WEIRS FOR COMBINATION WATER CONTROL AND MEASUREMENT

by

E. Gordon Kruse

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The cost of structures needed for proper management of water on irrigated farms can be reduced if a single structure can be designed to perform more than one function. Structures that control the flow rate of water and simultaneously measure discharge are examples.

At least three types of structure are in use in the United States at the present time (1965) that perform the two functions mentioned above. The constant head orifice farm turnout [3/] [4/] and the Twin Falls headgate both use two gates in series, but in a single structure, to regulate the flow rate of water and to provide for orifice-type measurement. The adjustable Cipoletti weir is used by the U. S. Bureau of Reclamation to serve the same purposes. It consists of a sharp-crested Cipoletti weir constructed in the top

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1/ Contribution from Northern Plains Branch, Soil and Water Conservation Research Division, Agricultural Research Service, USDA, in cooperation with the Colorado Agricultural Experiment Station, CER65EGK25.

2/ Research Agricultural Engineer, USDA, Fort Collins, Colorado.

3/ Calibration of the constant head orifice turnout--one to two scale model, Hydraulic Laboratory Report No. 216, U. S. Bureau of Reclamation, Denver, Colorado, November 1946.

4/ Kruse, E. Gordon, The Constant-Head-Orifice Farm Turnout, ARS 41-93, Agricultural Research Service, USDA, January 1965.

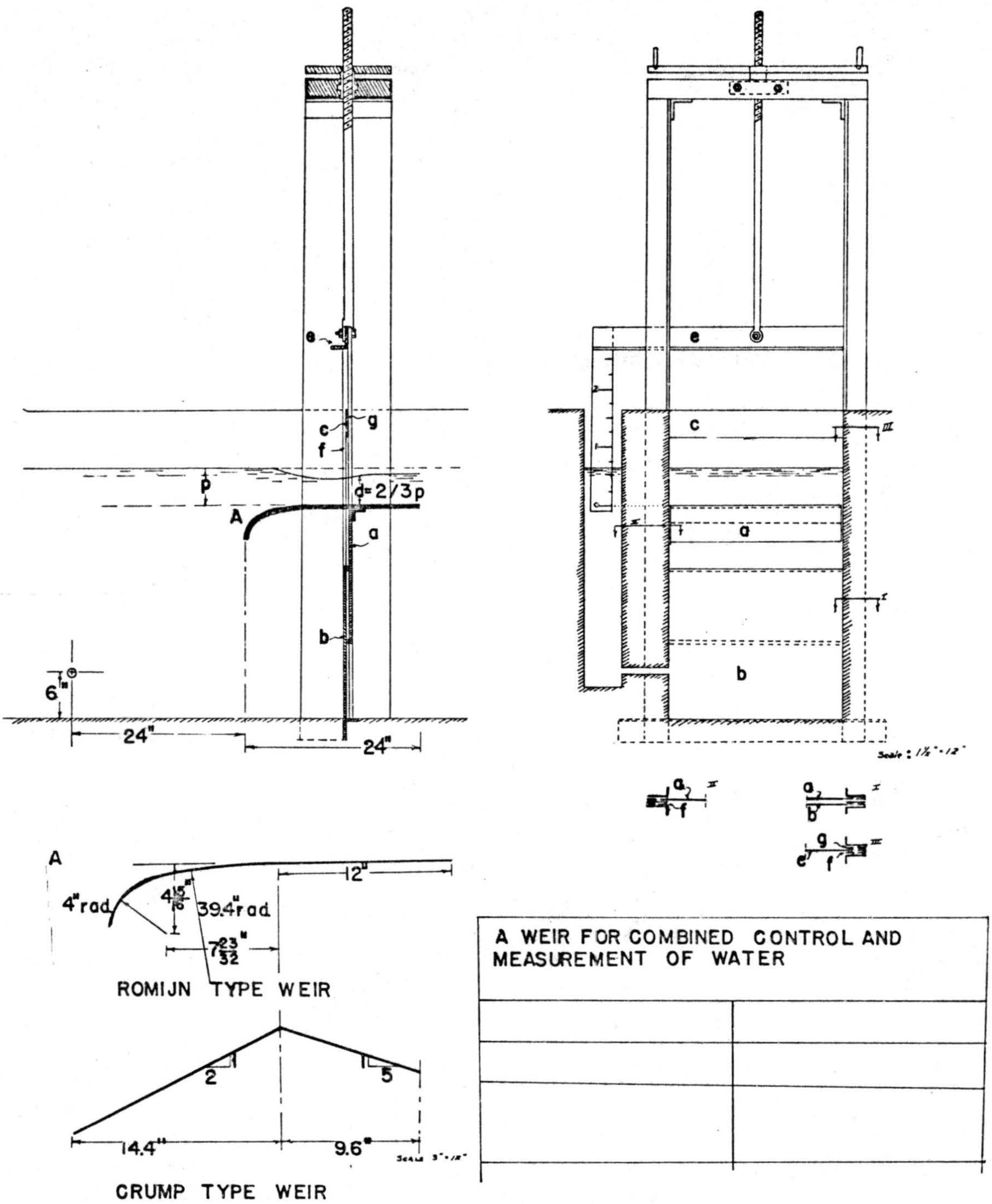
of a telescoping gate. Raising or lowering the gate controls the rate at which water overflows it. Discharge measurements are made in the same way as for a stationary weir. The adjustable Cipoletti weir is not suitable for submerged flow conditions.

A third type of structure for combined control and measurement of water is used in some parts of Asia and Europe. It is known as the Romijn weir and consists of a suppressed weir, not sharp crested, on top of a telescoping gate. [1/] [2/] Varying the elevation of the gate regulates the discharge. The weir crest extends across the entire width of channel and is therefore well adapted for use in rectangular channel cross sections.

The remainder of this report deals with the calibration and evaluation of the operating characteristics of such a structure with weirs of two different shapes--both possibly suitable for use as combination flow control and measuring devices. The difference in the two weirs is in the cross-sectional shape of the crest. One is very similar to the original Romijn weir; the other has the same proportions as the "Crump" weir, currently used in the British Isles. Figure 1 illustrates the shapes and dimensions of the two weirs studied.

1/ Bos, R. J., The Romijn Measuring Weir, International Organization for Standardization/T. C. 30/S. C. 1/W. G. 2, Netherlands, 1961.

2/ Draft Netherlands Proposal for an ISO Recommendation on the Measurement of Liquid Flow in Open Channels Using Broad-Crested Weirs, International Organization for Standardization, T. C. 113/W. G. 2, Netherlands, 1965.



e
c
g
f
p
d=2/3p
A
a
b
6"
24"
24"
c
a
b
e
Scale: 1½" = 12"
A
4"rad
$4\frac{15}{16}$"
39.4"rad
12"
$7\frac{23}{32}$"
ROMIJN TYPE WEIR
2
5
14.4"
9.6"
Scale 3" = 12"
CRUMP TYPE WEIR
A WEIR FOR COMBINED CONTROL AND
MEASUREMENT OF WATER

Figure 1.

Equipment and Procedure

The first weir studied, the Romijn weir, (Figure 1) has a rounded leading edge and a horizontal downstream section with an abrupt drop at the downstream edge. Dimensions of the weir are 24-13/32 inches in overall length and 24-1/8 inches wide. The second, to be referred to as the Crump weir, consists of two sloping plane surfaces. The upstream surface angles forward and downward at a slope of 2 horizontal to 1 vertical. The rear surface slopes sharply in the downstream direction at a slope of 5:1. Overall length of the Crump weir is 24 inches.

The weirs were studied in a 20-foot-long laboratory test channel having a nominal width of 2 feet. Water was circulated through the channel by pumping from a laboratory sump. A tank and baffle at the upstream end of the channel provided a smooth water surface at the upstream approach to the weir.

Flow rates were measured by means of a concentric $10\frac{1}{2}$-inch orifice in the 14-inch pipeline supplying the test channel. The orifice was previously calibrated volumetrically. At low flows, discharges were measured with a sharp-crested 90° V-notch weir.

The weir crests were fixed in position in the test channel during each series of runs. By adding shims, the elevations could be changed from one series of runs to the next.

A point gage, mounted on a movable carriage above the test channel, was used for measurements of the water surface and weir crest elevations. A slotted tailgate at the extreme downstream end of the channel allowed the tailwater elevation downstream of the weir to be adjusted to any desired level.

Each weir was set at the lowest elevation possible for the first run. This placed the Romijn weir crest 1.0 foot and the Crump weir crest 1.28 feet above the channel floor. Both free and submerged flows were then measured for a range of upstream water surface elevations. Degree of submergence was controlled by varying the tailgate. The weir crest was then raised to a higher position and the series of flow measurements repeated. The highest weir crest elevations studied were 2.17 feet and 1.55 feet for the Romijn and Crump weirs, respectively.

Point gage determinations of the water surface elevation at a distance of 1.0 foot upstream from the leading edge of the weir were used to plot calibration curves of head versus discharge. The water surface elevation at this location varied by not more than 0.001 foot from the elevation in the next 2-foot reach upstream. In addition a piezometer opening was located at various positions upstream of the weir in order to define the locations at which the piezometric head readings would accurately reflect direct water surface elevation readings. The piezometer was connected to a stilling well where water surface elevation was read with a hook gage.

Results

Romijn Weir

A graph of free flow discharge over the Romijn weir is shown in Figure 2. Values of head used for this plotting were taken by point gage 1 foot upstream from the front edge of the weir and are referenced to the elevation of the weir crest. Figure 2 includes data for five different weir elevations relative to the channel bottom. The calibrations for all weir elevations are represented by a single line.

Reductions in discharge caused by varying degrees of submergence are indicated in Figures 3 and 4. In Figure 3 submergence is measured by the ratio of h_3/h_1 where h_3 is the minimum water surface elevation just downstream of the weir and h_1 is the upstream head, the same value used to determine free flow discharge.

A similar relationship between discharge reduction and submergence is shown in Figure 4 where submergence is characterized by the ratio h_4/h_1. The value h_4 represents the average water surface elevation through the rollers in the first 2 feet downstream of the weir. Elevation at the recommended location, just downstream of the disturbed water surface, could not be obtained because of lack of adequate channel length. The recommended elevation should be closely approximated by h_4, however.

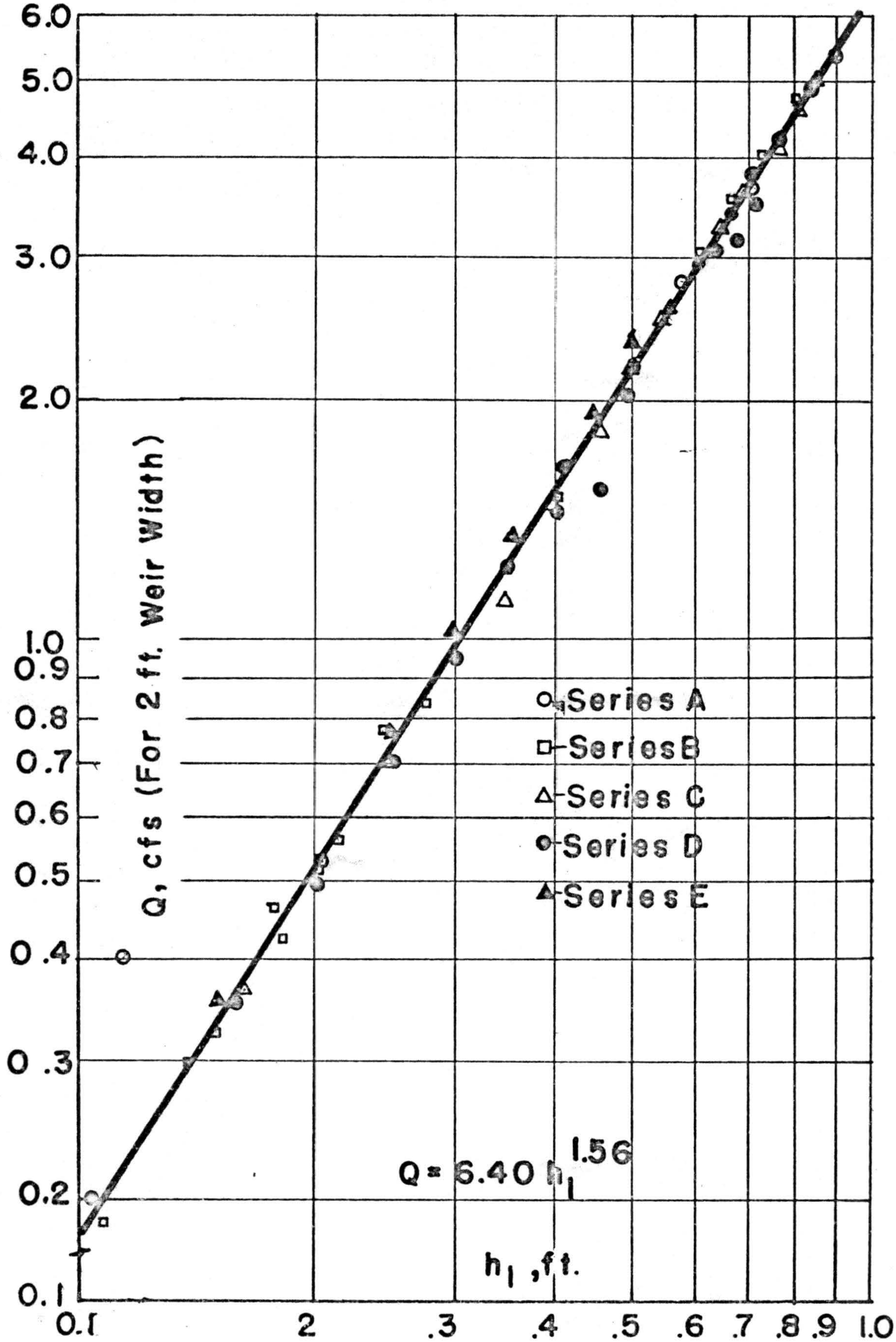


Figure 2. Calibration curve for 2-foot Romijn type weir.

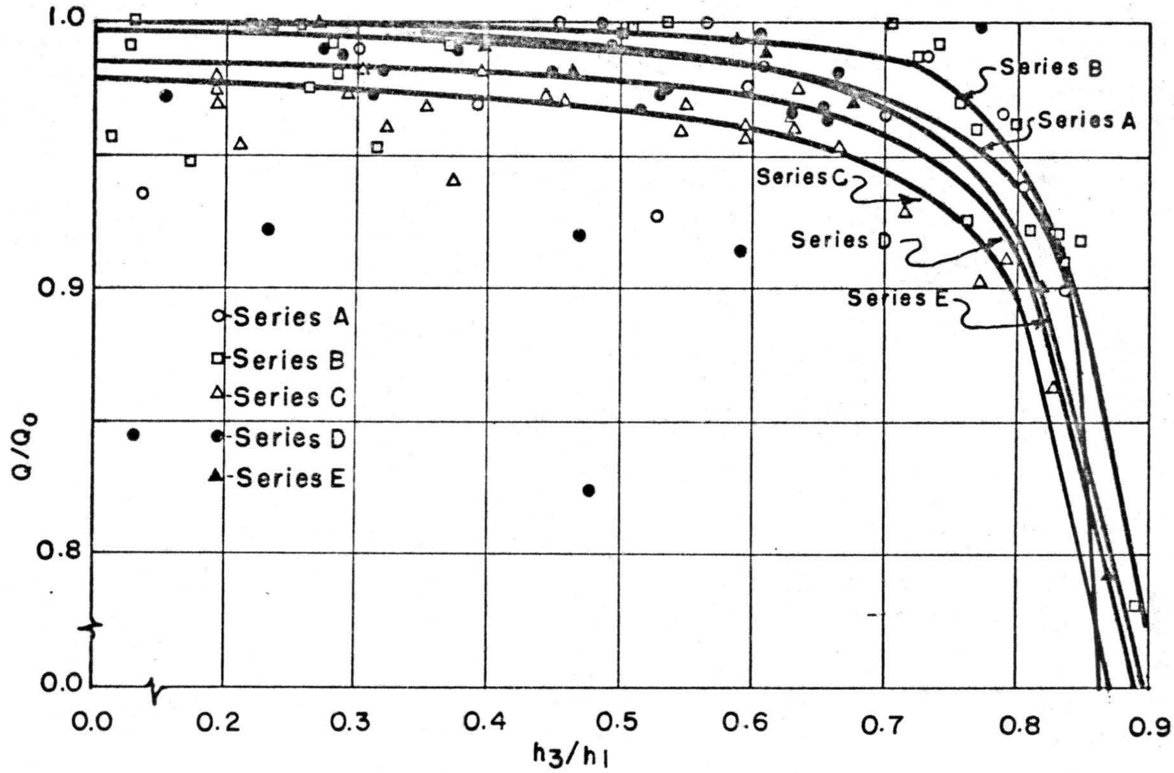


Figure 3. Submergence correction for Romijn type weir using h_3 stage reading.

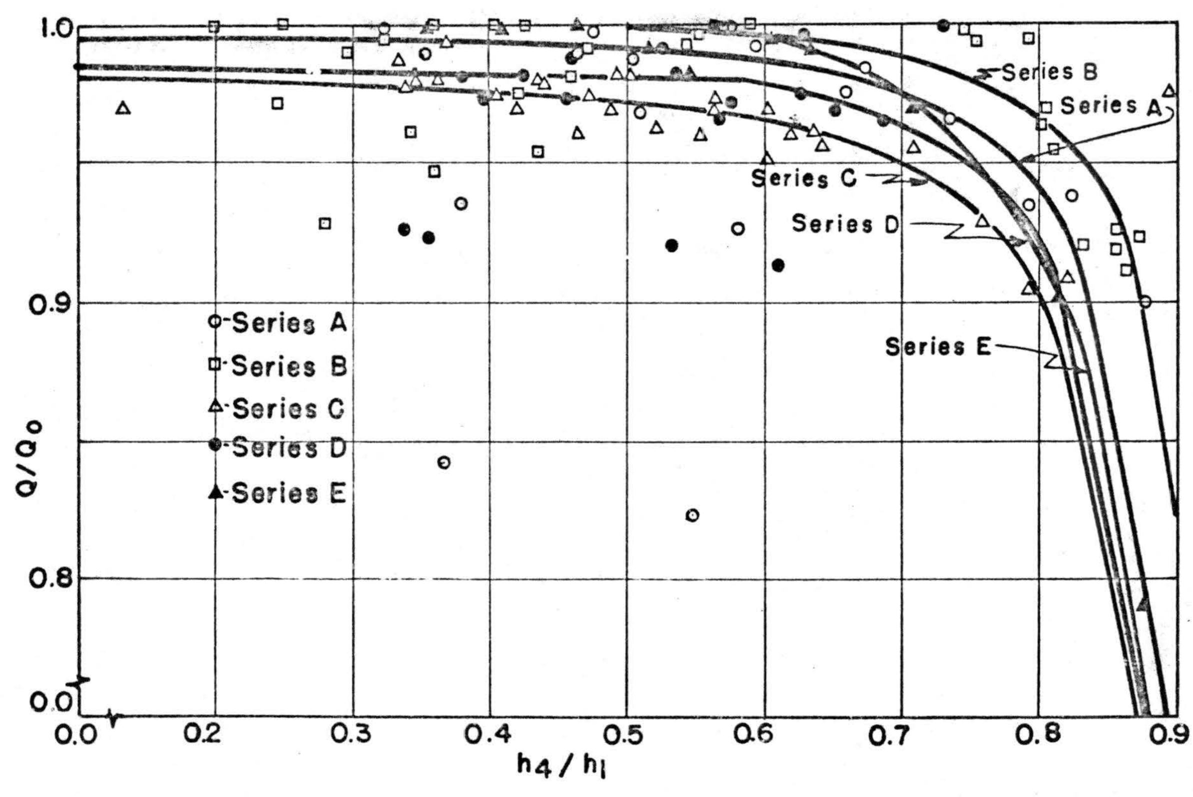


Figure 4. Submergence correction for Romijn type weir using h_4 stage reading.

Crump Weir

The head-discharge rating curve for free flow over the Crump-type weir is shown in Figure 5. Values of head, h_1, were again measured by point gage one foot upstream of the leading edge of the weir. The data points on Figure 5 represent two different elevations of the weir crest.

Figures 6 and 7 show the relation of degree of weir submergence and discharge reduction. Submergence ratios h_3/h_1 and h_4/h_1 are defined in the same way as for the Romijn-type weir.

Discussion

The relation between head and discharge under free flow conditions can be represented by a straight line on log-log graph paper for both the Romijn- and Crump-type weirs. For the Romijn type the formula expressing the relationship is $Q = 6.40h_1^{1.56}$. Discharge for the Crump-type weir is expressed by $Q = 7.26h_1^{1.486}$. The single formula is adequate for all values of weir elevation for the Romijn-type weir and for the Crump-type weir when values of h_1 are greater than 0.40 foot. At lower head values some divergence is evident for different weir elevations. For accurate discharge measurements a separate rating curve should be used for each weir elevation above the channel floor.

In using Figures 2 and 5 or the rating equations, it should be remembered that discharge values are for a 2-foot weir width. The discharge values could be extended to wider weirs of the same shape

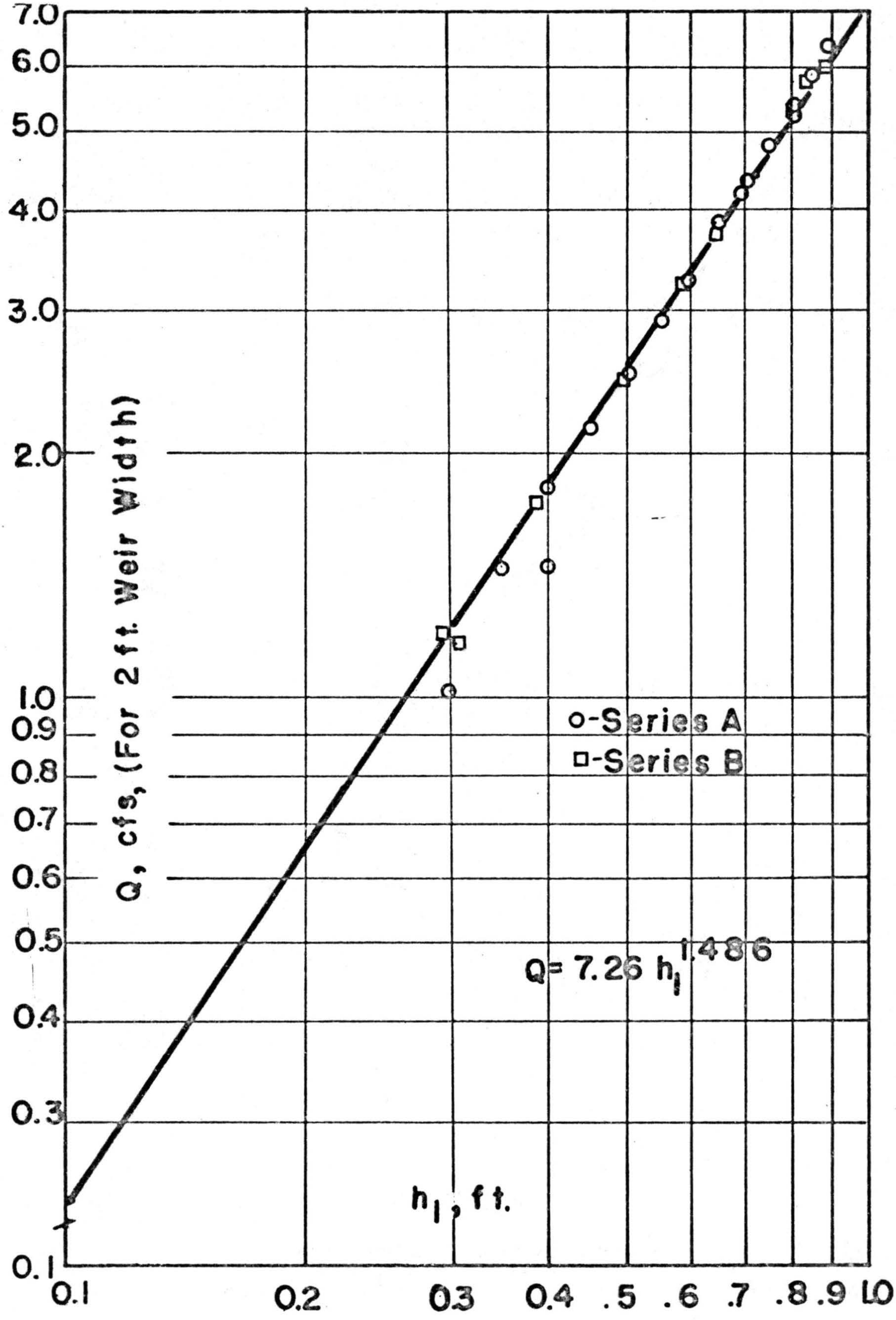


Figure 5. Calibration curve for 2-foot Crump type weir.

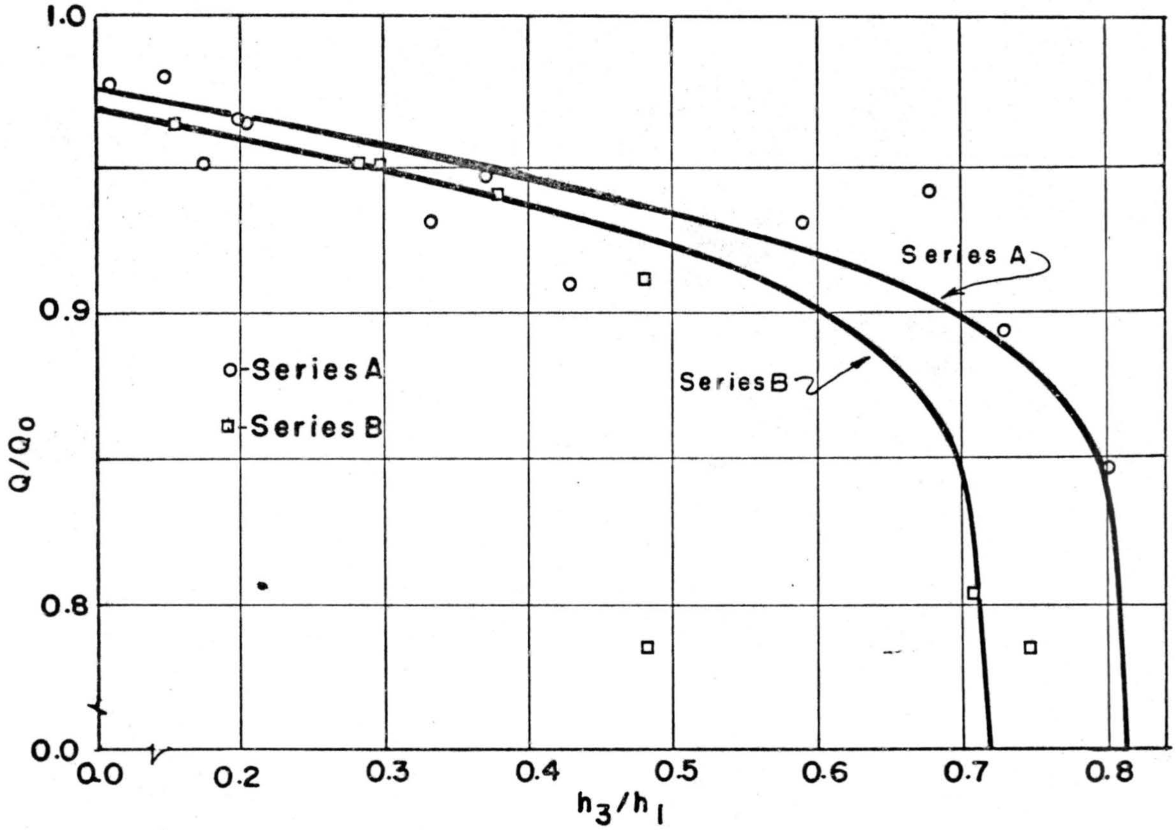


Figure 6. Submergence correction for Crump type weir using h_3 stage reading.

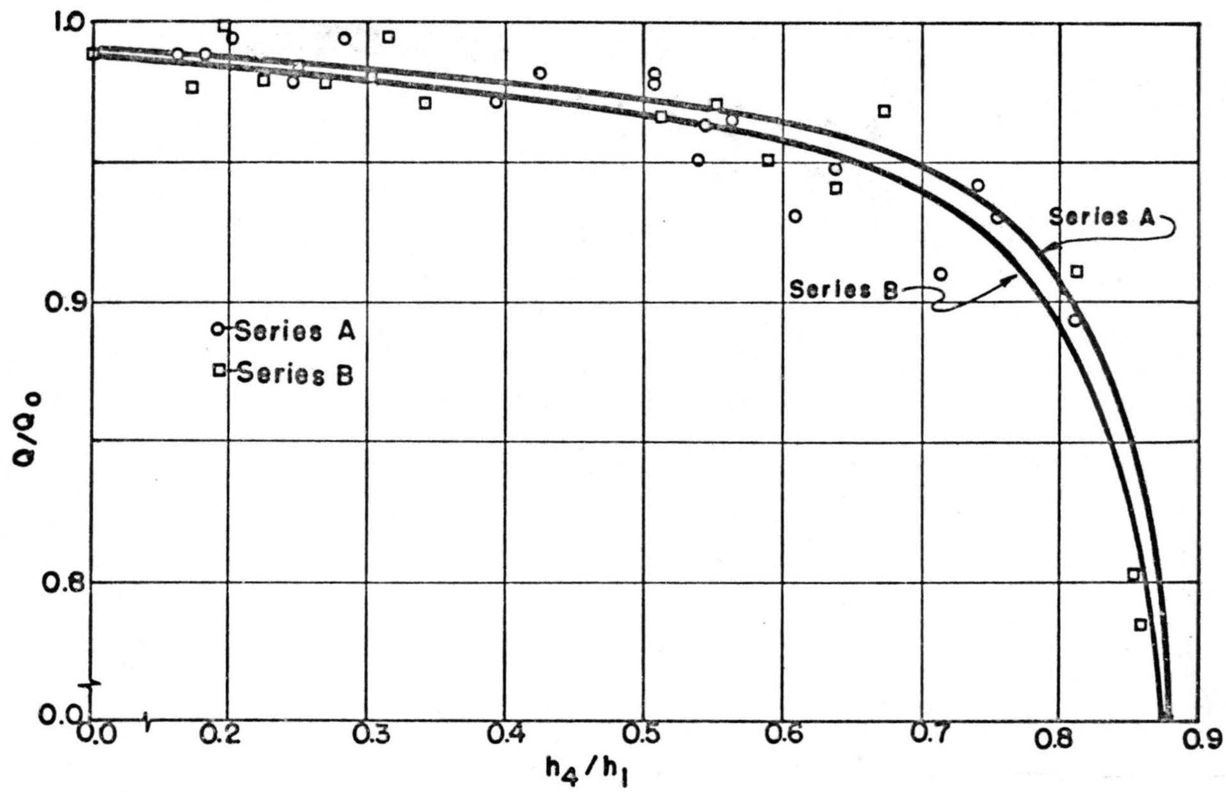


Figure 7. Submergence correction for Crump type weir using h_4 stage reading.

with little loss of accuracy, especially at the lower head values. However, for narrower weirs, where sidewall effects might be important, independent ratings should be obtained.

Submergence

Weir submergence occurs when the water surface elevation downstream of the weir is greater than the weir crest elevation. Submergence reduces the effective head causing flow over the weir, and therefore reduces discharge from comparable free flow conditions. For low values of submergence this discharge reduction may be so slight as to be negligible. For higher submergence, free flow discharge values must be corrected if accurate results are to be obtained. When weir submergence is great enough to significantly affect discharge, two water surface elevation readings, one upstream and one downstream of the weir, are required for accurate determination of the discharge. Thus a weir for which the rating follows the free flow relationship over a large operating range of submergence is advantageous in that head readings need to be taken at only one position, that designated by h_1.

In Figures 3, 4, 6, and 7, submergence corrections for both types of weirs are plotted as Q/Q_o versus h_3/h_1 or h_4/h_1. Discharge is determined after values of h_1 and h_3 or h_4 have been measured, as follows: First the discharge corresponding to h_1 under free flow conditions is determined from the free flow rating curve. This discharge is Q_o. Then the submergence ratio,

h_3/h_1 or h_4/h_1 is computed and the value of Q/Q_o corresponding to this ratio is obtained from the figures. The true discharge occurring under submerged conditions, Q, is then equal to $Q/Q_o \times Q_o$.

The limiting submergence above which discharge corrections must be made depends on the desired accuracy of the discharge measurement. Assume that for farm usage, discharges must be accurate to within 5 percent. From Figures 3 and 4, the limiting submergence h_3/h_1 or h_4/h_1 for the Romijn weir can be seen to be 0.7. For lower submergence the upstream head reading will be sufficient to determine discharge. Figures 6 and 7 indicate limiting values of h_3/h_1 of 0.35 and h_4/h_1 of 0.50 for the Crump weir. Accurate discharge measurements using only h_1 are difficult to obtain with this weir unless submergence is low.

In many irrigation systems low head losses in all structures and conveyance channels are desirable so that a maximum amount of land can be served from a given source of water. Operating all measuring weirs and flumes submerged may preserve head in the system. For example, with a head, h_1 of 1.0 foot on the Romijn weir and 0.7 submergence (h_4/h_1) only 0.3 foot of head loss occurs through the structure.

Piezometer Location

In the original version of the Romijn weir a stilling well is often connected hydraulically to the channel just upstream of the weir. The upstream head, h_1, on the weir can be determined from the water surface in the well. If the scale used in the well is fastened rigidly to the movable weir crest and the zero point elevation of the scale coincides with the crest elevation of the weir, the upstream head can be read directly, or the scale can be calibrated in terms of discharge rate.

During several of the experimental runs a piezometer opening was located in the wall of the channel upstream of the weir and connected to a stilling well by a length of tubing. The location of the opening was varied to define the range of locations where the head indicated in the stilling well corresponded to the water surface elevations used to calibrate the weir. A piezometer opening located 0.50 foot above the floor of the channel and 2.0 feet upstream from the leading edge of the weir appears satisfactory.

Comparison with Other Data

The results of weir calibrations by Bazin are reported by King.[5/] Values are given for C in the formula $Q = CLH^{1.5}$. For level broadcrested weirs with the upstream corner rounded to a radius of 0.33 ft., a weir breadth of 2.62 feet and height of 2.46 feet, Bazin found C values ranging from 2.93 to 3.01 feet for heads varying from 0.4 to 1.0 foot. For weirs having a breadth of 6.56 feet, C values were lowered from 4 percent to 8 percent at comparable heads.

5/ King, H. W., Handbook of Hydraulics, Third Edition, McGraw Hill, New York, 1939.

King also provides C values for triangular weirs having equal upstream and downstream slopes of 2 horizontal to 1 vertical. For heads from 0.2 to 1.0 foot, C values vary over a range from 3.81 to 3.88.

The values given by King are comparable on a unit width basis to those obtained in the present study.

Conclusions

Weirs of the type studied, mounted on telescoping gates, should be suitable for combined measurement and control of irrigation water in many instances. Measurement accuracy is acceptable and submergence effects are small using the Romijn-type weir crest. A lined, rectangular channel section is necessary at the weir location. When the flows carry large amounts of suspended sediments, a structure of this type may not be feasible because of deposition of solids in the low flow velocity area just upstream of the gate.

The Romijn-type weir seems to be superior to the Crump weir for water measurement. The two main advantages are a constant rating for different crest elevations and toleration of a high degree of submergence without deviation from the free flow rating.

Submergence of the weir should be measured as the ratio of h_4 to h_1. A mean line through the points in Figure 4 should provide suitable accuracy in making discharge correction for most farm usage.

Summary

Two shapes of weir crests were evaluated with regard to their suitability as combination flow measurement and control devices. One, similar to the European "Romijn Weir", has many desirable characteristics for farm measurement of irrigation water. The Romijn-type weir has a single rating curve over a range of crest elevations (necessary for a control device) and will operate under a high degree of submergence without deviation from the free flow rating.

Calibration curve and submergence corrections are presented for both weir shapes evaluated.