REPORT NO. T-5

CONVERTING A FABRICATED CUTTHROAT FLUME INTO A DISCHARGE MEASURING INSTRUMENT

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CONVERTING A FABRICATED CUTTHROAT FLUME INTO A DISCHARGE MEASURING INSTRUMENT

1. GENERAL DESCRIPTION

The Cutthroat Flume is a device to measure the discharge rate of flowing water in hydraulic channels.This flume was developed during 1966-67 at the Utah water Research Laboratory, Utah State University, Logan, Utah, U.S.A. As shown in Figure 1, the Cutthroat Flume (CTF) is simple in appearance. Since the flume has zero throat length, this device was given the name "Cutthroat" by the developers (Skogerboe, Hyatt,Anderson and Eggleston, 1967). but, meticulous care is needed during both installation and the observation of upstream and downstream flow depths in order to obtain accurate discharge measurements.

Three dimensions are required to completely specify all dimensions for a Cutthroat Flume (CTF). The most important dimension is the throat width (W,in Figure 1). Secondly, the flume length, L, must be specified. Finally, the height of the flume walls,H, must be listed. The information required for establishing the dimensions W*L*H are provided in the report, "Cutthroat Flume Discharge Ratings, Size Selection and Installation" (Skogerboe, Ren and Yang, 1993).

2. CHECKING THE FABRICATED FLUME

A newly fabricated Cutthroat Flume(CTF) should have the dimensions checked. Unless this is done, the user will not have any idea regarding the accuracy of the discharge measurements.

2.1 Throat Width

The most important dimension is the throat width,W. Steel calipers should be used to measure the inside dimensions of the throat width as indicated in Figure 2. The throat width, W, along the lower half of the wall height, H, is more important than the throat width along the upper half of the wall height.

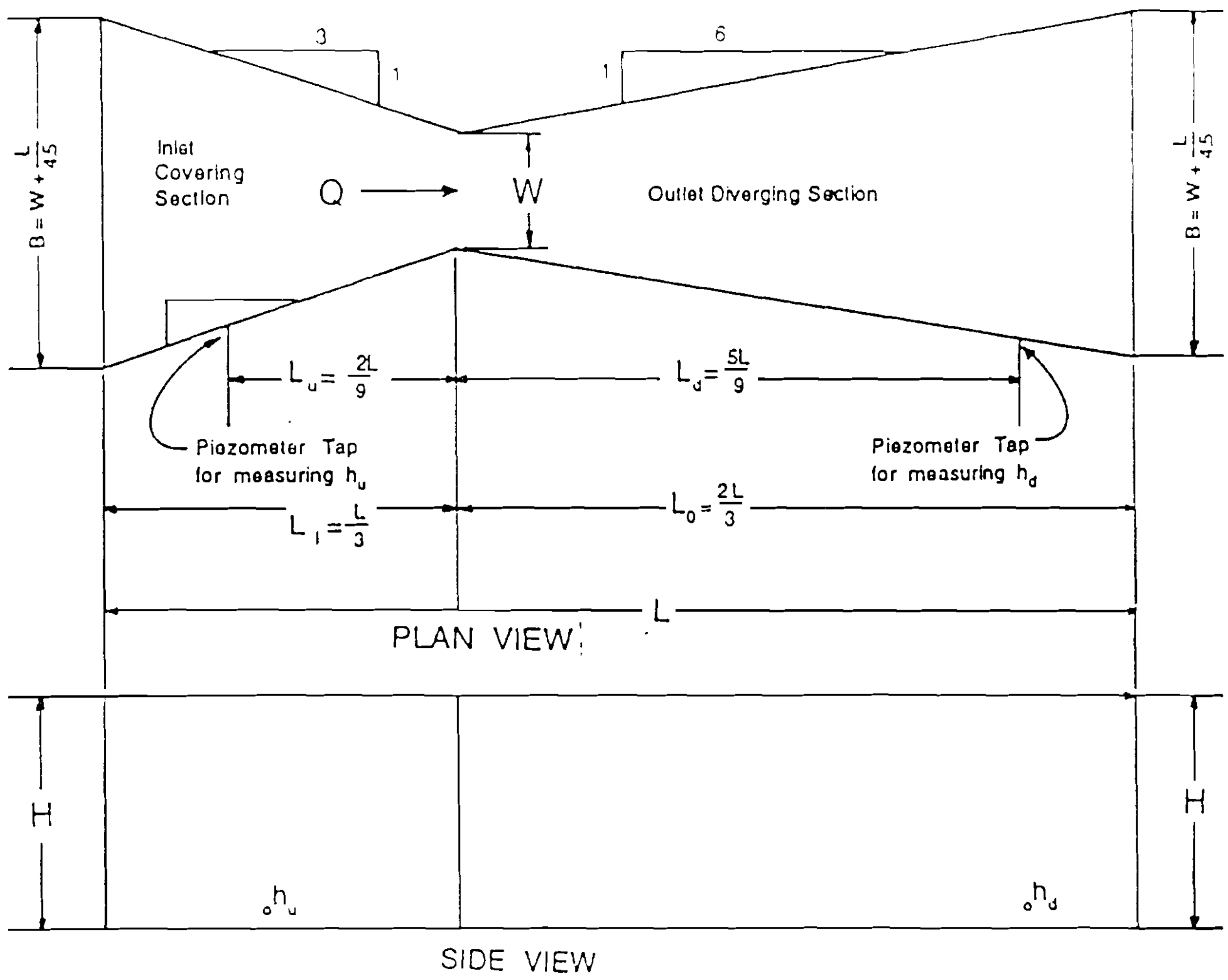
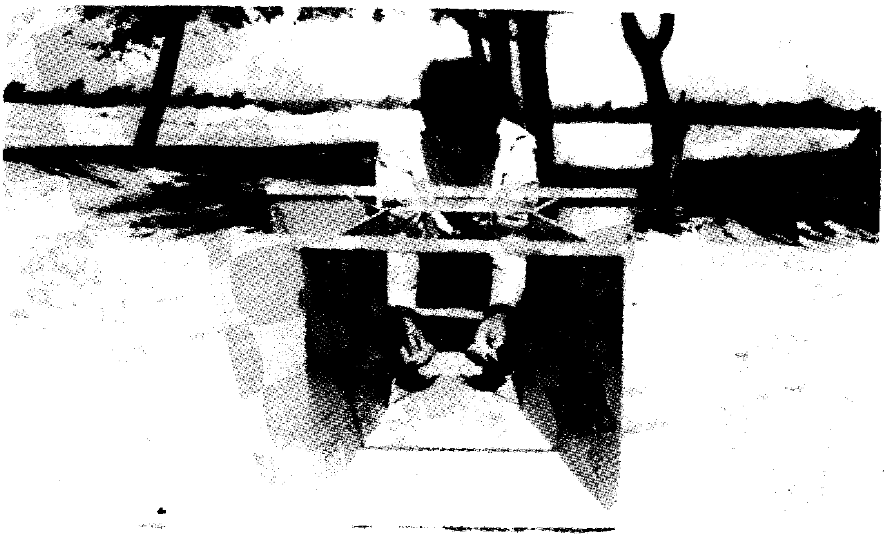
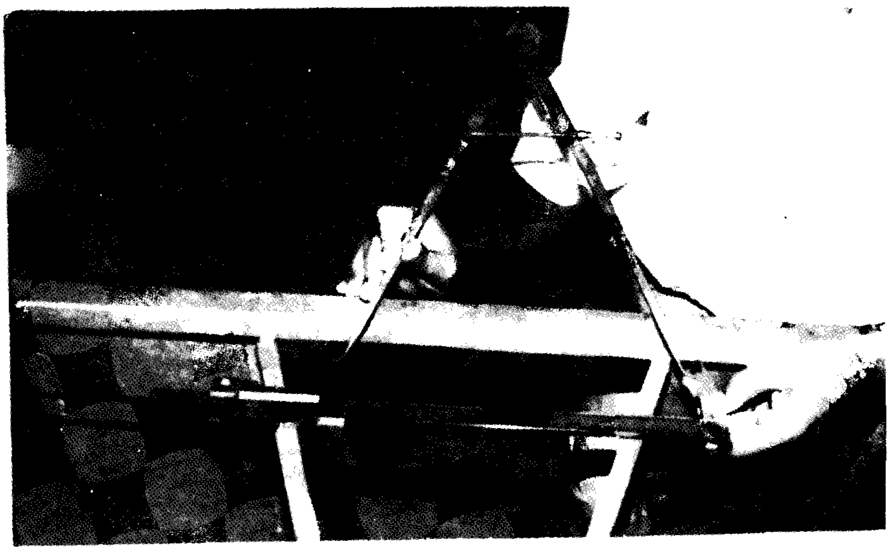


Figure 1. Definition sketch of a Cutthroat Flume



(a) Placement of internal calipers in the throat section.



(b) Using vernier calipers to accurately measure the throat width from the internal calipers.

Figure 2. Measuring the throat width of a Cutthroat Flume using internal calipers.

First measure the throat width one-half inch (twelve millimeters) above the flume floor; note that at the flume floor there is a slight curvature, which reduces the throat width by a small amount(a few millimeters). Then, measure the throat width every three inches(75 mm) above the flume floor. Finally, the throat width at the top of the flume walls is measured.

If there is a slight difference between the specified value for the fabricated CTF and the actual throat width measurements, the free flow and submerged flow discharge ratings can be easily corrected. This can be done by calculating a free flow discharge correction factor, K_{tf}, and a submerged flow discharge correction factor, K_{ts}.

Free Flow. For free flow conditions, the mean throat width, W_f, is the average of all measured values of throat width from one-half inch above the flume floor, $W_{1/2}$, to one-third of the wall height, $W_{H/3}$:

$$W_f = \frac{W_{1/2} + W_3 + W_6 + ... + W_{H/3}}{N} \tag{1}$$

Thus,

$$K_{tf} = \frac{W_f}{W_{specified}} \tag{2}$$

where,

K_{tf} = free flow discharge correction factor;

W_f = mean throat width from one-half inch above the flume floor, $W_{1/2}$ to one-third of the wall height, H.

W_3 = throat width measured three inches (or 75 mm) above the flume floor;

$W_{specified}$ = standard throat width specified to the manufacturer; and

N = number of observations.

Now, the free flow discharge rate, Q_f, becomes:

$$Q_f = K_{tf} C_f h_u^{n_f} \tag{3}$$

where,

C_f = free flow coefficient;

h_u = free flow depth measured in the upstream stilling well; and

n_f = free flow exponent.

Example 1: Throat Width Correction for Free Flow conditions

Calculate the free flow discharge correction factor for a newly fabricated Cutthroat Flume having a specified throat width of 12 inches a specified flume length of 36 inches, and a specified wall height of 18 inches.

The following measurements are obtained by using calipers (see the photographs in Figure 2):

$W_{1/2}$ = 12.047"

W_3 = 12.023"

W_6 = 12.017"= $W_{H/3}$

Using Equation 1,

$$W_f = \frac{W_{(1/2)} + W_{(3)} + W_{(6)} + \ldots + W_{(H/3)}}{N}$$

$$= \frac{12.047 + 12.023 + 12.017}{3}$$

= 12.029" = Using Equation 2,

$$K_{tf} = \frac{W_f}{W_{specified}}$$

$$K_{tf} = \frac{12.029}{12.0} = 1.002$$

Therefore,

$$Q_f = 1.002 C_f h_u^{n_f}$$

Or, Q_f is equal to the value of Q_f from Table 2 multiplied by 1.002.

Submerged flow. For submerged flow conditions, the same procedure is used as for free flow except for a slight modification. For submerged flow, the mean throat width, W_s, is the average of all measured values of throat width from one-half inch above the flume floor to two-thirds of the wall height, $W_{2H/3}$:

$$W_s = \frac{W_{1/2} + W_3 + W_6 + W_9 + W_{12} + \ldots + W_{2H/3}}{N} \tag{4}$$

Thus,

$$K_{ts} = \frac{W_s}{W_{specified}} \tag{5}$$

Now, the submerged flow discharge rate, Q_s, becomes

$$Q_s = K_{ts}(Q_s/Q_f)Q_f \tag{6}$$

where,

Q_s/Q_f = submerged flow multiplication factor obtained from Table 3 ; and

Q_f = free flow discharge rate obtained from Table 2.

Example 2: Throat Width Correction for Submerged Flow Conditions

Calculate the submerged flow discharge correction factor, K_{ts}, for a newly fabricated Cutthroat Flume having a specified throat width of 12 inches, a specified flume length of 36 inches, and a specified wall height of 18 inches.

The following measurements were obtained by using calipers (see the photographs in Figure 2).

$W_{1/2}$ = 12.047"

W_3 = 12.023"

W_6 = 12.017"

W_9 = 12.055"

W_{12} = 12.055" = $W_{2H/3}$

Using Equation 4,

$$W_s = \frac{W_{1/2} + W_3 + W_6 + W_9 + W_{12} + \ldots\ldots + W_{2H/3}}{N}$$

$$W_s = \frac{12.047 + 12.023 + 12.017 + 12.055 + 12.055}{5}$$

W_s = 12.0394"

Using Equation 5,

$$K_{ts} = \frac{W_s}{W_{specified}}$$

$$= \frac{12.0394}{12.0}$$

$$= 1.003$$

Therefore, $Q_s = 1.003\ (Q_s/Q_f)Q_f$ (From Table 3)

2.2 Piezometer Taps

After the throat width, the second most important dimension is the length from the throat to the upstream piezometer tap(L_u) for measuring the upstream flow depth(h_u), followed by the length from the throat to the downstream piezometer tap (L_d) for measuring the downstream flow depth(h_d) when submerged flow occurs in the CTF.

Upstream piezometer tap. As shown in Figure 1, the distance from the throat to the upstream piezometer tap (L_u) is:

$$L_u = \frac{2L}{9} \tag{7}$$

Where,

L	=	specified length of Cutthroat Flume; and
L_u	=	specified distance along the flume centerline from the throat to the centerline of the upstream piezometer tap.

This dimension should conform with Equation 7 within an accuracy of 0.02(L/3);in other words, the measured distance $(L_u)_{meas}$ should be:

$$(L_u)_{meas} = 2L/9 \pm 0.02(L/3) \tag{8}$$

Thus, for a Cutthroat Flume having a specified length(L) of 3 feet, the measured value of L as$(L_u)_{meas}$ should be within 0.02(3 feet/3) = 0.02 foot of the specified value of L_u (Equation 7).

Example 3: Location of Upstream Piezometer Tap

Find the error in location of upstream piezometer tap of the newly fabricated Cutthroat Flume having throat width 12.0 inches, if any.

Measurement is obtained by using the T-square (see the photographs in Figure 3).

$(L_u)_{meas}$ = 0.692 ft (Distance from centerline of flume width to centerline of piezometer tap)

According to Equation 7,

$(L_u)_{specified} = 2L/9$

$= 2*3/9 = 0.667$ ft

The difference is;

$0.667 - 0.692 = 0.025$ ft

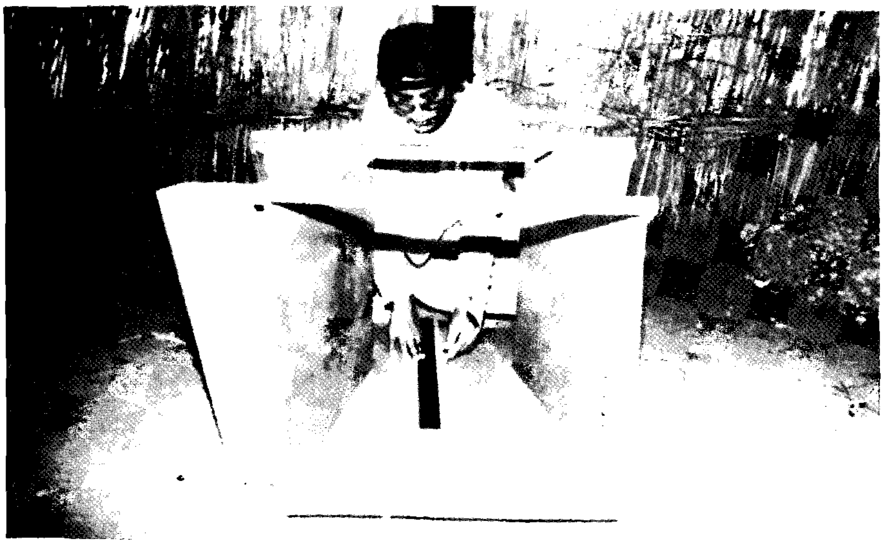
Note: According to Equation 8, the difference should be within 0.02 ft, whereas it is 0.025 ft, the difference is nearly within acceptable range,Therefore, the result would be satisfactory.

<u>**Downstream piezometer tap.**</u> The distance from the throat to the downstream piezometer tap (L_d) is shown in Figure 1 as:

$$L_d = \frac{5L}{9} \tag{9}$$

where,

L_d = specified distance along the flume centerline from the throat to the centerline of the downstream piezometer tap.



(a) Establishing the flume centerline.

(b) Measuring the perpendicular distance from the flume centerline to the upstream piezometer tap.

Figure 3. Measuring the distance from the throat to the upstream piezometer tap.

Because the water surface profile in the outlet diverging section does not change so rapidly compared with the inlet converging section, there can be more tolerance allowed for the placement of the downstream piezometer tap (L_d).

Thus, an accuracy of 0.02(2L/3) is recommended. Consequently, the measured distance for L_d should be:

$$(L_d)_{meas} = \frac{5L}{9} \pm 0.02(\frac{2L}{3}) \qquad (10)$$

Therefore, for a Cutthroat Flume having a specified length(L) of 3 feet, the measured value of L_d, $(L_d)_{meas}$, should be within 0.02[2(3 feet)/3]= 0.04 foot of the specified value of L_d (Equation 9).

Example 4: Location of Downstream Piezometer Tap

Find the error, if any, in the location of the downstream piezometer tap of a newly fabricated Cutthroat Flume having a specified throat width of 12.0 inches, a specified length of 36 inches, and a specified wall height of 18 inches.

Measurement of L_d is obtained by using the T-square (see the photographs in Figure 4)

$(L_d)_{meas}$ = 1.677 ft (Distance from the centerline of the flume width, perpendicular to the centerline of the piezometer tap)

Using Equation 9,

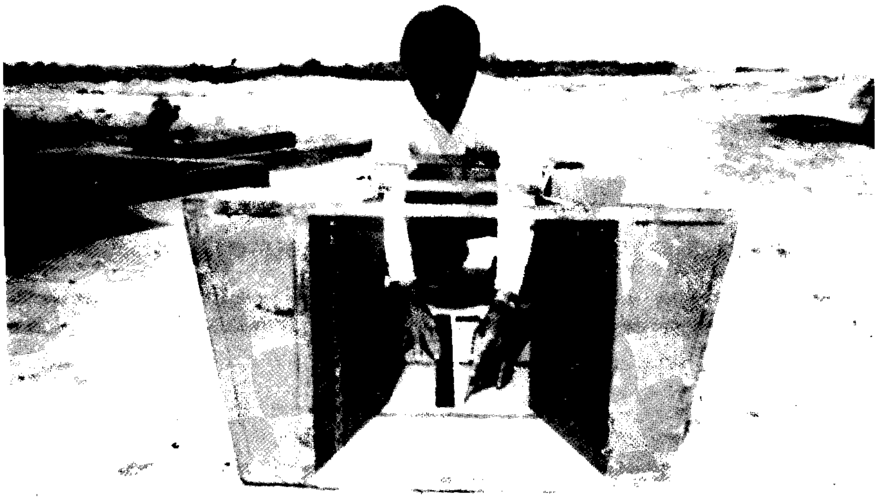
$(L_d)_{specified}$ = 5L/9

= 5*3/9
= 1.667 ft

The difference is;

1.667-1.677 = 0.010 ft

Note: According to Equation (10), the difference should be within 0.04 feet. It is found that the difference is 0.01 which is excellent. In either case, the accuracy within 0.04 ft would be satisfactory.



(a) Establishing the flume centerline.

(b) Measuring the perpendicular distance from the flume centerline to the downstream piezometer tap.

Figure 4. Measuring the distance from the throat to the downstream piezometer tap.

2.3 Entrance and Exit Widths

The next step in checking the dimensions of a fabricated Cutthroat Flume is to measure; (1) the width at the entrance of the inlet converging section, B_i and (2) the width at the exit of the outlet diverging section, B_0. The procedure is similar to measuring the throat width, except a scale can be used rather than calipers. The first width measurement is made one-half inch above the floor; then, width measurement are made 3 inches above the floor, 6 inches above the floor, etc. until the width is measured at the top of the flume at height H above the floor. The measured values of $(B_i)_{meas}$ and $(B_o)_{meas}$ are calculated from the following simple equations for a arithmetic average:

$$(B_i)_{meas} = \frac{(B_i)_{1/2} + (B_i)_3 + (B_i)_6 + \ldots + (B_i)_H}{N} \tag{11}$$

and

$$(B_o)_{meas} = \frac{(B_o)_{1/2} + (B_o)_3 + (B_o)_6 + \ldots + (B_o)_H}{N} \tag{12}$$

where,

$(B_i)_{meas}$	=	arithmetic average of entrance width measurements;
$(B_o)_{meas}$	=	arithmetic average of exit width measurements;
$(B_i)_{1/2}$ or $(B_o)_{1/2}$	=	width measurement one-half inch above the flume floor at entrance and exit, respectively;
$(B_i)_3$ or $(B_o)_3$	=	width measurement three inches above the flume floor at entrance and exit, respectively;
$(B_i)_H$ or $(B_o)_H$	=	width measurement at top of wall at entrance and exit, respectively; and
N	=	Number of Observations.

These width measurements at the entrance to the inlet converging section $(B_i)_{meas}$ and the exit to the outlet diverging section $(B_o)_{meas}$ need to be combined with flume length measurements described below to assess the quality of fabrication.

From Figure 1, the expected values of $(B_i)_{meas}$ and $(B_o)_{meas}$ are:

$$(B_i)_{meas} = W + L/4.5 \tag{13}$$

and

$$(B_o)_{meas} = W + L/4.5 \tag{14}$$

where W and L are the specified throat width and specified flume length, respectively. These measured width are expected to be accurate within 1 percent.

Example 5: Measurement of Entrance and Exit Widths

Calculate the entrance and exit widths of a newly fabricated Cutthroat Flume having a specified throat width of 12 inches, a specified height of 18 inches, and a specified length of 36 inches.

Entrance width (B_i). The following measurements are obtained by using Steel Caliper (see photograph a in Figure 5).

$(Bi)_{1/2}$ = 1.672 ft

$(Bi)_3$ = 1.672 ft

$(Bi)_6$ = 1.667 ft

$(Bi)_9$ = 1.669 ft

$(Bi)_{12}$ = 1.667 ft

$(Bi)_{15}$ = 1.664 ft

$(Bi)_{18}$ = 1.667 ft

Using Equation 11,

$$(B_i)_{meas}=\frac{(B_i)_{1/2}+(B_i)_3+(B_i)_6+(B_i)_9+(B_i)_{12}+(B_i)_{15}+(B_i)_{18}}{N}$$

$$(B_i)_{meas}=\frac{1.672+1.672+1.667+1.669+1.667+1.664+1.667}{7}$$

$$(B_i)_{meas}=\frac{11.678}{7}=1.668ft$$

Exit width (B_o). The following measurements are obtained by using Steel Caliper (see photograph b in Figure 5).

$(B_o)_{1/2}$ = 1.672 ft

$(B_o)_3$ = 1.677 ft

$(B_o)_6$ = 1.682 ft

$(B_o)_9$ = 1.672 ft

$(B_o)_{12}$ = 1.664 ft

$(B_o)_{15}$ = 1.664 ft

$(B_o)_{18}$ = 1.667 ft

Using Equation 12,

$$(B_o)_{meas} = \frac{(B_o)_{1/2} + (B_o)_3 + (B_o)_6 + (B_o)_9 + (B_o)_{12} + (B_o)_{15} + (B_o)_{18}}{N}$$

$$(B_o)_{meas} = \frac{1.672 + 1.677 + 1.682 + 1.672 + 1.664 + 1.664 + 1.667}{7}$$

$(B_o)_{meas}$ = 11.698/7 = 1.671 ft

Comparison between the measured and specified values of entrance and exit widths is made by the following equations:

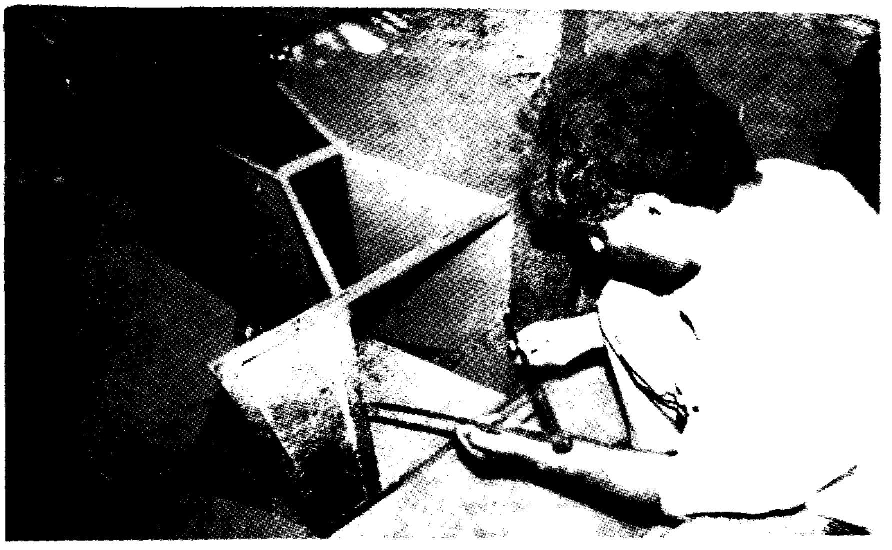
$(B_i)_{meas}$ = W+L/4.5

= 1+3/4.5 = 1.667 ft

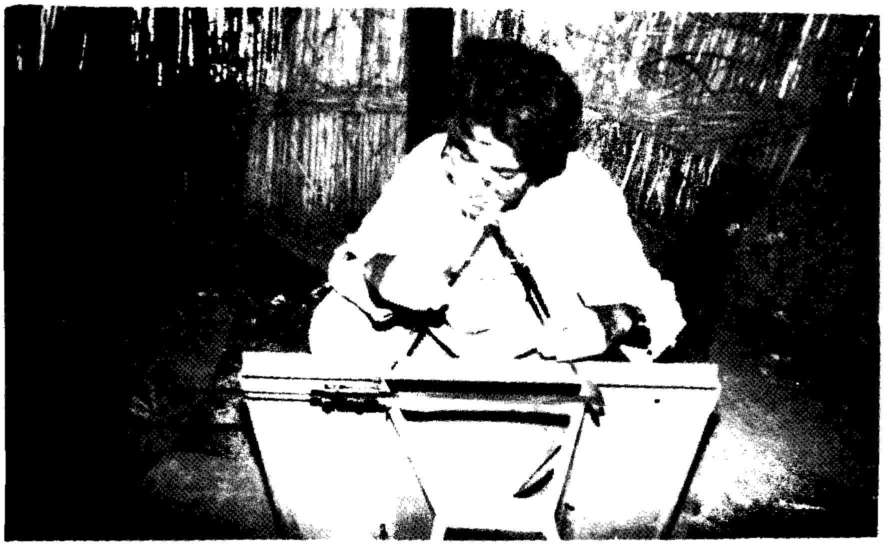
$(B_o)_{meas}$ = W+L/4.5

= 1+3/4.5 = 1.667 ft

Note: It is observed from the above example that the quality of the flume in terms of the exit widths is accurate within one-half of 1 percent which is quite satisfactory. More importantly, the entrance width is accurate within one-tenth of 1 percent, which is excellent. In either case, an accuracy of 1 percent would be satisfactory.



(a) Measurement of flume width using internal calipers.



(b) Measurement of flume width using vernier calipers.

Figure 5. Measurements of flume entrance and exit widths.

2.4 Flume Lengths

The total flume length is not as important as the individual lengths of the inlet converging section (L_i) and diverging outlet section (L_o). A single measurement is made along the centerline of the flume, with $(L_i)_{meas}$ being the measured length from the entrance to the throat and the length from the throat to the exit is $(L_o)_{meas}$. The photographs in Figure 6 depict the procedure.

The inlet section converges at a rate of 3:1, while the outlet section diverges at a rate of 6:1. The measured rate of convergence would be;

$$Convergence = \frac{(L_i)_{meas}}{(B_i)_{meas} - W_s - \frac{(L_i)_{meas}}{3}} \tag{15}$$

where the expected value is 3.00. The measured rate of divergence would be:

$$Divergence = \frac{(L_o)_{meas}}{(B_o)_{meas} - W_s - \frac{(L_o)_{meas}}{6}} \tag{16}$$

where the expected value is 6.00 . Hopefully, the convergence and divergence will be accurate within one percent. However, the accuracy of the convergence is more important than the divergence.

Example 6: Measurement of Inlet and Outlet Flume Lengths

To verify the convergence and divergence rates of the newly fabricated Cutthroat Flume specified in the previous examples with the following measurements:

Length of converging inlet section $(L_i)_{meas}$	= 1.010 ft
Length of diverging outlet section $(L_o)_{meas}$	= 1.997 ft
Entrance width $(B_i)_{meas}$	= 1.668 ft
Exit width $(B_o)_{meas}$	= 1.671 ft
Submerged throat width (W_s)	= 1.003 ft

Using Equation 15,

$$Convergence = \frac{(L_i)_{meas}}{(B_i)_{meas} - W_s - \frac{(L_i)_{meas}}{3}}$$

$$Convergence = \frac{1.0104}{1.668 - 1.003 - \frac{(1.0104)}{3}}$$

$= 3.079$

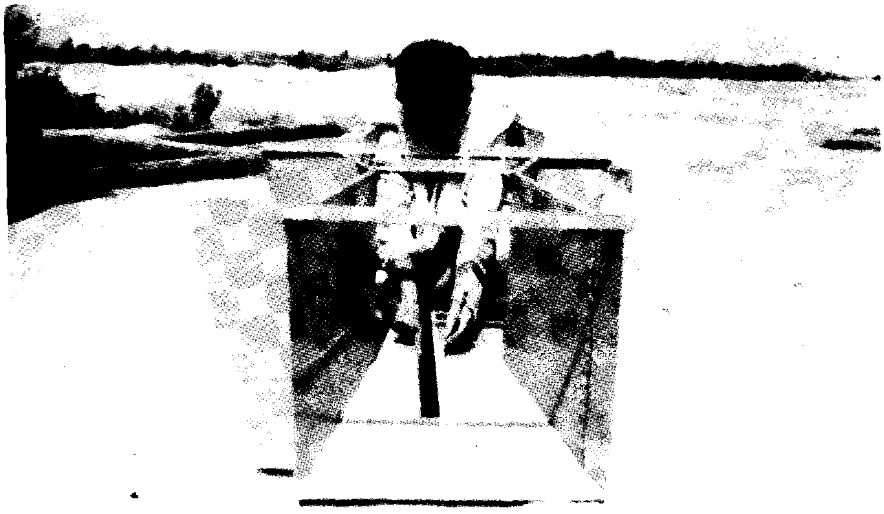
Using Equation 16,

$$Divergence = \frac{(L_o)_{meas}}{(B_o)_{meas} - W_s - \frac{(L_o)_{meas}}{6}}$$

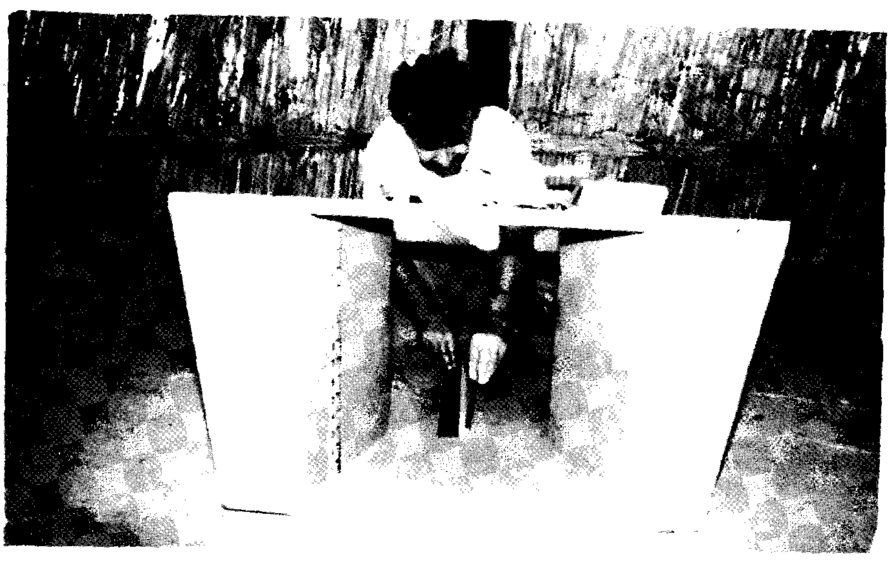
$$Divergence = \frac{1.997}{1.67 - 1.003 - \frac{1.997}{6}}$$

$= 5.961$

Note: The accuracy in the specified divergence is within 1 percent for the newly fabricated Cutthroat Flume, but the error in the specified convergence is 2.6nt, which is not very satisfactory.



(a) Measuring the length of the converging inlet section.



(b) Measuring the length of the diverging outlet section.

Figure 6. Measurements of flume inlet and outlet lengths.

2.5 Summary

The most critical dimension for a Cutthroat Flume is the throat width, W. The accuracy is measured by W_f (Equation 1) and W_s (Equation 4). Fortunately, if the measured values of W_f and W_s differ from the specified throat width, W, then correction coefficients can be calculated (Equations 2 and 5), so that if free flow occurs, Q_f can be calculated from Equation 3; likewise, if submerged flow occurs , Q_s can be computed from Equation 6.

The second most important dimension is the length along the flume centerline from the throat to the piezometer tap in the inlet converging section, with the accuracy criterion specified in Equation 8. The next most important dimension is the length along the flume centerline from the throat to the piezometer tap in the outlet diverging section, with the required accuracy specified by Equation 10. If the required accuracy is not met, then the piezometer taps should be sealed and new piezometer taps placed at the proper location(s).

Finally, the rate of convergence (Equation 15) for the inlet section is quite important, while the rate of divergence (Equation 16) is less important. However, the convergence and divergence are good indicators regarding the quality of the fabricated Cutthroat Flume.

In order to facilitate this procedure, appropriate forms have been prepared, which have been placed in the annex. These forms can be photo copied for field use, or they can be placed on a computer. A complete set of the forms are required for each fabricated flume.

3. CREATING AN INSTRUMENT

Often, a considerable amount of the accuracy in a Cutthroat Flume is lost due to a variety of reasons, but the two most important reasons are:(1) the zero reading on the staff gage in either stilling well (for measuring the upstream flow depth, h_u

or the downstream flow depth, h_d) is assumed to correspond with the invert floor of the flume ; and (2) when installing a flume, the top of the walls, along with the braces between the walls, are assumed to be perfectly parallel with the flume floor. In order to convert the Cutthroat Flume into an instrument, these assumptions must be overcome by: (1) determining the correction to each stilling well gauge (h_u and h_d) so that the gauge readings can be converted to true values of h_u and h_d; and (2) identifying locations for placing a spirit level on the top of the wall for longitudinal levelness and on the cross braces for latitudinal (transverse) levelness that can be used when installing a portable Cutthroat Flume in a channel with flowing water. The procedures that follow will accomplish these tasks in inverse order for a portable flume. For a permanent installation, the same procedures would apply, except that finding locations on top of the flume that are parallel to the flume floor would not be necessary, but still considerable effort would go into assuring that the flume floor is level. There are forms in the annex that can be used to record the data while doing the following procedures.

3.1 Marking Spirit Level Locations on Top of Flume

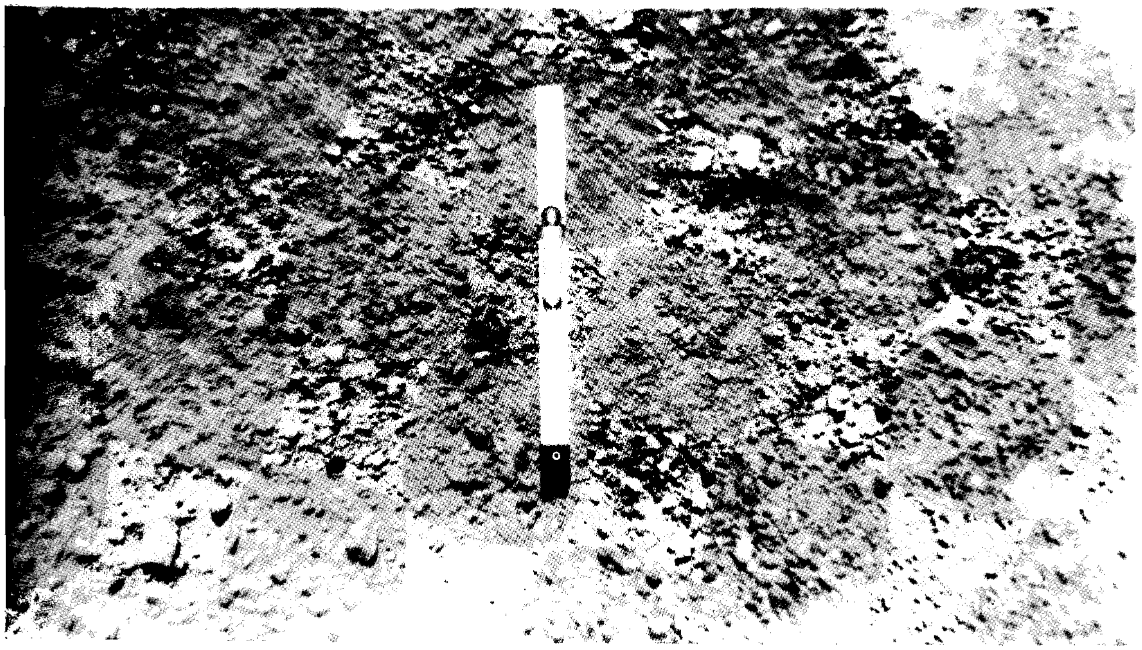
Leveling of bare ground. Before using a Cutthroat Flume for measuring discharge in an irrigation or drainage channel, it is necessary to prepare the flume so that it can be easily used in the field. For preparing the Cutthroat Flume to serve as an instrument, the first step in the field procedure is to establish locations on the top of the walls, as well as on the cross braces, which are level with the flume floor, particularly the flume floor in the vicinity of the throat. For doing this, select some bare ground larger than the size of the flume. The bare ground is first leveled using a spade and spirit level. The spirit level is placed at different points so as to remove the high and low spots in order to level the ground (see photographs Figure 7). This will require some time and many iterations of placing the spirit level both longitudinally and latitudinally.

Leveling of Cutthroat Flume. Once the ground is quite level, then the flume is placed on this leveled ground. The spirit level is used to check the levelness of the flume floor. Leveling of the flume floor is measured by placing the spirit level both longitudinally and transversely (latitudinally) many times. When the bubble of the spirit level is not at the center, then some soil is placed beneath the flume at the appropriate location. Simultaneously, the levelness in the vicinity of the throat is checked again and again (see photographs in Figure 8). This exercise is repeated numerous times until the flume floor in the vicinity of the throat is very level.

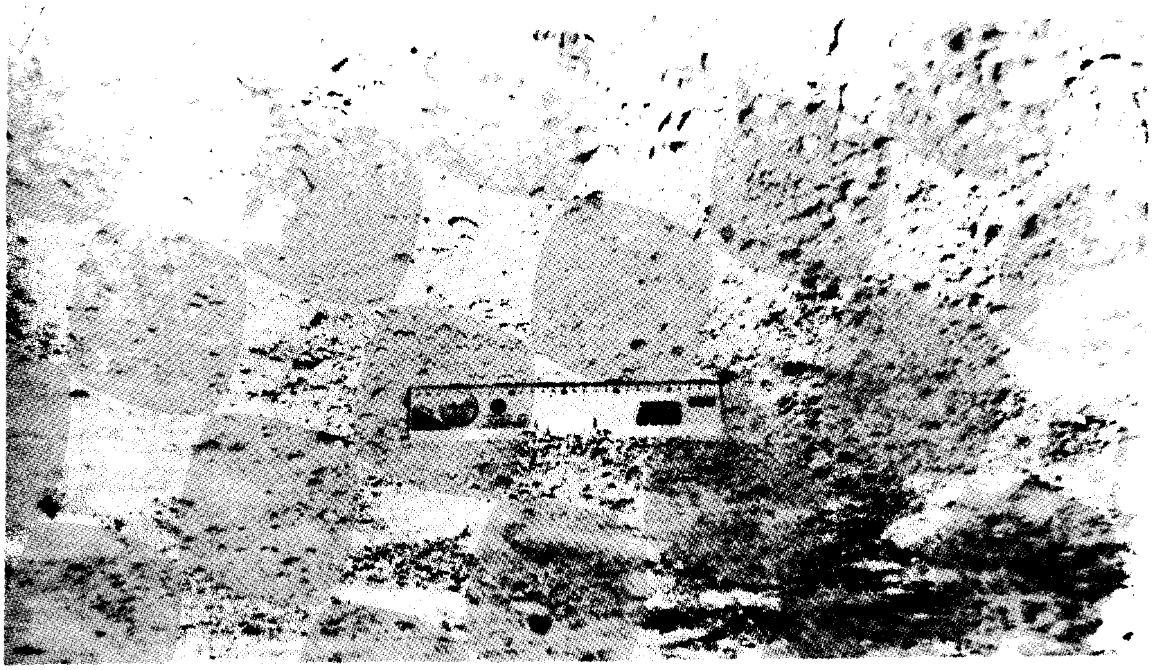
Marking the top of the wall and cross braces. Marks on the top of the wall and the cross braces are called reference points for placing the spirit level to check the levelness of the flume during installation in an irrigation or drainage channel for measuring of discharge rate. The spirit level is first moved along the top of the wall until a location is found where the bubble is perfectly centered. Then, the spirit level is moved along the cross brace at the flume entrance (see photographs in Figure 9). These marks are etched or scratched on the top of the flume wall and on the cross braces using a steel file or nail. These marks are permanent. The marks are used during installation in flowing water, since a spirit level cannot be seen on the flume floor when water is flowing through the flume.

3.2 Checking the Staff Gauges

Elevation of flume floor. With the Cutthroat flume level on the bare ground, the elevation of the floor in the vicinity of the throat is obtained by using a surveyor's level. The surveyor's level is set about 15-20 feet away from the Cutthroat Flume and is properly set and then leveled. The datum is assumed ten feet; in other words, the height of instrument (H.I) is ten feet, which becomes the assumed elevation of the horizontal centerline cross-hair in the surveyor's level. Then, three vertical readings using a surveyor's rod are taken and recorded, one at the center of the throat and one inch from each side wall at the throat. Each rod reading is subtracted from the assumed

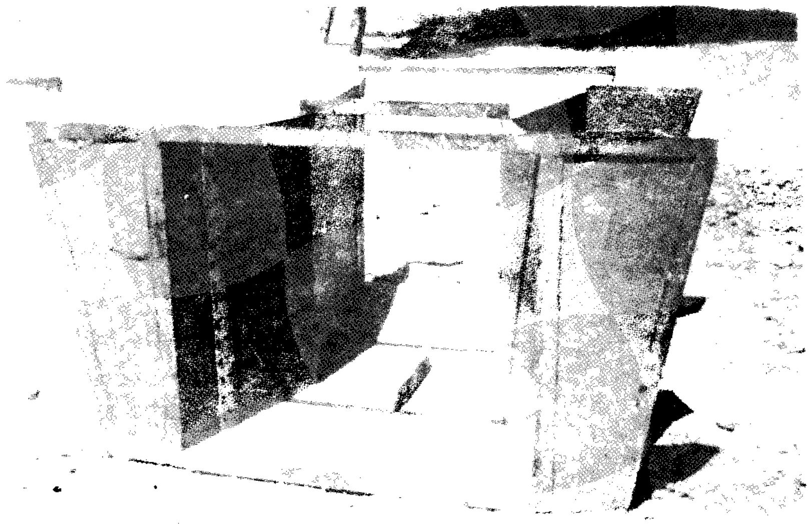


(a) Checking the levelness of the bare ground.

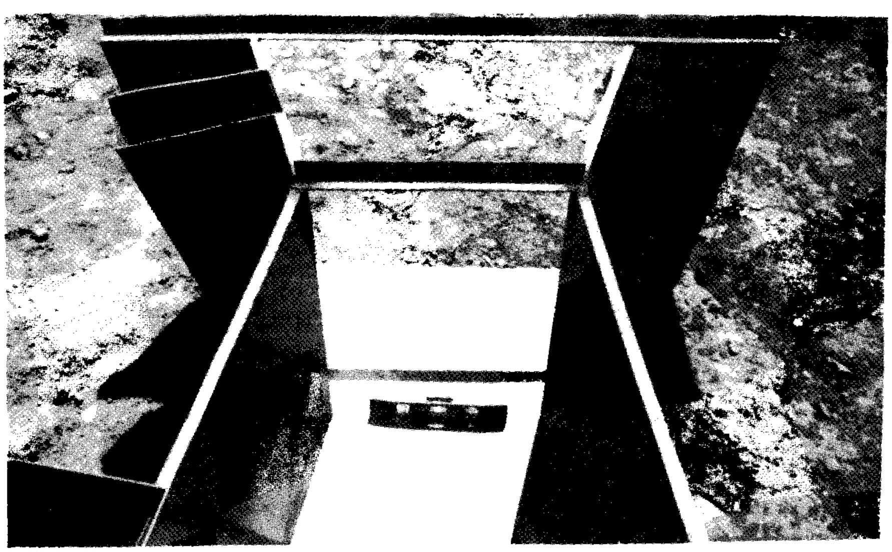


(b) Checking the transverse levelness of the ground.

Figure 7. Leveling of bare ground.

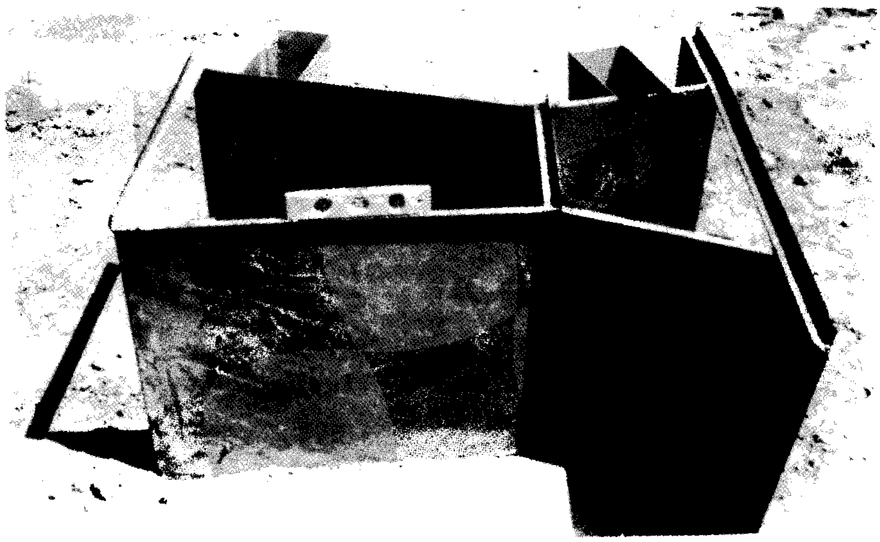


(a) Checking the level of the flume floor in the longitudinal direction.



(b) Checking the level of the flume floor in the latitudinal (transverse) direction.

Figure 8. Leveling the Cutthroat Flume on bare ground.



(a) Finding a location on the flume wall that is level with the flume floor.

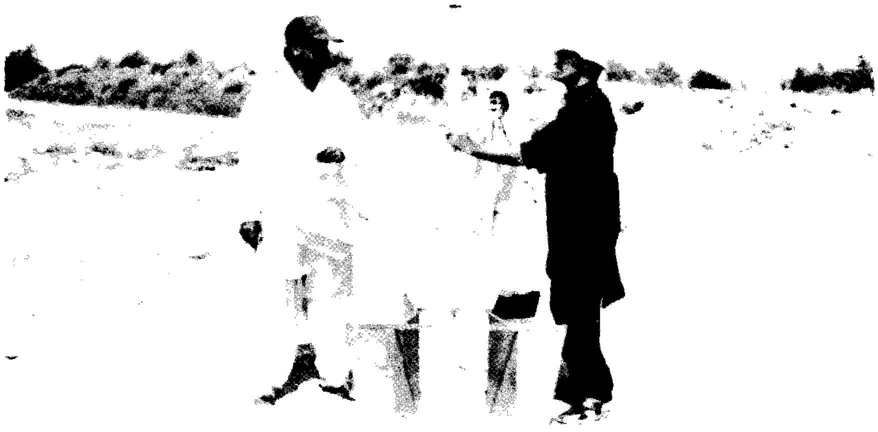
(b) Finding a location on the entrance cross brace that is level with the flume floor.

Figure 9. Marking the top of the flume wall and cross brace.

elevation of ten feet to arrive at the flume floor elevation in the throat. Then, the average of the three floor elevations is calculated, which is used as the flume floor elevation. This elevation will be applied for determining if any correction to the staff gauge in either stilling well (see Figure 10) upstream or downstream is required.

Establishing staff gauge corrections. The basis for establishing any necessary correction to either the h_u or h_d stilling well staff gauge is the flume floor elevation as described above. The surveyor's rod is placed on the top of the graduated h_u staff gauge in the stilling well upstream and the rod reading is recorded in a field book (see photograph a in Figure 11). This rod reading is subtracted from the assumed H.I elevation to arrive at the elevation of the top of the gauge. Then, the graduated reading at the top of the staff gauge is subtracted from the elevation of the top of the gauge to arrive at the elevation for a zero reading on the h_u staff gauge. This is compared with the flume floor elevation to establish the amount of correction (either plus or minus) to be applied when reading the h_u gauge in the field. Similarly, the same procedure should be applied to the h_d staff gauge in the downstream stilling well (see photograph b in Figure 11). The correction in the h_u and h_d staff gauges is obtained by comparing the flume floor elevation with the elevations for the zero reading on the upstream staff gauge and downstream staff gauge These corrections are then applied whenever discharge measurements are being conducted in the field . These corrections are valid only for that flume. Every flume should be checked before using it in the field for discharge measurements. Also, it is advised that if the scale on the staff gauges, which is painted, is no longer clear, and there is a problem in observing the readings, the staff gauges should be painted so that the accuracy in observing the upstream and downstream flow depths can be maintained.

Repeating this field procedure periodically. The above mentioned field procedure should be repeated after some time to check the corrections for the staff gauges obtained before. There is a possibility that these corrections may change, because frequent use of the flume may affect the geometry. Such changes will likely alter the correction for each staff gauge; hence, the field procedure should be repeated from time-to-time (e.g. after an irrigation season or annually depending on the degree of use).



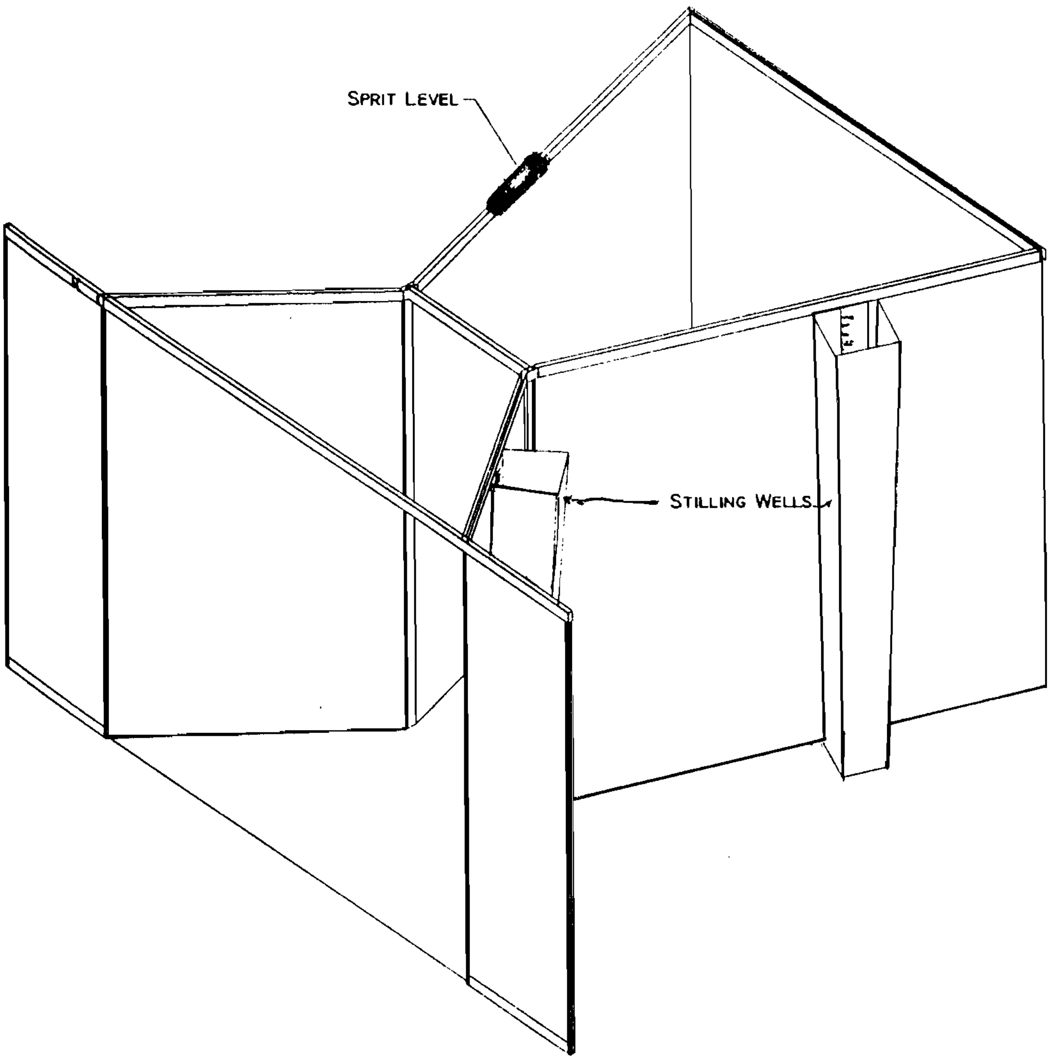
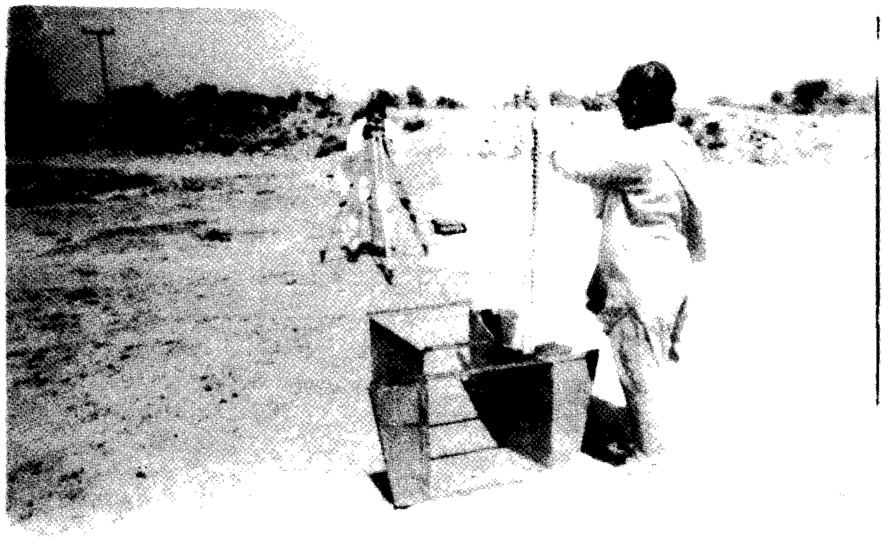
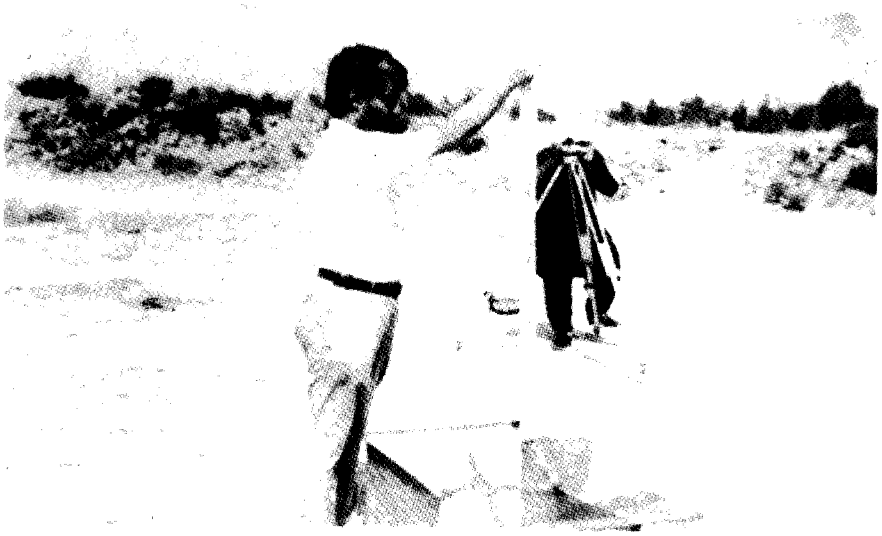


Figure 10. Establishing an assumed elevation for the floor of the Cutthroat Flume lying on bare ground.



(a) Establishing the elevation of the staff gauge in the upstream stilling well.



(b) Establishing the elevation of the staff gauge in the downstream stilling well.

Figure 11. Establishing the elevations of the tap of staff gauges in the stilling wells.

Example 7: Establishing Staff Gauge Corrections

Find the error in each gauge reading for the upstream and downstream of stilling wells with reference to floor elevation in the vicinity of the throat of a newly fabricated Cutthroat Flume having a specified throat width of 12 inches and a specified wall height of 18 inches. Assuming H.I = 10 ft.

Using the surveyor's level, the following measurements are obtained:

Elevation of throat bottom at center	= 10.00-5.708	= 4.292 ft
Elevation of throat bottom at left side	= 10.00-5.706	= 4.294 ft
Elevation of throat bottom at right side	= 10.00-5.710	= 4.290 ft
	Average	= 4.292 ft
Upstream stilling well elevation at top	= 10.00-4.215	= 5.785 ft
Downstream stilling well elevation at top	= 10.00-4.208	= 5.792 ft
Upstream gauge height		= 1.510 ft
Downstream gauge height		= 1.500 ft
Upstream bottom stilling well elevation	= 5.785-1.510	= 4.275 ft
Downstream bottom stilling well elevation	= 5.792-1.500 ft	= 4.292 ft

Therefore,

U/s stilling well correction = Ave. throat ele. - U/s bottom stilling well ele.

= 4.292 - 4.275 = 0.017 ft

D/s stilling well correction = Ave. throat ele. - D/s bottom stilling well ele.

= 4.292 - 4.292 = 0.000

Downstream stilling well correction is zero.

Suggestion: During a field measurement of discharge, the upstream gauge correction should be subtracted from the gauge reading, while no correction is required for the downstream gauge.

4. INSTALLATION OF CUTTHROAT FLUME

4.1 Site Selection

Any flow measuring device must be properly installed to yield adequate results. The first consideration prior to installing a Cutthroat Flume is the location or site of the structure. The flume should be placed in a straight section of channel. If operating conditions require frequent changing of the discharge, the flume may be conveniently located near a point of diversion or regulating gate. However, care should be taken to see that the flume is not located too near a gate or control structure (e.g. outlet) because of unstable or surging effects which might result downstream from the constriction.

After the site has been selected, it is necessary to determine certain design criteria. The maximum quantity of water to be measured, the depth of flow in the channel corresponding to this discharge, and the allowable head loss through the flume must be determined. The head loss may be taken as the difference in water surface elevation between the flume entrance and exit, which is approximately equal to h_u-h_d. The downstream depth of flow will remain essentially the same after installation of the flume as it was prior to installation, but the upstream depth will increase by the head loss. The allowable increase in upstream depth may be limited by the height of the canal banks upstream from the flume. Such a limiting condition dictates the minimum flume size, and may require operation as a submerged flow structure.

A properly installed Cutthroat Flume is aligned straight with the channel and should be level longitudinally and laterally. Flumes tend to settle in time, with the exit usually becoming lower than the entrance.

Experience both in the laboratory and the field indicates that a transition structure between the open channel and Cutthroat Flume is not necessary. However, the ratio of upstream flow depth to flume length (h_u/L) should be 0.33, or less, for free flow conditions. For most installations in flat gradient channels, this will insure that approach conditions will satisfy the laboratory conditions under which the ratings were developed. Measurements should be made in the Cutthroat Flume by the use of piezometers connected to stilling wells. The staff gauges must be carefully referenced to the elevation of the flume floor. Stilling wells have the advantage of providing a calm water surface compared with the fluctuation or " bounce" of the water surface that usually exists within the Cutthroat Flume.

4.2 Installation to Ensure Free Flow

If circumstances allow, it is preferable to have a flow measuring device operate under free flow conditions. The obvious advantage is that only the upstream flow depth need be measured to determine the discharge. Also, the accuracy in determining the discharge rate is better for free flow as compared with submerged flow. The procedure to follow for installing a Cutthroat Flume to operate under free flow conditions is listed below:

1. Determine the maximum flow rate to be measured.

2. At the site selected for installing the flume, locate the high water line on the canal bank and determine the maximum depth of flow.

3. For a selected flume size, use the free flow discharge rating. Calculate the depth of water that corresponds to the maximum discharge capacity of the canal.

4. Place the floor of the flume at an elevation which does not exceed h_u multiplied by the transition submergence ($S_t h_u$) below the high water line. Generally, the flume bottom should be placed as high as grade and other conditions permit to insure free flow.

Example 8: Installation of Flume to Ensure Free Flow Conditions

A Cutthroat Flume having a size of 12" * 3' is to be used for measuring the discharge in a channel, of maximum capacity 3.15 cusecs. At what depth should the flume floor be placed below the high water mark in this channel so that the flume will work under free flow conditions?

From Table 1, the free flow discharge rating equation is:

$$Q_f = 4.33 h_u^{1.811}$$

For $Q_f = 3.15$ cfs,

$$h_u = (3.15/4.33)^{1/1.811}$$
$$= 0.84 \text{ ft}$$

Since the transition submergence is 0.754

$$S_t{*}h_u = 0.754{*}0.84 = 0.633 \text{ ft}$$

Therefore, the floor of the 12"*3' Cutthroat Flume should be placed 0.633 ft below the channel high water mark as shown in Figure 12 so that it will work as a free flow measuring device.

Example 9: Installation of Flume to Ensure Free Flow Conditions

Select an appropriate size of Cutthroat Flume for a discharge of 1.3 cfs under free flow conditions. The depth of flow in a channel is 0.49 ft and the available freeboard is 0.4 ft.

From the above conditions, the downstream flow depth, h_d, would be 0.49 ft and the upstream flow depth, h_u, would be 0.89 ft (0.49+0.4). Thus, the submergence would be:

$$S = 0.49/0.89 = 0.55$$

Table 1 indicates that a 4" * 3' Cutthroat Flume might be suitable:

$$Q_f = 1.404(0.89)^{1.84}$$
$$= 1.133 \text{ cfs}$$

Since Q_f is less than given discharge i.e., 1.30 cfs. So, this size of flume is small.

Therefore, another 8" * 3' Cutthroat Flume size would be suitable:

$$Q_f = 2.858(0.89)^{1.826}$$
$$= 2.310 \text{ cfs}$$

Consequently, this would be the appropriate size of Cutthroat Flume to install.

For a free flow discharge rate of 1.3 cfs:

$$h_u = (1.30/2.858)^{1/1.826}$$
$$= 0.65 \text{ ft}$$

Since the transition submergence is 0.674:

$$S_t{*}h_u = 0.674{*}0.65 = 0.438 \text{ ft}$$

Consequently, the floor of the 8" * 3' Cutthroat Flume should be set no lower than 0.438 ft below the present maximum water level, which would be lower than the channel bed. However, in order to take advantage of the available freeboard, the flume floor could be placed 0.65 ft below the maximum water level as shown in Figure 13, which would result in h_u = 0.65 ft and h_d = 0.65 - 0.4 = 0.25 ft.

4.3 Installation under Submerged Flow Conditions

The existence of certain conditions, such as insufficient grade or the growth of moss and vegetation, sometimes makes it impossible or impractical to install a flume to operate under free flow condition. Where such situations exist, a flume may be set in the channel to operate under submerged flow conditions. The principal advantage of submerged flow operation is the smaller head loss which occurs in the flume as compared with free flow. This reduction in head loss may mean that the channel banks upstream from the flume do not have to be raised to enable the same maximum flow capacity in the channel that existed prior to the installation of the flume. When a flat-bottomed Cutthroat Flume is installed to operate under submerged flow conditions, the flume floor may be placed at the canal bottom. This placement will allow quicker drainage of the canal section upstream from the flume, particularly for flow rates which are less than the maximum discharge. The following procedure should be used in placing a Cutthroat Flume to operate under submerged flow conditions.

1. Determine the maximum flow rate, Q_s, to be measured.

2. On the channel bank, where the flume is to be installed, locate the high water line to determine the maximum flow depth.

3. Giving consideration to the amount of free-board in the channel at maximum discharge and maximum flow depth, determine how much higher the water surface can be raised in the channel upstream from the flume location.

4. With the floor of the flume being placed at essentially the same elevation as the bottom of the channel, the maximum depth of flow (Step 2) becomes h_d, and the additional amount that the water surface in the canal can be raised (Step 3), becomes h_u-h_d. Using this information, the submergence, h_d/h_u can be computed.

5. Select an appropriate size of Cutthroat Flume by trial-and- error. Knowing Q_s, S and h_u is important in guiding the procedure.

a. First, the submerged flow rating tables would be consulted. The submerged flow multiplication factor, Q_s/Q_f, could be read for each flume size for the known value of submergence, S. Actually, by already knowing (or having an estimate of) Q_s will indicate to some extent the range of flume sizes that might be appropriate.

b. Then, the estimated or known value of Q_s can be divided by the submerged flow multiplication factor, Q_s/Q_f, for each flume size to arrive at a required value of the free-flow discharge rate, Q_f.

c. Now, the known maximum value of the upstream flow depth, h_u, can be used in the free flow discharge rating tables for each flume size being investigated in order to determine whether the value of Q_f in the rating table equals or exceeds the required value of Q_f calculated in Step 5b.

d. Based on the results from Step 5c, the most appropriate size of Cutthroat Flume can be selected.

Example 10:Installation of Flume to Ensure the Submerged Flow Conditions

A channel carries a maximum discharge of 2.2 cfs with a maximum flow depth of 0.9 ft. The available channel freeboard is 2 inches. Select an appropriate size of Cutthroat Flume for this channel that will work under submerged flow conditions.

Thus, the maximum value of the upstream flow depth could be 1.067 ft (0.9+0.167). If the downstream flow depth was 0.9 ft, then the submergence would be:

$$\mathbf{S = 0.90/1.067 = 0.84}$$

When looking at the submerged flow discharge rating Table 3, two sizes of Cutthroat Flume could be possibly feasible:

8" * 3' $Q_s/Q_f = 0.920$

12" * 3' $Q_s/Q_f = 0.977$

For each flume size, the value of Q_f for h_u = 1.067 ft can be obtained from free flow discharge equation but, if the upstream flow depth is less or equal to 1 ft then free flow discharge rating Table 2 could be used, which can then be multiplied by the submerged flow multiplication factor, Q_s/Q_f, to obtain the submerged flow discharge capacity corresponding to S = 0.84.

Flume Size	Q_f,cfs	Q_s/Q_f	Q_s,cfs
8" * 3'	3.21	0.920	2.950
12" * 3'	4.87	0.977	4.750

Thus, the smallest size of Cutthroat Flume that would satisfy the requirements for this situation would be 8" * 3'. Also, since h_u is 1.067 ft for discharge rate of 2.2 cfs hence, it is recommended that the wall height, H, to be preferred 1.5 ft.

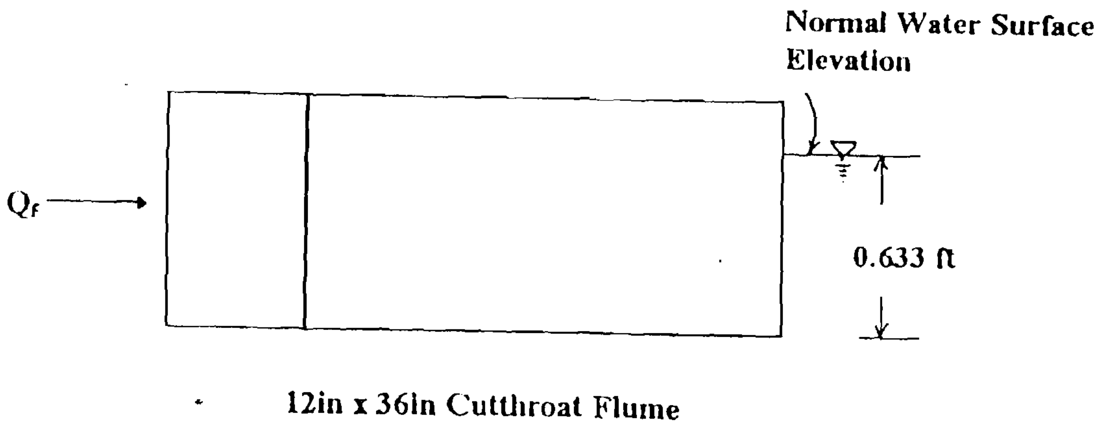


Figure 12. Floor elevation placement for free flow operation of 12 in * 3.0 ft. Cutthroat Flume in Example 8.

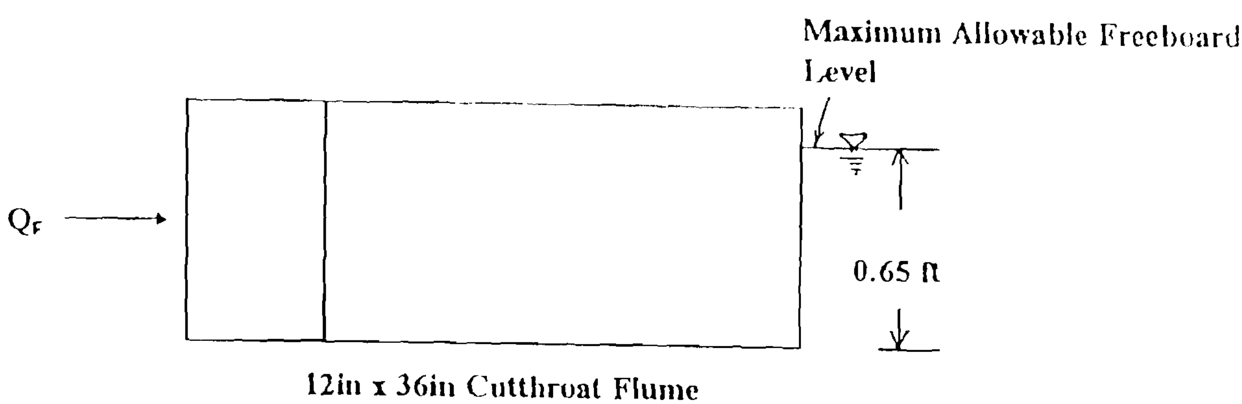


Figure 13. Floor elevation placement for free flow operation of 12 in * 3.0 ft. Cutthroat Flume in Example 9.

4.4 Selection of Flume Size

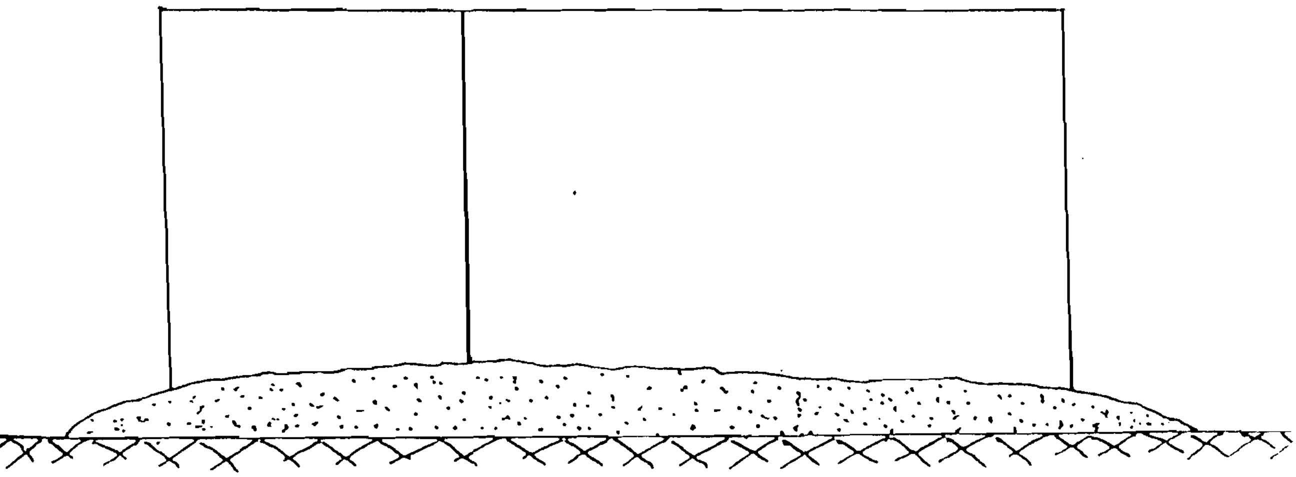
Before placing the flume in any watercourse or channel for the measurement of discharge, consideration must be given to selecting an appropriate size of the flume. For the selection of a flume size, it is considered necessary to have some idea about the flow of water and its depth in the channel, and the allowable head loss through the flume as described in Sections 4.2 and 4.3. The head loss which has been taken as the difference in water surface elevation between the flume entrance and exit. The downstream depth of flow will remain essentially the same after installation of the flume, but the upstream depth will increase by the head loss.For measuring the discharge in a watercourse, the following flume sizes have been commonly used; in Pakistan.

Table 1. Sizes of Cutthroat Flume commonly used in Pakistan.

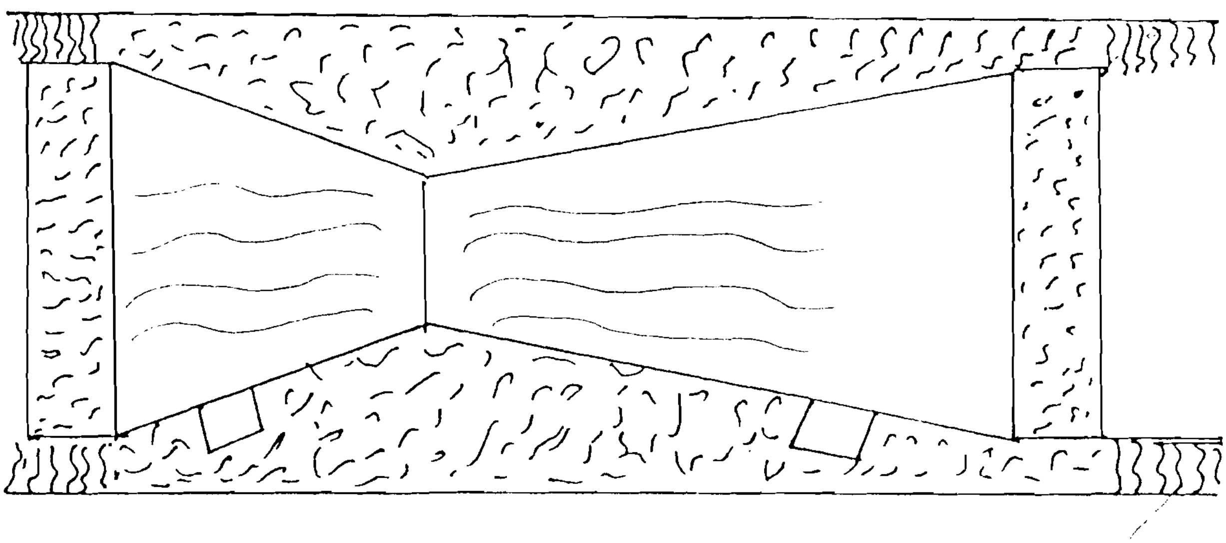
Flume size	C_f	n_f	S_t	C_s	n_s	$Q_{f(max)}$ cusecs
4"* 3'	1.404	1.84	0.580	0.942	1.384	1.40
8"* 3'	2.858	1.826	0.674	1.600	1.489	2.86
12"* 3'	4.330	1.811	0.754	2.048	1.567	4.33

4.5 Building the Pad

Most commonly, the floor of the Cutthroat Flume will be placed on an earthen pad prepared in the channel bed. This pad is constructed just prior to installing the flume. The major consideration is the elevation of this pad. To insure free flow conditions, the pad should be constructed up to $S_t h_u$ below the high water line in the channel (see Step 4 in Section 4.2). If there is a necessity to operate under submerged flow conditions, then Step 5c in Section 4.3 must be completed.



Side View



Top View

Figure 14. Constructing an earthen pad for placement of Cutthroat Flume with flowing water.

Before beginning the construction of the pad, the top elevation of the pad should be marked using a stick pounded into the channel bed with the top of the stick being the pad elevation, or a pile of rocks placed on the channel bed, or a pile of bricks. Then, soil can be used to build the pad. Sod (soil with plant material) is useful because it is not so easily eroded. The size of the pad needs to be slightly larger than the area of the flume floor.

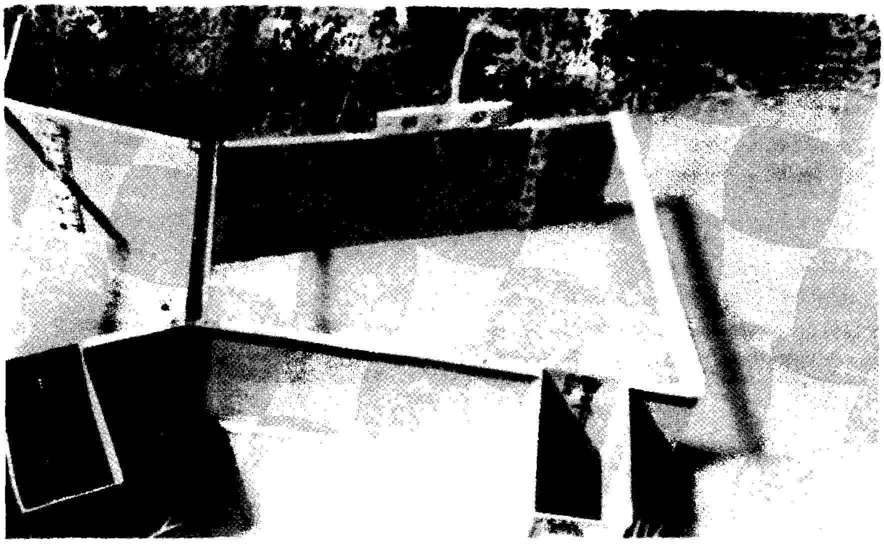
4.6 Leveling the Installed Flume

Once the pad has been constructed, the Cutthroat Flume is placed on the pad. A spirit level is first placed on the flume wall at a location previously marked (Section 3.1) as being parallel with the flume floor. After leveling the flume longitudinally, the spirit level is placed at the marked place on a cross bar so that the flume can be leveled transversely.

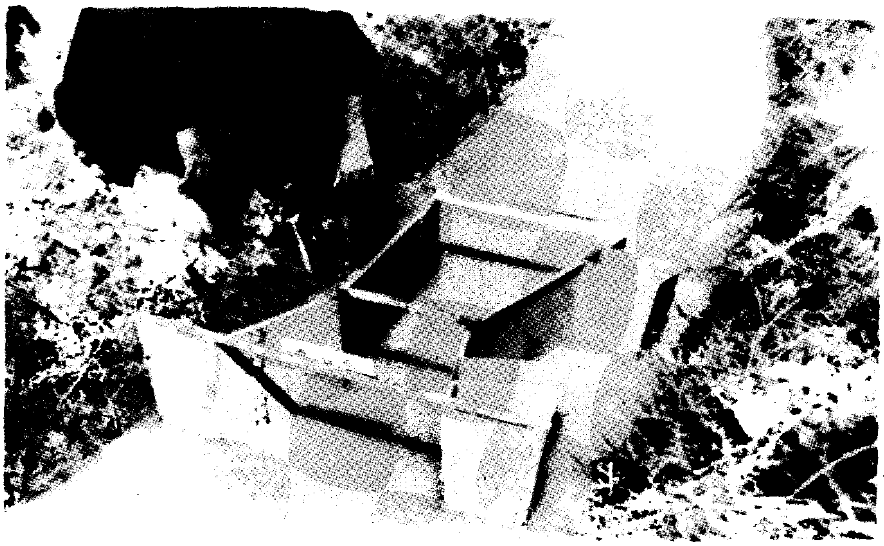
4.7 Sealing the Sides and Underneath the Flume

Once the Cutthroat Flume has been leveled on the pad, the sides of the flume are sealed with hard soil containing grass, because soil without grass could not withstand the flowing water. The sides and underneath the flume are carefully sealed so that very little leakage could occur when observing the flow rate.

Once most of the flow is passing through the flume,the longitudinal and latitudinal levelness of the flume should again be checked using the spirit level. Then, more soil should be placed along the sides of the flume. Again, the levelness should be checked. This procedure should be repeated a number of times until the sides are sealed. Then, more soil should be placed underneath the flume entrance to be sure that there is no leakage beneath the flume.



(a) Checking the longitudinal levelness on top of the Cutthroat Flume wall.



(b) Checking the latitudinal (transverse) levelness at the entrance cross brace of the Cutthroat Flume wall.

Figure 15. Leveling a Cutthroat Flume with water flowing.

(a) Sealing between the Cutthroat Flume and the embankment.

(b) Sealing underneath the Cutthroat Flume to prevent leakage.

Figure 16. Sealing the sides and underneath the floor while installing a Cutthroat Flume in flowing water.

5. DETERMINING THE DISCHARGE RATE

5.1 Reading Flow Depths in a Cutthroat Flume

Once the Cutthroat Flume has been properly installed and leveled, then the staff gauges in the upstream and downstream stilling wells must be periodically monitored, say every five minutes, until the water levels have stabilized. In other words, until steady- state flow is occurring in the flume. The water level in the upstream stilling well is of primary importance because the flume will raise the upstream water level, thereby increasing the storage in the channel upstream from the flume. Usually, 20-40 minutes are required for steady-state flow to occur.

During the time when the flow is trying to reach an equilibrium, the upstream and downstream stilling well gauges should be read about every five minutes and the observations recorded on scratch paper that can later be discarded. When two consecutive sets of readings are identical, then the gauge readings can be permanently recorded in a field book.

5.2 Correcting the Gauge Readings

Once the upstream and downstream staff gauge readings in the stilling wells have been entered, then the appropriate correction determined for each gauge (in Section 3.2) should be applied. The corrected upstream stilling well gauge reading becomes the value of the upstream flow depth, h_u. Likewise, the corrected downstream stilling well gauge reading becomes the value of the downstream flow depth, h_d.

5.3 Determining the Submergence

Once the values of the upstream flow depth(h_u) and downstream flow depth (h_d) are known, then the submergence, S, can be calculated.

$$S = \frac{h_d}{h_u} \tag{17}$$

For the particular size of Cutthroat Flume used in the field, the value of the transition submergence, S_t, will be known. If $S < S_t$, then free flow occurred in the flume. But, if $S > S_t$, then submerged flow was occurring at the time of the field measurement.

5.4 Representation of Discharge Ratings

Free flow. The most useful method for representing the free flow discharge equation is in a free flow discharge rating table. Then, an individual can measure the upstream flow depth, h_u, in the Cutthroat Flume and then find the corresponding free flow discharge rate, Q_f, in the rating table as shown in Table 2 for the Cutthroat Flumes having a flume length, L, of 3 feet.

Submerged flow. A technique for representing a submerged flow discharge rating table is to use a factor that has a unique value for each value of the submergence, S. This can be done by calculating the ratio of the submerged flow discharge rate by the free flow discharge, Q_s/Q_f:

$$\frac{Q_s}{Q_f} = \frac{C_s(h_u - h_d)^{n_f}}{(-\log S)^{n_f}} \frac{1}{C_f h_u^{n_f}} \tag{18}$$

$$\frac{Q_s}{Q_f} = \frac{C_s(1-S)^{n_f}}{C_f(-\log S)^{n_s}} \tag{19}$$

Values of the submergence, S, greater than the transition submergence, S_t, are substituted into Equation 19 and the submerged flow multiplication factor, Q_s/Q_f, calculated. The results are listed in Table 3 for flumes having a length of 3 feet. Note that this submerged flow multiplication factor is equal to unity(1.0000) when the free flow condition exists. This factor is less than unity when submerged flow occurs. Also, for all open channel constrictions, the submerged flow multiplication factor is equal to zero when the submergence is unity, which means that the upstream flow depth equals the downstream flow depth, so h_u-h_d = 0, and there is no flow (Q_s= 0).

The procedure for using the rating tables to determine the submerged flow discharge rate, Q_s, is to:

1. Use the measured value of the upstream flow depth, h_u, to obtain the free flow discharge rate, Q_f, from the free flow rating table(e.g.,Table 2);

2. Use the measured value of the downstream flow depth,h_d, and divide by the measured upstream flow depth, h_u, to calculate the value of the submergence, $S = h_d/h_u$;

3. Using the calculated value of the submergence obtained in Step 2, obtain the value of the submerged flow multiplication factor, Q_s/Q_f, from the submerged flow rating table (e.g., Table 3); and

4. Multiply the results from Steps 1 and 3 to calculate the value of the submerged flow discharge rate, Q_s.

$$\mathbf{Q_s = (step\ 1)\ (step\ 2) = Q_f\ (Q_s/Q_f)} \tag{20}$$

Table 2. Free flow discharge ratings for Cutthroat Flumes having a length L = 3.0'
Source: Skogerboe, G.V., Ren.L., and Yang, D. 1993

h_u ft	W = 4" cfs	W = 8" cfs	W = 12" cfs	W = 16" cfs
0.30	0.153	0.317	0.489	0.668
0.32	0.173	0.357	0.550	0.750
0.34	0.193	0.399	0.614	0.837
0.36	0.214	0.442	0.681	0.927
0.38	0.237	0.488	0.751	1.022
0.40	0.260	0.536	0.824	1.121
0.42	0.285	0.586	0.900	1.223
0.44	0.310	0.638	0.979	1.330
0.46	0.336	0.692	1.061	1.441
0.48	0.364	0.748	1.146	1.555
0.50	0.392	0.806	1.234	1.673
0.52	0.422	0.866	1.325	1.796
0.54	0.452	0.928	1.419	1.922
0.56	0.483	0.991	1.515	2.051
0.58	0.515	1.057	1.615	2.185
0.60	0.548	1.125	1.717	2.322
0.62	0.583	1.194	1.822	2.463
0.64	0.618	1.265	1.930	2.608
0.66	0.654	1.338	2.040	2.756
0.68	0.691	1.413	2.154	2.908
0.70	0.728	1.490	2.270	3.063
0.72	0.767	1.569	2.388	3.222
0.74	0.807	1.649	2.510	3.385
0.76	0.847	1.732	2.634	3.551
0.78	0.889	1.816	2.761	3.721
0.80	0.931	1.902	2.891	3.894
0.82	0.975	1.989	3.023	4.071
0.84	1.019	2.079	3.158	4.251
0.86	1.064	2.170	3.295	4.434
0.88	1.110	2.263	3.435	4.622
0.90	1.157	2.358	3.578	4.812
0.92	1.204	2.454	3.723	5.006
0.94	1.253	2.553	3.871	5.203
0.96	1.302	2.653	4.021	5.404
0.98	1.353	2.754	4.174	5.608
1.00	1.404	2.858	4.330	5.815

Table 3. Submerged flow mutliplication factors for Cutthroat Flumes with L=3.0'
Source: Skogerboe, G.V., Ren.L., and Yang, D. 1993

S	W = 4" Q_s/Q_f	W = 8" Q_s/Q_f	W = 12" Q_s/Q_f	W = 18" Q_s/Q_f
0.610	0.998			
0.620	0.997			
0.630	0.995			
0.640	0.992			
0.650	0.989			
0.660	0.986			
0.670	0.982			
0.680	0.978			
0.690	0.973	0.999		
0.700	0.967	0.998		
0.710	0.961	0.997		
0.720	0.955	0.995		
0.730	0.948	0.992		
0.740	0.940	0.989		
0.750	0.931	0.986		
0.760	0.922	0.981		
0.770	0.912	0.976	0.999	
0.780	0.902	0.971	0.998	
0.790	0.890	0.964	0.996	
0.800	0.878	0.957	0.994	
0.810	0.865	0.949	0.991	
0.820	0.851	0.940	0.987	
0.830	0.836	0.931	0.982	0.999
0.840	0.819	0.920	0.977	0.998

Table 3. (Complete)

Source: Skogerboe, G.V., Ren.L., and Yang, D. 1993

S	W = 4" Q_s/Q_f	W = 8" Q_s/Q_f	W = 12" Q_s/Q_f	W = 18" Q_s/Q_f
0.850	0.802	0.908	0.970	0.996
0.855	0.793	0.901	0.966	0.994
0.860	0.783	0.894	0.963	0.993
0.865	0.773	0.887	0.958	0.991
0.870	0.763	0.880	0.954	0.989
0.875	0.753	0.872	0.949	0.986
0.880	0.742	0.863	0.943	0.983
0.885	0.730	0.855	0.938	0.980
0.890	0.718	0.845	0.932	0.977
0.895	0.706	0.836	0.925	0.973
0.900	0.693	0.825	0.918	0.969
0.905	0.679	0.815	0.911	0.965
0.910	0.665	0.803	0.902	0.960
0.915	0.651	0.791	0.894	0.954
0.920	0.635	0.778	0.884	0.948
0.925	0.619	0.764	0.874	0.941
0.930	0.602	0.750	0.863	0.934
0.935	0.584	0.734	0.851	0.925
0.940	0.565	0.717	0.838	0.916
0.945	0.545	0.699	0.824	0.906
0.950	0.524	0.680	0.808	0.895

5.5 Obtaining the Discharge Rate

Free flow. The free flow discharge rate, Q_f, can be calculated using the appropriate values of C_f and n_f from Table 1:

$$Q_f = C_f h_u^{n_f} \tag{21}$$

where,

Q_f = Free flow discharge in cusecs;
C_f = Free flow coefficient;
h_u = Upstream flow depth in ft; and
n_f = Free flow exponent.

However, this value of Q_f should be multiplied by the free flow throat width correction, K_{tf}, if this value is not exactly 1.00:

$$Q_f = K_{tf} C_f h_u^{n_f} \tag{22}$$

The easiest way to determine the free flow discharge rate is to use the appropriate free flow rating listed in Table 2, which should be multiplied by the free flow throat width correction factor, K_{tf}:

$$\mathbf{Q_f = K_{tf}\, Q_f \text{ (from Table 2)}} \tag{23}$$

Example 11: Computation of Free Flow Discharge Rate

Compute the free flow discharge rate using the newly calibrated Cutthroat Flume having a specified throat width of 12 inches, a specified flume length of 36 inches and a specified wall height of 18 inches. The measured upstream flow depth (h_u) is 1.2 ft and downstream flow depth (h_d) is 0.80 ft and free flow discharge correction factor (K_{tf}) is 1.002.

$$Q_f = K_{tf}\ C_f\ (h_u)^{n_f}$$

$$S = h_d/h_u = 0.82/1.2 = 0.67$$

Since the transition submergence is 0.754, hence the flow conditions will be free flow

$$Q_f = 1.002 * 4.33\ (1.2)^{1.811}$$
$$= 6.036 \text{ cfs}$$

Submerged flow. The submerged flow discharge rate, Q_s, can be calculated using the appropriate values of C_s, n_f, and n_s from Table 1:

$$Q_s = \frac{C_s(h_u - h_d)^{n_f}}{(-\log S)^{n_s}} \qquad (24)$$

where,

Q_s = submerged flow discharge in cusecs;

C_s = submerged flow coefficient;

h_d = Downstream flow depth in ft;

S = Submergence; and

n_s = Submerged flow exponent.

This calculated value of Q_s should be multiplied by the submerged flow throat width correction factor, K_{ts}, if different from 1.00:

$$\mathbf{Q_s = K_{ts}\, Q_s \text{ (from Equation 20)}} \qquad (25)$$

The more common way to determine Q_s is to use the 4-step procedure described at the end of section 5.4. The value of Q_s obtained from this procedure would be multiplied by K_{ts} to obtain the corrected value of the submerged flow discharge rate.

Example 12: Computation of Submerged Flow Discharge Rate

Compute the submerged flow discharge rate using the newly calibrated Cutthroat Flume having a specified throat width of 12 inches, a specified flume length of 36 inches and a specified wall height of 18 inches. The measured upstream flow depth (h_u) is 1.25 ft and downstream flow depth (h_d) is 1.1 ft and submerged flow discharge correction factor (K_{ts}) is 1.003.

$$Q_s = \frac{K_{ts} C_s (h_u - h_d)^{n_f}}{(-\log S)^{n_s}}$$

S = 1.1/1.25 = 0.88

Since, the transition submergence is 0.754, hence the flow conditions will be submerged flow

Therefore,

Q_s = [1.003*2.048(1.25-1.1)$^{1.811}$]/(-log 0.88)$^{1.567}$

= 6.137 cfs = 6.14 cfs.

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ANNEXURE

FORMS FOR RECORDING THE MEASUREMENTS OF THE CUTTHROAT FLUME DIMENSIONS

FORMS FOR RECORDING THE MEASUREMENTS OF THE CUTTHROAT FLUME DIMENSIONS

Flume size : ____________________

Flume number : ____________________

Field location : ____________________

Date : ____________________

Equations used:

$$W_f = \frac{W_{1/2}+W_3+W_6\ldots+W_{H/3}}{N}$$

$$K_{tf} = \frac{W_f}{W_{specified}}$$

$$W_s = \frac{W_{1/2}+W_3+W_6+W_9+W_{12}+\ldots+W_{2H/3}}{N}$$

$$K_{ts} = \frac{W_s}{W_{specified}}$$

1. THROAT WIDTH

Width of Throat Section for Free Flow (W_f)

$W_{1/2}$	W_3	W_6	Total	Average	W_{sp}	K_{tf}	Remarks

Width of Throat Section for Submerged Flow (W_s)

$W_{1/2}$	W_3	W_6	W_9	W_{12}	Total	Average	W_{sp}	K_{tf}	Remarks

Observer ____________________ Checked by: ____________________

FORMS FOR RECORDING THE MEASUREMENTS OF THE CUTTHROAT FLUME DIMENSIONS

Flume size : ______________________

Flume number : ______________________

Field location : ______________________

Date : ______________________

Equations used:

$(L_u)_{meas} = 2L/9 \pm 0.02(L/3)$

$(L_d)_{meas} = 5L/9 \pm 0.02(2L/3)$

2. PIEZOMETER TAPS

UPSTREAM PIEZOMETER TAP			
$(L_u)_{meas}$	$(L_u)_{sp} = 2L/9$	Difference (%)	Remarks

DOWNSTREAM PIEZOMETER TAP			
$(L_d)_{meas}$	$(L_u)_{sp} = 5L/9$	Difference (%)	Remarks

Observer: ______________________ Checked by: ______________________

FORMS FOR RECORDING THE MEASUREMENTS OF THE CUTTHROAT FLUME DIMENSIONS

Flume size : ____________________

Flume number : ____________________

Field location : ____________________

Date : ____________________

Equations used:

$$(B_i)_{meas} = \frac{(B_i)_{1/2}+(B_i)_3+(B_i)_6+\ldots+(B_i)_H}{N}$$

$$(B_i)_{specified} = (W+L)/4.5$$

$$(B_o)_{meas} = \frac{(B_o)_{1/2}+(B_o)_3+(B_o)_6+\ldots+(B_o)_H}{N}$$

$$(B_o)_{specified} = (W+L)/4.5$$

3. FLUME ENTRANCE AND EXIT WIDTHS

3a. Entrance Width $(B_i)_{meas}$

Width of Entrance Section										
$(B_i)_{1/2}$	$(B_i)_3$	$(B_i)_6$	$(B_i)_9$	$(B_i)_{12}$	$(B_i)_{15}$	$(B_i)_{18}$	Ave.	specified width	diff-erence	Remarks

3b. Exit Width $(B_o)_{meas}$

Width of Exit Section										
$(B_o)_{1/2}$	$(B_o)_3$	$(B_o)_6$	$(B_o)_9$	$(B_o)_{12}$	$(B_o)_{15}$	$(B_o)_{18}$	Ave	specified width	diff-erence	Remarks

Observer: ____________________ Checked by: ____________________

FORMS FOR RECORDING THE MEASUREMENTS OF THE CUTTHROAT FLUME DIMENSIONS

Flume size : ______________________

Flume number : ______________________

Field location : ______________________

Date ______________________

CONVERGENCE=

$$\frac{(L_i)_{meas}}{(B_i)_{meas} \quad W_s \quad (L_i)_{meas}/3}$$

DIVERGENCE=

$$\frac{(L_o)_{meas}}{(B_o)_{meas} - W_s - (L_o)_{meas}/6}$$

4. FLUME LENGTHS

INLET CONVERGING SECTION						Remarks
$(L_i)_{meas}$	$(B_i)_{meas}$	W_s	CON.	Given CON.	Diff. %	

OUTLET DIVERGING SECTION						Remarks
$(L_o)_{meas}$	$(B_o)_{meas}$	W_s	CON.	Given DIV.	Diff. %	

Observer: ______________________ Checked by: ______________________

FORMS FOR RECORDING THE MEASUREMENTS OF THE CUTTHROAT FLUME DIMENSIONS

Flume size : ____________________

Flume number : ____________________

Field location : ____________________

Date : ____________________

STAFF GAUGE CORRECTIONS ASSUME H.I = __________ ELEVATION=H.I-STAFF ROD READING

Floor at vicinity of throat						
	Center (1)	Left Side (2)	Right Side (3)	Total (4)	Average (5)	Remarks
Rod reading						
Elevation						

Upstream Stilling Well								
	Top (6)	Actual Gauge Height (7)	Gauge Correction (8)	Corrected Gauge Height (7±8) (9)	Total (5+9) (10)	Elevation at bottom (H.1-Col 10) (11)	Diff. or error (5-11 (12)	Remarks
Rod Reading								

Downstream Stilling Well								
	Top (13)	Actual Gauge Height (14)	Gauge Correction (15)	Corrected Gauge Height (14±15) (16)	Total (13+16) (17)	Elevation at bottom (H.1-Col 17) (18)	Diff. or error (5-18) (19)	Remarks
Rod Reading								

Observer: ________________ Checked by: ____________

IIMI-PAKISTAN PUBLICATIONS

TRAINING REPORTS

Report Number	Title	Author	Year
T-1	How Do Water Users Perceive the Quality of Their Irrigation Services? Report on a Training Course in the Use of Participatory Rural Appraisal for Irrigation Management Research	IIMI-Pakistan	Dec 1994
T-2	Rapid Appraisal of Agricultural Knowledge Systems (RAAKS) and its use in Irrigation Management Research: Training Workshop Report	IIMI-Pakistan	Dec 1995
T-3	Training Course on Field Calibration of Irrigation Structures Fordwah Canal: Technical Report	IIMI-Pakistan	Aug 1995
T-4	Training Course on Field Calibration of Irrigation Outlets Hakra 4-R and Sirajwah Distributaries: Technical Report	IIMI-Pakistan	1996
T-5	Converting a Fabricated Cutthroat Flume into a Discharge Measurement Instrument	Rubina Siddiqui Bakhshal Lashari Gaylord V. Skogerboe	Nov 1996