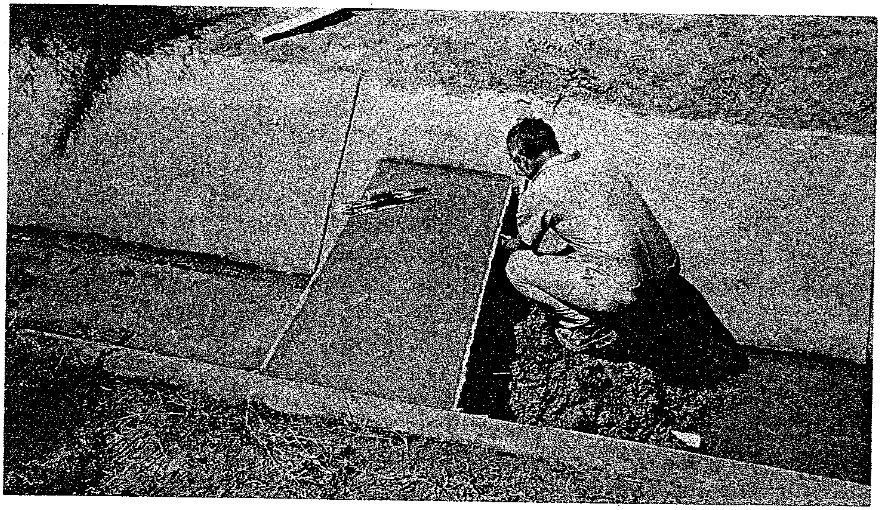
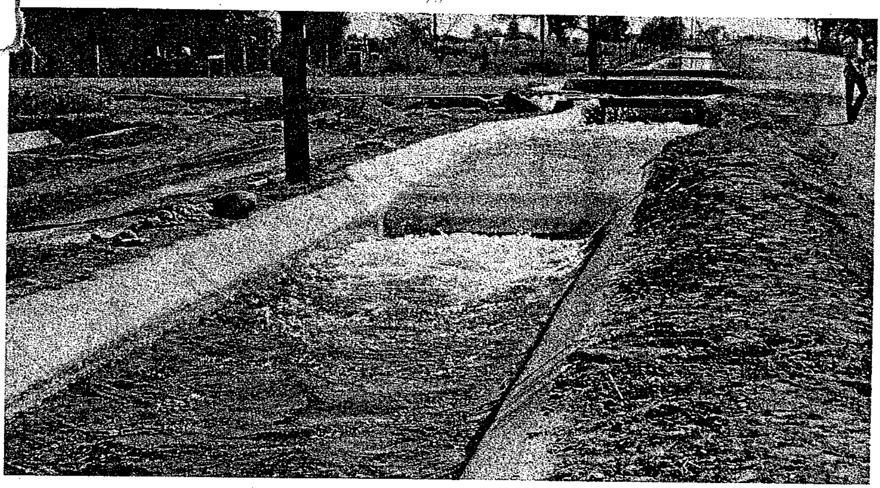
Constructing Simple Measuring Flumes For Irrigation Canals





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Constructing Simple Measuring Flumes For Irrigation Canals

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Introduction

Poor irrigation water management causes many serious water-supply and water-quality problems. Farmers and other water users are being encouraged to develop their own water management plans or improve existing ones. A major step in implementing any plan is measuring the amount of irrigation water applied. Correct application depends on accurate discharge rate information, both for the main irrigation stream entering the field and for runoff leaving the field.

Typical water-measuring devices—sharp- and broad-crested weirs and flumes such as the parshall, cutthroat, and short- and long-throated trapezoidal that are used in open channels or ditches—are cumbersome and expensive. Since most of these measuring devices require laboratory calibration, flumes used in the field are limited to the particular shapes and sizes for which these calibrations are available.

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Any deviation in the field-constructed flumes or weirs from the exact dimensions of the laboratory-calibrated devices may cause the depth-discharge relationship (rating curve) to change and often requires the new as-built flume to be duplicated and recalibrated in the laboratory. This strict dimensional requirement makes most flumes difficult and costly to construct. Another disadvantage of weirs and conventional flumes is the amount of head loss (or water depth change) necessary to obtain a valid measurement of water flow rate.

A new style flume that is simply constructed has been developed that eliminates most of the problems connected with other flumes. The rating curves for these flumes are derived from a laboratory-tested mathematical modeling technique which can be used because the flume has a control section (flume throat) that is long enough to cause nearly parallel flow. The resulting flow properties make it possible to design flumes that cause very low head losses, yet produce accurate discharge measurements. The mathematical model can be used to determine changes in discharge rate that

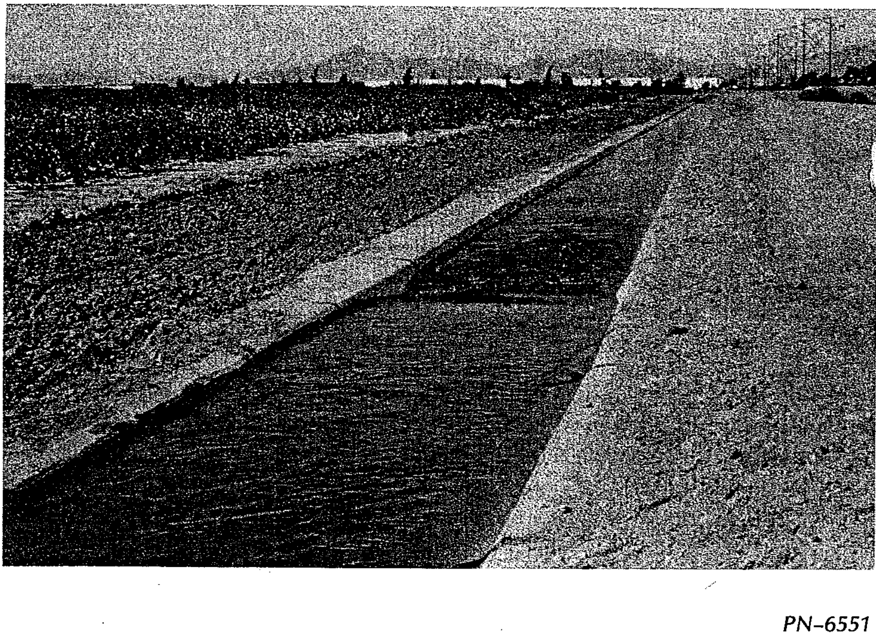

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FIGURE 1.—Flume installation at the University of Arizona Cotton Research Center in Phoenix shows the low head loss requirements of the b-c-w style flume. Here, b-c-w flume FA2 is running at 8-9 ft^3/s in a 24-in ditch.

result from changes in the flume dimensions. Information on the changes can then be used to determine allowable tolerances in various flume dimensions.

The new, simplified flumes resemble modified broad-crested weirs (b-c-w) and are actually a style of long-throated flume. The b-c-w flumes are generally much easier to construct and have lower absolute design head losses (head loss at design discharge) than conventional trapezoidal flumes. The b-c-w flumes, as shown in figures 1 and 2, and flume designs presented here for standard slipform ditches can make flow measurement simpler, more convenient, and more accurate than formerly available devices.

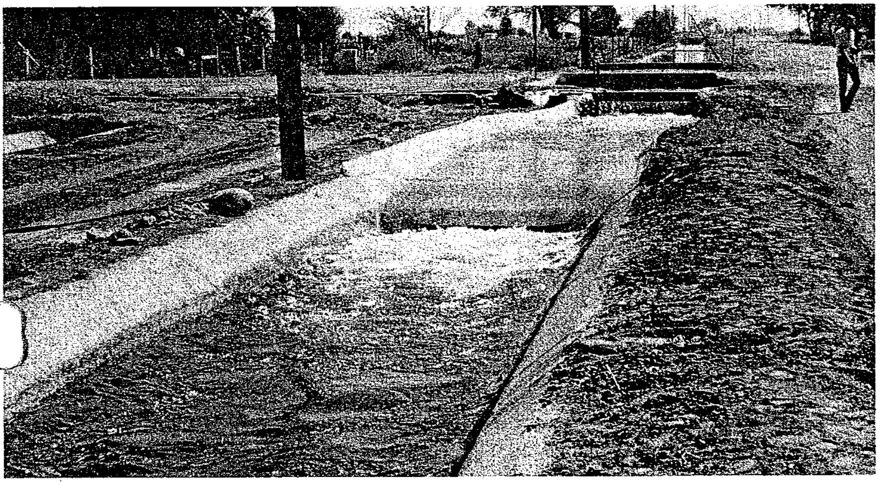

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FIGURE 2.—Flume installed near Gilbert, Ariz., for the Salt River Project. The flow rate shown (40 to 50 ft^3/s) is much less than the design flow rate (75 ft^3/s) resulting in more head loss than necessary. The flume is FC2, but with $L=4.0$ feet. The ditch is 36 inches deep.

Flume Design Criteria

The profile and cross section of the b-c-w flume are shown in figure 3. The important design dimensions are the sill height, *S*, and the sill length, *L*. The sill represents the floor of the throat section for these flumes. The sides of the throat section are the existing channel walls. The sill length is less important for design and need not be considered in selecting sizes for the new style measuring flume. There are certain conditions, however, under which the sill length limits the design. If it is too short, the flow lines will not be parallel enough in the throat section and the flume ratings may deviate by as much as 5 percent from those presented in this publication (see p.9). When this condition exists, the rating tables are marked to indicate that a longer throat should be used.

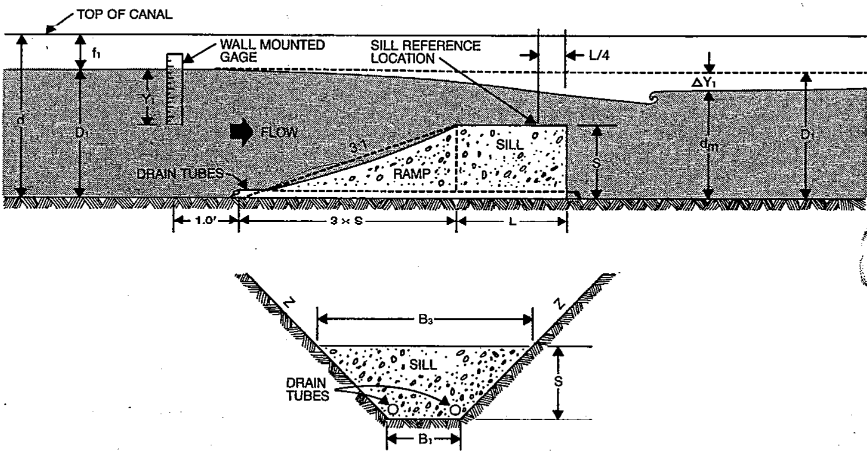

FIGURE 3.—Flume dimensions in profile (top) and cross section (bottom). Abbreviations used in the profile are as follows: d = constructed depth; D_1 = upstream water depth; f_1 = actual freeboard; Y_1 = sill-referenced flow depth; L = sill length; ΔY_1 = actual increase in water depth caused by the flume; S = sill height; d_m = flow depth; $3 \times S$ = three times the sill height (ramp length)..
Abbreviations used in the cross section (bottom) are as follows: B_3 = sill width; B_1 = canal bottom width; Z = sideslopes; S = sill height.

The sill height is the most important design dimension for controlling the water levels in the ditch. The sill must be high enough so that it obstructs the usual flow in the ditch, causing the water surface upstream from the flume to rise as shown in figure 3. Field and laboratory experience with this style of flume has shown that flumes will operate satisfactorily at 85 percent submergence. For example, the downstream water depth should be no more than 85 percent of the upstream water depth, both measured from the elevation of the top of the sill. Thus, one criterion for design is that the required minimum depth change caused by the flume at maximum flow should be 15 percent of the sill reference depth, Y_1.

Another criterion of sill height is that it not cause so much of an obstruction in flow that the ditch upstream from the flume is overtopped. The Soil Conservation Service recommends that the freeboard for stable subcritical flow in trapezoidal channels be 20 percent of the energy head at normal depth. (This is approximately 20 percent of the flow depth for canals with very slow-moving flow.) Because of the stable nature of the flow upstream from the b-c-w flumes, the free board requirement there can usually be reduced from 20 percent of D_1 to 20 percent of Y_1, which is the sill reference depth (fig. 3). These two criteria must be met for the full range of expected flow conditions. The conditions for both criteria are most crucial at the maximum expected flow rate, Q_m, for these shapes of flumes. Thus, the design is based on the maximum expected discharge and the associated depth, d_m. Since this water depth is important to the design, some engineering assistance may be required to get accurate maximum depth-discharge relationships.

Three selected sill heights have been chosen to accommodate the usual range of flows for three standard-sized slipformed canals. Design and selection of a flume is a simple, straightforward procedure.

Flume Design Procedure

Table 1 can be used as a design aid for selecting the appropriate flume. The example shown in table 1 is for a 36-inch ditch with a 2-foot bottom and 1:1 sideslopes that is used to carry a maximum of 20 cubic feet per second (ft^3/s). If the ditch flows about 25 inches deep at this discharge, what sill height should be selected? To use the table for this example, begin by filling in the basic information about the canal or ditch where the flume is to be located (lines 1-3). Line 1 is simply the vertical depth of the canal, *d*, line 2 is the width of the canal bottom, B_1, and line 3 is the canal wall sideslope, *Z*, expressed as a ratio of horizontal to vertical distance. Line 4 is the maximum discharge rate. Line 5 is the flow depth. Line 6 is the existing freeboard in the ditch prior to flume construction (line 1 minus line 5).

Once this information is obtained, the selection procedure is straightforward. Table 2 gives flume calibrations for three sizes of flumes (sill heights) for each of three ditch shapes. To begin the selection procedure, find the ditch shape in table 2 (A, B, or C) that matches lines 2 and 3 in table 1. For this example, the ditch shape corresponds to canal shape B. Choose any one of the three flume sizes from that group. For this example, FB1 was tried first. Record the information from table 2 for that flume size in the blanks provided for lines 7 through 12 on table 1. (The repetition of some information in table 1 assures that the appropriate flume group and size are chosen from table 2.)

The remaining section of table 1 is a check on the flow conditions that would exist if the trial flume size were installed. Figure 3 shows a profile of the flume and a typical water surface resulting from flume placement. From the appropriate column of table 2, find the sill-referenced flow depth, Y_1, for the design discharge, Q_m and enter it under line 13 in table 1. For the example, Y_1=1.143, for Q_m=20. Add lines 12 and 13 to obtain the total ditch flow depth, line 14, $D_1=S+Y_1$. Subtract line 5 from line 14 to get the aetual increase in water level caused by the flume, line 15, $\Delta Y_1 = D_1 - d_m$ (fig. 3).

Next, calculate the rise in water surface that the flume must cause so that it will operate properly, line 16, $\Delta Y_2 = 0.15\ Y_1$. If the actual increase in water depth, ΔY_1, is less than that required, ΔY_2 ($\Delta Y_1 - \Delta Y_2 = \Delta Y_3 < 0$) then the flume cannot be expected to operate properly (line 17), because it will be submerged, as for FB1 of the example.

This limit on the flume submergence assures that the water depth downstream from the flume will not affect the water depth reading upstream from the flume at the gage location. If ΔY_3 is negative, a higher sill must be used, so lines 7-17 are repeated for a higher sill height, as for FB2. For this flume size , ΔY_3 is positive and the design criteria have been met. Where the first selection produces a ΔY_3 that is greater than about 3 inches, a lower and more economical sill should be tried.

Table 1. **Broad-crested weir design and selection**

Canal Data

1. Constructed depth-- d = *3* ft. = *36* in.
2. Bottom width ----- B_1 = *2* ft. = *24* in.
3. Sideslopes ------- Z = *1:1*

Flow Data for Canal Without Weir in Place

4. Maximum discharge rate - Q_m = *20* cfs
5. Flow depth for Q_m ------ d_m = *2.08* ft.= *25* in.
6. Freeboard ------------- f_b = *0.92* ft.= *11* in.
(line 1 minus line 5)

Weir Selection Using Tables

		Trial 1	Trial 2	Trial 3	
7. Trial flume identification:		*FB1*	*FB2*	*FB3*	
8. Bottom width, B_1 (matches line 2)	B_1 =	*2.0*	*2.0*	*2.0*	ft.
9. Sill width, B_3	B_3 =	*4.00*	*4.50*	*5.00*	ft.
10. Sideslopes, Z (matches line 3)	Z =	*1:1*	*1:1*	*1:1*	-
11. Critical section (sill) length, L	L =	*3.00*	*2.50*	*2.00*	ft.
12. Trial sill height, S	S =	*1.00*	*1.25*	*1.50*	ft.

Submergence - Freeflow Check, Weir in Place

		Trial 1	Trial 2	Trial 3	
13. Sill-referenced flow depth for Q_m, (tables)	Y_1 =	*1.14*	*1.09*	*1.04*	ft.
14. Upstream water depth (line 12 plus line 13)	D_1 =	*2.14*	*2.34*	*2.54*	ft.
15. Actual increase in water depth: (line 14 minus line 5)	ΔY_1 =	*0.06*	*0.26*	*0.46*	ft.
16. Required increase in water depth: (15% x line 13)	ΔY_2 =	*0.17*	*0.16*	*0.16*	ft.
17. Submergence check: (line 15 minus line 16)	ΔY_3 =	*- 0.11*	*0.09*	*0.30*	ft.

(If negative a higher sill must be used, and repeat lines 7-17 with a new trial).
(If positive, this flume is okay, but a lower sill might also be used).

		Trial 1	Trial 2	Trial 3	
18. Actual freeboard: (line 1 minus line 14)	f_1 =	*-*	*0.66*	*0.46*	ft.
19. Required freeboard: (20% x line 13)	f_2 =	*-*	*0.22*	*0.21*	ft.
20. Freeboard check: (line 18 minus line 19)	f_3 =	*-*	*0.44*	*0.25*	ft.

(If negative, try a lower sill and repeat lines 7-20)
(If positive, this flume is okay, but a higher sill might also be used).

21. Flume selection: If both checks, (lines 17 and 20), are okay, use that trial. If one or the other are not met, repeat lines 7-20 for a new trial. If none of the standard flumes works, see text.

22. Flume selected *FB3*

Location *Example Problem*

Comments *FB3 was chosen due to uncertainty about the actual water depths. Since ΔY_3 and f_3 are both fairly large, FB 3 should work.*

How were Q_m and d_m determined? *estimated.*

The actual freeboard with the flume in place, line 1 minus line 14, is entered in line 18. The required freeboard, 20 percent × line 13, is entered in line 19. If the actual freeboard, f_1, is less than the required freeboard, f_2, ($f_1 - f_2 = f_3 < 0$) then the freeboard requirement has not been met (line 20).

If the criteria outlined for lines 17 and 29 are both met ($\Delta Y_3 > 0$ and $f_3 > 0$), as in the example for FB2, then the flume trial will work for that situation. If one or the other is not met, a different flume size (sill height) should be tried. For the example, flume FB2 could have been selected; however, if FB3 had been tried first, as shown in trial 3 of table 1, it also would satisfy the criteria of line 19 and could be selected.

For individual situations, the selection may be based on the certainty of the values used for Q_m and d_m. Here, if d_m were actually 27 inches (2.25 ft), ΔY_3 for flume FB2 would be −0.073′, and the flume would be submerged. Then flume FB3 would probably be chosen, since there is still plenty of freeboard (line 20, table 1). If two trials work and neither is close to the two limits, then in general, select the lowest sill that satisfies the criteria; in this case FB2 would have been chosen. The reason for choosing the lower sill is that it will cause the least head loss in the canal if it works, and if it doesn't work, the sill can easily be raised by capping it with new concrete. If the largest sill height had been used and the design flow rate had been too low, the canal might overtop and the sill height would be difficult to lower.

In some situations, more than one sill height will work. In other situations none of the flume sizes given here will work. If the highest sill is too low or the lowest sill too high, try another location along the ditch where the flow conditions are different. If a suitable location cannot be found, a new flume size can be computed that will be tailored to the particular site. If a flume sill is too low and the next largest sill is too high, either look for a location where the lower sill can be used or use the larger sill and add additional sidewall height to the ditch upstream from the flume.

There are some limitations on these flumes that are related to the ratio between the throat or sill length, L, and the upstream depth, Y_1, presented in the discussion of parallel flow in the section on Flume Design Criteria (p.4). In table 2, several columns have a horizontal dashed line near the bottom dividing the column (that is, for FA3, between 0.720 and 0.773). If flow depths and corresponding discharges below these lines (higher values) are used, about 6 inches should be added to the throat length, L. This will not have a significant effect on the other discharge ratings as listed above the dashed line.

Table 2. **Flume calibrations—water depth at gage location referenced to weir crest (in feet)**

CANAL SHAPE A B = 1.0′ Z = 1:1				CANAL SHAPE B B_1 = 2.0′ Z = 1:1				CANAL SHAPE C B_1 = 2.0′ Z = 1.25:1			
Flow rate (ft^3/s)	*FA1 B_3=2.50′ L=2.00′ S=0.75′*	*FA2 B_3=3.00′ L=1.50′ S=1.00′*	*FA3 B_3=3.50′ L=1.00′ S=1.25′*	*Flow rate (ft^3/s)*	*FB1 B_3=4.00′ L=3.00′ S=1.00′*	*FB2 B_3=4.50′ L=2.50′ S=1.25′*	*FB3 B_3=5.00′ L=2.00′ S=1.50′*	*Flow rate (ft^3/s)*	*FC1 B_3=5.125′ L=3.50′ S=1.25′*	*FC2 B_3=5.75′ L=3.00′ S=1.50′*	*FC3 B_3=6.375′ L=2.50′ S=1.75′*
0.5	0.160	0.143	0.130	1	0.189	0.175	0.164	2	0.252	0.234	0.217
.6	.179	.161	.146	2	.292	.271	.254	4	.387	.362	.340
.7	.197	.177	.161	3	.375	.350	.328	6	.495	.465	.437
.8	.214	.192	.175	4	.447	.418	.393	8	.589	.554	.523
.9	.230	.207	.189	5	.511	.480	.452	10	.673	.634	.599
1.0	.246	.221	.202	6	.570	.536	.506	12	.749	.708	.670
1.2	.275	.248	.226	7	.625	.589	.556	14	.819	.776	.735
1.4	.302	.273	.249	8	.676	.638	.604	16	.885	.839	.796
1.6	.327	.296	.271	9	.725	.685	.649	18	.947	.899	.854
1.8	.351	.318	.292	10	.771	.729	.691	20	1.006	.956	.909
2.0	.374	.340	.312	11	.814	.771	.732	22	1.061	1.010	.962
2.5	.427	.389	.358	12	.856	.812	.771	24	1.115	1.062	1.012
3.0	.476	.434	.400	13	.896	.851	.809	26	1.166	1.112	1.061
3.5	.520	.477	.440	14	.935	.889	.845	28	1.215	1.159	1.107
4.0	.562	.516	.477	15	.973	.925	.881	30	1.26	1.206	1.153
4.5	.601	.553	.512	16	1.009	.960	.915	32	1.31	1.25	1.196
5.0	.638	.588	.546	17	1.044	.994	.948	34	1.35	1.29	1.24
6.0	.707	.654	.608	18	1.078	1.027	.980	36	1.40	1.34	1.28
7.0	.771	.715	.666	20	1.143	1.091	1.042	38	1.44	1.38	1.32
8.0	.829	.772	.720	22	1.205	1.152	1.101	40	1.48	1.42	1.36
9.0	.885	.825	.773	24	1.26	1.21	1.158	45	1.58	1.51	1.45
10.0	.937	.875	.821	26	1.32	1.27	1.21	50	1.67	1.60	1.54
11.0	.986	.923	.867	28	1.38	1.32	1.26	55	1.75	1.69	1.62
12.0	1.033	.968	.911	30	1.43	1.37	1.31	60	1.84	1.77	1.70
13.0	1.078	1.014	.954	32	1.48	1.42	1.37	65	1.92	1.85	1.78
14.0	1.121	1.056	.994	34	1.53	1.47	1.41	70	1.99	1.92	1.85
15.0	1.162	1.096	1.034	36	1.58	1.52	1.46	75	2.06	1.99	1.92
16.0	1.20	1.135	1.071	38	1.62	1.56	1.50	80	2.13	2.06	1.99
17.0	1.24	1.173	1.108	40	1.67	1.60	1.55	85	2.20	2.13	2.06

Add 6 in. to *L* if depths and discharges below dashed line (higher flow rates) are used.

Flume Construction

Once a satisfactory flume design has been chosen, flume construction is simple and straightforward. The flume has two sections—a ramp and a sill (throat section) (fig. 3). The sill should be level with no large irregularities. The width of the sill, B_3, should be as close to the value given in table 2 as the desired accuracy of measurement (that is, a 1 percent error in B_3 will produce roughly a 1 percent error in discharge). With the wide sills used here, an error of one-half inch in sill width would cause about a 1 percent error. Within limits, the sill length in the flow direction has very little effect on the discharge reading. Errors of 2 or 3 inches in length would cause virtually no change in discharge reading, especially if the error makes the throat longer.

While the sill height is of prime importance to design because it controls the water surface elevation and submergence properties, precise vertical location of the sill is not critical to discharge rating, except when it causes the flume width dimension to deviate significantly. For example, an error of one-half inch in sill height, which can be caused by irregularities in the channel bottom, would change the sill width by 1 inch for a channel with 1:1 sideslopes. This would cause only about a 2 percent error. The flume dimensional tolerances thus allow flumes to be placed in slipform ditches, which vary slightly in shape from the standard. These tolerances should not, however, be an excuse for sloppy or poor construction but can make construction quick and easy.

The upper edge of the ramp should join the sill edge such that it does not rise above the sill to cause unpredictable flow separation. Precision edge matching of the two sections or slight rounding of the joint corner is desirable. When the ramp is hand-troweled into place avoid making large lumps or bumps. The ramp should be fairly uniform across with an approximate 3:1 slope. The ramp may be slightly concave as shown in figure 3. The ramp need not taper to zero thickness but can be ended abruptly when it becomes 2 to 3 inches thick.

Drain tubes should be installed as shown in figure 3 to allow the ditch to drain for mosquito control. Flow through the drain tubes will usually be negligible compared with flow through the flume. If tubes 2 to 3 inches in diameter or larger are used, the upper ends can be plugged to stop the flow. Sediment, which tends to accumulate at the base of the ramp, may plug the drains and should be cleaned out periodically. Sediment will not significantly accumulate in the ditch behind the flume if it did not normally accumulate in the ditch previously. Special flumes can be designed for sediment-laden ditches where 6 inches or more of sediment is normally deposited between cleanout periods.

Cast-in-place construction is straightforward. Cut out two pieces of plywood, each matching the cross section of the sill as shown in figure 3, with the corners cut out for inserting the drain tubes (cutting out the corners is necessary anyway since few slipform ditches have distinct corners). Cut 2- by

2-inch spacers to length, *L*, for holding the two forms apart. With the spacers between the two plywood forms, wire tie the plywood forms together. This makes the form for pouring the sill. Next, clean out a section of the ditch and place the forms on the bottom of the ditch. Insert the drain tubes and shim the forms so that the tops are level in the cross-ditch direction and with respect to each other. It is easy to see whether the form closely matches the ditch. Small errors are not important. As the form is filled with concrete, remove the 2- by 2-inch spacers. The concrete will hold the plywood apart. Use the plywood forms as screed edges for screeding and troweling the sill to a smooth, level surface.

After the concrete in the sill has taken initial set, the upstream form can be removed and the ramp hand-troweled into place (fig. 4). Both the ramp and sill can be broom-finished.

For single-pour construction, the upstream form can be made of a metal frame constructed from angle iron. This frame provides the upstream screeding edge for finishing the sill and is left permanently in place within the flume structure. Thus, both the sill and the ramp can be constructed at the same time, without waiting or returning to the site.

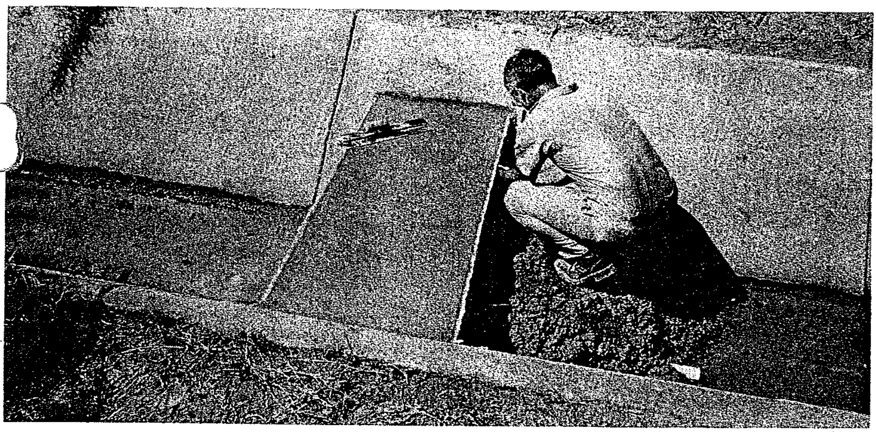

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FIGURE 4.—Construction of b-c-w flume FB3 installed in a 30-in ditch near Tacna, Ariz. The sill (throat section) has been poured. The upstream form is being removed so that the ramp can be poured (flow will be from right to left).

Gage Construction and Placement

A convenient type of gage to use is one marked in discharge units and attached to the canal wall. Gages can be constructed of 0.125- by 1.5-inch aluminum bar stock and stamped with a chisel, hammer, and a metal-stamping die set. The gages must be cleaned with a wire brush periodically to remove deposits. Since baked enamel gages are easier to read but must be custom ordered, they are considerably more expensive (fig. 5). The gage is placed on the sidewall and the vertical depths given in table 2 must be converted to sloping distances by multiplying the vertical depths by 1.414,

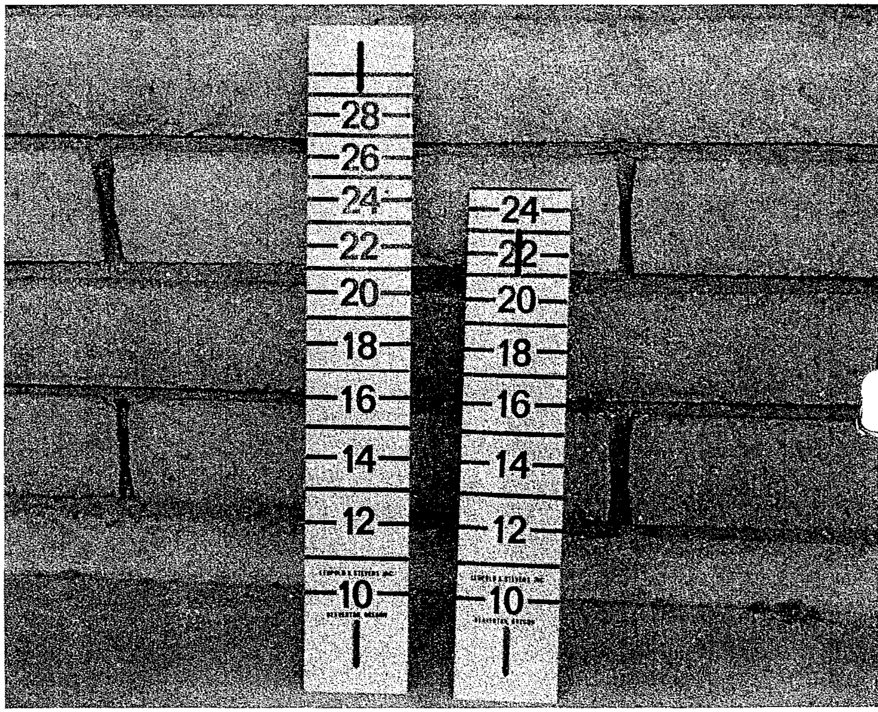

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FIGURE 5.—Commercially available baked enamel, wall-mounted gages marked in ft^3/s. The slotted holes make gage placement easier.

1.414, and 1.601 for ditch shapes A, B, and C, respectively. The discharge values are then marked on the gage at these calculated distances from the gage zero (the zero point need not be marked on the gage).

To obtain accurate discharge ratings, the gage must be carefully surveyed into place with a surveyor's level and rod. The reference elevation for mounting the gage is along the centerline of the canal on top of the sill at about L/4 from the downstream end of the flume (fig. 3). This eliminates errors caused by a nonlevel sill. Often the ditch sideslopes are not exactly as intended, thus a wall-mounted gage could be in error. To eliminate most of the error, the gage is referenced and mounted so that the gage is most accurate at the most commonly used discharge. The greatest errors will then occur at gage readings which are seldom used. Mount the gage so that the mark for the most commonly used discharge is at a vertical distance, Y_1, above the sill reference location, corresponding to the same discharge in table 2.

The gage can be mounted on the wall with lead anchors and screws. A slotted hole can be used to adjust the gage to the proper elevation, or the holes can be drilled in the gage after the anchors are in place. Always check the gage after it has been fastened to make sure that is hasn't slipped. Because of the controlled error in the design and construction processes, which can hold the basic uncertainty of the device to less than ±2 percent, most of the introduced error will be in the final gage reading. The wall-mounted gage is easily read to within ±5 percent at most all flows, and for the midrange and higher flows ±5 percent of the true discharge is easily accomplished. If the water surface is choppy, a skimmer can be placed upstream to reduce the surface waves. Use a stilling well and point gage if greater accuracy is desired.

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