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The Measurement of Irrigation Waters

BY

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THE MEASUREMENT OF IRRIGATION WATER

By DON H. BARK
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INTRODUCTION

Irrigation water is as necessary for crop production in a large part of Idaho as food and drink are for man, and it is becoming more valuable every year. In the days gone by when water was cheap and plentiful there was enough for everyone and no one troubled himself over its accurate measurement. These conditions, however, have all been changed by the great influx of settlers who have taken up nearly all of the available land and water until at the present time water is worth ten or more times as much as it was fifteen years ago. This has brought home to us the fact that irrigation water should be measured as carefully as sugar, coal or flour. During the past two years so many inquiries have been received concerning the proper method of water measurement that it has been deemed best to assemble the information and publish it in the form of a bulletin describing the measurement of water, which it is hoped will fill a long felt want. It has been the attempt to present the information in such plain terms that all references may be plain to anyone, the bulletin being intended for the use of farmers rather than engineers.

MINER'S INCH

Water was first used in Idaho and other western states for mining purposes, the common method of measurment being called the miner's inch method. The miner's inch was the unit upon which such measurement was based, being the amount of water that would flow through a sharp edged orifice one inch square under a given pressure. The quantity called for by a miner's inch, however, varied in different states, due to the fact that the pressure over the orifice was not the same. The Idaho statute called for a pressure of 4 inches over the center of the orifice while the Montana law called for a 6-inch pressure. This variation resulted in no end of confusion and as the miner's inch was not adapted to the measurement of large streams its use has been discontinued for the cubic foot per second.

CUBIC FOOT PER SECOND

The cubic foot per second which represents a definite tangible amount that is easily understood, was adopted as the legal standard for the measurement of water by the Idaho Legislature in 1899. It is commonly known as the "second foot" and represents the flow of water which will exactly fill a vessel containing one cubic foot each second of time for as long a period as it is allowed to flow. Hence, a flow of one cubic foot per second delivers 60 cubic feet per minute, or 3600 cubic feet per hour, or 86,400 cubic feet in a day of twenty-four hours.

It is found that one cubic foot per second equals a flow of almost exactly 50 Idaho miner's inches, or 450 gallons per minute. A flume one foot wide and one foot deep if filled with water that is flowing at the rate of exactly one foot per second, will carry one cubic foot per second, and other flumes or ditches in the same proportion. The quantity discharged depends upon both the velocity of the flow and the area of cross section of the advancing stream of water. These two factors are taken into consideration when determining the flow of large streams and canals, it being only necessary to determine the area of the cross section and the average velocity, which two amounts multiplied together gives the discharge. The cross section is found by multiplying the average depth of the stream by the width. The average velocity is found by measuring the rate of the same either with floats or with a current meter especially constructed for the purpose. A close approximation of the velocity can be secured by noting the time that is required for a surface float to advance through 100 or more lineal feet of the ditch. This gives the surface velocity, and to find the average velocity one must multiply the surface velocity by 0.8, since the average velocity is that much slower than the surface velocity, owing to the friction on the sides and bottom of the channel.

While the above mentioned methods are those used by engineers and others for the measurement of large canals and rivers, this method is not adapted to the continuous measurement of small streams and ditches because of the time involved and the liability for error where the measurements are not carefully made.

ACRE FOOT

Where large volumes of water are to be considered the expression of the amount in cubic feet would involve the use of such large numbers that the same would be cumbersome. In order to simplify these expressions the term "acre-foot" is used, which represents enough water to cover an acre one foot in depth, or 43,560 cubic feet. The use of this term has the additional advantage of being easily compared with the acreage; as for example, a reservoir containing 50,000 acre feet of water would furnish a depth of two feet for 25,000 acres of land. A cubic foot of water per second flowing continuously for twenty-four hours furnishes almost exactly two acre feet of water.

WEIRS AND WEIR MEASUREMENTS

The most accurate, practical and economical method of water measurement that has been devised for the measurement of comparatively small heads of water is the weir measurement. The weir consists essentially of a thin notch of a specific shape, which the water is caused to flow over. The amount of flow depends upon the depth of water flowing over the crest, as the bottom of the notch is called. The weir has been used for the measurement of water for hundreds of years and the method of its installation and the discharge of water over it have both been worked out so carefully that water can be measured over it with an error of less than one per cent., if care is used.

There are several forms of weirs, the names of each designating the shape of the notch. Cippoletti, an Italian engineer, evolved and perfected the weir which bears his name, many years ago, this being the weir that is now most generally used in the west, and the one which will be described in detail in this bulletin. Other weirs, namely, the rectangular and the triangular weirs, are constructed and operated in much the same way, the same rules being observed in the measurement, practically the only difference existing being, as has been stated, in the shape of the notch and the formula used in the computation of the discharge. The Cippoletti weir notch is trapezoidal in shape, having a straight bottom or crest with sides that slope outward from the vertical at the rate of one horizontal to four vertical. A one foot Cippoletti weir has a straight horizontal bottom or crest, one foot in length with a width between the sides of 15 inches at a height of 6 inches above the crest.

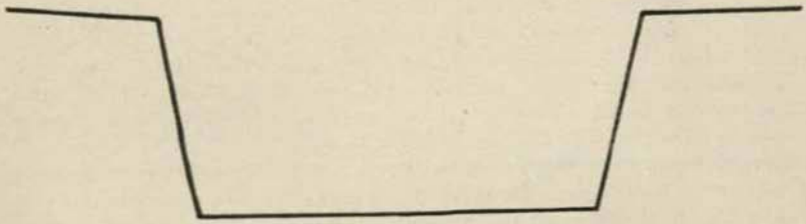

Fig. I. A Cippoletti Weir Notch.

If the notch is made of wood the sides and bottom should be beveled off on the down stream side, leaving a sharp thin edge on the up-stream side. This is necessary in order to secure a sharp clear-cut issuing stream which it is necessary to secure if accurate measurement is to be obtained. It is usually the best policy to line or face the upper side of the weir board with a piece of galvanized iron from which the proper size and shape notch has been cut. This may be seen clearly from the illustration in Figure II.

In this case the notch in the board should be cut slightly larger than that in the galvanized iron sloping or beveling the edges in the same manner as before. The use of the galvanized iron or other metallic crest is especially recommended as it not only insures a sharp clear-cut issuing stream upon which accurate measurement depends, but in addition, it also furnishes a permanent unchangeable crest for the water to flow through. Provided the necessary requirements are observed in the construction and installation of a weir, the amout of water flowing over it depends upon but two factors, the length of crest and the depth of water on the crest. The length of crest being known, the depth of the water should be measured, not on the crest, but from a point level with the crest and up stream from it a distance equal to its length as indicated in Figure II.

Weir Box.—In order to maintain the weir in a proper and constant position and to prevent leakage around and under it, and in order that all water that is to be measured should be conducted over it, it is usually necessary to construct some sort of box or frame to hold the weir in place. A common form or type of this box which is recommended for a one foot Cippoletti weir is shown in Figure III.

This box is 9 feet long, 2 1-2 feet deep and 3 feet wide with inside measurement, and with a one foot weir will measure with accuracy amounts ranging from 10 to 50 Idaho miner's inches.

Where a weir box is built it is necessary that it be made of sufficient size and depth in comparison to the size of the weir notch to

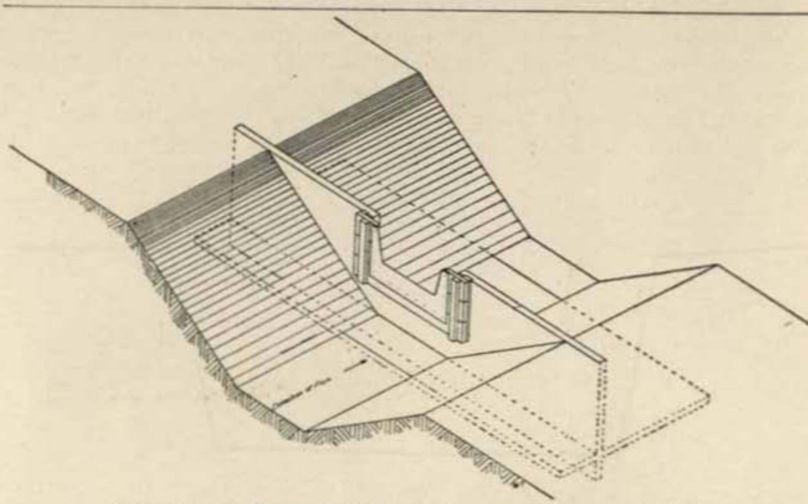

Fig. II. A Cippoletti Weir Properly Set in Ditch.

eliminate all excess velocity of approach. If the box is built too narrow or too shallow it will add to the velocity of approach to such an extent that correct measurement can not be secured. It is but a mere matter of convenience, however, to have a box of the exact length prescribed, for that part of the box above the weir may be omitted if a settling basin or pool of the same size is constructed in the ditch above the weir. The weir boxes and pools which should be constructed for weirs of larger sizes should be in the same proportion with respect to the size of the weir as for the one foot. The size of the weir box that is required in order to eliminate velocity of approach has been found by experiment to be approximately seven times the cross section of the weir notch.

Discharge.—The discharge of weirs has been accurately calculated by various engineers who have carried on hundreds of experiments covering years of time, and it is found that under like conditions the same depth always produces the same discharge over the same size of a weir. The conditions given for the construction and installation of weirs must be rigidly adhered to, however, if accurate measurement is to be made. The formula which has been evolved and which gives the discharge of accurately constructed Cippoletti weirs is:

Q equals 3.367 L H 3-2.

Where Q equals the number of cubic feet per second,
L equals the length of crest in feet,
And H equals the depth of water on the crest in feet,

provided the same is measured from a point level with the crest and up stream from it at a distance equal to the length of the crest.

In order to facilitate the determination of the discharge over weirs and to reduce the liability for error to a minimum, tables of discharge for weirs have been compiled and are given in this bulletin.

Throughout all of the experiments upon which the weir formula

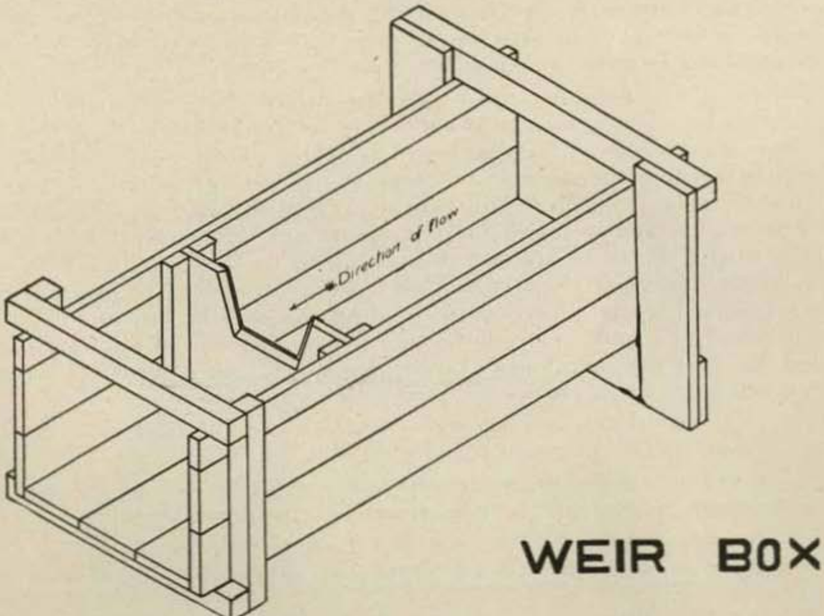

Fig. III. A Weir Box for a Cippoletti Weir.

is based certain conditions have been observed with regard to the setting and placing of the weir and these conditions must be reproduced if it is expected to secure accurate measurement. These conditions are given below and if they are rigidly carried out, water can be measured with the Cippoletti weir with an error of less than one per cent. These conditions apply equally to all weirs whether triangular, rectangular or Cippoletti.

1. The weir box should be set with its floor even with the bottom of the ditch and should be level in all directions. The weir itself, should be exactly level and perpendicular.

2. The channel leading to the weir should be of uniform cross section, or what is still better, should gradually enlarge as the weir is approached. The axis of the stream should pass through the weir and perpendicular to it; or, in other words, the weir should be located at right angles to the middle of the stream. The advancing stream should be free from internal cross currents or eddies as these have an influence upon the discharge.

3. THE WATER SHOULD BE BROUGHT AS NEARLY AS POSSIBLE TO A STATE OF REST BEFORE IT ENTERS THE

WEIR. An excess velocity of approach due to the velocity of the advancing current will affect (increase) the discharge more than almost any other one thing. This velocity can be reduced by widening and deepening the box or pool above the weir. It is calculated that weirs three feet long with a depth of water of twelve inches, should not have a greater velocity of approach than six inches per second, which amount may be allowed to increase very slightly where greater depths over wider weirs are used. By constructing the box or pool above the weir with a cross section at least seven times that of the weir notch, a sufficiently low velocity of approach is usually secured.

4. The issuing stream of water must have full contraction: that is, it must be sharp and clear-cut. This is brought about by making the up-stream edge of the weir board as nearly a knife edge as possible, and by keeping the sides and bottom of the box below the weir at a good distance from the falling stream so that the air may pass freely clear around and in under the issuing stream. The water below the weir should never be allowed to back up to the level of the crest so as to exclude the air from under the issuing stream else complete contraction will not be secured and the discharge will be affected. If air can pass freely underneath the issuing stream the level of the water below the weir has no influence on the discharge. An observance of the following rules will usually insure complete contraction:

a. The opening of the weir or the weir notch must be made in a plane surface perpendicular to the direction of the flow of water.

b. The opening itself must have a sharp edge on the up-stream side and the walls should be beveled away on the down-stream side.

c. The distance of the crest of the weir from the bottom of the box or basin should be at least 3 times the depth of the water on the crest.

d. The distance of the sides of the weir notch from the sides of the box or channel should be at least twice as great as the depth of the water flowing over the crest.

e. In order that the lateral contraction should not be disturbed the length of the weir crest should be approximately three times that of the depth of water flowing over it.

5. The depth of water flowing over the weir should not be less than two inches nor more than one-third of the length of the crest, and it should be measured where it will not be affected by waves, wind or eddies, and far enough up stream so that it will not be influenced by the curvature induced by the falling water, This CAN NOT be done by measuring it exactly over the crest. The distance above the crest which is usually found sufficient, is up stream from the crest a distance equal to the length of the crest. A handy method of establishing a point from which to measure the head, and a method which is to be recommended, is to drive a heavy stake up stream from the weir and at the side where it can be easily reached. This stake should be driven in firmly so as not to be easily changed and should be sawed off squarely at a point slightly below the level of the crest which can be determined by the aid of a carpenter's level and a straight edge. A heavy spike or nail should then be driven vertically into the top of the stake and the top of its head should be exactly leveled with the

crest by the same method. The head of water flowing over the weir can then be found by measuring down from the surface of the water to the head of the nail with an ordinary carpenter's rule or square, as shown in Figure IV. The head must be measured within 1-300 of the length of crest in order to limit the error to one-half of one per cent. A very accurate measurement of the head can only be made with the hook guage which consists of a long rod terminating in an upturned metalic hook, the rod sliding up and down on a fixed support being actuated by a screw motion, while the head of water is read from a vernier attached to the rod. The rod is run down until the point of the hook is below water and then raised slowly until the point reaches the surface, which is indicated by the appearance of a "pimple" on the surface immediately over the hook.

This method eliminates the effect of capillary attraction on the rule, but is not practical for farmer's weirs, on account of the expense of installation. If care is used the head can be measured accurately enough for all practical purposes with an ordinary rule in the manner previously described.

The most frequent cause of error in weir measurements is excess volocity of approach and this must be guarded against by providing a good sized pool above the weirs which must be kept clean and free from sediment.

"DON'TS" IN REGARD TO WEIRS

1. Do not set a weir immediately below a curve in the ditch, for the curve will cause the water to flow to the side of the crest.

2. Do not set it immediately below or too close to a head gate where the water has high velocity, as by so doing, it will cause too high a velocity of approach.

3. Don't allow the water below the weir to back up even with the crest as it will not allow complete contraction and will cut down the discharge.

4. Do not set the weir any other way than perpendicular and at right angles to the flow of the stream.

5. Do not attempt to use too small a weir. Put in a larger weir where the water to be measured exceeds a depth on the crest of one-third the crest length.

6. Do not allow the pool above the weir to fill up with sediment, as the resulting decrease in the cross section will increase the velocity of approach.

WEIRS FOR LARGE STREAMS

It is frequently necessary to install a weir in a canal or stream carrying a considerable volume of water. In such cases it is usually best to install a permanent weir of concrete if conditions permit. Figure IV represents a type of concrete weir that is recommended for such locations.

The floor below the weir should be built of such size that it will amply protect the canal bed below the weir from erosion by the falling water, and care should be exercised that the ends of the concrete should project far enough into the banks to insure stability.

WEIR TABLE

The following table is based on the formula Q equals 3.367LH3-2 and has been calculated with depths reading in inches and fractions thereof rather than tenths of a foot, in order that the depths may be accurately read with an ordinary carpenter's rule or square.

DISCHARGE OF CIPPOLETTI WEIRS

Depth of water on Crest	1 Foot Weir		2 Foot Weir		3 Foot Weir	
	Second Feet	Miners Inches	Second Feet	Miners Inches	Second Feet	Miners Inches
inches						
1-4	.010	0.5	.020	1.0	.030	1.5
1-2	.029	1.5	.058	2.9	.087	4.4
3-4	.053	2.7	.106	5.3	.159	8.0
1.	.081	4.1	.162	8.1	.243	12.2
1-4	.113	5.7	.226	11.3	.339	17.0
1-2	.149	7.5	.298	14.9	.447	22.4
3-4	.188	9.4	.376	18.8	.564	28.2
2.	.229	11.5	.458	22.9	.687	34.4
1-4	.273	13.7	.546	27.3	.819	41.0
1-2	.320	16.0	.640	32.0	.960	48.0
3-4	.369	18.5	.738	36.9	1.107	55.4
3.	.421	21.1	.842	42.1	1.263	63.2
1-4	.474	23.7	.948	47.4	1.422	71.1
1-2	.530	26.5	1.060	53.0	1.590	79.5
3-4	.588	29.4	1.176	58.8	1.764	88.2
4.	.648	32.4	1.296	64.8	1.944	97.2
1-4	.709	35 5	1.418	70.9	2.127	106.4
1-2	.773	38.7	1.546	77.3	2.319	116.0
3-4	.839	42 0	1.678	83.9	2.517	125.9
5.	.906	45.3	1.812	90.6	2.718	135.9
1-4	.974	48.7	1.948	97.4	2.922	146.1
1-2	1.044	52.2	2.088	104.4	3.132	156.6
3-4	1.116	55.8	2.232	111.6	3.348	167.4
6.	1.191	59.6	2.382	119.1	3.573	178.7
1-4			2.531	126.6	3.796	189.8
1-2			2 684	134.2	4.026	201.3
3-4			2.841	142.1	4.261	213.1
7.			3.000	150.0	4.500	225.0
1-4			3.162	158.1	4.743	237.1
1-2			3.327	166.4	4.990	249.5
3-4			3.496	174.8	5.244	262.2
8.			3.664	183.2	5.496	274.8
1-4			3.838	191.9	5.757	287.9
1-2			4.014	200.7	6.021	301.1
3-4			4.192	209.6	6.288	314.4
9.			4.374	218.7	6.561	328.0
1-4			4.557	227.9	6.835	341.8
1-2			4.744	237.2	7.116	355.8
3-4			4.932	246.6	7.398	369.9
10.			5.124	256.2	7.686	384.3
1-4			5.316	265.8	7.974	398.7
1-2			5.510	275.5	8.265	413.3
3-4			5.709	285.5	8.563	428.2
11.			5.910	295.5	8.865	443.2
1-4			6.112	305.6	9.168	458.4
1-2			6.317	315.9	9.475	473.9
3-4			6.525	326.3	9.787	489.4
12.			6.734	336.7	10.101	505.0

METHOD OF USING WEIR TABLE

The head flowing over the crest should not be measured until after the water has been running a sufficient time so that a steady uniform flow is obtained. It can then be measured with an ordinary rule graduated in inches by holding the rule on top of the nail head and carefully observing where the surface of the water strikes the rule. Due allow-

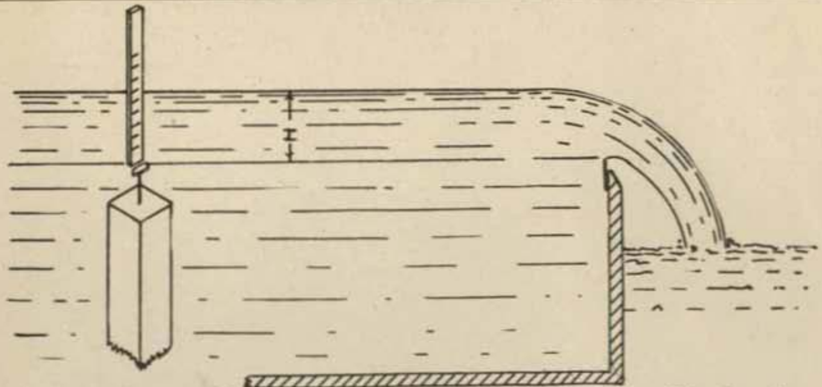

Fig. IV. Proper Method of Measuring Depth of Water Flowing Over Weir.

ance should be made for the capillary attraction which causes the water to creep up slightly on the sides of the rule. The eye should be held as nearly as possible to the level of the water's surface when reading the rule, in order to avoid the errors liable to occur where the same is observed from an angle. When the depth of water is noted, say 4 1-2 inches on a 1-foot weir, the column headed "1-foot weir" in the table should be used, the amount opposite the 4 1-2 inches, which is 0.773 cubic feet per second, or 38.7 miner's inches, is the correct discharge for that amount over a 1-foot weir. The same method is used with 2 and 3 foot weirs, care being used to read the amount from the proper column. Where weirs longer than 3 feet are required, the discharge can be calculated by multiplying the discharge for that depth on a 1-foot weir as taken from the table by the length of the larger weir in feet, as the discharge of weirs is always proportional to their length.

HYDRAULIC EQUIVALENTS WHICH WILL BE FOUND USEFUL TO IRRIGATORS

1. One Idaho miner's inch equals approximately 1-50 of a cubic foot per second, or 9 gallons per minute.
2. A cubic foot per second equals approximately 50 miner's inches, or 450 gallons per minute.
3. One cubic foot per second for 24 hours equals approximately 2 acre feet.
4. One cubic foot equals enough water to cover an acre exactly a foot in depth, or 43,560 cubic feet.
5. One miner's inch per acre for 100 days equals 3.97 feet deep on the land.
6. One miner's inch per acre for 150 days equals 5.95 feet deep on the land.
7. 5-8 miner's inch per acre for 100 days equals 2.48 feet deep on the land.
8. 5-8 miner's inch per acre for 150 days equals 3.72 feet deep on the land.
9. 1-2 miner's inch per acre for 100 days equals 1.98 feet deep on the land.
10. 1-2 miner's inch per acre for 150 days equals 2.98 feet deep on the land.