make and operate measuring devices with a satisfactory degree of accuracy.

This Circular is written primarily for the farmer rather than the ditch rider who has many sources of information on the measurement of water and the operation of the delivery and measuring devices in use on his system. The object is to advise the farmer how he may make, install, and operate the simpler devices.

Measurement of Water

Water is measured in two ways, at rest and in motion. While at rest as in reservoirs, tanks, and in the soil, it is measured in units of volume, the most common of which are the gallon, the cubic foot, the acre-inch, and the acre-foot.

Water in motion (flowing in pipes, streams, and flumes) is measured in rates of flow which are the units of volume passing a point in a unit of time. The common rates of flow are the cubic foot per second, the gallon per minute, and the miner's inch. The rates of flow are called "discharges."

Units of volume should not be confused with rates of flow as the rates of flow always consider the time element.†

Measuring Devices

The measuring devices discussed in this Circular are all for the measurement of rates of flow and the tables are computed from formulas derived from careful experimental data. They assume that under standard conditions a reading of head *(H* for weirs, h for submerged orifices, and H_a for the Parshall measuring flume) represents a definite rate of flow over or through the particular device. If the conditions are not standard, the results will not be correct.

Weirs, submerged orifices, and the Parshall measuring flume are devices that can be farm-made and operated. They are the only ones that are described in this Circular and discharge tables are given for them.

Each device has its advantages, disadvantages, and limita-

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† Definition of terms will be found in Appendix III

tions. The proper device should be selected to suit the local conditions of rate of flow, available drop in the ditch, amount of silt and trash in the water, and relative cost. All the common measuring devices require the use of head or fall for operation. The loss of head depends upon the device and the maximum amount of water to be measured.†

Combined Regulating and Measuring Devices

Combined regulating and measuring devices are not farm-made and operated as often they are patented, made, and installed by the water company, and operated by the ditch rider delivering water to the farmer. A special table is necessary for each size and type of device. On account of the large variety of such devices, they will not be treated in this Circular.

Weirs*

The weir is the simplest form of water-measuring device in common use for measuring water in open channels. It is easily farm-constructed and operated. Under standard conditions it will give reliable results. Tables given are for triangular, trapezoidal, and rectangular weirs.

Standard Conditions for Weirs

The weir wall or bulkhead must be vertical (not leaning upstream or downstream), set at right angles to the direction of flow of the stream, and extend far enough into the bank to be secure. The weir box or weir pond must be large enough to reduce the velocity of the water approaching the weir to less than ½ foot per second (practically still water), and to bring it to the weir in a straight even flow without eddies or swirls. Baffles may be put in the weir pond to reduce velocity and equalize the flow throughout the section of the weir pond. The weir box or pond must be kept clean of silt accumulations or the velocity of approach will be increased due to the reduction in section, and more water will pass over the weir than the gauge indicates.

The weir notch must have a bottom contraction and, except in the case of the suppressed weir, must have end contractions. The bottom contraction should be equal to three times the head *(H)* of water over the crest and the end contractions should be twice the head. The weir notch must be regular in shape and its edges must be rigid, straight, and sharp on the upstream face. The edges need not be knife edges but they must not be rounded nor more than ⅛ inch thick except for large discharges. When cut directly from a wooden bulkhead, the weir notch should be beveled on the downstream side to an angle of 45 degrees so that the water flowing over the weir will not touch the bulkhead or weir notch except at the upstream edge and

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† A table of range of capacity and loss of head of the various devices will be found in Appendix I

* Definition of terms will be found in Appendix III

will have an air pocket under the sheet of falling water. When the edges of the weir notch are made of metal strips nailed to the wall, the wooden notch is beveled or is cut enough larger (1½ inches deeper and 3 inches wider) to obtain the same effect. Wooden weir notches are likely to crack and warp and metal strips always are desirable.

The weir crest must be level and accurate as to length. (⅛-inch error in the length of a 12-inch weir will change the discharge approximately 1 per cent.)

The level of the water below the weir must not be higher than the weir crest at the maximum flow to be measured, or

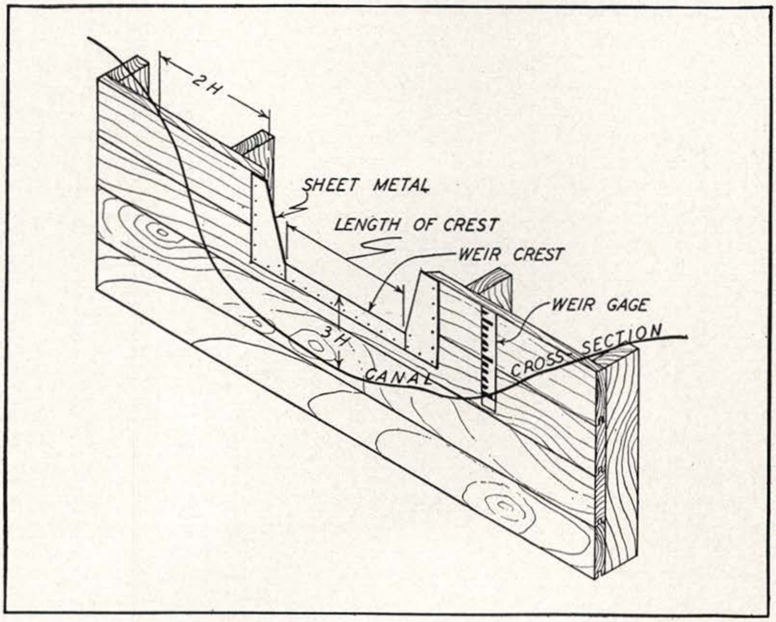

Figure 1.—Simple weir bulkhead

there will be no air pocket under the crest of falling water and free-flow conditions will not result. In order to get the correct discharge two readings will have to be taken and corrections for submerged flow made. (All discharge tables in this Circular are for free-flow conditions although the Parshall measuring flume may be partly submerged without altering the free-flow formula.)

The depth of the water flowing over the crest of the weir should not be less than 2 inches (.17 ft.) for accurate measurement.

The weir gauge must be set at a distance from the weir notch. It may be set on the weir wall far enough from the side of the notch to be in practically still water. A better place to set the gauge is 3 or 4 feet upstream from the notch as near the side of the weir pond as possible and yet be in the water at all discharges. The zero of the gauge should be set with a good level at the exact elevation of the weir crest. (Do not set the gauge by filling the pond with water to the point where it starts to flow over the weir crest as, due to surface tension, the setting will not be correct.)

Construction and Setting of Weirs

Weirs may be constructed of wood, metal, or concrete and may be either permanent or portable. The simplest type of weir installation is a notch cut in a plain wooden bulkhead set across

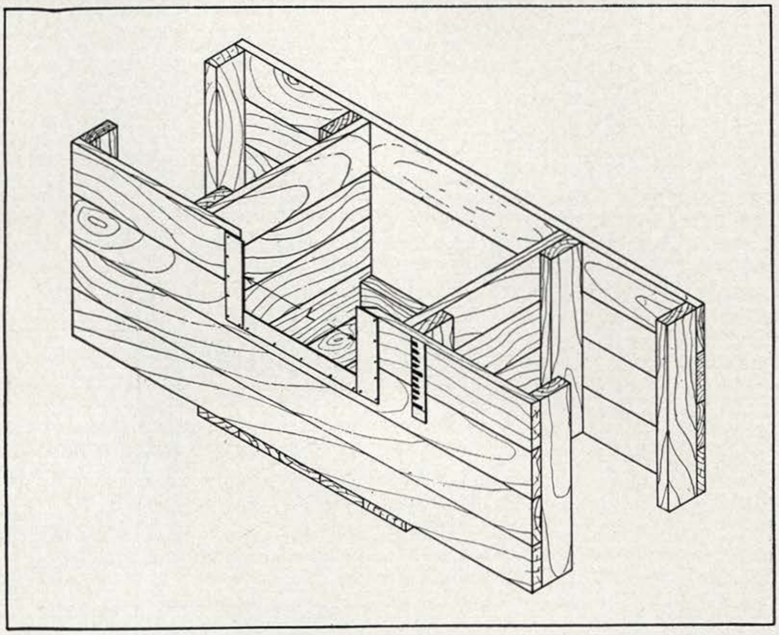

Figure 2.—Weir bulkhead for light soils

the stream where there is ample fall. When banks are high and the soil is of a nature that will hold the bulkhead without other protection than careful setting, the installation may be made as shown in Figure 1.

Very often the setting of a weir in a deep ditch will back the water up far enough to form a suitable weir pond without further excavation. If the pond is not large enough to cause complete contractions on the weir, it may be enlarged evenly for a distance and then tapered gradually to the ditch section.

When the soil is light and will not hold a simple weir wall or bulkhead, a box is built with wings and cutoff walls as shown in Figure 2 and Figure 3. Figure 2 shows the weir wall upstream with the box below it to prevent scouring and washing while Figure 3 shows a complete weir box with the weir wall in the box. The box above the weir in this case forms the weir pond and must be of a size to give complete contraction to the weir. This installation does not permit the cleaning of the pond

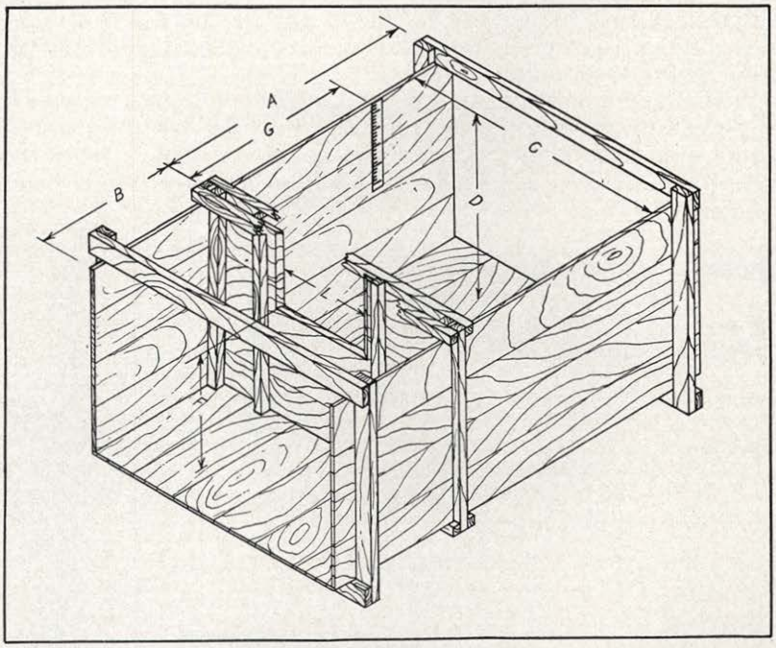

Figure 3.—Standard weir box

Table 1.—Dimensions of weir box for Cipolletti rectangular and 90° triangular weirs, rectangular and Cipolletti weirs

Flow Second feet	Max. Head	Length of crest	Length of box above notch	Length of box below notch	Total width of box	Total depth of box	Crest to bottom	Gauge distance
		L	A	B	C	D	E	G
½ to 3	1.0	1.0	6.0	2.0	5.5	3.5	2.0	4.0
2 to 5	1.1	1.5	7.0	3.0	7.0	4.0	2.5	4.5
4 to 8	1.2	2.0	8.0	4.0	8.5	4.5	2.75	5.0
6 to 14	1.3	3.0	9.0	5.0	12.0	5.0	3.25	5.5
10 to 22	1.5	4.0	10.0	6.0	14.0	5.5	3.5	6.0
90° triangular weirs								
½ to 2½	1.0		6.0	2.0	5.0	3.0	1.5	4.0
2 to 4⅓	1.25		6.5	3.0	6.5	3.25	1.5	5.0

All dimensions in feet. Letters refer to Figure 3.

by teams and scrapers and often the weir bulkhead is made to fit in grooves so that it is removable for the cleaning of the box. There is little need for an installation of this kind as the pattern shown in Figure 2 is equally reliable and is cheaper.

The dimensions given in Table 2 are ample for conditions close enough to standard that they may be used without appreciable error.

Portable weirs usually are small (triangular-notch weirs, 1-foot Cipolletti and 1-foot rectangular) and commonly are made of sheet metal suitably reenforced. They may have the weir scales fastened to the bulkhead and, if there is a scale on each side of the notch, the weir can be leveled by having the same water level on each side.

Free-flow conditions can be obtained by setting the weir at an elevation that will give free fall and then building up the banks above the weir; or, if there is excess grade below the weir location, the weir may be set low and the ditch below deepened to obtain the same effect.

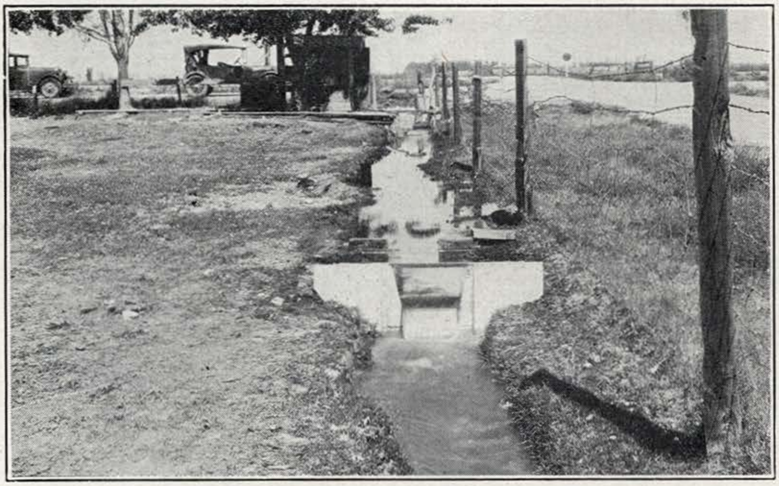

Figure 4.—Portable one-foot Cipolletti weir measuring discharge from a pumping plant*

Weir Scales or Gauges

The weir scale consists of a strip of wood or metal graduated in inches and fractions, feet and decimals, or in units of flow or discharge such as miner's inches, cubic feet per second, or gallons per minute. A scale graduated directly in discharge units will fit all weirs of the same design and size when operated under standard conditions but will not fit another weir of a different design, or of a different crest length.

The scale or gauge may be set in the weir pond or in a stilling well or still box at the side of the pond. The still box is connected to the weir pond by a small tube or pipe set below the water level. The function of the still box is to present a water surface at the same elevation as the water surface of the pond but without waves or surges. The connecting pipe must be

* Courtesy of J. C. Marr, Irrigation Engineer, Soil Conservation Service, United States Department of Agriculture.

small in comparison with the area of the box and must be kept open as, if it is too large, it will transmit surges and, if clogged, will not give a reliable reading.

Gauges in the weir pond may be placed on the bulkhead far enough to the side to be in practically still water but more often are placed upstream from the weir at a distance of 3 or 4 feet and to the side of the pond. Gauges are not read directly on the crest of the weir for the reason that the surface of the water has a decided curve downward as it approaches the weir.

The practice of reading the head by holding a rule on the crest and allowing the velocity of the water to "pile up" on the rule is not recommended although, with a rule of the right proportion and operated by an expert, it gives very close results. If the rule is not of the proper width or leans from the vertical, the reading will not be correct.

The scale should not be nailed directly to the structure but should be nailed to a board slightly longer than the scale and the board fastened to the structure. This will permit the removal and resetting of the gauge if it becomes necessary.

Weir gauges must be set accurately and checked occasionally.

If a permanent scale is not wanted on the weir, a stake may be driven in the weir pond with its top at the elevation of the weir crest or a block may be nailed to the bulkhead with its top at the elevation of the weir crest and the reading of the head may be made with a pocket rule or scale.

Operation of Weirs

Having made and set the weir and gauge, there is little difficulty in determining the discharge. If a gauge is installed, read the gauge at the water surface, look in the correct table under "Head" for that reading, and carry over to the right to the column headed by the length of crest of the weir you are using and the discharge in cubic feet per second will be found. If you want the discharge in miner's inches, multiply by 50.*

Be sure you have the right table and the right weir crest length.

Be sure you find the head *(H)* in the same units in which the measurement of the head was made. Commercial weir scales commonly are made in feet and decimals and most rules are in inches and fractions. Heads in all tables are given both in feet and decimals and in inches and fractions.

Example: The head on a 1.5-foot (18-inch) Cipolletti weir is read at $3\frac{3}{4}$ inches. What is the discharge in miner's inches? Look in Table 3 which is the discharge table for Cipolletti weirs and under the column headed "Head in Inches" find $3\frac{3}{4}$. Opposite this in the column headed 1.5 feet is .87, which is the discharge in cubic feet per second. To convert to miner's inches (Idaho) multiply by 50: $50 \times .87 = 43.5$ miner's inches flowing over the weir.

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* The length of crest may be painted on the bulkhead to insure the use of the correct table.

Advantages of Weirs

Weirs are simple, cheap, durable, and reliable. They require only one reading of the head to determine the discharge. They are not clogged easily by moss and floating trash.

Disadvantages of Weirs

They require an excess fall in the stream equal to the head of the largest stream to be measured.

Silt accumulates in the weir pond making its cleaning necessary for accurate measurement.

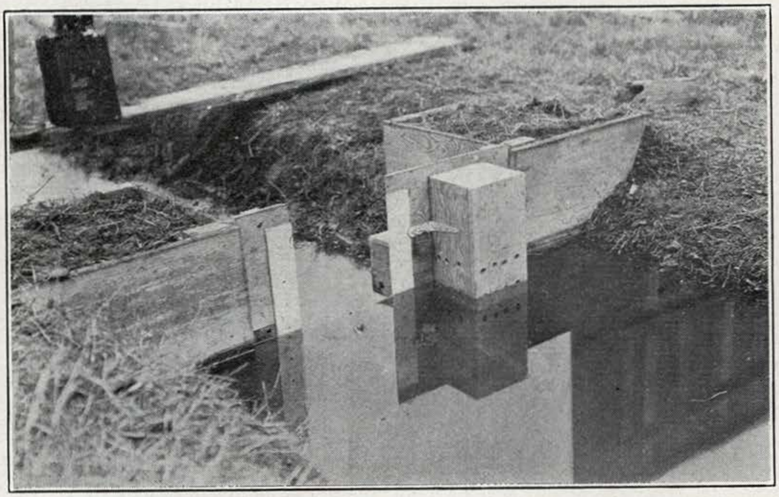

Figure 5—Rectangular weir

The Rectangular Weir

The rectangular weir as its name suggests is a weir whose crest is horizontal and whose sides are perpendicular. It is the oldest form of measuring weir and is the most easily farm-made.

Table 2 gives the discharges over rectangular weirs with complete contractions for crest lengths from 1 foot to 4 feet.

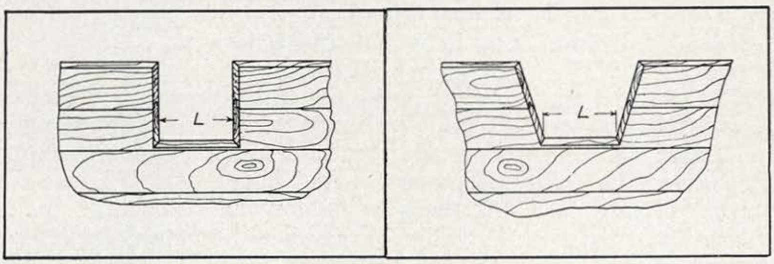

Figure 6.—Rectangular (left) and Cipolletti (right) weir notches

Table 2.—Discharge table for rectangular weirs with complete contraction * computed from the formula $Q = 3.247LH^{1.48} - \left\{\dfrac{0.566L^{1.8}}{1 + 2L^{1.8}}\right\} H^{1.9}$

Head, H †		Discharge, Q, for crest lengths, L, of—					Head, H		Discharge, Q, for crest lengths, L, of—				
		1 foot	1.5 feet	2 feet	3 feet	4 feet			1 foot	1.5 feet	2 feet	3 feet	4 feet
Feet	*Inches*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Feet*	*Inches*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
0.10	1 3/16	0.11	0.16	0.22	0.33	0.44	0.75	9	2.01	3.05	4.10	6.21	8.33
.11	1 5/16	.12	.18	.25	.37	.50	.76	9 1/8	2.05	3.11	4.18	6.33	8.49
.12	1 7/16	.14	.20	.28	.42	.57	.77	9 1/4	2.09	3.17	4.26	6.45	8.66
.13	1 9/16	.15	.22	.32	.47	.64	.78	9 3/8	2.13	3.23	4.34	6.58	8.82
.14	1 11/16	.17	.25	.35	.53	.71	.79	9 1/2	2.17	3.29	4.42	6.70	8.99
.15	1 13/16	.19	.28	.39	.58	.79	.80	9 5/8	2.21	3.35	4.51	6.83	9.16
.16	1 15/16	.21	.31	.43	.64	.86	.81	9 3/4	2.25	3.41	4.59	6.95	9.33
.17	2 1/16	.23	.34	.47	.70	.95	.82	9 13/16	2.29	3.47	4.67	7.08	9.50
.18	2 3/16	.25	.37	.51	.76	1.03	.83	9 15/16	2.33	3.54	4.75	7.21	9.67
.19	2 1/4	.27	.40	.55	.83	1.11	.84	10 1/16	2.37	3.60	4.84	7.33	9.84
.20	2 3/8	.29	.44	.59	.89	1.19	.85	10 3/16	2.41	3.66	4.92	7.46	10.0
.21	2 1/2	.31	.47	.63	.95	1.28	.86	10 5/16	2.46	3.72	5.01	7.59	10.2
.22	2 5/8	.34	.50	.68	1.02	1.37	.87	10 7/16	2.50	3.79	5.10	7.72	10.4
.23	2 3/4	.36	.54	.72	1.09	1.46	.88	10 9/16	2.54	3.85	5.18	7.85	10.5
.24	2 7/8	.38	.57	.77	1.16	1.55	.89	10 11/16	2.58	3.92	5.27	7.99	10.7
.25	3	.40	.61	.82	1.23	1.65	.90	10 13/16	2.62	3.98	5.35	8.12	10.9
.26	3 1/8	.43	.65	.86	1.31	1.75	.91	10 15/16	2.67	4.05	5.44	8.25	11.1
.27	3 1/4	.45	.68	.91	1.38	1.85	.92	11 1/16	2.71	4.11	5.53	8.38	11.2
.28	3 3/8	.48	.72	.96	1.46	1.95	.93	11 3/16	2.75	4.18	5.62	8.52	11.4
.29	3 1/2	.50	.76	1.02	1.53	2.05	.94	11 1/4	2.79	4.24	5.71	8.65	11.6
.30	3 5/8	.53	.80	1.07	1.61	2.16	.95	11 3/8	2.84	4.31	5.80	8.79	11.8
.31	3 3/4	.55	.84	1.12	1.69	2.26	.96	11 1/2	2.88	4.37	5.89	8.93	12.0
.32	3 13/16	.58	.88	1.18	1.77	2.37	.97	11 5/8	2.93	4.44	5.98	9.06	12.2
.33	3 15/16	.61	.92	1.23	1.86	2.48	.98	11 3/4	2.97	4.51	6.07	9.20	12.3
.34	4 1/16	.63	.96	1.28	1.94	2.60	.99	11 7/8	3.01	4.57	6.15	9.34	12.5
.35	4 3/16	.66	1.00	1.34	2.02	2.71	1.00	12	3.06	4.64	6.25	9.48	12.7
.36	4 5/16	.69	1.04	1.40	2.11	2.82	1.01	12 1/8	.....	4.71	6.34	9.62	12.9
.37	4 7/16	.72	1.08	1.45	2.20	2.94	1.02	12 1/4	.....	4.78	6.43	9.76	13.1
.38	4 9/16	.74	1.13	1.51	2.28	3.06	1.03	12 3/8	.....	4.85	6.52	9.90	13.3
.39	4 11/16	.77	1.17	1.57	2.37	3.18	1.04	12 1/2	.....	4.92	6.62	10.0	13.5
.40	4 13/16	.80	1.21	1.63	2.46	3.30	1.05	12 5/8	.....	4.98	6.71	10.2	13.7
.41	4 15/16	.83	1.26	1.69	2.55	3.42	1.06	12 3/4	.....	5.05	6.80	10.3	13.8
.42	5 1/16	.86	1.30	1.75	2.65	3.54	1.07	12 13/16	.....	5.12	6.90	10.5	14.0
.43	5 3/16	.89	1.35	1.81	2.74	3.67	1.08	12 15/16	.....	5.20	6.99	10.6	14.2
.44	5 1/4	.92	1.40	1.88	2.83	3.80	1.09	13 1/16	.....	5.26	7.09	10.8	14.4
.45	5 3/8	.96	1.44	1.94	2.93	3.93	1.10	13 3/16	.....	5.34	7.19	10.9	14.6
.46	5 1/2	.99	1.49	2.00	3.03	4.05	1.11	13 5/16	.....	5.41	7.28	11.0	14.8
.47	5 5/8	1.02	1.54	2.07	3.12	4.18	1.12	13 7/16	.....	5.48	7.38	11.2	15.0
.48	5 3/4	1.05	1.59	2.13	3.22	4.32	1.13	13 9/16	.....	5.55	7.47	11.3	15.2
.49	5 7/8	1.08	1.64	2.20	3.32	4.45	1.14	13 11/16	.....	5.62	7.57	11.5	15.4
.50	6	1.11	1.68	2.26	3.42	4.58	1.15	13 13/16	.....	5.69	7.66	11.6	15.6
.51	6 1/8	1.15	1.73	2.33	3.52	4.72	1.16	13 15/16	.....	5.77	7.76	11.8	15.8
.52	6 1/4	1.18	1.78	2.40	3.62	4.86	1.17	14 1/16	.....	5.84	7.86	11.9	16.0
.53	6 3/8	1.21	1.84	2.46	3.73	4.99	1.18	14 3/16	.....	5.91	7.96	12.1	16.2
.54	6 1/2	1.25	1.89	2.53	3.83	5.13	1.19	14 1/4	.....	5.98	8.06	12.2	16.4
.55	6 5/8	1.28	1.94	2.60	3.94	5.27	1.20	14 3/8	.....	6.06	8.16	12.4	16.6
.56	6 3/4	1.31	1.99	2.67	4.04	5.42	1.21	14 1/2	.....	6.13	8.26	12.5	16.8
.57	6 13/16	1.35	2.04	2.74	4.15	5.56	1.22	14 5/8	.....	6.20	8.35	12.7	17.0
.58	6 15/16	1.38	2.09	2.81	4.26	5.70	1.23	14 3/4	.....	6.28	8.46	12.8	17.2
.59	7 1/16	1.42	2.15	2.88	4.36	5.85	1.24	14 7/8	.....	6.35	8.56	13.0	17.4
.60	7 3/16	1.45	2.20	2.96	4.47	6.00	1.25	15	.....	6.43	8.66	13.1	17.6
.61	7 5/16	1.49	2.25	3.03	4.59	6.14	1.26	15 1/8	.....	.....	.....	13.3	17.9
.62	7 7/16	1.52	2.31	3.10	4.69	6.29	1.27	15 1/4	.....	.....	.....	13.4	18.1
.63	7 9/16	1.56	2.36	3.17	4.81	6.44	1.28	15 3/8	.....	.....	.....	13.6	18.3
.64	7 11/16	1.60	2.42	3.25	4.92	6.59	1.29	15 1/2	.....	.....	.....	13.8	18.5
.65	7 13/16	1.63	2.47	3.32	5.03	6.75	1.30	15 5/8	.....	.....	.....	13.9	18.7
.66	7 15/16	1.67	2.53	3.40	5.15	6.90	1.31	15 3/4	.....	.....	.....	14.1	18.9
.67	8 1/16	1.71	2.59	3.47	5.26	7.05	1.32	15 13/16	.....	.....	.....	14.2	19.1
.68	8 3/16	1.74	2.64	3.56	5.38	7.21	1.33	15 15/16	.....	.....	.....	14.4	19.3
.69	8 1/4	1.78	2.70	3.63	5.49	7.36	1.34	16 1/16	.....	.....	.....	14.6	19.6
.70	8 3/8	1.82	2.76	3.71	5.61	7.52	1.35	16 3/16	.....	.....	.....	14.7	19.8
.71	8 1/2	1.86	2.81	3.78	5.73	7.68	1.36	16 5/16	.....	.....	.....	14.9	20.0
.72	8 5/8	1.90	2.87	3.86	5.85	7.84	1.37	16 7/16	.....	.....	.....	15.0	20.2
.73	8 3/4	1.93	2.93	3.94	5.97	8.00	1.38	16 9/16	.....	.....	.....	15.2	20.4
.74	8 7/8	1.97	2.99	4.02	6.09	8.17	1.39	16 11/16	.....	.....	.....	15.4	20.6

* Taken from United States Department of Agriculture Farmers' Bulletin No. 1683, *Measuring Water in Irrigation Channels.*

† Values of discharge for heads up to 0.20 foot do not follow the formula, but are taken directly from the calibration curve.

Table 3.—Discharge table for Cipolletti weirs with complete contraction * computed from the formula $Q = 3.247LH^{1.48} - \left\{\frac{0.566L^{1.8}}{1+2L^{1.8}}\right\}H^{1.9} + 0.609H^{2.5}$

Head, H †		Discharge, Q, for crest lengths, L, of—					Head, H		Discharge, Q, for crest lengths, L, of—				
		1 foot	1.5 feet	2 feet	3 feet	4 feet			1 foot	1.5 feet	2 feet	3 feet	4 feet
Feet	*Inches*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Feet*	*Inches*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
0.10	1 3/16	0.11	0.16	0.23	0.33	0.44	0.75	9	2.31	3.35	4.40	6.51	8.62
.11	1 5/16	.12	.18	.26	.38	.50	.76	9 1/8	2.36	3.42	4.49	6.64	8.80
.12	1 7/16	.14	.21	.29	.43	.57	.77	9 1/4	2.41	3.49	4.58	6.77	8.97
.13	1 9/16	.16	.24	.32	.48	.64	.78	9 3/8	2.46	3.56	4.67	6.90	9.15
.14	1 11/16	.17	.26	.36	.54	.71	.79	9 1/2	2.51	3.63	4.76	7.04	9.33
.15	1 13/16	.19	.29	.39	.59	.79	.80	9 5/8	2.56	3.70	4.85	7.18	9.51
.16	1 15/16	.21	.32	.43	.65	.87	.81	9 3/4	2.61	3.77	4.95	7.31	9.69
.17	2 1/16	.23	.36	.47	.71	.96	.82	9 13/16	2.66	3.84	5.04	7.45	9.87
.18	2 3/16	.25	.39	.51	.77	1.04	.83	9 15/16	2.71	3.92	5.14	7.59	10.0
.19	2 1/4	.28	.42	.56	.83	1.12	.84	10 1/16	2.77	3.99	5.23	7.73	10.2
.20	2 3/8	.30	.45	.60	.90	1.20	.85	10 3/16	2.82	4.07	5.33	7.87	10.4
.21	2 1/2	.32	.48	.64	.97	1.29	.86	10 5/16	2.87	4.14	5.43	8.01	10.6
.22	2 5/8	.35	.52	.69	1.04	1.38	.87	10 7/16	2.93	4.22	5.52	8.15	10.8
.23	2 3/4	.37	.55	.74	1.11	1.47	.88	10 9/16	2.98	4.29	5.62	8.30	11.0
.24	2 7/8	.39	.59	.79	1.18	1.57	.89	10 11/16	3.04	4.37	5.72	8.44	11.2
.25	3	.42	.63	.84	1.25	1.67	.90	10 13/16	3.09	4.45	5.82	8.59	11.4
.26	3 1/8	.45	.67	.89	1.33	1.77	.91	10 15/16	3.15	4.53	5.92	8.73	11.6
.27	3 1/4	.47	.70	.94	1.40	1.87	.92	11 1/16	3.20	4.60	6.02	8.88	11.7
.28	3 3/8	.50	.74	.99	1.48	1.97	.93	11 3/16	3.26	4.68	6.13	9.03	11.9
.29	3 1/2	.53	.79	1.04	1.56	2.08	.94	11 1/4	3.32	4.76	6.23	9.17	12.1
.30	3 5/8	.56	.83	1.10	1.64	2.19	.95	11 3/8	3.37	4.84	6.33	9.32	12.3
.31	3 3/4	.59	.87	1.15	1.73	2.30	.96	11 1/2	3.43	4.92	6.44	9.48	12.5
.32	3 13/16	.61	.91	1.21	1.80	2.41	.97	11 5/8	3.49	5.00	6.55	9.62	12.7
.33	3 15/16	.64	.95	1.27	1.89	2.52	.98	11 3/4	3.55	5.09	6.64	9.78	12.9
.34	4 1/16	.67	1.00	1.32	1.98	2.64	.99	11 7/8	3.61	5.17	6.75	9.93	13.1
.35	4 3/16	.70	1.04	1.38	2.07	2.75	1.00	12	3.67	5.25	6.86	10.1	13.3
.36	4 5/16	.73	1.09	1.44	2.16	2.87	1.01	12 1/8	.....	5.33	6.96	10.2	13.5
.37	4 7/16	.77	1.13	1.50	2.25	2.99	1.02	12 1/4	.....	5.42	7.07	10.4	13.7
.38	4 9/16	.80	1.18	1.57	2.34	3.11	1.03	12 3/8	.....	5.50	7.18	10.6	13.9
.39	4 11/16	.83	1.23	1.63	2.43	3.24	1.04	12 1/2	.....	5.59	7.29	10.7	14.2
.40	4 13/16	.87	1.28	1.69	2.53	3.36	1.05	12 5/8	.....	5.67	7.40	10.9	14.4
.41	4 15/16	.90	1.32	1.76	2.62	3.49	1.06	12 3/4	.....	5.76	7.51	11.0	14.6
.42	5 1/16	.93	1.37	1.82	2.72	3.61	1.07	12 13/16	.....	5.84	7.62	11.2	14.8
.43	5 3/16	.97	1.42	1.89	2.81	3.74	1.08	12 15/16	.....	5.93	7.73	11.4	15.0
.44	5 1/4	1.00	1.47	1.95	2.91	3.87	1.09	13 1/16	.....	6.02	7.84	11.5	15.2
.45	5 3/8	1.04	1.53	2.02	3.01	4.01	1.10	13 3/16	.....	6.11	7.96	11.7	15.4
.46	5 1/2	1.07	1.58	2.09	3.11	4.14	1.11	13 5/16	.....	6.20	8.07	11.8	15.6
.47	5 5/8	1.11	1.63	2.16	3.21	4.28	1.12	13 7/16	.....	6.29	8.18	12.0	15.8
.48	5 3/4	1.15	1.68	2.23	3.32	4.41	1.13	13 9/16	.....	6.37	8.29	12.2	16.0
.49	5 7/8	1.18	1.74	2.30	3.42	4.55	1.14	13 11/16	.....	6.46	8.41	12.3	16.3
.50	6	1.22	1.79	2.37	3.53	4.69	1.15	13 13/16	.....	6.56	8.53	12.5	16.5
.51	6 1/8	1.26	1.85	2.44	3.64	4.83	1.16	13 15/16	.....	6.65	8.65	12.7	16.7
.52	6 1/4	1.30	1.90	2.51	3.74	4.97	1.17	14 1/16	.....	6.74	8.76	12.8	16.9
.53	6 3/8	1.34	1.96	2.59	3.85	5.12	1.18	14 3/16	.....	6.83	8.88	13.0	17.2
.54	6 1/2	1.38	2.02	2.66	3.96	5.26	1.19	14 1/4	.....	6.93	9.00	13.2	17.4
.55	6 5/8	1.42	2.07	2.74	4.07	5.41	1.20	14 3/8	.....	7.02	9.12	13.4	17.6
.56	6 3/4	1.46	2.13	2.81	4.18	5.56	1.21	14 1/2	.....	7.11	9.24	13.5	17.8
.57	6 13/16	1.50	2.19	2.89	4.30	5.71	1.22	14 5/8	.....	7.20	9.36	13.7	18.0
.58	6 15/16	1.54	2.25	2.97	4.41	5.86	1.23	14 3/4	.....	7.30	9.48	13.9	18.3
.59	7 1/16	1.58	2.31	3.05	4.53	6.01	1.24	14 7/8	.....	7.40	9.60	14.0	18.5
.60	7 3/16	1.62	2.37	3.13	4.64	6.17	1.25	15	.....	7.49	9.72	14.2	18.7
.61	7 5/16	1.67	2.43	3.20	4.76	6.32	1.26	15 1/8	.....	.....	.....	14.4	19.0
.62	7 7/16	1.71	2.49	3.28	4.88	6.47	1.27	15 1/4	.....	.....	.....	14.6	19.2
.63	7 9/16	1.75	2.55	3.37	5.00	6.63	1.28	15 3/8	.....	.....	.....	14.7	19.4
.64	7 11/16	1.80	2.62	3.45	5.12	6.79	1.29	15 1/2	.....	.....	.....	14.9	19.6
.65	7 13/16	1.84	2.68	3.53	5.24	6.95	1.30	15 5/8	.....	.....	.....	15.1	19.9
.66	7 15/16	1.89	2.75	3.61	5.36	7.11	1.31	15 3/4	.....	.....	.....	15.3	20.1
.67	8 1/16	1.93	2.81	3.70	5.48	7.28	1.32	15 13/16	.....	.....	.....	15.5	20.3
.68	8 3/16	1.98	2.87	3.79	5.61	7.44	1.33	15 15/16	.....	.....	.....	15.6	20.6
.69	8 1/4	2.02	2.94	3.87	5.73	7.61	1.34	16 1/16	.....	.....	.....	15.8	20.8
.70	8 3/8	2.07	3.01	3.95	5.86	7.77	1.35	16 3/16	.....	.....	.....	16.0	21.1
.71	8 1/2	2.12	3.07	4.04	5.99	7.94	1.36	16 5/16	.....	.....	.....	16.2	21.3
.72	8 5/8	2.16	3.14	4.13	6.12	8.11	1.37	16 7/16	.....	.....	.....	16.4	21.5
.73	8 3/4	2.21	3.21	4.22	6.24	8.28	1.38	16 9/16	.....	.....	.....	16.6	21.8
.74	8 7/8	2.26	3.28	4.31	6.38	8.45	1.39	16 11/16	.....	.....	.....	16.8	22.0

* Taken from United States Department of Agriculture Farmers' Bulletin No. 1683, *Measuring Water in Irrigation Channels.*

† Values of discharge for heads up to 0.20 foot do not follow the formula but are taken directly from the calibration curve.

The Cipolletti Weir

The Cipolletti weir or the trapezoidal weir with side slopes of 1 to 4 (1 inch horizontal to 4 inches vertical) is the most common weir in general use although it is no more accurate than the rectangular, which is easier to make. It is named after the Italian engineer who first proposed its use.

Discharges over Cipolletti weirs with complete contraction with crest lengths of 1 foot to 4 feet are given in Table 3.

The 90° Triangular-Notch Weir

The 90° triangular-notch weir or the 90° V-notch weir has no crest length as the sloping sides come together to form the crest. Each side has an angle with the vertical or horizontal of 45°, making the total angle 90°.

The advantage of the triangular-notch weir is its ability to measure small flows accurately. Small flows that would adhere to the weir crest over a 1-foot Cipolletti or rectangular weir flow over the triangular notch with a head that can be measured readily.*

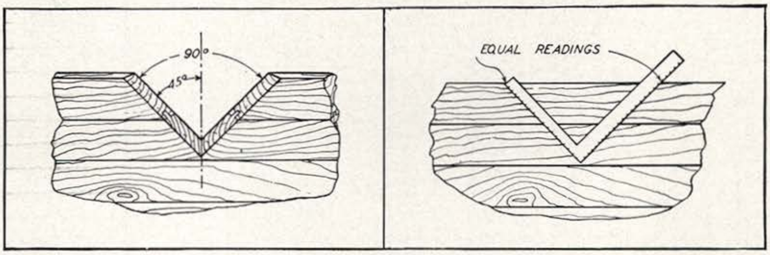

Figure 7.—90° Notch weir (left) and method of laying out 90° notch with a steel square (right)

The sides of the 90° triangular-notch weir may be set readily with a carpenter's square and level. The notch can be marked out by placing the point of the angle of the square at the point selected for the bottom of the notch and adjusting the square so that the same figures on both arms are at the edge of the board or metal sheet.

If the board is then set with the edge level, the sides of the notch will have the same slope.

Table 4 gives the discharge over the 90° triangular-notch weir.

The Suppressed Weir

A rectangular weir without end contractions sometimes is used in the measurement of water when the device must be placed in a flume or box not large enough to give complete con-

* "Experiments have shown that the rectangular and Cipolletti weirs with 6-inch crests do not follow the same laws of discharge as the longer weirs," United States Department of Agriculture Farmers' Bulletin No. 813, *Construction and Use of Farm Weirs*, by Victor M. Cone.

traction. This is called a suppressed weir. It must have a bottom contraction but the sides of the flume or box form the sides of the weir notch. Holes must be made in the sides of the box below the weir crest to admit air under the sheet of falling water.

The discharge of the suppressed weir follows closely the discharge of the Cipolletti weir of the same crest length and the discharge table for the Cipolletti weir (Table 3) may be used without a great amount of error although discharges over suppressed weirs of the same crest length vary with different bottom contractions.

Table 4.—Discharge table 90° triangular-notch weir with complete contractions computed from the formula $Q = 2.49H^{2.48}$ *

Head, H		Discharge, Q	Head, H		Discharge, Q	Head, H		Discharge, Q
Feet	*Inches*	*Sec.-ft.*	*Feet*	*Inches*	*Sec.-ft.*	*Feet*	*Inches*	*Sec.-ft.*
0.20	2 3/8	0.046	0.55	6 5/8	0.564	0.90	10 13/16	1.92
.21	2 1/2	.052	.56	6 3/4	.590	.91	10 15/16	1.97
.22	2 5/8	.058	.57	6 13/16	.617	.92	11 1/16	2.02
.23	2 3/4	.065	.58	6 15/16	.644	.93	11 3/16	2.08
.24	2 7/8	.072	.59	7 1/16	.672	.94	11 1/4	2.13
.25	3	.080	.60	7 3/16	.700	.95	11 3/8	2.19
.26	3 1/8	.088	.61	7 5/16	.730	.96	11 1/2	2.25
.27	3 1/4	.096	.62	7 7/16	.760	.97	11 5/8	2.31
.28	3 3/8	.106	.63	7 9/16	.790	.98	11 3/4	2.37
.29	3 1/2	.115	.64	7 11/16	.822	.99	11 7/8	2.43
.30	3 5/8	.125	.65	7 13/16	.854	1.00	12	2.49
.31	3 3/4	.136	.66	7 15/16	.887	1.01	12 1/8	2.55
.32	3 13/16	.147	.67	8 1/16	.921	1.02	12 1/4	2.61
.33	3 15/16	.159	.68	8 3/16	.955	1.03	12 3/8	2.68
.34	4 1/16	.171	.69	8 1/4	.991	1.04	12 1/2	2.74
.35	4 3/16	.184	.70	8 3/8	1.03	1.05	12 5/8	2.81
.36	4 5/16	.197	.71	8 1/2	1.06	1.06	12 3/4	2.87
.37	4 7/16	.211	.72	8 5/8	1.10	1.07	12 13/16	2.94
.38	4 9/16	.225	.73	8 3/4	1.14	1.08	12 15/16	3.01
.39	4 11/16	.240	.74	8 7/8	1.18	1.09	13 1/16	3.08
.40	4 13/16	.256	.75	9	1.22	1.10	13 3/16	3.15
.41	4 15/16	.272	.76	9 1/8	1.26	1.11	13 5/16	3.22
.42	5 1/16	.289	.77	9 1/4	1.30	1.12	13 7/16	3.30
.43	5 3/16	.306	.78	9 3/8	1.34	1.13	13 9/16	3.37
.44	5 1/4	.324	.79	9 1/2	1.39	1.14	13 11/16	3.44
.45	5 3/8	.343	.80	9 5/8	1.43	1.15	13 13/16	3.52
.46	5 1/2	.362	.81	9 3/4	1.48	1.16	13 15/16	3.59
.47	5 5/8	.382	.82	9 13/16	1.52	1.17	14 1/16	3.67
.48	5 3/4	.403	.83	9 15/16	1.57	1.18	14 3/16	3.75
.49	5 7/8	.424	.84	10 1/16	1.61	1.19	14 1/4	3.83
.50	6	.445	.85	10 3/16	1.66	1.20	14 3/8	3.91
.51	6 1/8	.468	.86	10 5/16	1.71	1.21	14 1/2	3.99
.52	6 1/4	.491	.87	10 7/16	1.76	1.22	14 5/8	4.07
.53	6 3/8	.515	.88	10 9/16	1.81	1.23	14 3/4	4.16
.54	6 1/2	.539	.89	10 11/16	1.86	1.24	14 7/8	4.24
						1.25	15	4.33

The Submerged Orifice

The submerged orifice is a regularly shaped hole in a bulkhead through which the water flows, the level of the water surface both above and below the bulkhead being higher than the top of the hole. The hole or orifice usually should be rectangular or square and have sharp edges and complete contraction as in the case of the weirs. The area of the orifice should be marked on the structure.

Two readings are necessary to get the effective head *(h)* causing the flow. One reading is taken of the water surface up-

* From United States Department of Agriculture Farmers' Bulletin No. 1683, *Measuring Water in Irrigation Channels*

Table 5.—Discharge table of submerged orifices

Effective head h		Discharge in cubic feet per second for orifices of various areas				
In Feet	In Inches	.25 Sq. Ft.	.5 Sq. Ft.	1.0 Sq. Ft.	1.5 Sq. Ft.	2.0 Sq. Ft.
.01	1/8	.122	.245	.489	.734	.978
.02	1/4	.173	.346	.692	1.038	1.384
.03	3/8	.212	.424	.847	1.271	1.695
.04	1/2	.245	.489	.978	1.468	1.957
.05	5/8	.273	.547	1.094	1.641	2.186
.06	3/4	.300	.599	1.198	1.797	2.397
.07	13/16	.324	.647	1.294	1.941	2.589
.08	15/16	.346	.692	1.384	2.076	2.767
.09	1 1/16	.367	.734	1.468	2.201	2.935
.10	1 3/16	.387	.774	1.547	2.321	3.094
.11	1 5/16	.406	.811	1.623	2.434	3.245
.12	1 7/16	.424	.847	1.694	2.542	3.389
.13	1 9/16	.441	.882	1.764	2.646	3.528
.14	1 11/16	.458	.915	1.830	2.745	3.661
.15	1 13/16	.474	.947	1.895	2.842	3.789
.16	1 15/16	.489	.978	1.957	2.935	3.914
.17	2 1/16	.504	1.069	2.017	3.026	4.034
.18	2 3/16	.519	1.038	2.076	3.113	4.151
.19	2 1/4	.533	1.066	2.132	3.198	4.265
.20	2 3/8	.547	1.094	2.188	3.282	4.376
.21	2 1/2	.560	1.121	2.242	3.363	4.484
.22	2 5/8	.574	1.147	2.295	3.442	4.589
.23	2 3/4	.587	1.173	2.346	3.519	4.692
.24	2 7/8	.599	1.198	2.397	3.595	4.793
.25	3	.612	1.223	2.446	3.669	4.892
.26	3 1/8	.624	1.247	2.495	3.742	4.989
.27	3 1/4	.636	1.271	2.542	3.813	5.084
.28	3 3/8	.647	1.294	2.589	3.883	5.177
.29	3 1/2	.659	1.317	2.635	3.952	5.269
.30	3 5/8	.670	1.340	2.680	4.019	5.359
.31	3 3/4	.681	1.362	2.724	4.086	5.448
.32	3 13/16	.692	1.384	2.767	4.151	5.535
.33	3 15/16	.703	1.405	2.810	4.215	5.620
.34	4 1/16	.713	1.426	2.853	4.279	5.705
.35	4 3/16	.724	1.447	2.894	4.341	5.788
.36	4 5/16	.734	1.468	2.935	4.403	5.871
.37	4 7/16	.744	1.488	2.976	4.464	5.952
.38	4 9/16	.754	1.508	3.016	4.523	6.031
.39	4 11/16	.764	1.528	3.055	4.583	6.110
.40	4 13/16	.774	1.547	3.094	4.641	6.188
.41	4 15/16	.783	1.567	3.133	4.699	6.265
.42	5 1/16	.793	1.585	3.170	4.756	6.341
.43	5 3/16	.802	1.604	3.208	4.812	6.416
.44	5 1/4	.811	1.623	3.245	4.868	6.490
.45	5 3/8	.820	1.641	3.282	4.923	6.564
.46	5 1/2	.830	1.659	3.318	4.977	6.636
.47	5 5/8	.838	1.677	3.354	5.031	6.708
48	5 3/4	.847	1.695	3.389	5.084	6.779
.49	5 7/8	.856	1.712	3.424	5.136	6.848
.50	6	.865	1.730	3.459	5.189	6.919
.51	6 1/8	.873	1.747	3.494	5.241	6.987
.52	6 1/4	.882	1.764	3.528	5.292	7.056
.53	6 3/8	.890	1.781	3.562	5.342	7.123
.54	6 1/2	.899	1.798	3.595	5.393	7.190
.55	6 5/8	.907	1.814	3.628	5.442	7.256
.56	6 3/4	.915	1.830	3.661	5.491	7.322
.57	6 13/16	.923	1.847	3.694	5.540	7.387
.58	6 15/16	.931	1.863	3.726	5.589	7.452
.59	7 1/16	.939	1.879	3.758	5.637	7.515
.60	7 3/16	.947	1.895	3.789	5.684	7.579
.61	7 5/16	.955	1.910	3.821	5.731	7.642
.62	7 7/16	.963	1.926	3.852	5.778	7.704
.63	7 9/16	.971	1.942	3.883	5.825	7.766
.64	7 11/16	.978	1.957	3.914	5.871	7.828
.65	7 13/16	.986	1.972	3.944	5.916	7.888

Discharge table for standard submerged orifices computed from: $Q = .61\,A\sqrt{2gh}$

stream and the other downstream and both must be taken from the same datum or elevation. The head *(h)* is the difference in the readings.

The advantage of the submerged orifice is that it uses relatively little fall in measuring the discharge.

The disadvantages are: It clogs easily with trash and weeds.

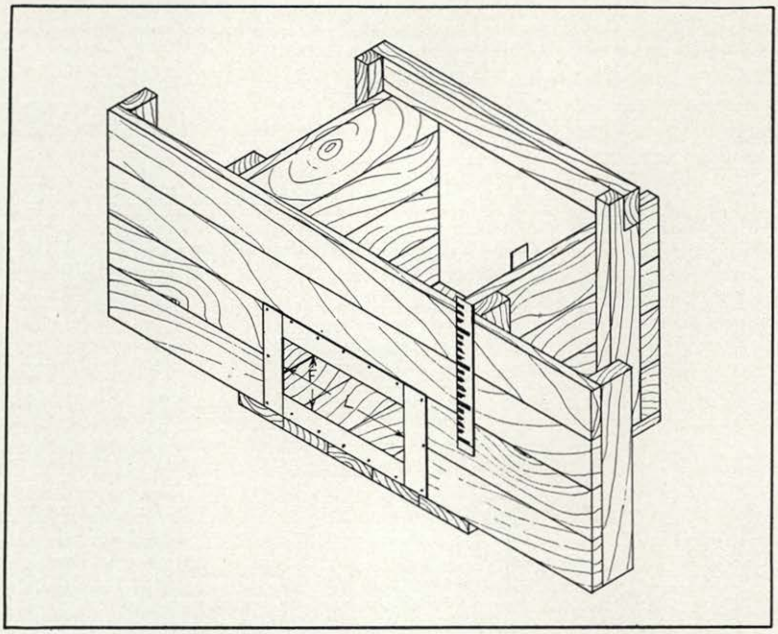

Figure 8.—Submerged orifice

It requires two readings. A slight error in reading the head makes a large error in the discharge. An orifice of a given size has a relatively small range of discharge. (Adjustable orifices often are calibrated and used as combined regulating and measuring devices.)

Table 5 gives the discharge of submerged orifices with complete contraction for openings of from .25 square feet to 2 square feet.

The Parshall Measuring Flume

The improved Venturi flume or the Parshall measuring flume is a measuring device developed by Ralph L. Parshall at

Table 6.—Dimensions and capacities of Parshall measuring flume for various crest lengths
(Letters refer to Figure 9)

W	A		⅔A		B		C		D		E		F	G	K	N	X	Y	Free-flow capacity	
																			Maximum	Minimum
Feet	*Ft.*	*in.*	*Ft.*	*in.*	*Ft.*	*in.*	*Ft.*	*in.*	*Ft.*	*in.*	*Ft.*	*in.*	*Ft.*	*Ft.*	*In.*	*In.*	*In.*	*In.*	*Sec. ft.*	*Sec. ft.*
0.25	1	6⅜	1	¼	1	6		7		10 3/16	1	3	½	1	1	2¼	1	1½	1.2	0.03
.50	2	7/16	1	4 5/16	2		1	3½	1	3½	1	6	1	2	3	4½	2	3	2.9	.05
.75	2	10⅝	1	11⅛	2	10	1	3	1	10⅝	2		1	1½	3	4½	2	3	5.7	.1
1	4	6	3		4	4⅞	2		2	9¼	3		2	3	3	9	2	3	16	.4
2	5		3	4	4	10⅞	3		3	11½	3		2	3	3	9	2	3	33	.7
3	5	6	3	8	5	4¾	4		5	1⅞	3		2	3	3	9	2	3	50	1.0
4	6		4		5	10⅝	5		6	4¼	3		2	3	3	9	2	3	68	1.3

(From United States Department of Agriculture Farmers' Bulletin No. 1683) the Colorado Agricultural Experiment Station. It is not so simple to build as a weir; yet it is not complicated.

It combines many of the advantages of the weir and the submerged orifice and in addition has points of superiority over both. There is no need of a pond above the flume as the velocity of approach has little effect on the accuracy of the measurement. It uses a small amount of head as it can have a high degree of submergence without the necessity of reading two heads or making corrections in the free-flow formula. It does not clog

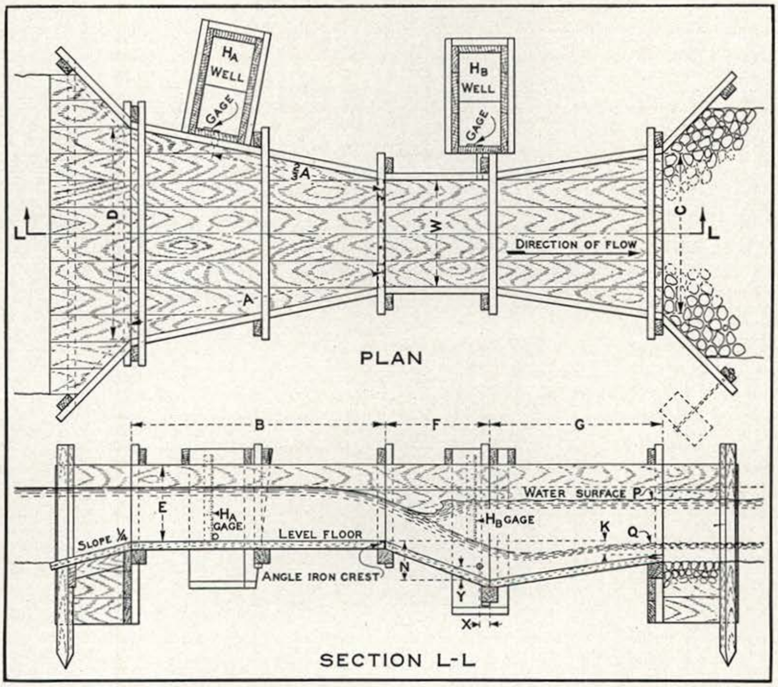

Figure 9.—Parshall measuring flume (from United States Department of Agriculture Farmers' Bulletin No. 1683)

readily with floating trash and it keeps itself clean of sand and silt. It requires but one reading of head *(H_a)* for determining the discharge except in case of extreme submergence (60 per cent in the case of the .25, .50, and .75 foot flumes and 70 per cent in the 1 foot to 4 foot).

The head *(H_a)* should be measured in a stilling well at a specified point or specified distance from the throat.

The flume can be made of lumber or concrete or may be purchased ready-made of sheet metal.

Table 7.—Free flow discharge through Parshall measuring flume *

Head H_a	Discharge, Q, for throat widths, W, of—							Head, H_a	Discharge, Q, for throat widths, W, of—						
	0.25 foot	0.50 foot	0.75 foot	1foot	2 feet	3 feet	4 feet		.025 foot	.050 foot	.075 foot	1 foot	2 feet	3 feet	4 feet
Feet	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Feet*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
0.10	0.028	0.05	0.09	....	....	....	....	0.75	....	1.31	1.98	2.58	5.12	7.65	10.2
.11	.033	.06	.10	....	....	....	....	.76	....	1.34	2.02	2.63	5.23	7.81	10.4
.12	.037	.07	.12	....	....	....	....	.77	....	1.36	2.06	2.68	5.34	7.97	10.6
.13	.042	.08	.14	....	....	....	....	.78	....	1.39	2.10	2.74	5.44	8.13	10.8
.14	.047	.09	.15	....	....	....	....	.79	....	1.42	2.14	2.80	5.55	8.30	11.0
.15	.053	.10	.17	....	....	....	....	.80	....	1.45	2.18	2.85	5.66	8.46	11.2
.16	.058	.11	.19	....	....	....	....	.81	....	1.48	2.22	2.90	5.77	8.63	11.5
.17	.064	.12	.20	....	....	....	....	.82	....	1.50	2.27	2.96	5.88	8.79	11.7
.18	.070	.14	.22	....	....	....	....	.83	....	1.53	2.31	3.02	6.00	8.96	11.9
.19	.076	.15	.24	....	....	....	....	.84	....	1.56	2.35	3.07	6.11	9.13	12.2
.20	.082	.16	.26	0.35	0.66	0.97	1.26	.85	....	1.59	2.39	3.12	6.22	9.30	12.4
.21	.089	.18	.28	.37	.71	1.04	1.36	.86	....	1.62	2.44	3.18	6.33	9.48	12.6
.22	.095	.19	.30	.40	.77	1.12	1.47	.87	....	1.65	2.48	3.24	6.44	9.65	12.8
.23	.102	.20	.32	.43	.82	1.20	1.58	.88	....	1.68	2.52	3.29	6.56	9.82	13.1
.24	.109	.22	.35	.46	.88	1.28	1.68	.89	....	1.71	2.57	3.35	6.68	10.0	13.3
.25	.117	.23	.37	.49	.93	1.37	1.80	.90	....	1.74	2.61	3.41	6.80	10.2	13.6
.26	.124	.25	.39	.51	.99	1.46	1.91	.91	....	1.77	2.66	3.46	6.92	10.4	13.8
.27	.131	.26	.41	.54	1.05	1.55	2.03	.92	....	1.81	2.70	3.52	7.03	10.5	14.0
.28	.138	.28	.44	.58	1.11	1.64	2.15	.93	....	1.84	2.75	3.58	7.15	10.7	14.3
.29	.146	.29	.46	.61	1.18	1.73	2.27	.94	....	1.87	2.79	3.64	7.27	10.9	14.5
.30	.154	.31	.49	.64	1.24	1.82	2.39	.95	....	1.90	2.84	3.70	7.39	11.1	14.8
.31	.162	.32	.51	.68	1.30	1.92	2.52	.96	....	1.93	2.88	3.76	7.51	11.3	15.0
.32	.170	.34	.54	.71	1.37	2.02	2.65	.97	....	1.97	2.93	3.82	7.63	11.4	15.2
.33	.179	.36	.56	.74	1.44	2.12	2.78	.98	....	2.00	2.98	3.88	7.75	11.6	15.5
.34	.187	.38	.59	.77	1.50	2.22	2.92	.99	....	2.03	3.02	3.94	7.88	11.8	15.8
.35	.196	.39	.62	.80	1.57	2.32	3.06	1.00	....	2.06	3.07	4.00	8.00	12.0	16.0
.36	.205	.41	.64	.84	1.64	2.42	3.19	1.01	....	2.09	3.12	4.06	8.12	12.2	16.2
.37	.213	.43	.67	.88	1.72	2.53	3.34	1.02	....	2.12	3.17	4.12	8.25	12.4	16.5
.38	.222	.45	.70	.92	1.79	2.64	3.48	1.03	....	2.16	3.21	4.18	8.38	12.6	16.8
.39	.231	.47	.73	.95	1.86	2.75	3.62	1.04	....	2.19	3.26	4.25	8.50	12.8	17.0
.40	.241	.48	.76	.99	1.93	2.86	3.77	1.05	....	2.22	3.31	4.31	8.63	13.0	17.3
.41	.250	.50	.78	1.03	2.01	2.97	3.92	1.06	....	2.26	3.36	4.37	8.76	13.2	17.5
.42	.260	.52	.81	1.07	2.09	3.08	4.07	1.07	....	2.29	3.40	4.43	8.88	13.3	17.8
.43	.269	.54	.84	1.11	2.16	3.20	4.22	1.08	....	2.32	3.45	4.50	9.01	13.5	18.1
.44	.279	.56	.87	1.15	2.24	3.32	4.38	1.09	....	2.36	3.50	4.56	9.14	13.7	18.3
.45	.289	.58	.90	1.19	2.32	3.44	4.54	1.10	....	2.40	3.55	4.62	9.27	13.9	18.6
.46	.299	.61	.94	1.23	2.40	3.56	4.70	1.11	....	2.43	3.60	4.68	9.40	14.1	18.9
.47	.309	.63	.97	1.27	2.48	3.68	4.86	1.12	....	2.46	3.65	4.75	9.54	14.3	19.1
.48	.319	.65	1.00	1.31	2.57	3.80	5.03	1.13	....	2.50	3.70	4.82	9.67	14.5	19.4
.49	.329	.67	1.03	1.35	2.65	3.92	5.20	1.14	....	2.53	3.75	4.88	9.80	14.7	19.7
.50	.339	.69	1.06	1.39	2.73	4.05	5.36	1.15	....	2.57	3.80	4.94	9.94	14.9	19.9
.51	.350	.71	1.10	1.44	2.82	4.18	5.53	1.16	....	2.60	3.85	5.01	10.1	15.1	20.2
.52	.361	.73	1.13	1.48	2.90	4.31	5.70	1.17	....	2.64	3.90	5.08	10.2	15.3	20.5
.53	.371	.76	1.16	1.52	2.99	4.44	5.88	1.18	....	2.68	3.95	5.15	10.3	15.6	20.8
.54	.382	.78	1.20	1.57	3.08	4.57	6.05	1.19	....	2.71	4.01	5.21	10.5	15.8	21.0
.55	.393	.80	1.23	1.62	3.17	4.70	6.23	1.20	....	2.75	4.06	5.28	10.6	16.0	21.3
.56	.404	.82	1.26	1.66	3.26	4.84	6.41	1.21	....	2.78	4.11	5.34	10.8	16.2	21.6
.57	.415	.85	1.30	1.70	3.35	4.98	6.59	1.22	....	2.82	4.16	5.41	10.9	16.4	21.9
.58	.427	.87	1.33	1.75	3.44	5.11	6.77	1.23	....	2.86	4.22	5.48	11.0	16.6	22.2
.59	.438	.89	1.37	1.80	3.53	5.25	6.96	1.24	....	2.89	4.27	5.55	11.2	16.8	22.5
.60	.450	.92	1.40	1.84	3.62	5.39	7.15	1.25	....	....	4.32	5.62	11.3	17.0	22.8
.61	.462	.94	1.44	1.88	3.72	5.53	7.34	1.26	....	....	4.37	5.69	11.4	17.2	23.0
.62	.474	.97	1.48	1.93	3.81	5.68	7.53	1.27	....	....	4.43	5.76	11.6	17.4	23.3
.63	.485	.99	1.51	1.98	3.91	5.82	7.72	1.28	....	....	4.48	5.82	11.7	17.7	23.6
.64	.497	1.02	1.55	2.03	4.01	5.97	7.91	1.29	....	....	4.53	5.89	11.9	17.9	23.9
.65	.509	1.04	1.59	2.08	4.11	6.12	8.11	1.30	....	....	4.59	5.96	12.0	18.1	24.2
.66	.522	1.07	1.63	2.13	4.20	6.26	8.31	1.31	....	....	4.64	6.03	12.2	18.3	24.5
.67	.534	1.10	1.66	2.18	4.30	6.41	8.51	1.32	....	....	4.69	6.10	12.3	18.5	24.8
.68	.546	1.12	1.70	2.23	4.40	6.56	8.71	1.33	....	....	4.75	6.18	12.4	18.8	25.1
.69	.558	1.15	1.74	2.28	4.50	6.71	8.91	1.34	....	....	4.80	6.25	12.6	19.0	25.4
.70	.571	1.17	1.78	2.33	4.60	6.86	9.11	1.35	....	....	4.86	6.32	12.7	19.2	25.7
.71	.584	1.20	1.82	2.38	4.70	7.02	9.32	1.36	....	....	4.92	6.39	12.9	19.4	26.0
.72	.597	1.23	1.86	2.43	4.81	7.17	9.53	1.37	....	....	4.97	6.46	13.0	19.6	26.3
.73	.610	1.26	1.90	2.48	4.91	7.33	9.74	1.38	....	....	5.03	6.53	13.2	19.9	26.6
.74	.623	1.28	1.94	2.53	5.02	7.49	9.95	1.39	....	....	5.08	6.60	13.3	20.1	26.9

* Letters, H_a and W, refer to Figure 9. To convert decimal fractions of a foot to inches and fractions, see corresponding units in Table 2.

(From United States Department of Agriculture Farmers' Bulletin No. 1683)

Setting and Size of Parshall Measuring Flume*

Successful operation of the Parshall flume depends upon setting the crest at the correct elevation with reference to the bed of the channel. Free-flow conditions are desirable so that computations for submergence of flow need not be made. The smallest practical size of flume should be selected as a matter of economy, but as the size of the flume decreases the loss of head increases.

The dimensions as given in Table 6, which correspond to the same letter in Figure 9, must be followed accurately. The crest must be straight and level and the floor of the converging section must be level in both directions.

Measurement of head should be made in a stilling well with the zero of the gauge level with the crest of the flume. The connection from the flume to the stilling well should take out of the flume at a point exactly two thirds of the length of the converging section back from the crest and about 1½ inches above the floor line.

Appendix I

Table 8.—Comparison of loss of head in feet for equal discharges through Parshall measuring flume and over weirs

Discharge	Loss of head of Parshall measuring flume				Loss of head of rectangular weir				Loss of head of Cipolletti weir				Loss of head of 90° triangular-notch weir
	6-inch	1-foot	2-foot	4-foot	6-inch	1-foot	2-foot	4-foot	6-inch	1-foot	2-foot	4-foot	
Sec.-ft.	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
0.10	0.06	....	....	....	0.15	....	....	....	0.15	....	....	....	0.27
.50	.16	0.08	....	....	.46	0.29	0.18	....	.43	0.28	0.18	....	.52
1.00	.25	.12	0.08	....	.74	.46	.29	0.18	.64	.44	.28	0.18	.69
2.00	.41	.19	.12	0.08	1.16	.75	.46	.29	.96	.69	.45	.28	.92
3.00	....	.25	.16	.11	....	.99	.61	.38	....	.88	.58	.37	1.08
5.00	....	.35	.22	.14	....	....	.86	.53	....	....	.82	.52	1.32
7.50	....	.45	.29	.19	....	....	1.13	.70	....	....	1.06	.68	.....
10.00	....	.55	.35	.22	....	....	....	.85	....	....	1.27	.83	.....
12.50	....	.63	.40	.26	....	....	....	.99	....	....	....	.96	.....
15.00	....	....	.45	.29	....	....	....	1.12	....	....	....	1.08	.....
20.00	....	....	.54	.35	....	....	....	1.36	....	....	....	1.31	.....

(From United States Department of Agriculture Farmers' Bulletin No. 1683)

The figures given in the body of the table are the minimum loss of head required to measure a stream whose maximum discharge is given in the first column.†

Example: The table may be used in the following manner. A stream whose maximum discharge will be 2.0 cubic feet per second and whose minimum discharge will be .6 cubic feet per second has an excess fall of .5 feet. What device should be used?

Try the rectangular weir of 1-foot crest length. A discharge of 2 cubic feet per second requires a loss of .75 feet and there-

* Complete instructions for setting, size, construction, and operation of Parshall measuring flume are given in United States Department of Agriculture Farmers' Bulletin No. 1683, *Measuring Water in Irrigation Channels,* by R. L. Parshall.

† The figures for the .25, .50, and .75 foot Parshall measuring flume are for 60 per cent submergence and for the 1-4 foot flume are 70 per cent submergence.

fore is unsuitable. Next try a rectangular weir with a 2-foot crest. The 2-foot crest will need a fall of .46 which is available. Now we can look at the 2-foot crest to see if it will measure a flow of .6 cubic feet per second and we find that a flow of .6 cubic feet per second on a 2-foot rectangular weir will have a head of about .2 feet, and, as accurate measurements can be made when the head is 2 inches or more, the 2-foot rectangular weir is suitable. Further study of the table shows that the 90° triangular-notch weir, while covering the range of discharges, requires too much fall and cannot be used. A submerged orifice of 1 square foot would measure the maximum flow with little loss of head but would not measure the minimum flow accurately. Either the 6-inch (.5 foot) throat or 1-foot throat Parshall measuring flume would measure both the maximum and minimum flow without loss of more than .5 foot of head.

Appendix II

Equivalents

1 cubic foot = 7.48 gallons or approximately 7.5 gallons.
1 cubic foot of water weighs about 62.4 pounds.
1 cubic foot per second = 448.8 gallons per minute or approximately 450 gallons per minute = 50 miner's inches (Idaho).
1 cubic foot per second flowing 24 hours = 1.9835 acre-feet or approximately 2 acre-feet.
1 cubic foot per second flowing 12 hours = .9917 acre-feet or approximately 1 acre-foot.
1 cubic foot per second flowing 1 hour = .9917 acre-inches or approximately 1 acre-inch.

The table of equivalents may be used to determine the depth of water applied to a field when the time and flow are known.

Problem: A flow of 60 miner's inches (Idaho) has been running on a 20-acre field for 48 hours. How deep would it cover the field if evenly applied?

Solution: From the table of equivalents 1 cubic foot per second equals 50 miner's inches; therefore, 60 inches will equal 60/50 or 1.2 cubic feet per second. From the table 1 cubic foot per second flowing 1 hour equals 1 acre-inch and 1.2 cubic feet per second will equal 1.2 acre-inches per hour or 1.2 times 48 or 57.6 acre-inches in 48 hours. 57.6 acre-inches distributed evenly over 20 acres would amount to 57.6/20 or 2.88 acre-inches per acre or a depth of 2.88 inches (about $2\frac{7}{8}$ inches).

Also the tables may be used to compute the time necessary to irrigate a field of known size to a certain depth with a known stream.

Problem: A stream of 40 miner's inches (Idaho) is being delivered. How long will it take to cover a 15-acre field to a depth of 4 inches? 15 acres to a depth of 4 inches is 60 acre-inches. From the table of equivalents 1 cubic foot per second equals 50 inches and 40 inches will be 40/50 cubic feet per second or .8 cubic feet per second. From the table of equivalents 1 cubic foot per second equals 1 acre-inch per hour and .8 cubic feet per second will equal .8 acre inch per hour. But 60 acre-inches are required so it will take 60/.8 or 75 hours to irrigate the field to the required depth of 4 inches.

Note: The average waste runoff from irrigated fields is 11 per cent and, if allowance is to be made for this waste, the length of time will be increased by this amount or $1.11 \times 75 =$ 82.5 hours.

Appendix III

Definition of Terms

Gallon: The United States standard gallon or 231 cubic inches.

Cubic foot: A volume equal to that of a cube of 12 inches in length, breadth, and thickness (1,728 cubic inches).

Acre-foot: The volume necessary to cover 1 acre to a depth of 1 foot (43,560 cubic feet).

Acre-inch: The volume necessary to cover 1 acre to a depth of 1 inch (1/12 acre-foot or 3,630 cubic feet).

Gallon per minute: A continuous flow amounting to 1 gallon passing a point each minute of time.

Cubic foot per second (c. f. s. or second foot): A continuous flow amounting to 1 cubic foot passing a point each second of time.

Miner's inch (Idaho): A continuous flow equal to 1/50 cubic foot per second. The Idaho miner's inch originally was the amount of water that would flow through an orifice 1-inch square under a head of 4 inches above the center of the orifice but has been defined by court decision as 1/50 cubic foot per second.

Weir: A regularly shaped notch in a vertical wall.

Weir wall or weir bulkhead: A wall or bulkhead placed across the channel of a stream to check the stream and cause it to flow through a weir notch.

Weir crest: The bottom point or the horizontal edge of a weir notch.

Weir pond or weir box: The enlarged section of the stream bed immediately above the weir wall.

Head: The depth of the water above the weir crest measured at a distance from the weir notch so as to be unaffected by the curve of the water surface as the water flows over the weir. In the submerged orifice the head is the difference in elevation between the water surfaces above and below the orifice. In the Parshall measuring flume it is the elevation of the water surface above the floor of the flume measured at a definite distance from the throat. Head on a weir is generally called "H." Head on an orifice is called "h." Head on a Parshall measuring flume is called "H_a."

Weir gauge or weir scale: A gauge or scale placed upstream from the weir notch to measure the head "H" on the weir. It may be a piece of rule or made of metal or enameled metal.

Free-flow: The condition of flow over a weir wherein the sheet of falling water falls freely into the air and meets no obstruction above the elevation of the weir crest.

End contraction: The condition of weir flow obtained when the weir pond is wider than the weir notch or the distance from the side of weir notch to the side of the weir pond.

Bottom contraction: The condition of weir flow obtained when the weir crest is above the bottom of the weir pond or the vertical distance from the bottom of the weir pond to the weir crest.

Complete contraction: End and bottom contractions large enough to give practically a still-water condition in the weir pond.

Baffles: Obstructions placed in a stream to reduce turbulence or velocity or to equalize the flow throughout the section of the stream.

Velocity of approach: Water approaching the weir notch with appreciable velocity.

Submergence or submerged flow: The condition of flow wherein the elevation of the water surface below the weir or flume or orifice is higher than the bottom of the flume, the top of the orifice, or the crest of the weir.

Acknowledgment

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