TRAPEZOIDAL FLUMES FOR MEASURING DISCHARGES IN IRRIGATION CHANNELS

by

E. Gordon Kruse

CER64EGK14

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E. Gordon Kruse

Northern Plains Branch
Soil and Water Conservation Research Division
Agricultural Research Service
U. S. Department of Agriculture
Fort Collins, Colorado

in cooperation with

Civil Engineering Section
Colorado State University
Fort Collins, Colorado

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E. Gordon Kruse[2/]

A measuring flume of trapezoidal cross section (1,2,3) has been developed in recent years that has several advantages over other traditional measuring devices. The flume is extremely versatile and has been adapted for use from measuring a few gallons per minute in individual irrigation furrows to measuring runoff in steep mountain streams.

Another advantage of the trapezoidal measuring flume is the ease with which it may be constructed. The entire floor of the structure forms a single, plane surface. The trapezoidal cross-section corresponds closely to the form of many ditches where it may be installed without construction of extensive transition section. For these reasons it is thought that the flume might be very useful for water measurement in farm irrigation laterals, either earth ditches or concrete-lined channels of trapezoidal section. For earth ditches, semi-permanent flumes of galvanized steel sheets are available. For lined channels the flumes can be cast in place at the time of lining or temporary inserts of sheet metal or other material can be placed in the ditch at any desired location.

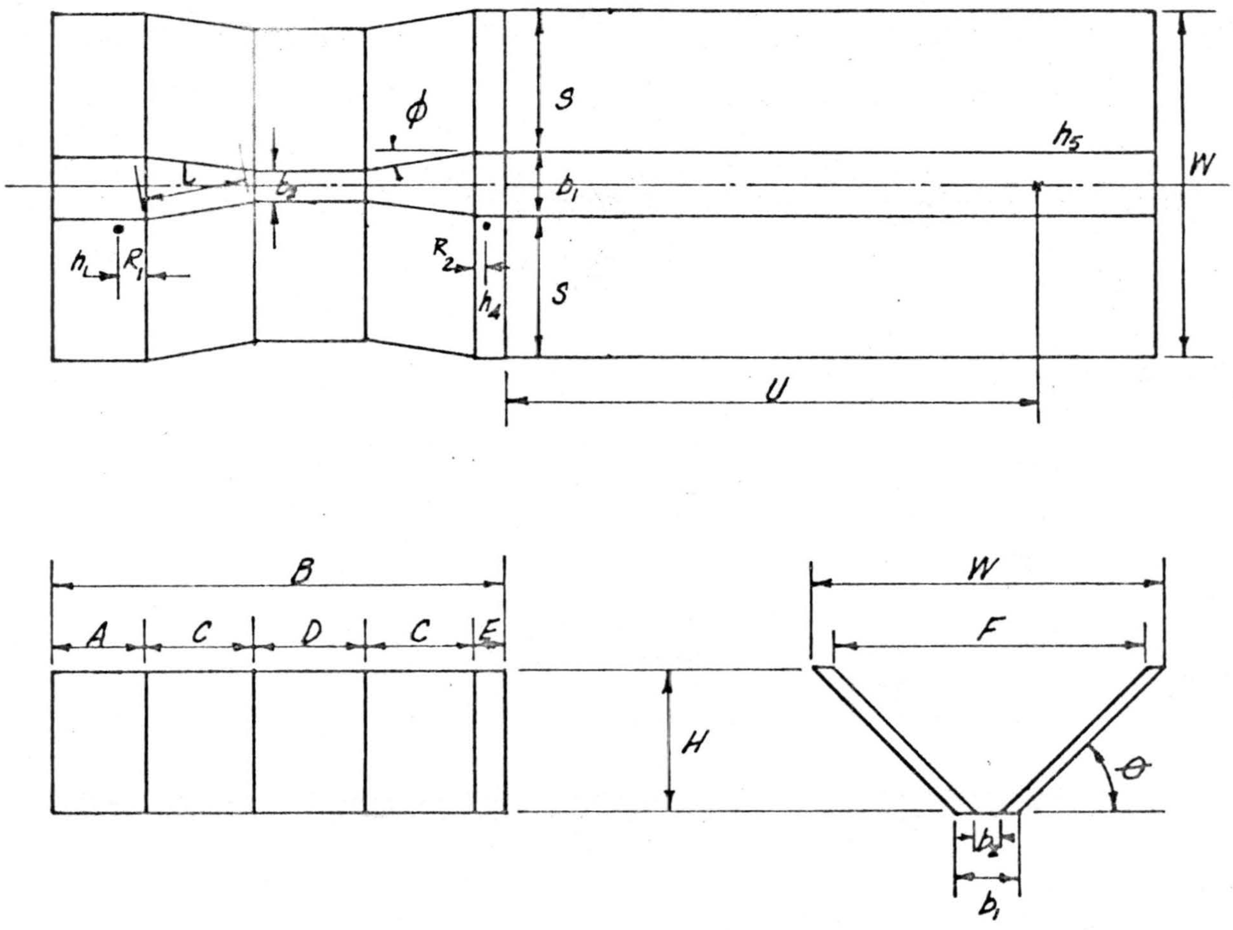
1/ Contribution from Soil and Water Conservation Research Division, Agricultural Research Service, USDA, in cooperation with the Colorado Agricultural Experiment Station.

2/ Agricultural Engineer USDA, Fort Collins, Colorado.

This report presents the results of calibrations on flumes adapted for two sizes of trapezoidal channel. The first has 1 on 1 side slopes and a bottom width of 1.0 foot. Flumes with a throat width of 0.4 feet and 12-inch and 22-inch throat lengths were built and rated for this channel. Robinson initially calibrated flumes with 0.4 and 0.6 foot throat widths for this channel in 1962. Flumes for a channel with side slopes of 1(horizontal) to 2(vertical) and bottom width of 1.5 feet were also rated. These flumes had throat widths of 0.6 foot and 0.9 foot. These channel dimensions are the same as those of two commonly used concrete-lined ditches constructed with slipform equipment.

The several designs of the flumes are given in figure 1. In this figure the places where depths were measured are also indicated (h_1, h_4, and h_5).

The flumes were installed in a 4-foot test channel for calibration and leveled both laterally and longitudinally. An approach channel of the same cross-sectional shape as the entrance of the flume was installed for a distance of 16 feet upstream. Discharges were checked by a $10\frac{1}{2}$-inch orifice in the line supplying the test channel. This orifice had been previously calibrated with a volumetric tank.

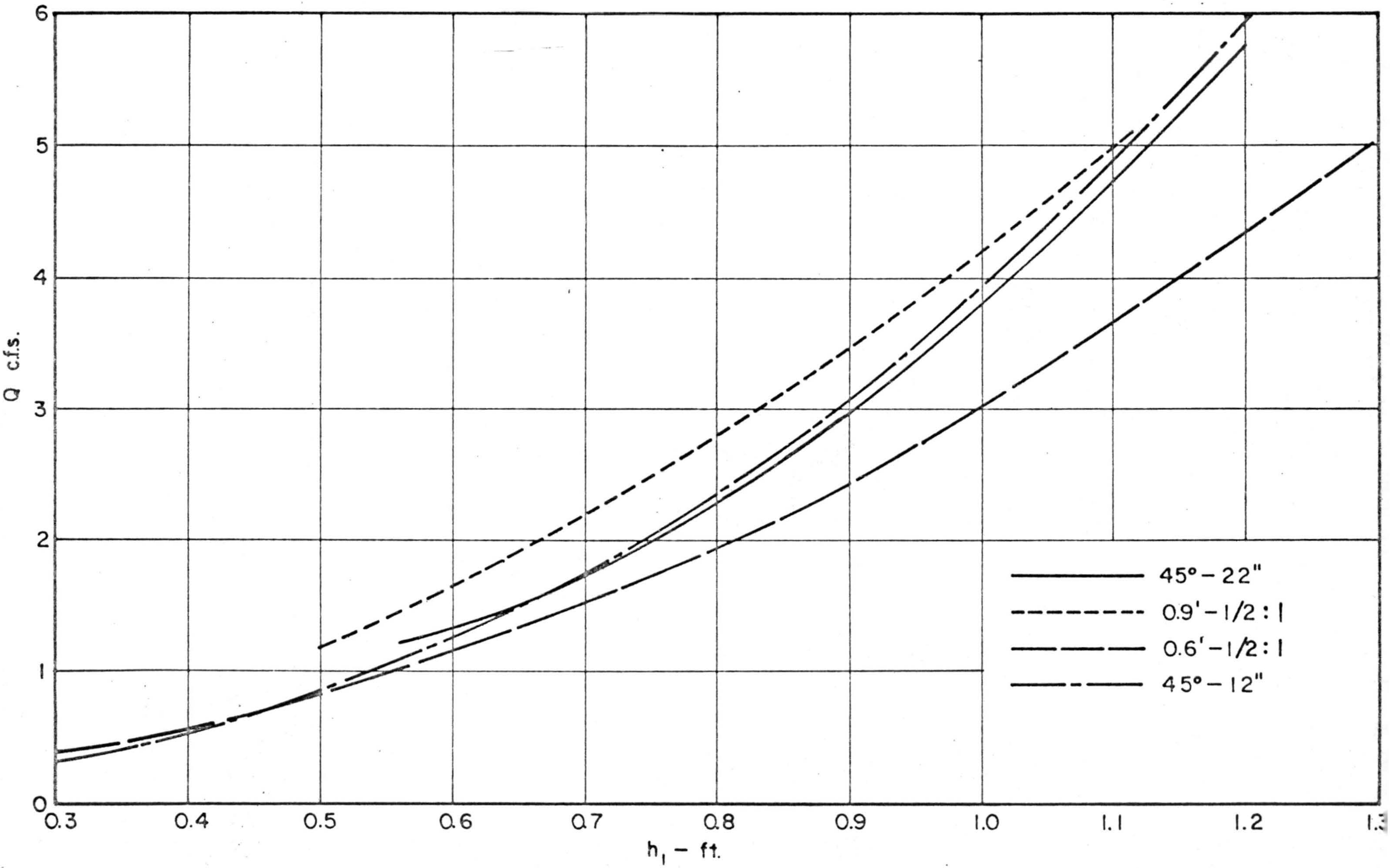


Flume No.	Description	b_1	b_2	A	L	C	D	E	F	H	B	R_1	R_2	S	U	W	θ	ϕ
1	45°-12"	12	$4\frac{13}{16}$	12	$17\frac{7}{16}$	$17\frac{1}{16}$	12	6	$36\frac{13}{16}$	16	$64\frac{1}{8}$	$1\frac{3}{4}$	$\frac{3}{4}$	16	72	44	45°	11.9°
2	45°-22"	12	$4\frac{13}{16}$	12	$17\frac{7}{16}$	$17\frac{1}{16}$	22	6	$36\frac{13}{16}$	16	$74\frac{1}{8}$	1	$\frac{3}{4}$	16	60	44	45°	11.9°
3	0.6'-1:2	18	$7\frac{3}{16}$	12	$17\frac{29}{32}$	$17\frac{1}{16}$	22	6	24	$16\frac{13}{32}$	$74\frac{1}{8}$	1	1	$8\frac{13}{32}$	60	$34\frac{13}{16}$	63.43°	17.6°
4	0.9'-1:2	18	$10\frac{13}{16}$	12	$17\frac{7}{16}$	$17\frac{1}{16}$	22	6	$27\frac{5}{8}$	$16\frac{13}{32}$	$74\frac{1}{8}$	$1\frac{1}{2}$	1	$8\frac{13}{32}$	60	$34\frac{13}{16}$	63.43°	11.9°

Figure 1. Design Drawings of Trapezoidal Flumes for Slipform Concrete Ditches.

The depth measured at h_4 has been used as an indication of submergence in previous studies as this is the practical point of measurement for field applications. However, the velocity head gained in the throat section has not yet been completely reconverted to potential head at the h_4 point. Therefore, in these studies an additional reading, h_5, was taken several feet downstream of the flumes. The location of h_5 was selected so that it would reflect the complete recovery of the potential head but yet be close enough to the flume so that friction losses between the h_4 and h_5 points would not be significant. To provide a smooth water surface for reading h_5, an overflow tailgate was installed at the downstream end of the test channel. Height of this tailgate was varied to provide different degrees of submergence in the flume.

The first objective of the study was to find the discharge as a function of the upstream head, h_1. The results are given in figure 2. Another purpose of the study was determination of the influence of the downstream submergence on the discharge. The downstream submergence is defined as the ratio of h_4 to h_1 or h_5 to h_1, where h_1, h_4 and h_5 are depths measured at points indicated in figure 1. The influence of submergence on discharge measurements is shown in figures 3 and 4. In these figures, Q is the discharge occurring at the indicated degree of submergence while Q_o' is the free flow discharge corresponding to the observed value of h_1.



Q c.f.s.
0
1
2
3
4
5
6
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
h_1 – ft.
45° – 22"
0.9' – 1/2 : 1
0.6' – 1/2 : 1
45° – 12"

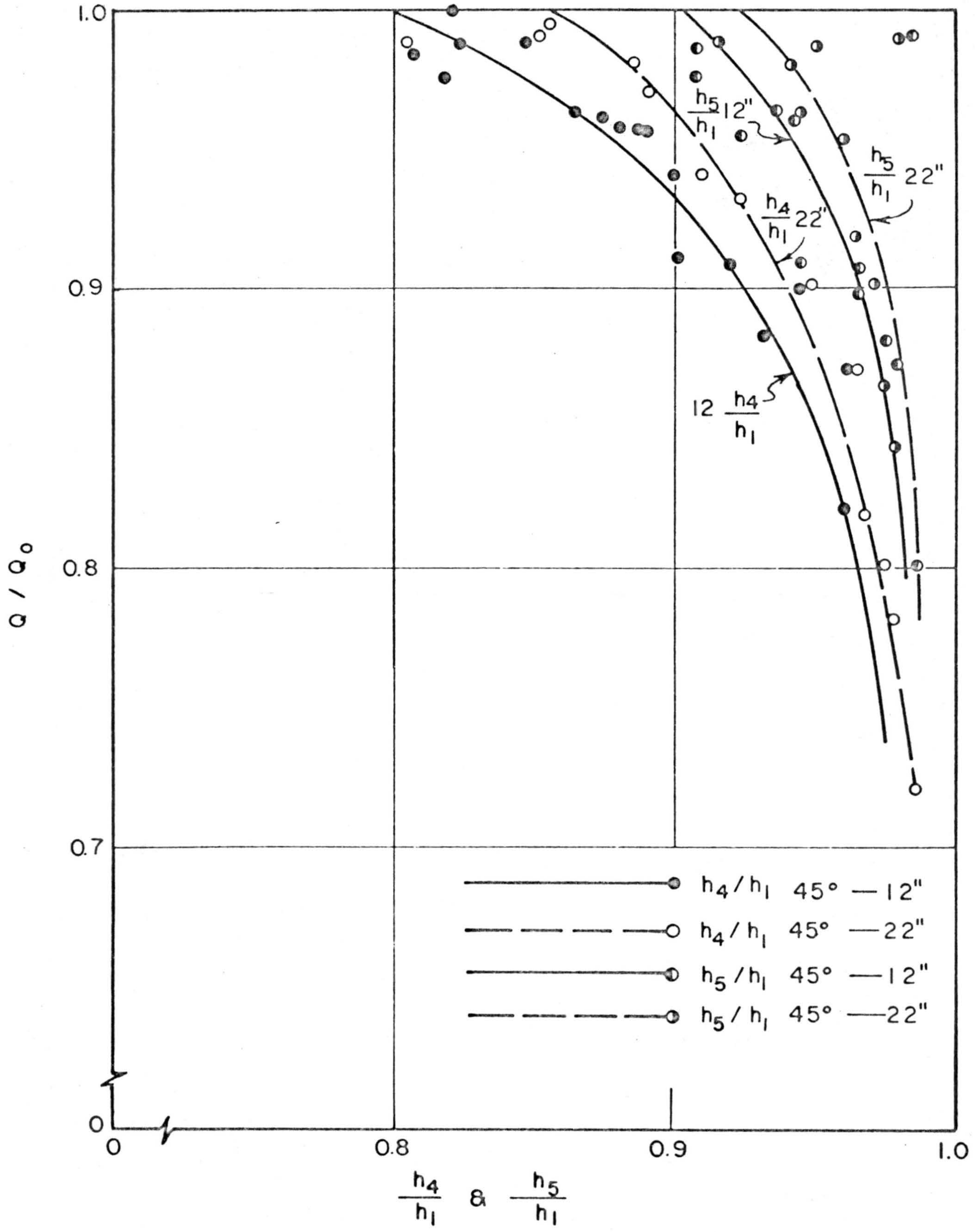


Figure 3. Influence of Flow Submergence on Discharge of Trapezoidal Measuring Flumes.

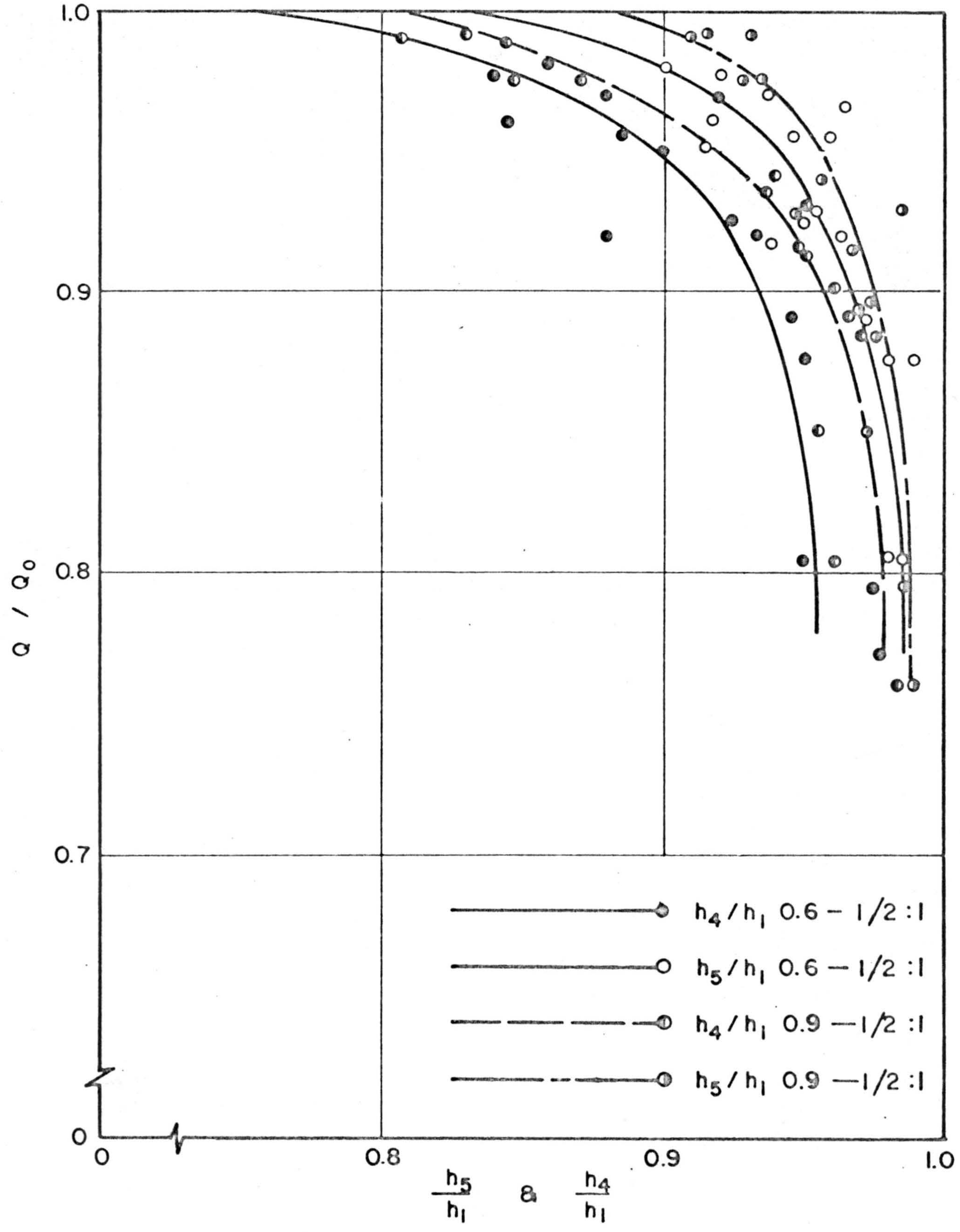


Figure 4. Influence of Flow Submergence on Discharge of Trapezoidal Measuring Flumes.

The maximum total head loss when the effect of the downstream submergence on the discharge is not greater than 5 percent was also calculated, figure 5. The total headloss is equal to $h_1 - h_5$.

Discussion. One advantage of a flume of trapezoidal cross section is the large range of flows that can be measured for given minimum and maximum depths. In this study the flumes were calibrated for discharges from 0.3 to 6.0 cfs. As shown in figure 2, the flume with the steeper side wall slopes (1:2) has the lesser capacity although the throat widths are considerably greater than for the 1:1 side slope flumes.

The flume with 1:2 side walls was rated for two different throat contractions: 1.5 to 0.60 and 1.5 to 0.90 , respectively. The flume with the wider throat will pass higher discharges at the same depth. For instance, with free flow conditions and $h_1 = 1.2$ feet, the discharges are 5.75 and 4.30 cfs. for the 0.90 and 0.60 foot flumes, respectively. Thus the flume with the wider throat has the advantage of requiring less depth of ditch upstream for a given discharge. However, the wider throat may not serve as a positive control at low flows. There was some evidence that flow did not pass through critical depth for flows less than 1.5 cfs., for the 0.9 throat width. If low flows are anticipated, then the flume with 0.60 foot throat width should be used.

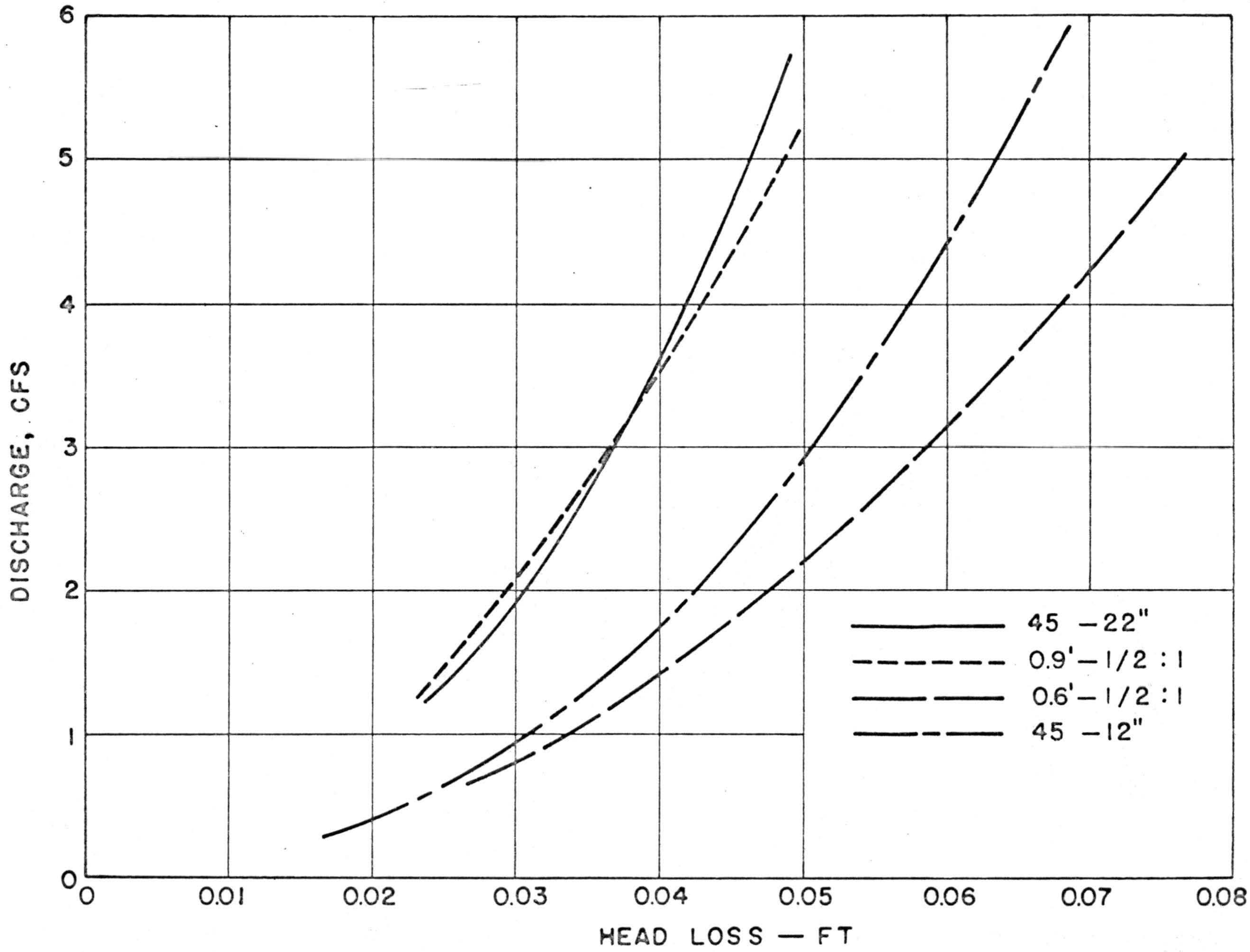


Figure 5. Head Losses Through Trapezoidal Flumes At Submergence Causing Five Percent Reduction From Free Flow Discharge

The effects of flume submergence on the reduction in discharge are shown in figures 3 and 4. The effect of the point of measurement of the downstream head was determined as well as the effect of the throat length. It is shown in figure 3 that the necessary discharge correction for the 45^{o} flume with 22-inch throat length is less than that for the flume with 12-inch throat length for a given degree of submergence, measured either as h_4/h_1 or h_5/h_1 . This phenomena was observed earlier by Robinson on similar flumes except with 0.6 foot throat widths. The figures also show that when the submergence is measured by h_5/h_1 the necessary correction of the free flow discharge is less than for the same submergence measured by h_4/h_1 . This is a result of the greater recovery of potential energy at the h_5 measuring point.

To make a discharge measurement in the field for submerged flow conditions, h_1 and h_4 are measured and recorded. The value of Q_o corresponding to h_1 is taken from figure 2. The value of Q/Q_o corresponding to the ratio h_4/h_1 is selected from figure 3. The actual discharge through the flume, Q , is then equal to $Q_o \times Q/Q_o$.

In many field installations it is desirable to minimize head losses in the water conveyance system. In these situations, the measuring flume should be designed and placed so that the difference in water surface at the h_1 and h_5 gages is as small as possible. This can be done by operating the flume at a high degree of submergence. Note that the head loss, $h_1 - h_5 = h_1 - \frac{h_5}{h_1} h_1 = h_1 (1 - \frac{h_5}{h_1})$. Discharge corrections may be necessary for flow under such submerged conditions.

In figure 5 the minimum head losses are plotted versus the discharge for the case where Q/Q_o is 0.95. In other words, these are the minimum head losses for cases where the h_1 reading alone can be used to determine discharge with errors less than five percent. For example, for the 45^o-0.4-foot flume with 12-inch throat length, when $Q/Q_o = 0.95$, $h_5/h_1 = 0.943$. The head loss then equals $h_1(1 - 0.943) = 0.057h_1$.

Head losses can be computed in a similar manner for any other degree of submergence; for conditions where discharge corrections might or might not be considered necessary. For instance, flow measurements with an accuracy of $\pm$ two percent may be desired. In this case the limiting submergence, without discharge corrections for the 45^o-0.4-foot, 12-inch flume is 0.922. The head loss can again be computed if the value of h_1 is known.

In designing and using the flume, the h_4 measuring point will be used to measure submergence and correct the discharge, because it is actually in the flume section and piezometer taps or staff gages can be installed when the flume is constructed. However, the reading h_5 is more useful in determining the total head loss through the flume.

Conclusions. 1. The use of trapezoidal measuring flumes for lined irrigation ditches should result in easy, accurate measurements of a wide range of discharges.

2. The flumes can be used with submergences up to 90 per cent with no discharge correction and rating will be correct within two per cent.

3. Lengthening the throat length (up to 22 inches) reduces the necessary discharge correction for a given degree of submergence.

4. Head loss through the flumes may be held to a minimum by operating at a high degree of submergence.

Acknowledgments

This study was a continuation of a project on design and calibration of trapezoidal flumes directed by A. R. Robinson. The flume for the one-foot, 1:1 channel with 0.4 x 1 foot throat was the same one studied by Robinson. Results of Robinson's work have not yet (March, 1964) been published.

Mr. Hans Kaag, a graduate assistant in Civil Engineering, Colorado State University, obtained the calibration data reported and assisted in its analysis.

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