# CAST-IN-PLACE CONCRETE TRAPEZOIDAL MEASURING FLUMES

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# CONTENTS

# Cast-In-Place Concrete Trapezoidal Measuring Flumes

by

James A. Bondurant,
Allan S. Humpherys, and A. R. Robinson[2]

Water measurement is an important part of the operation of an efficient irrigation system. It serves several purposes: (1) Assures equitable water distribution according to right or need, (2) assures the design flow rate for correct functioning of the farm irrigation system, and (3) provides a record of delivery for payment. Irrigation water is usually measured with measuring flumes, weirs, or submerged orifices.

Measuring flumes, such as the Parshall flume, are widely used and have operational characteristics superior to those of other methods of water measurement. Flumes with trapezoidal cross-sections are used to a lesser extent, but they have certain advantages over rectangular flumes. They have less head loss and better trash clearance capability; they can be installed without a transition section since their trapezoidal shape corresponds to that of most irrigation ditches; and they are easily cast in existing slipform concrete-lined ditches.

This report describes the construction and operation of trapezoidal cast-in-place flumes for standard 1-foot-bottom concrete ditches. Flumes of other sizes and capacities can be installed in the same manner.

## FLUME DESIGN AND OPERATION

Standard designs and free-flow discharge tables for trapezoidal measuring flumes up to 60 cubic feet per second capacity are available.[3] The flume with a 1-foot bottom width and 1:1 sidewall slopes has a flow capacity from 0.16 to 7.0 cfs. The dimensions of this flume are given in figure 1. Rating tables for both free and submerged flow through such a flume are presented in the Appendix on page 9.

Measuring flumes operating under free-flow conditions require only one depth observation for accurate flow measurement. A minimum ditch slope must be exceeded to insure free flow through the flume. At ditch slopes exceeding this minimum, flumes can be installed directly on the ditch bottom with the invert serving as the flume floor. Since many concrete irrigation ditches have less than this minimum slope, the floor of most flumes must be raised above the ditch invert to provide free flow. Flumes normally need to be raised only the amount required to assure free flow, thus minimizing freeboard and conserving elevation head. Elevating flumes more than the free-flow elevation results in unnecessary head loss and excessive turbulence downstream.

Accurate flow measurement with a single depth observation is assured if submergence does not exceed 75 percent (free-flow condition). Free-flow conditions will exist if the flume is raised an amount equal to the difference between the normal downstream depth and $0.75\ h_1$. The normal downstream depth can be determined by observing the existing design flow or by using figure 2. Recommended free-flow elevations can be determined from figure 3. If the flume is installed on the bottom of the ditch, the slope required for free flow is given in figure 3 at $\Delta Z = 0$.

Because a relatively small head loss is required, most trapezoidal flumes can be designed for free-flow conditions. For submerged-flow conditions, a staff gage is required at the downstream ($h_4$) location as shown in figure 1. Flow depths at both locations are observed and the discharge determined from the submerged-flow

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[1] Contribution from the Northwest Branch, Soil and Water Conservation Research Division, Agricultural Research Service, USDA; Idaho Agricultural Experiment Station cooperating.

[2] Agricultural Engineers, Northwest Branch, Snake River Conservation Research Center, Kimberly, Idaho 83341.

[3] Robinson, A. R. Water measurement in small irrigation channels using trapezoidal flumes. Trans. ASAE 9(3): 382-385, 388. 1966.

Robinson, A. R. Trapezoidal flumes for irrigation channels. U. S. Department of Agriculture, ARS-SWC, ARS 41-140, March 1968.

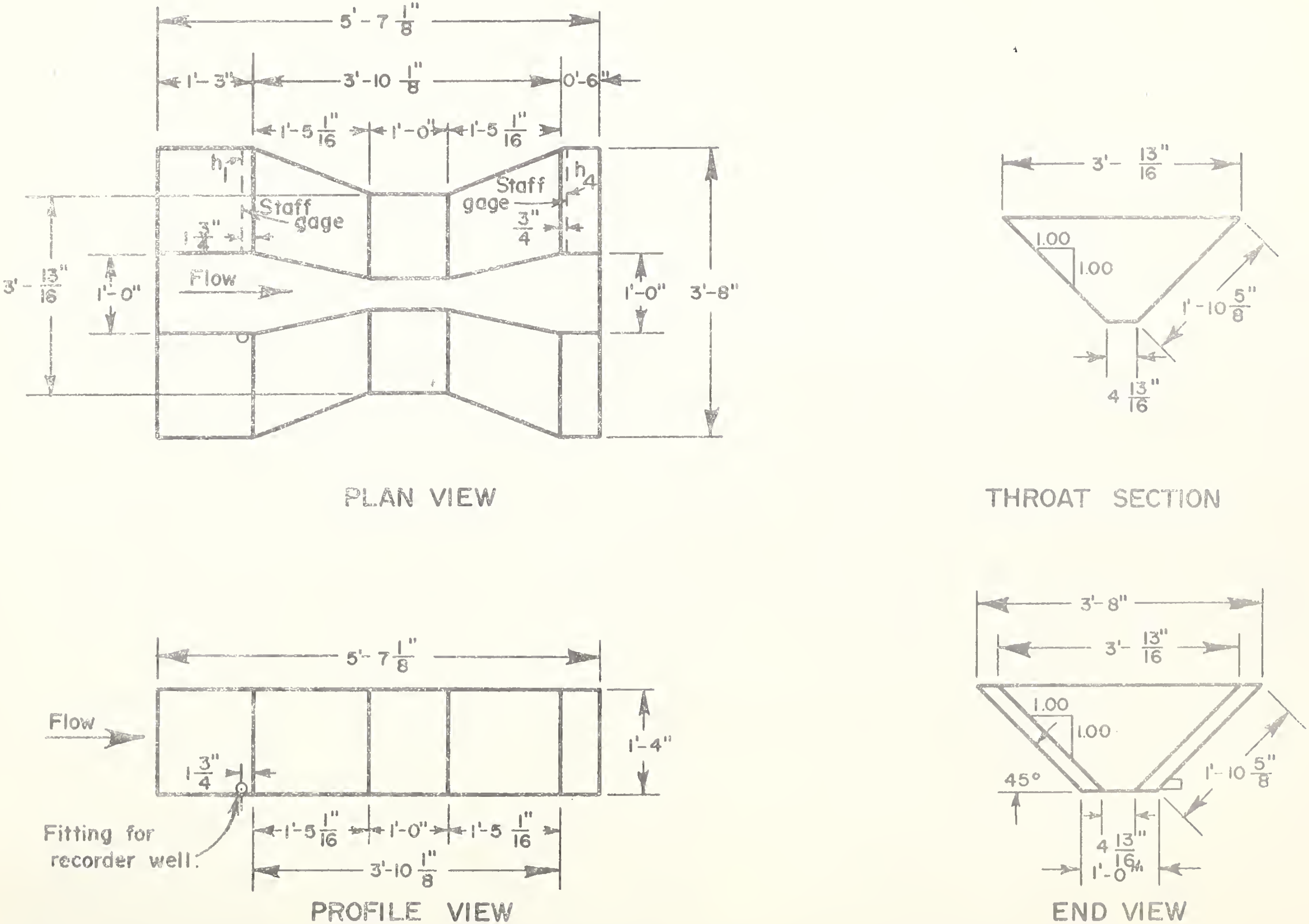


Figure 1. Trapezoidal flume for 1-foot irrigation channels.

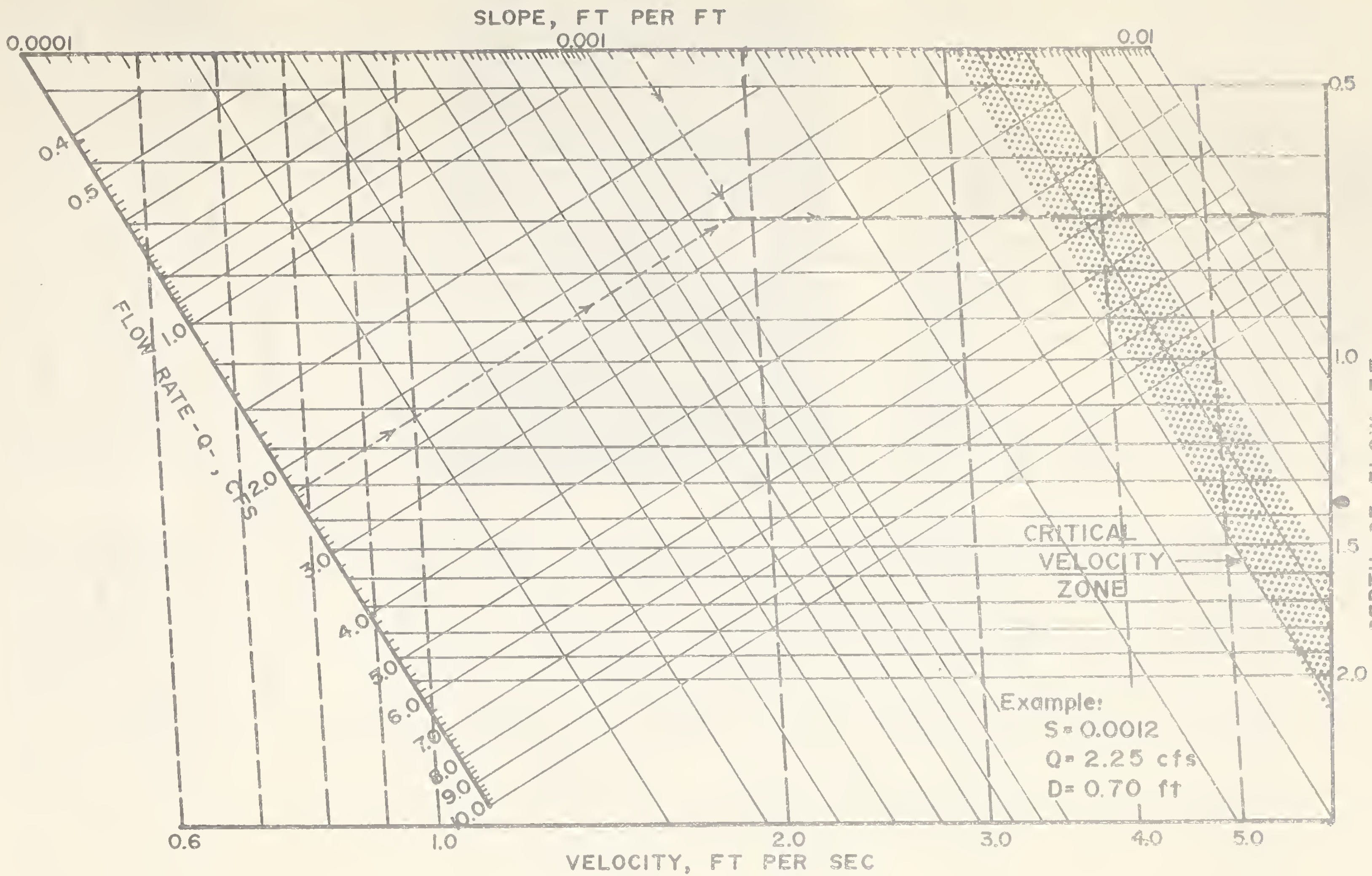


Figure 2. Capacity of concrete-lined ditch; 1.0 ft. bottom, 1:1 side slope, and n = 0.015

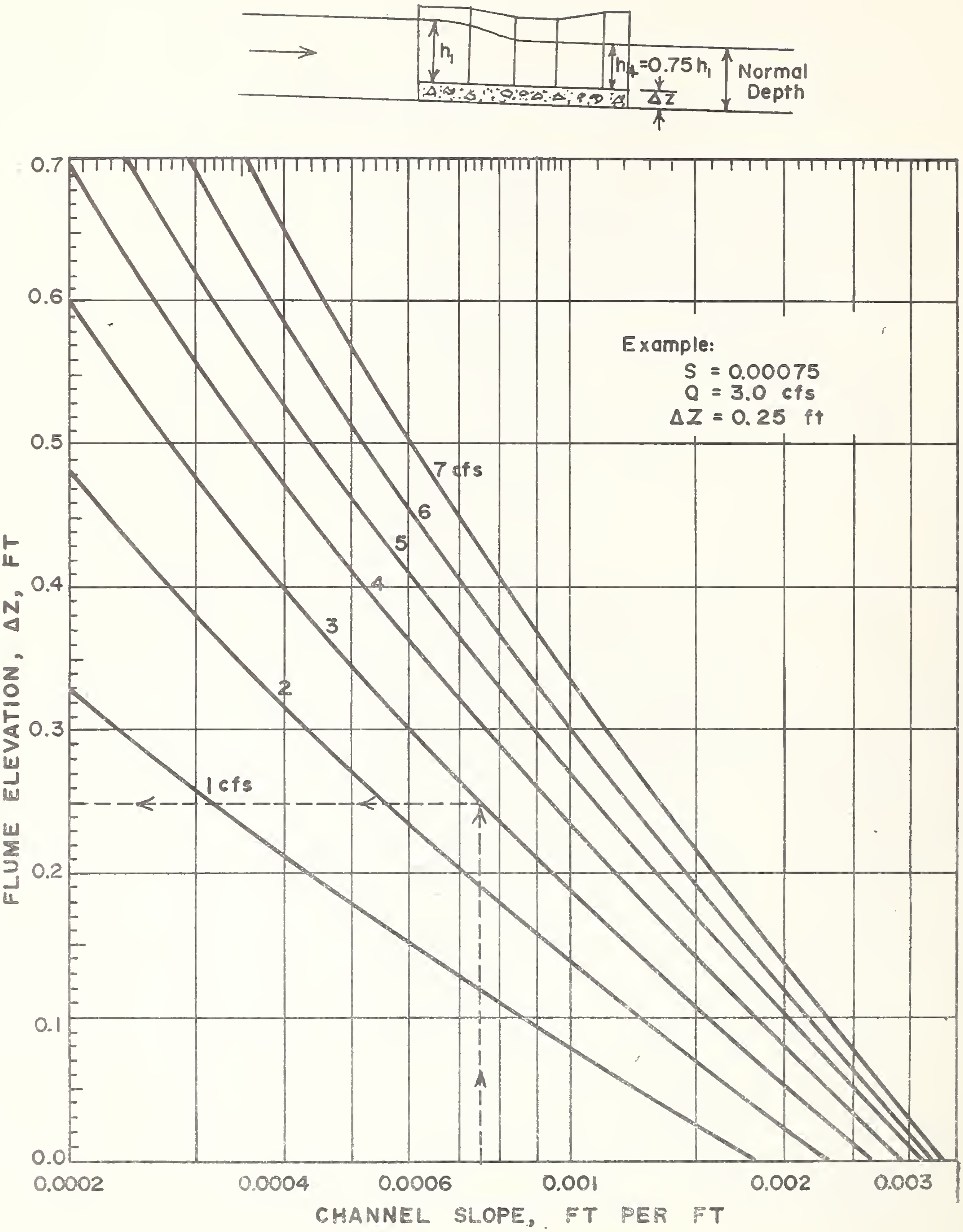


Figure 3. Flume elevation for free flow at various slopes and flow rates; n = 0.015.

tables. For best accuracy, flumes should not be operated at submergences greater than 95%.

Trapezoidal flumes convert subcritical flow in the approach section to critical flow in the throat; therefore, the velocity immediately upstream must be subcritical. If the velocity is supercritical, the backwater depth above a flume installed on the ditch bottom may not be great enough to create a hydraulic jump upstream from the flume. In this case the flume should be elevated to accomplish the conversion to subcritical velocity. Figure 2 may be used to determine whether the normal flow velocity is critical or supercritical.

The flow should approach the flume in a straight path and should be reasonably smooth and uniformly distributed across the width and depth of the approach channel. Flow to be measured should be relatively free from turbulence and eddies such as might occur below a control gate. The flow pattern should be observed before installing a flume in an existing ditch, especially if the flume is to be installed near an object that would create a flow disturbance.

## FORM DESIGN

The form for casting flumes in concrete-lined ditches was made with an angle iron frame covered with 3/16-inch sheet metal, figure 4. The outside dimensions corresponded to the inside dimensions of the flume in figure 1. The frame was cross braced on the interior and across the ends to give rigidity and resistance to torsion stresses. If only a small number of flumes are to be installed, a lighter form, constructed from plywood, is cheaper and may be satisfactory.

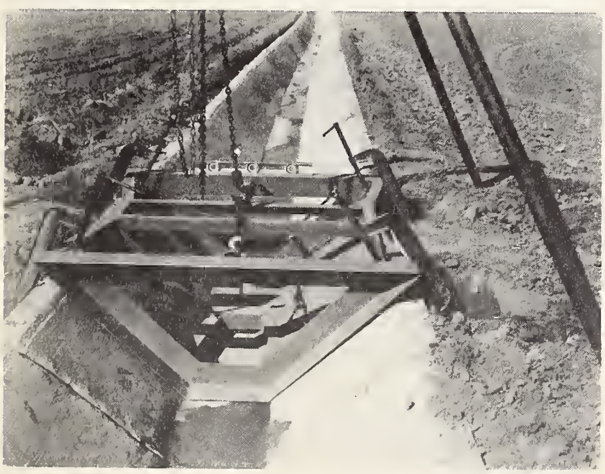

Figure 4. Form without the removable approach section for casting trapezoidal flumes. The ditch invert served as the bottom of the flume in this installation.

All joints were mitered and ground to obtain sharp intersections in the castings. The form was made with a removable section on the approach end. Each end had an adjustable end plate so that the elevation of the flume above the bottom of the ditch could be changed as required for free flow. The approach section, end plates, and a removable bottom were used when a flume was installed with a raised floor. When the flume was cast directly on the bottom of the ditch, the end plates and the bottom were removed and the invert of the existing ditch served as the bottom of the finished flume.

Angle iron clips were welded onto the end plates so that the form could be clamped in place. Holes, drilled in the adjustable end plates, permitted raising the flume form by 3/8-inch increments. Dummy staff gages of strap iron were attached to the under side of the form at both the upstream ($h_1$) and downstream ($h_4$) gage locations to form recesses in the concrete for standard gages. This permitted staff gages to be installed flush with the flume surface. The downstream dummy gage could be removed if only one gage was required.

## RECOMMENDED INSTALLATION PROCEDURE

The ditch section selected for installation of the flume should be of sound concrete. Cracked sections and areas where frost damage may occur should be avoided. After the site for the cast-in-place flume is selected, it should be thoroughly cleaned to obtain a good bond between the existing concrete and the cast flume. Cleaning while water is flowing in the ditch helps remove sediment from the bottom of the ditch. A wire brush will usually remove moss and dirt accumulations on the concrete as well as any loose cement particles that would interfere with the bonding. Most slipform concrete ditches have a sufficiently rough surface so that scarifying is not required to obtain a good bond.

After the ditch section has been cleaned, the form is fitted to the ditch. A steel pipe tripod and a chain hoist can be used for raising and lowering the form (fig. 5).

Figure 5. Form in place for casting a flume with a raised bottom. Note end extension section, tripod and chain hoist for handling the form, and "C" clamps which secure the form to existing lining.

After the form has been centered in the ditch, it is leveled in two directions by chipping concrete from under the contact points, by shimming under the adjustable end plates, or by end plate adjustment. If the form is set directly on the bottom of the ditch, a good fit is essential, particularly in the throat section. This may require considerable work unless a smooth section of lining is selected for the installation.

After the form has been leveled, it is clamped to the existing ditch lining with large "C" clamps. The clamps should be tightened at approximately the same rate on all four corners so that the form is not warped. The form may not fit the sides of the ditch exactly, since some concrete slipform ditches have slightly flatter side slopes than the specified 1:1.

The maximum aggregate size that can be used depends on the elevation of the flume above the floor of the existing ditch. If the form is placed directly on the lining invert, the ends fit against the ditch, and both the upstream and downstream ends of the casting are feather edged. This requires a fine sand aggregate and more slump than a flume cast with a raised bottom. Larger size of aggregate can be used if the flume is elevated above the bottom of the ditch. In general, the maximum aggregate size should be about 1/2 the minimum clearance between the form and the sides of the ditch lining so that concrete may be readily forced underneath the form. All aggregate and water should be clean and free from dirt and organic material.

Type 2 (low alkali) cement is recommended. Air-entrained concrete should be used where freezing and thawing occur. The concrete mix can be batched by volume measurement with a cement content of about five bags per cubic yard. To insure adequate strength, a relatively dry mix should be used. A 3-inch slump is needed for concrete that is forced under the bottom of the form, but a 2-inch slump is adequate for the balance of the pour. When the flume is to be poured directly on the floor of the ditch, the amount of concrete required will vary from 3 to 4 cubic feet, depending on the depth of the ditch. When cast with a raised bottom and the added approach section, the amount of concrete required increases about one cubic foot for each 3/4 inch of elevation. For example, a flume cast with a 1 1/2-inch raised bottom will require about 6 cubic feet, and one cast with a 2 1/4-inch raised bottom will require about 7 cubic feet of concrete.

When the form has been leveled and securely clamped to the ditch lining, the flume is ready to be poured. For good bonding, it is advisable to wet the surface of the concrete ditch before pouring the concrete. Flumes installed with a raised bottom should be poured from one side until the concrete has been forced under the entire bottom section to eliminate voids under the form. After concrete has completely filled the bottom section, the flume may be poured from either side of the form. The concrete should be well rodded to prevent voids either against the concrete ditch or against the form. An electric-impact hammer can be used on the inside of the form to vibrate the concrete. After the concrete has been placed, the top surface edges are finished by troweling. A flume cast directly on the bottom of the ditch is shown in figure 6, and an elevated flume is shown in figure 7.

The length of time the form must be left in place depends on climatic conditions. In hot weather the concrete may set sufficiently in one hour to allow the form to be pulled, whereas in cold weather it may be necessary to wait overnight before removing the form. Considerable care must be exercised if the form is removed before the concrete is hard. The hoist used to lift the form must be accurately centered so that the form can be lifted vertically instead of at an angle. When

Figure 6. Cast trapezoidal flume using the ditch invert as the flume bottom.

Figure 7. Trapezoidal measuring flumes with a raised bottom cast in a concrete ditch.

the flume is cast with a raised bottom, the end plates must be removed before the form is lifted to prevent damage to the ends of the casting. A well-oiled form makes removal easier, particularly if it must be removed before the concrete is fully hardened.

When the form is removed shortly after initial set, the concrete can be troweled to give a smooth surface; however, troweling at this stage may change the flume throat dimensions. The form should be left in place until the concrete is hard enough to insure that dimensions will not change when the flume is being finished. Cast flumes left long enough to preclude troweling of the surface usually are smooth enough that the flow characteristics of the flume are not affected. Small voids can be filled with a fine sand-cement mix or a neat cement mixture. Small ridges can be removed with a trowel. If the concrete has set for several days or longer, a carborundum block is needed for smoothing ridges. A curing compound should be applied to the finished casting, or it should be kept moist for 3 to 5 days. A garden-type sprayer can be used to apply the curing compound.

In cold weather, precautions should be taken to prevent the freshly cast concrete from freezing. The ditch lining on which the flume is cast should be above freezing temperature at the time of installation. It may be necessary to add calcium chloride to the concrete mix and, if possible, heat the aggregate and water. The casting can be adequately protected by covering with a tarp and loosely piled hay or straw. It is advisable to protect the concrete from freezing for at least three days.

Staff gages may be cemented to the flume sidewall with a waterproof cement or attached with lead anchors and screws. If they are cemented, wax-type curing agents must be removed from the gage area. The gage should be placed exactly at a 45° angle with the bottom so that depth measurements are indicated accurately for determining flow rates. Conventional, enameled-iron staff gages, 2 1/2 inches wide, can be used.

## OPERATIONAL CHARACTERISTICS

Visual observations of the flow pattern through cast flumes have been made. Differences in flow pattern between flumes due to sidewall roughness were minor, although it appeared that the most uniform flow was obtained where the form was not removed until the concrete was well set. Those flumes from which the form was removed while the concrete was still green enough to trowel finish appeared to have slight variations in the flow pattern. No visible differences were observed when the abrupt elevation change at the entrance section of the flume was rounded. Figure 8 shows a flume with a raised bottom operating at 70% submergence.

Measurement accuracy depends on maintaining exact dimensions in the casting so that standard rating tables apply. Since the dimensional tolerance is best on those castings that are allowed to set completely before the form is removed, this procedure should also give the most accurate flow measurement. Cast-in-place concrete flumes may be more accurate than light sheet metal ones installed in an earthen ditch, because the sheet metal may bulge during backfilling. Accuracy of flow measurement should be approximately ±3% over most of the flow range. The staff gages can be read ±0.01 of a foot.

Stilling wells for recorders are easily installed on the flumes. The flume can be connected to the recorder well by a pipe finished flush with the side of the flume.

Figure 8. The flume shown in figure 7 with a flow of 1.2 cfs, operating at a submergence of about 70%.

## COST

The on-site installation cost of cast-in-place trapezoidal flumes is approximately \$20 to \$25 each, based on prices current in 1968. A two-man crew requires about 4 man-hours to install and finish one flume. The cost is apportioned as follows:

| | |
|---|---|
| Cement | \$2.00 |
| Aggregate | 0.50 |
| Equipment depreciation | 2.00 |
| Form depreciation | 2.00 |
| Staff gage | 2.25 |
| Labor, 4 hours | 12.00 |

Site preparation time is reduced when the ditch is free from accumulated sediment and debris. Setting and leveling the form is easier and requires less time when the flume is elevated. A raised flume is stronger and also requires less finishing time, since all feather edges are eliminated. When the flume is poured directly onto the existing ditch bottom, considerable time may be spent in fitting the metal form to slight variations in the concrete surface of the ditch. The estimated cost of the metal form and tripod is \$200, including about \$50 for materials and 30 hours of construction time.

Cast-in-place trapezoidal flumes installed in existing or new slipform concrete-lined ditches provide an economical and accurate method of irrigation water measurement at less cost than other devices. Metal or fiberglass measuring flumes of equivalent capacity cost about \$85 to \$100 each, plus installation. Cast-in-place Cipolletti weirs of this size not only require more operating head, but they also cost about \$100 each.

## SUMMARY

Concrete trapezoidal measuring flumes cast in existing slipform concrete-lined ditches provide economical and accurate water measurement. Cast-in-place flumes for a standard 1-foot-bottom ditch can be installed in about 4 man-hours at a cost of \$20 to \$25. With an accurately constructed form, flumes can be cast to dimensions that are as accurate as those made of metal or fiberglass.

The bottom of the cast flume can be elevated above the floor of the ditch to insure free-flow conditions for the design flow. Elevated flumes are also easier to install. Using the existing ditch bottom as a floor requires more time to fit the form to the ditch lining, a more fluid concrete mix, smaller aggregate size, and more hand finishing.

* * * * *

TABLE 1.—Free- and submerged-flow discharge, in cubic feet per second, through a trapezoidal flume with a 1-foot bottom width and 1:1 sidewall slopes ($h_1$, $h_4$ measured in vertical direction)

| $h_1$ (feet) | Free-flow discharge (cfs) | Submerged-flow discharge with $h_4$ (ft.) measuring– | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.16 | 0.18 | 0.20 | 0.22 | 0.24 | 0.26 | 0.28 | 0.30 | 0.32 | 0.34 | 0.36 | 0.38 | 0.40 | 0.42 | 0.44 | 0.46 | 0.48 | 0.50 | 0.52 |
| 0.20 | 0.16 | 0.16 | 0.15 | | | | | | | | | | | | | | | | | |
| 0.21 | .18 | .18 | .17 | | | | | | | | | | | | | | | | | |
| 0.22 | .19 | .19 | .18 | 0.17 | | | | | | | | | | | | | | | | |
| 0.23 | .20 | | .20 | .19 | | | | | | | | | | | | | | | | |
| 0.24 | .22 | | .22 | .21 | 0.20 | | | | | | | | | | | | | | | |
| 0.25 | .23 | | .23 | .23 | .22 | | | | | | | | | | | | | | | |
| 0.26 | .24 | | | .24 | .24 | 0.22 | | | | | | | | | | | | | | |
| 0.27 | .26 | | | .26 | .25 | .24 | | | | | | | | | | | | | | |
| 0.28 | .28 | | | .28 | .28 | .27 | 0.25 | | | | | | | | | | | | | |
| 0.29 | .29 | | | | .29 | .28 | .27 | | | | | | | | | | | | | |
| 0.30 | .31 | | | | .31 | .31 | .30 | 0.28 | | | | | | | | | | | | |
| 0.31 | .33 | | | | .33 | .33 | .32 | .30 | | | | | | | | | | | | |
| 0.32 | .35 | | | | | .35 | .34 | .33 | 0.31 | | | | | | | | | | | |
| 0.33 | .37 | | | | | .37 | .37 | .35 | .34 | | | | | | | | | | | |
| 0.34 | .39 | | | | | .39 | .39 | .38 | .37 | 0.34 | | | | | | | | | | |
| 0.35 | .41 | | | | | | .41 | .41 | .39 | .37 | | | | | | | | | | |
| 0.36 | .44 | | | | | | .44 | .43 | .42 | .40 | 0.38 | | | | | | | | | |
| 0.37 | .46 | | | | | | .46 | .46 | .44 | .44 | .41 | | | | | | | | | |
| 0.38 | .49 | | | | | | | .48 | .48 | .46 | .44 | 0.42 | | | | | | | | |
| 0.39 | .51 | | | | | | | .51 | .50 | .49 | .48 | .45 | | | | | | | | |
| 0.40 | .54 | | | | | | | | .53 | .53 | .51 | .49 | | | | | | | | |
| 0.41 | .56 | | | | | | | | .56 | .56 | .54 | .53 | 0.50 | | | | | | | |
| 0.42 | .59 | | | | | | | | .59 | .58 | .58 | .56 | .53 | | | | | | | |
| 0.43 | .62 | | | | | | | | | .61 | .61 | .59 | .58 | 0.55 | | | | | | |
| 0.44 | .65 | | | | | | | | | .64 | .64 | .62 | .61 | .58 | | | | | | |
| 0.45 | .68 | | | | | | | | | .67 | .67 | .67 | .64 | .62 | 0.59 | | | | | |
| 0.46 | .71 | | | | | | | | | | .70 | .70 | .68 | .67 | .64 | | | | | |
| 0.47 | .74 | | | | | | | | | | .73 | .73 | .73 | .70 | .67 | 0.65 | | | | |
| 0.48 | .78 | | | | | | | | | | .77 | .77 | .76 | .74 | .73 | .69 | | | | |
| 0.49 | .81 | | | | | | | | | | | .80 | .80 | .77 | .76 | .73 | 0.70 | | | |
| 0.50 | .84 | | | | | | | | | | | .83 | .83 | .83 | .80 | .79 | .75 | | | |
| 0.51 | .88 | | | | | | | | | | | .87 | .87 | .86 | .84 | .83 | .79 | 0.76 | | |
| 0.52 | .92 | | | | | | | | | | | | .91 | .90 | .90 | .87 | .86 | .81 | | |
| 0.53 | .95 | | | | | | | | | | | | .94 | .94 | .94 | .91 | .90 | .86 | 0.82 | |
| 0.54 | .99 | | | | | | | | | | | | .93 | .98 | .98 | .95 | .94 | .90 | .83 | |
| 0.55 | 1.03 | | | | | | | | | | | | | 1.02 | 1.02 | 1.01 | .98 | .97 | .92 | 0.88 |
| 0.56 | 1.07 | | | | | | | | | | | | | 1.06 | 1.06 | 1.05 | 1.02 | 1.01 | .97 | .94 |

TABLE 1.—Free-and submerged-flow discharge, in cubic feet per second, through a trapezoidal flume with a 1-foot bottom width and 1:1 sidewall slopes ($h_1$, $h_4$ measured in vertical direction)—Continued

| $h_1$ (feet) | Free-flow discharge (cfs) | Submerged-flow discharge with $h_4$ (ft.) measuring— | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.40 | 0.42 | 0.44 | 0.46 | 0.48 | 0.50 | 0.52 | 0.54 | 0.56 | 0.58 | 0.60 | 0.62 | 0.64 | 0.66 | 0.68 | 0.70 | 0.72 | 0.74 | 0.76 |
| 0.57 | 1.11 | 1.10 | 1.10 | 1.10 | 1.09 | 1.05 | 1.04 | .99 | 0.95 | | | | | | | | | | | |
| 0.58 | 1.16 | | 1.14 | 1.14 | 1.13 | 1.10 | 1.09 | 1.04 | 1.01 | | | | | | | | | | | |
| 0.59 | 1.20 | | 1.19 | 1.18 | 1.18 | 1.14 | 1.13 | 1.12 | 1.07 | 1.01 | | | | | | | | | | |
| 0.60 | 1.24 | | | 1.23 | 1.22 | 1.22 | 1.18 | 1.17 | 1.12 | 1.08 | | | | | | | | | | |
| 0.61 | 1.29 | | | 1.27 | 1.27 | 1.26 | 1.23 | 1.22 | 1.17 | 1.14 | | | | | | | | | | |
| 0.62 | 1.34 | | | 1.32 | 1.32 | 1.31 | 1.31 | 1.26 | 1.25 | 1.20 | 1.16 | | | | | | | | | |
| 0.63 | 1.38 | | | | 1.36 | 1.36 | 1.35 | 1.31 | 1.30 | 1.25 | 1.22 | | | | | | | | | |
| 0.64 | 1.43 | | | | 1.41 | 1.41 | 1.40 | 1.36 | 1.35 | 1.34 | 1.28 | 1.24 | | | | | | | | |
| 0.65 | 1.48 | | | | 1.46 | 1.46 | 1.45 | 1.45 | 1.40 | 1.39 | 1.34 | 1.31 | | | | | | | | |
| 0.66 | 1.53 | | | | | 1.51 | 1.51 | 1.50 | 1.46 | 1.45 | 1.43 | 1.37 | 1.32 | | | | | | | |
| 0.67 | 1.58 | | | | | 1.56 | 1.56 | 1.55 | 1.55 | 1.50 | 1.49 | 1.43 | 1.39 | | | | | | | |
| 0.68 | 1.63 | | | | | 1.61 | 1.61 | 1.61 | 1.60 | 1.55 | 1.54 | 1.53 | 1.46 | 1.41 | | | | | | |
| 0.69 | 1.69 | | | | | | 1.67 | 1.66 | 1.66 | 1.61 | 1.60 | 1.58 | 1.52 | 1.48 | | | | | | |
| 0.70 | 1.74 | | | | | | 1.72 | 1.72 | 1.71 | 1.71 | 1.65 | 1.64 | 1.58 | 1.55 | 1.49 | | | | | |
| 0.71 | 1.80 | | | | | | 1.78 | 1.77 | 1.77 | 1.76 | 1.71 | 1.70 | 1.69 | 1.62 | 1.58 | | | | | |
| 0.72 | 1.86 | | | | | | | 1.83 | 1.83 | 1.82 | 1.81 | 1.76 | 1.75 | 1.68 | 1.65 | 1.58 | | | | |
| 0.73 | 1.91 | | | | | | | 1.89 | 1.88 | 1.88 | 1.87 | 1.82 | 1.81 | 1.79 | 1.72 | 1.67 | | | | |
| 0.74 | 1.97 | | | | | | | 1.95 | 1.94 | 1.94 | 1.93 | 1.88 | 1.87 | 1.85 | 1.78 | 1.75 | 1.68 | | | |
| 0.75 | 2.03 | | | | | | | | 2.00 | 2.00 | 1.99 | 1.99 | 1.93 | 1.92 | 1.90 | 1.82 | 1.77 | | | |
| 0.76 | 2.09 | | | | | | | | 2.07 | 2.06 | 2.06 | 2.05 | 1.99 | 1.98 | 1.96 | 1.89 | 1.85 | 1.78 | | |
| 0.77 | 2.16 | | | | | | | | 2.13 | 2.12 | 2.12 | 2.11 | 2.11 | 2.04 | 2.03 | 2.01 | 1.93 | 1.87 | | |
| 0.78 | 2.22 | | | | | | | | | 2.19 | 2.18 | 2.18 | 2.17 | 2.11 | 2.10 | 2.03 | 2.00 | 1.96 | 1.88 | |
| 0.79 | 2.28 | | | | | | | | | 2.25 | 2.25 | 2.24 | 2.24 | 2.17 | 2.16 | 2.15 | 2.07 | 2.04 | 1.98 | |
| 0.80 | 2.35 | | | | | | | | | 2.32 | 2.32 | 2.31 | 2.30 | 2.30 | 2.23 | 2.22 | 2.20 | 2.11 | 2.07 | |
| 0.81 | 2.42 | | | | | | | | | | 2.38 | 2.38 | 2.37 | 2.37 | 2.30 | 2.28 | 2.27 | 2.19 | 2.15 | 2.09 |
| 0.82 | 2.48 | | | | | | | | | | 2.45 | 2.45 | 2.44 | 2.43 | 2.43 | 2.35 | 2.34 | 2.32 | 2.23 | 2.18 |
| | | 0.60 | 0.62 | 0.64 | 0.66 | 0.68 | 0.70 | 0.72 | 0.74 | 0.76 | 0.78 | 0.80 | 0.82 | 0.84 | 0.86 | 0.88 | 0.90 | 0.92 | 0.94 | 0.96 |
| 0.83 | 2.55 | 2.52 | 2.51 | 2.51 | 2.50 | 2.42 | 2.41 | 2.40 | 2.31 | 2.27 | 2.20 | | | | | | | | | |
| 0.84 | 2.62 | 2.59 | 2.58 | 2.58 | 2.57 | 2.56 | 2.48 | 2.47 | 2.45 | 2.35 | 2.30 | | | | | | | | | |
| 0.85 | 2.70 | 2.66 | 2.65 | 2.65 | 2.64 | 2.63 | 2.56 | 2.54 | 2.52 | 2.43 | 2.39 | 2.32 | | | | | | | | |
| 0.86 | 2.77 | | 2.73 | 2.72 | 2.72 | 2.71 | 2.63 | 2.62 | 2.60 | 2.58 | 2.48 | 2.42 | | | | | | | | |
| 0.87 | 2.84 | | 2.80 | 2.80 | 2.79 | 2.78 | 2.78 | 2.69 | 2.68 | 2.66 | 2.56 | 2.51 | 2.43 | | | | | | | |
| 0.88 | 2.92 | | 2.88 | 2.87 | 2.87 | 2.86 | 2.85 | 2.77 | 2.76 | 2.74 | 2.64 | 2.60 | 2.54 | | | | | | | |
| 0.89 | 2.99 | | | 2.95 | 2.94 | 2.94 | 2.93 | 2.92 | 2.83 | 2.82 | 2.80 | 2.69 | 2.64 | 2.56 | | | | | | |
| 0.90 | 3.07 | | | 3.03 | 3.02 | 3.02 | 3.01 | 3.00 | 2.91 | 2.90 | 2.88 | 2.78 | 2.74 | 2.67 | | | | | | |
| 0.91 | 3.15 | | | 3.11 | 3.10 | 3.10 | 3.09 | 3.08 | 2.99 | 2.98 | 2.96 | 2.94 | 2.83 | 2.78 | 2.68 | | | | | |
| 0.92 | 3.23 | | | | 3.18 | 3.18 | 3.17 | 3.16 | 3.15 | 3.06 | 3.04 | 3.02 | 2.92 | 2.87 | 2.80 | | | | | |
| 0.93 | 3.31 | | | | 3.26 | 3.26 | 3.25 | 3.24 | 3.24 | 3.14 | 3.13 | 3.11 | 3.09 | 2.97 | 2.91 | 2.81 | | | | |
| 0.94 | 3.39 | | | | 3.34 | 3.34 | 3.33 | 3.33 | 3.32 | 3.31 | 3.21 | 3.20 | 3.17 | 3.06 | 3.01 | 2.94 | | | | |

TABLE 1.—Free- and submerged-flow discharge, in cubic feet per second, through a trapezoidal flume with a 1-foot bottom width and 1:1 sidewall slopes ($h_1$, $h_4$ measured in vertical direction)—Continued

| $h_1$ (feet) | Free-flow discharge (cfs) | Submerged-flow discharge with $h_4$ (ft.) measuring— | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.68 | 0.70 | 0.72 | 0.74 | 0.76 | 0.78 | 0.80 | 0.82 | 0.84 | 0.86 | 0.88 | 0.90 | 0.92 | 0.94 | 0.96 | 0.98 | 1.00 | 1.02 |
| 0.95 | 3.47 | 3.42 | 3.42 | 3.41 | 3.40 | 3.39 | 3.30 | 3.28 | 3.26 | 3.24 | 3.11 | 3.05 | 2.94 | | | | | | |
| 0.96 | 3.56 | 3.51 | 3.50 | 3.50 | 3.49 | 3.48 | 3.38 | 3.37 | 3.35 | 3.33 | 3.21 | 3.16 | 3.08 | | | | | | |
| 0.97 | 3.65 | 3.60 | 3.59 | 3.58 | 3.58 | 3.57 | 3.56 | 3.45 | 3.44 | 3.42 | 3.30 | 3.26 | 3.19 | 3.08 | | | | | |
| 0.98 | 3.73 | | 3.68 | 3.67 | 3.67 | 3.66 | 3.65 | 3.54 | 3.53 | 3.51 | 3.49 | 3.36 | 3.30 | 3.22 | | | | | |
| 0.99 | 3.82 | | 3.77 | 3.76 | 3.75 | 3.75 | 3.74 | 3.73 | 3.62 | 3.60 | 3.58 | 3.45 | 3.41 | 3.34 | 3.22 | | | | |
| 1.00 | 3.91 | | 3.86 | 3.85 | 3.84 | 3.84 | 3.83 | 3.82 | 3.71 | 3.69 | 3.67 | 3.65 | 3.51 | 3.46 | 3.36 | | | | |
| 1.01 | 4.00 | | | 3.94 | 3.94 | 3.93 | 3.92 | 3.91 | 3.80 | 3.79 | 3.77 | 3.74 | 3.61 | 3.57 | 3.49 | | | | |
| 1.02 | 4.09 | | | 4.03 | 4.03 | 4.02 | 4.02 | 4.01 | 4.00 | 3.88 | 3.86 | 3.84 | 3.81 | 3.67 | 3.61 | 3.51 | | | |
| 1.03 | 4.19 | | | | 4.12 | 4.12 | 4.11 | 4.10 | 4.09 | 3.97 | 3.96 | 3.94 | 3.91 | 3.78 | 3.73 | 3.65 | | | |
| 1.04 | 4.28 | | | | 4.22 | 4.21 | 4.21 | 4.20 | 4.19 | 4.18 | 4.06 | 4.04 | 4.01 | 3.98 | 3.84 | 3.77 | 3.67 | | |
| 1.05 | 4.38 | | | | 4.31 | 4.31 | 4.30 | 4.29 | 4.29 | 4.27 | 4.15 | 4.14 | 4.12 | 4.09 | 3.94 | 3.89 | 3.81 | | |
| 1.06 | 4.47 | | | | | 4.41 | 4.40 | 4.39 | 4.38 | 4.37 | 4.25 | 4.23 | 4.22 | 4.19 | 4.05 | 4.00 | 3.94 | 3.82 | |
| 1.07 | 4.57 | | | | | 4.51 | 4.50 | 4.49 | 4.48 | 4.47 | 4.46 | 4.33 | 4.32 | 4.30 | 4.27 | 4.11 | 4.06 | 3.97 | |
| 1.08 | 4.67 | | | | | 4.61 | 4.60 | 4.59 | 4.59 | 4.58 | 4.57 | 4.44 | 4.42 | 4.40 | 4.37 | 4.22 | 4.17 | 4.10 | 3.98 |
| 1.09 | 4.77 | | | | | | 4.70 | 4.70 | 4.69 | 4.68 | 4.67 | 4.66 | 4.52 | 4.50 | 4.48 | 4.45 | 4.29 | 4.23 | 4.14 |
| | | 0.78 | 0.80 | 0.82 | 0.84 | 0.86 | 0.88 | 0.90 | 0.92 | 0.94 | 0.96 | 0.98 | 1.00 | 1.02 | 1.04 | 1.06 | 1.08 | 1.10 | 1.12 |
| 1.10 | 4.88 | 4.80 | 4.80 | 4.79 | 4.78 | 4.77 | 4.76 | 4.63 | 4.61 | 4.59 | 4.56 | 4.40 | 4.35 | 4.27 | 4.15 | | | | |
| 1.11 | 4.98 | 4.91 | 4.90 | 4.90 | 4.89 | 4.88 | 4.87 | 4.73 | 4.71 | 4.69 | 4.67 | 4.64 | 4.47 | 4.41 | 4.31 | | | | |
| 1.12 | 5.08 | | 5.01 | 5.00 | 4.99 | 4.99 | 4.97 | 4.96 | 4.82 | 4.80 | 4.78 | 4.75 | 4.59 | 4.53 | 4.45 | 4.31 | | | |
| 1.13 | 5.19 | | 5.12 | 5.11 | 5.10 | 5.09 | 5.08 | 5.07 | 4.93 | 4.91 | 4.89 | 4.86 | 4.83 | 4.65 | 4.59 | 4.48 | | | |
| 1.14 | 5.30 | | 5.22 | 5.22 | 5.21 | 5.20 | 5.19 | 5.18 | 5.17 | 5.02 | 5.00 | 4.98 | 4.95 | 4.77 | 4.72 | 4.63 | 4.49 | | |
| 1.15 | 5.41 | | | 5.33 | 5.32 | 5.31 | 5.30 | 5.29 | 5.28 | 5.13 | 5.11 | 5.09 | 5.06 | 4.89 | 4.84 | 4.77 | 4.66 | | |
| 1.16 | 5.52 | | | 5.44 | 5.43 | 5.42 | 5.41 | 5.40 | 5.39 | 5.24 | 5.22 | 5.20 | 5.18 | 5.15 | 4.97 | 4.90 | 4.81 | 4.66 | |
| 1.17 | 5.63 | | | 5.55 | 5.54 | 5.54 | 5.53 | 5.52 | 5.51 | 5.49 | 5.34 | 5.32 | 5.30 | 5.27 | 5.09 | 5.03 | 4.96 | 4.84 | |
| 1.18 | 5.74 | | | | 5.66 | 5.65 | 5.64 | 5.63 | 5.62 | 5.61 | 5.45 | 5.43 | 5.41 | 5.39 | 5.35 | 5.16 | 5.10 | 5.00 | 4.84 |
| 1.19 | 5.86 | | | | 5.77 | 5.77 | 5.76 | 5.75 | 5.74 | 5.73 | 5.71 | 5.55 | 5.53 | 5.51 | 5.47 | 5.29 | 5.23 | 5.15 | 5.03 |
| | | 0.86 | 0.88 | 0.90 | 0.92 | 0.94 | 0.96 | 0.98 | 1.00 | 1.02 | 1.04 | 1.06 | 1.08 | 1.10 | 1.12 | 1.14 | 1.16 | 1.18 | 1.20 |
| 1.20 | 5.97 | 5.88 | 5.87 | 5.87 | 5.86 | 5.85 | 5.83 | 5.67 | 5.65 | 5.63 | 5.60 | 5.56 | 5.36 | 5.29 | 5.19 | | | | |
| 1.21 | 6.09 | 6.00 | 5.99 | 5.98 | 5.97 | 5.96 | 5.95 | 5.94 | 5.77 | 5.75 | 5.72 | 5.69 | 5.49 | 5.43 | 5.35 | 5.22 | | | |
| 1.22 | 6.21 | 6.12 | 6.11 | 6.10 | 6.09 | 6.08 | 6.07 | 6.06 | 5.89 | 5.87 | 5.84 | 5.81 | 5.62 | 5.57 | 5.50 | 5.39 | | | |
| 1.23 | 6.33 | | 6.23 | 6.22 | 6.22 | 6.21 | 6.19 | 6.18 | 6.01 | 5.99 | 5.97 | 5.94 | 5.91 | 5.70 | 5.64 | 5.55 | 5.41 | | |
| 1.24 | 6.45 | | 6.35 | 6.35 | 6.34 | 6.33 | 6.32 | 6.31 | 6.29 | 6.11 | 6.09 | 6.07 | 6.03 | 5.83 | 5.78 | 5.70 | 5.59 | | |
| 1.25 | 6.57 | | 6.48 | 6.47 | 6.46 | 6.45 | 6.44 | 6.43 | 6.42 | 6.24 | 6.22 | 6.19 | 6.16 | 6.13 | 5.92 | 5.85 | 5.76 | 5.61 | |
| 1.26 | 6.70 | | | 6.60 | 6.59 | 6.58 | 6.57 | 6.56 | 6.54 | 6.53 | 6.34 | 6.32 | 6.29 | 6.26 | 6.05 | 5.99 | 5.91 | 5.79 | |
| 1.27 | 6.82 | | | 6.72 | 6.71 | 6.71 | 6.70 | 6.68 | 6.67 | 6.66 | 6.47 | 6.45 | 6.42 | 6.39 | 6.36 | 6.13 | 6.06 | 5.97 | 5.81 |
| 1.28 | 6.95 | | | 6.85 | 6.84 | 6.83 | 6.82 | 6.81 | 6.80 | 6.79 | 6.60 | 6.58 | 6.56 | 6.53 | 6.49 | 6.27 | 6.21 | 6.13 | 6.00 |
| 1.29 | 7.08 | | | | 6.97 | 6.96 | 6.95 | 6.94 | 6.93 | 6.92 | 6.90 | 6.71 | 6.69 | 6.66 | 6.63 | 6.59 | 6.36 | 6.28 | 6.18 |

TABLE 2.–Free- and submerged-flow discharge, in cubic feet per second, through trapezoidal flume with a 1-foot bottom width and 1:1 sidewall slopes ($h_1$, $h_4$ measured along sloping sidewall)

| $h_1$ (feet) | Free-flow discharge (cfs) | Submerged-flow discharge with $h_4$ (ft.) measuring– | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.21 | 0.23 | 0.25 | 0.27 | 0.29 | 0.31 | 0.33 | 0.35 | 0.37 | 0.28 | 0.30 | 0.32 | 0.34 | 0.36 | 0.38 | 0.40 | 0.42 | 0.44 | 0.46 |
| 0.30 | 0.18 | 0.18 | 0.18 | 0.17 | 0.16 | | | | | | | | | | | | | | | |
| 0.31 | .19 | | .19 | .19 | .18 | 0.17 | | | | | | | | | | | | | | |
| 0.32 | .20 | | .20 | .20 | .19 | .18 | | | | | | | | | | | | | | |
| 0.33 | .21 | | | .21 | .20 | .20 | 0.18 | | | | | | | | | | | | | |
| 0.34 | .22 | | | .22 | .21 | .21 | .20 | | | | | | | | | | | | | |
| 0.35 | .23 | | | .23 | .23 | .22 | .21 | 0.20 | | | | | | | | | | | | |
| 0.36 | .24 | | | | .24 | .23 | .23 | .21 | | | | | | | | | | | | |
| 0.37 | .25 | | | | .25 | .25 | .24 | .23 | 0.21 | | | | | | | | | | | |
| 0.38 | .26 | | | | .26 | .26 | .25 | .25 | .23 | | | | | | | | | | | |
| 0.39 | .27 | | | | | .27 | .27 | .26 | .25 | 0.23 | | | | | | | | | | |
| 0.40 | .28 | | | | | | | | | | 0.28 | 0.28 | 0.28 | 0.27 | 0.26 | | | | | |
| 0.41 | .29 | | | | | | | | | | | .29 | .29 | .28 | .28 | 0.26 | | | | |
| 0.42 | .31 | | | | | | | | | | | .31 | .31 | .30 | .29 | .28 | | | | |
| 0.43 | .32 | | | | | | | | | | | | .32 | .32 | .31 | .30 | 0.28 | | | |
| 0.44 | .33 | | | | | | | | | | | | .33 | .33 | .32 | .32 | .30 | | | |
| 0.45 | .35 | | | | | | | | | | | | .35 | .34 | .34 | .33 | .32 | 0.31 | | |
| 0.46 | .36 | | | | | | | | | | | | | .36 | .36 | .35 | .34 | .33 | | |
| 0.47 | .38 | | | | | | | | | | | | | .37 | .37 | .37 | .36 | .34 | 0.33 | |
| 0.48 | .39 | | | | | | | | | | | | | .39 | .39 | .39 | .37 | .37 | .35 | |
| 0.49 | .41 | | | | | | | | | | | | | | .40 | .40 | .39 | .39 | .37 | 0.35 |
| | | 0.35 | 0.37 | 0.39 | 0.41 | 0.43 | 0.45 | 0.47 | 0.49 | 0.49 | 0.53 | 0.55 | 0.42 | 0.44 | 0.46 | 0.48 | 0.50 | 0.52 | 0.54 | 0.56 |
| 0.50 | .42 | .42 | .42 | .42 | .40 | .40 | .38 | 0.37 | | | | | | | | | | | | |
| 0.51 | .44 | | .44 | .43 | .43 | .42 | .41 | .39 | | | | | | | | | | | | |
| 0.52 | .45 | | .45 | .45 | .45 | .43 | .43 | ,41 | 0.39 | | | | | | | | | | | |
| 0.53 | .47 | | | .47 | .47 | .45 | .45 | .43 | .42 | | | | | | | | | | | |
| 0.54 | .49 | | | .49 | .48 | .48 | .47 | .46 | .44 | 0.42 | | | | | | | | | | |
| 0.55 | .51 | | | .50 | .50 | .50 | .48 | .48 | .46 | .45 | | | | | | | | | | |
| 0.56 | .52 | | | | .52 | .52 | .52 | .50 | .49 | .47 | 0.45 | | | | | | | | | |
| 0.57 | .54 | | | | .54 | .54 | .54 | .52 | .51 | .49 | .48 | | | | | | | | | |
| 0.58 | .56 | | | | .56 | .56 | .55 | .54 | .53 | .53 | .50 | 0.48 | | | | | | | | |
| 0.59 | .58 | | | | | .58 | .57 | .57 | .55 | .55 | .53 | .51 | | | | | | | | |
| 0.60 | .60 | | | | | | | | | | | | .60 | .60 | .59 | .59 | .57 | .57 | .54 | 0.53 |
| 0.61 | .62 | | | | | | | | | | | | | .62 | .61 | .61 | .59 | .59 | .57 | .55 |

TABLE 2.—Free- and submerged-flow discharge, in cubic feet per second, through trapezoidal flume with a 1-foot bottom width and 1:1 sidewall slopes ($h_1$, $h_4$ measured along sloping sidewall)—Continued

| $h_1$ (feet) | Free-flow discharge (cfs) | Submerged-flow discharge with $h_4$ (ft.) measuring— | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.44 | 0.46 | 0.48 | 0.50 | 0.52 | 0.54 | 0.56 | 0.58 | 0.60 | 0.62 | 0.64 | | | |
| 0.62 | 0.64 | 0.64 | 0.64 | 0.63 | 0.63 | 0.61 | 0.61 | 0.58 | 0.56 | | | | | | |
| .63 | .66 | | .66 | .66 | .65 | .63 | .63 | .60 | .59 | | | | | | |
| .64 | .69 | | .68 | .68 | .67 | .65 | .65 | .64 | .62 | 0.60 | | | | | |
| .65 | .71 | | .70 | .70 | .70 | .69 | .67 | .67 | .64 | .63 | | | | | |
| .66 | .73 | | | .72 | .72 | .72 | .70 | .69 | .69 | .66 | 0.63 | | | | |
| .67 | .75 | | | .75 | .74 | .74 | .74 | .72 | .71 | .68 | .67 | | | | |
| .68 | .78 | | | .77 | .77 | .77 | .76 | .74 | .73 | .73 | .70 | 0.67 | | | |
| .69 | .80 | | | | .79 | .79 | .79 | .76 | .76 | .75 | .72 | .71 | | | |
| | | 0.49 | 0.51 | 0.53 | 0.55 | 0.57 | 0.59 | 0.61 | 0.63 | 0.65 | 0.67 | 0.69 | 0.71 | 0.73 | 0.75 |
| 0.70 | 0.82 | 0.82 | 0.82 | 0.81 | 0.81 | 0.79 | 0.78 | 0.78 | 0.74 | 0.73 | | | | | |
| .71 | .85 | | .84 | .84 | .84 | .83 | .81 | .80 | .77 | .76 | 0.73 | | | | |
| .72 | .87 | | .87 | .86 | .86 | .86 | .83 | .83 | .82 | .79 | .77 | | | | |
| .73 | .90 | | | .89 | .89 | .89 | .88 | .85 | .85 | .82 | .80 | 0.77 | | | |
| .74 | .93 | | | .92 | .91 | .91 | .91 | .88 | .88 | .87 | .83 | .81 | | | |
| .75 | .95 | | | .94 | .94 | .94 | .94 | .91 | .90 | .90 | .86 | .85 | 0.81 | | |
| .76 | .98 | | | | .97 | .97 | .96 | .96 | .93 | .93 | .92 | .88 | .85 | | |
| .77 | 1.01 | | | | 1.00 | .99 | .99 | .99 | .96 | .95 | .95 | .91 | .89 | 0.86 | |
| .78 | 1.04 | | | | 1.02 | 1.02 | 1.02 | 1.02 | 1.01 | .98 | .98 | .97 | .93 | .90 | |
| .79 | 1.06 | | | | | 1.05 | 1.05 | 1.05 | 1.04 | 1.01 | 1.01 | 1.00 | .96 | .94 | 0.90 |
| | | 0.56 | 0.59 | 0.62 | 0.64 | 0.66 | 0.68 | 0.70 | 0.72 | 0.74 | 0.76 | 0.78 | 0.80 | 0.82 | 0.84 |
| 0.80 | 1.09 | 1.08 | 1.08 | 1.07 | 1.07 | 1.04 | 1.03 | 1.03 | 0.99 | 0.96 | | | | | |
| .81 | 1.12 | | 1.11 | 1.11 | 1.10 | 1.07 | 1.06 | 1.06 | 1.02 | 1.00 | 0.97 | | | | |
| .82 | 1.15 | | 1.14 | 1.14 | 1.13 | 1.13 | 1.10 | 1.09 | 1.08 | 1.04 | 1.01 | | | | |
| .83 | 1.18 | | 1.17 | 1.17 | 1.16 | 1.16 | 1.13 | 1.12 | 1.11 | 1.07 | 1.05 | 1.02 | | | |
| .84 | 1.21 | | 1.20 | 1.20 | 1.20 | 1.19 | 1.19 | 1.15 | 1.15 | 1.14 | 1.09 | 1.07 | | | |
| .85 | 1.25 | | | 1.23 | 1.23 | 1.22 | 1.22 | 1.18 | 1.18 | 1.17 | 1.13 | 1.11 | 1.07 | | |
| .86 | 1.28 | | | 1.26 | 1.26 | 1.26 | 1.25 | 1.22 | 1.21 | 1.20 | 1.19 | 1.15 | 1.12 | | |
| .87 | 1.31 | | | 1.29 | 1.29 | 1.29 | 1.29 | 1.28 | 1.24 | 1.24 | 1.23 | 1.18 | 1.16 | 1.13 | |
| .88 | 1.34 | | | 1.33 | 1.33 | 1.32 | 1.32 | 1.32 | 1.28 | 1.27 | 1.26 | 1.22 | 1.20 | 1.17 | |
| .89 | 1.38 | | | | 1.36 | 1.36 | 1.35 | 1.35 | 1.35 | 1.31 | 1.30 | 1.29 | 1.24 | 1.22 | 1.18 |

TABLE 2.–Free- and submerged-flow discharge, in cubic feet per second, through trapezoidal flume with a 1-foot bottom width and 1:1 sidewall slopes ($h_1$, $h_4$ measured along sloping sidewall)–Continued

| $h_1$ (feet) | Free-flow discharge (cfs) | Submerged-flow discharge with $h_4$ (ft.) measuring– | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.63 | 0.66 | 0.69 | 0.72 | 0.75 | 0.77 | 0.79 | 0.81 | 0.83 | 0.85 | 0.87 | 0.89 | 0.91 | 0.93 |
| 0.90 | 1.41 | 1.39 | 1.39 | 1.39 | 1.38 | 1.34 | 1.33 | 1.32 | 1.27 | 1.25 | 1.21 | | | | |
| 0.91 | 1.45 | | 1.43 | 1.42 | 1.42 | 1.37 | 1.37 | 1.36 | 1.31 | 1.29 | 1.26 | | | | |
| 0.92 | 1.48 | | 1.46 | 1.46 | 1.45 | 1.41 | 1.40 | 1.39 | 1.38 | 1.33 | 1.31 | 1.26 | | | |
| 0.93 | 1.52 | | 1.50 | 1.49 | 1.49 | 1.48 | 1.44 | 1.43 | 1.42 | 1.37 | 1.35 | 1.32 | | | |
| 0.94 | 1.55 | | 1.53 | 1.53 | 1.53 | 1.52 | 1.48 | 1.47 | 1.46 | 1.45 | 1.39 | 1.37 | 1.32 | | |
| 0.95 | 1.59 | | | 1.57 | 1.56 | 1.56 | 1.51 | 1.51 | 1.50 | 1.49 | 1.43 | 1.41 | 1.38 | | |
| 0.96 | 1.63 | | | 1.60 | 1.60 | 1.60 | 1.59 | 1.54 | 1.54 | 1.53 | 1.48 | 1.46 | 1.43 | 1.38 | |
| 0.97 | 1.66 | | | 1.64 | 1.64 | 1.63 | 1.63 | 1.58 | 1.58 | 1.57 | 1.56 | 1.50 | 1.48 | 1.44 | |
| 0.98 | 1.70 | | | 1.68 | 1.68 | 1.67 | 1.67 | 1.66 | 1.62 | 1.61 | 1.60 | 1.54 | 1.52 | 1.49 | 1.44 |
| 0.99 | 1.74 | | | | 1.72 | 1.71 | 1.71 | 1.70 | 1.65 | 1.65 | 1.64 | 1.63 | 1.57 | 1.54 | 1.50 |
| | | **0.70** | **0.73** | **0.76** | **0.78** | **0.80** | **0.82** | **0.84** | **0.86** | **0.88** | **0.90** | **0.92** | **0.94** | **0.96** | **0.98** |
| 1.00 | 1.78 | 1.76 | 1.75 | 1.75 | 1.75 | 1.74 | 1.69 | 1.68 | 1.68 | 1.66 | 1.60 | 1.58 | 1.53 | | |
| 1.01 | 1.82 | | 1.79 | 1.79 | 1.79 | 1.78 | 1.73 | 1.72 | 1.72 | 1.71 | 1.65 | 1.62 | 1.59 | | |
| 1.02 | 1.86 | | 1.84 | 1.83 | 1.83 | 1.82 | 1.82 | 1.77 | 1.76 | 1.75 | 1.74 | 1.67 | 1.64 | 1.60 | |
| 1.03 | 1.90 | | 1.88 | 1.87 | 1.87 | 1.87 | 1.86 | 1.81 | 1.80 | 1.79 | 1.78 | 1.72 | 1.69 | 1.66 | |
| 1.04 | 1.94 | | 1.92 | 1.91 | 1.91 | 1.91 | 1.90 | 1.90 | 1.84 | 1.83 | 1.82 | 1.81 | 1.74 | 1.71 | 1.67 |
| | | **0.74** | **0.77** | **0.80** | **0.82** | **0.84** | **0.86** | **0.88** | **0.90** | **0.92** | **0.94** | **0.96** | **0.98** | **1.00** | **1.02** |
| 1.05 | 1.98 | 1.96 | 1.96 | 1.95 | 1.95 | 1.94 | 1.89 | 1.88 | 1.87 | 1.86 | 1.79 | 1.77 | 1.73 | | |
| 1.06 | 2.03 | | 2.00 | 1.99 | 1.99 | 1.98 | 1.93 | 1.92 | 1.91 | 1.90 | 1.84 | 1.82 | 1.79 | 1.73 | |
| 1.07 | 2.07 | | 2.04 | 2.04 | 2.03 | 2.03 | 2.02 | 1.97 | 1.96 | 1.95 | 1.93 | 1.87 | 1.84 | 1.80 | |
| 1.08 | 2.11 | | 2.09 | 2.08 | 2.08 | 2.07 | 2.07 | 2.01 | 2.00 | 1.99 | 1.98 | 1.91 | 1.89 | 1.86 | 1.80 |
| 1.09 | 2.16 | | 2.13 | 2.13 | 2.12 | 2.12 | 2.11 | 2.11 | 2.05 | 2.04 | 2.03 | 2.01 | 1.94 | 1.91 | 1.87 |
| | | **0.77** | **0.80** | **0.83** | **0.86** | **0.89** | **0.92** | **0.95** | **0.98** | **1.01** | **1.04** | **1.06** | **1.08** | **1.10** | **1.12** |
| 1.10 | 2.20 | 2.17 | 2.17 | 2.17 | 2.16 | 2.15 | 2.08 | 2.07 | 1.99 | 1.95 | 1.88 | | | | |
| 1.11 | 2.25 | | 2.22 | 2.21 | 2.21 | 2.20 | 2.13 | 2.12 | 2.10 | 2.01 | 1.95 | | | | |
| 1.12 | 2.29 | | 2.26 | 2.26 | 2.25 | 2.24 | 2.18 | 2.16 | 2.15 | 2.06 | 2.01 | 1.95 | | | |
| 1.13 | 2.34 | | 2.31 | 2.30 | 2.30 | 2.29 | 2.22 | 2.21 | 2.20 | 2.11 | 2.07 | 2.02 | | | |
| 1.14 | 2.39 | | 2.36 | 2.35 | 2.35 | 2.34 | 2.33 | 2.26 | 2.25 | 2.16 | 2.13 | 2.09 | 2.02 | | |
| 1.15 | 2.44 | | | 2.40 | 2.39 | 2.39 | 2.38 | 2.31 | 2.30 | 2.27 | 2.18 | 2.15 | 2.10 | | |
| 1.16 | 2.48 | | | 2.45 | 2.44 | 2.44 | 2.43 | 2.36 | 2.34 | 2.33 | 2.24 | 2.21 | 2.17 | 2.10 | |
| 1.17 | 2.53 | | | 2.50 | 2.49 | 2.49 | 2.48 | 2.41 | 2.39 | 2.38 | 2.29 | 2.27 | 2.23 | 2.18 | |
| 1.18 | 2.58 | | | 2.55 | 2.54 | 2.54 | 2.53 | 2.52 | 2.45 | 2.43 | 2.41 | 2.32 | 2.29 | 2.25 | 2.18 |
| 1.19 | 2.63 | | | | 2.59 | 2.59 | 2.58 | 2.57 | 2.50 | 2.48 | 2.46 | 2.38 | 2.35 | 2.32 | 2.26 |

TABLE 2.—Free- and submerged-flow discharge, in cubic feet per second, through a trapezoidal flume with a 1-foot bottom width and 1:1 sidewall slopes ($h_1$, $h_4$ measured along sloping sidewall)—Continued

| $h_1$ (feet) | Free-flow discharge (cfs) | Submerged-flow discharge with $h_4$ (ft.) measuring– | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.84 | 0.87 | 0.90 | 0.93 | 0.96 | 0.99 | 1.02 | 1.05 | 1.08 | 1.11 | 1.14 | 1.17 | 1.19 | 1.21 | | |
| 1.20 | 2.68 | 2.65 | 2.64 | 2.64 | 2.63 | 2.62 | 2.54 | 2.53 | 2.51 | 2.41 | 2.36 | | | | | | |
| 1.21 | 2.73 | | 2.69 | 2.69 | 2.68 | 2.67 | 2.59 | 2.58 | 2.56 | 2.47 | 2.42 | 2.34 | | | | | |
| 1.22 | 2.78 | | 2.75 | 2.74 | 2.73 | 2.73 | 2.65 | 2.63 | 2.62 | 2.52 | 2.49 | 2.42 | | | | | |
| 1.23 | 2.84 | | 2.80 | 2.79 | 2.79 | 2.78 | 2.77 | 2.69 | 2.67 | 2.65 | 2.55 | 2.49 | | | | | |
| 1.24 | 2.89 | | 2.85 | 2.85 | 2.84 | 2.83 | 2.82 | 2.74 | 2.73 | 2.71 | 2.60 | 2.56 | 2.47 | | | | |
| 1.25 | 2.94 | | | 2.90 | 2.89 | 2.89 | 2.88 | 2.79 | 2.78 | 2.76 | 2.66 | 2.62 | 2.55 | | | | |
| 1.26 | 3.00 | | | 2.95 | 2.95 | 2.94 | 2.93 | 2.92 | 2.84 | 2.82 | 2.80 | 2.68 | 2.62 | 2.56 | | | |
| 1.27 | 3.05 | | | 3.01 | 3.00 | 3.00 | 2.99 | 2.98 | 2.89 | 2.88 | 2.85 | 2.75 | 2.70 | 2.64 | | | |
| 1.28 | 3.11 | | | 3.06 | 3.06 | 3.05 | 3.05 | 3.04 | 2.95 | 2.93 | 2.91 | 2.81 | 2.76 | 2.72 | 2.65 | | |
| 1.29 | 3.16 | | | | 3.12 | 3.11 | 3.10 | 3.09 | 3.00 | 2.99 | 2.97 | 2.95 | 2.83 | 2.79 | 2.73 | | |
| | | 0.91 | 0.94 | 0.97 | 1.00 | 1.03 | 1.06 | 1.09 | 1.12 | 1.15 | 1.18 | 1.21 | 1.24 | 1.27 | 1.30 | 1.31 | |
| 1.30 | 3.22 | 3.18 | 3.17 | 3.16 | 3.16 | 3.15 | 3.06 | 3.04 | 3.02 | 3.00 | 2.88 | 2.81 | | | | | |
| 1.31 | 3.28 | | 3.23 | 3.22 | 3.22 | 3.21 | 3.20 | 3.10 | 3.08 | 3.06 | 2.94 | 2.89 | 2.78 | | | | |
| 1.32 | 3.33 | | 3.29 | 3.28 | 3.27 | 3.27 | 3.26 | 3.16 | 3.14 | 3.12 | 3.01 | 2.96 | 2.87 | | | | |
| 1.33 | 3.39 | | 3.34 | 3.34 | 3.33 | 3.32 | 3.32 | 3.22 | 3.20 | 3.18 | 3.07 | 3.03 | 2.96 | | | | |
| 1.34 | 3.45 | | 3.40 | 3.40 | 3.39 | 3.38 | 3.38 | 3.28 | 3.26 | 3.24 | 3.22 | 3.09 | 3.03 | 2.92 | | | |
| 1.35 | 3.51 | | | 3.46 | 3.45 | 3.44 | 3.44 | 3.43 | 3.32 | 3.31 | 3.28 | 3.16 | 3.11 | 3.02 | | | |
| 1.36 | 3.57 | | | 3.52 | 3.51 | 3.51 | 3.50 | 3.49 | 3.39 | 3.37 | 3.35 | 3.23 | 3.18 | 3.10 | | | |
| 1.37 | 3.63 | | | 3.58 | 3.57 | 3.57 | 3.56 | 3.55 | 3.45 | 3.43 | 3.41 | 3.38 | 3.25 | 3.19 | 3.06 | | |
| 1.38 | 3.69 | | | 3.64 | 3.64 | 3.63 | 3.62 | 3.61 | 3.51 | 3.49 | 3.47 | 3.45 | 3.32 | 3.26 | 3.16 | 3.11 | |
| 1.39 | 3.75 | | | | 3.70 | 3.69 | 3.68 | 3.68 | 3.66 | 3.56 | 3.54 | 3.52 | 3.39 | 3.34 | 3.26 | 3.21 | |
| | | 0.98 | 1.01 | 1.04 | 1.07 | 1.10 | 1.13 | 1.16 | 1.19 | 1.22 | 1.25 | 1.28 | 1.31 | 1.34 | 1.37 | 1.40 | |
| 1.40 | 3.82 | 3.76 | 3.76 | 3.75 | 3.74 | 3.74 | 3.72 | 3.61 | 3.60 | 3.57 | 3.44 | 3.39 | 3.31 | | | | |
| 1.41 | 3.88 | | 3.82 | 3.82 | 3.81 | 3.80 | 3.79 | 3.68 | 3.66 | 3.64 | 3.51 | 3.47 | 3.39 | | | | |
| 1.42 | 3.94 | | 3.89 | 3.88 | 3.87 | 3.86 | 3.85 | 3.74 | 3.73 | 3.71 | 3.68 | 3.54 | 3.48 | 3.37 | | | |
| 1.43 | 4.01 | | 3.95 | 3.95 | 3.94 | 3.93 | 3.92 | 3.81 | 3.79 | 3.77 | 3.75 | 3.61 | 3.56 | 3.47 | | | |
| 1.44 | 4.07 | | 4.02 | 4.01 | 4.00 | 4.00 | 3.99 | 3.98 | 3.86 | 3.84 | 3.82 | 3.68 | 3.63 | 3.56 | | | |
| 1.45 | 4.14 | | | 4.08 | 4.07 | 4.06 | 4.05 | 4.04 | 3.93 | 3.91 | 3.89 | 3.86 | 3.71 | 3.64 | 3.53 | | |
| 1.46 | 4.21 | | | 4.14 | 4.14 | 4.13 | 4.12 | 4.11 | 3.99 | 3.98 | 3.96 | 3.93 | 3.78 | 3.73 | 3.63 | | |
| 1.47 | 4.27 | | | 4.21 | 4.21 | 4.20 | 4.19 | 4.18 | 4.17 | 4.04 | 4.03 | 4.00 | 3.86 | 3.81 | 3.72 | | |
| 1.48 | 4.34 | | | 4.28 | 4.27 | 4.27 | 4.26 | 4.25 | 4.24 | 4.11 | 4.09 | 4.07 | 3.93 | 3.88 | 3.81 | 3.69 | |
| 1.49 | 4.41 | | | | 4.34 | 4.34 | 4.33 | 4.32 | 4.31 | 4.18 | 4.16 | 4.14 | 4.11 | 3.96 | 3.90 | 3.79 | |
| | | 1.05 | 1.08 | 1.11 | 1.14 | 1.17 | 1.20 | 1.23 | 1.26 | 1.29 | 1.32 | 1.35 | 1.38 | 1.41 | 1.44 | 1.47 | 1.50 |
| 1.50 | 4.48 | 4.42 | 4.41 | 4.40 | 4.39 | 4.38 | 4.37 | 4.25 | 4.23 | 4.21 | 4.18 | 4.02 | 3.96 | 3.85 | | | |
| 1.51 | 4.55 | | 4.48 | 4.47 | 4.46 | 4.46 | 4.44 | 4.32 | 4.30 | 4.28 | 4.25 | 4.10 | 4.04 | 3.95 | | | |
| 1.52 | 4.62 | | 4.55 | 4.54 | 4.54 | 4.53 | 4.52 | 4.50 | 4.37 | 4.35 | 4.33 | 4.17 | 4.12 | 4.05 | 3.91 | | |
| 1.53 | 4.69 | | 4.62 | 4.61 | 4.61 | 4.60 | 4.59 | 4.58 | 4.44 | 4.42 | 4.40 | 4.37 | 4.20 | 4.14 | 4.02 | | |
| 1.54 | 4.76 | | 4.69 | 4.69 | 4.68 | 4.67 | 4.66 | 4.65 | 4.52 | 4.50 | 4.47 | 4.44 | 4.28 | 4.22 | 4.13 | | |
| 1.55 | 4.83 | | | 4.76 | 4.75 | 4.74 | 4.73 | 4.72 | 4.59 | 4.57 | 4.55 | 4.52 | 4.36 | 4.31 | 4.23 | 4.08 | |
| 1.56 | 4.90 | | | 4.83 | 4.83 | 4.82 | 4.81 | 4.80 | 4.78 | 4.65 | 4.63 | 4.60 | 4.56 | 4.39 | 4.32 | 4.20 | |
| 1.57 | 4.98 | | | 4.91 | 4.90 | 4.89 | 4.88 | 4.87 | 4.86 | 4.72 | 4.70 | 4.68 | 4.64 | 4.48 | 4.41 | 4.31 | |
| 1.58 | 5.05 | | | 4.98 | 4.97 | 4.97 | 4.96 | 4.95 | 4.94 | 4.79 | 4.78 | 4.75 | 4.72 | 4.56 | 4.50 | 4.41 | 4.26 |
| 1.59 | 5.13 | | | | 5.05 | 5.04 | 5.03 | 5.02 | 5.01 | 4.87 | 4.85 | 4.83 | 4.80 | 4.64 | 4.59 | 4.51 | 4.38 |

TABLE 2.–Free- and submerged-flow discharge, in cubic feet per second, through trapezoidal flume with a 1-foot bottom width and 1:1 sidewall slopes ($h_1$, $h_4$ measured along sloping sidewall)–Continued

| $h_1$ (feet) | Free-flow discharge (cfs) | Submerged-flow discharge with $h_4$ (ft.) measuring–[1] | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1.12 | 1.15 | 1.18 | 1.21 | 1.24 | 1.27 | 1.30 | 1.33 | 1.36 | 1.39 | 1.42 | 1.45 | 1.48 | 1.51 | 1.54 | 1.57 | 1.60 | |
| 1.60 | 5.20 | 5.13 | 5.12 | 5.12 | 5.11 | 5.10 | 5.08 | 4.94 | 4.92 | 4.90 | 4.87 | 4.70 | 4.65 | 4.57 | 4.44 | | | | |
| 1.61 | 5.28 | | 5.20 | 5.19 | 5.18 | 5.17 | 5.16 | 5.15 | 5.00 | 4.98 | 4.95 | 4,92 | 4.74 | 4.67 | 4.56 | | | | |
| 1.62 | 5.36 | | 5.28 | 5.27 | 5.26 | 5.25 | 5.24 | 5.23 | 5.08 | 5.06 | 5.03 | 5.00 | 4.82 | 4.76 | 4.66 | | | | |
| 1.63 | 5.43 | | 5.35 | 5.35 | 5.34 | 5.33 | 5.32 | 5.31 | 5.16 | 5.14 | 5.11 | 5.08 | 4.91 | 4.85 | 4.77 | 4.63 | | | |
| 1.64 | 5.51 | | 5.43 | 5.43 | 5.42 | 5.41 | 5.40 | 5.39 | 5.23 | 5.22 | 5.19 | 5.17 | 5.13 | 4.94 | 4.87 | 4.75 | | | |
| 1.65 | 5.59 | | | 5.51 | 5.50 | 5.49 | 5.48 | 5.47 | 5.45 | 5.30 | 5.28 | 5.25 | 5.21 | 5.03 | 4.96 | 4.86 | | | |
| 1.66 | 5.67 | | | 5.59 | 5.58 | 5.57 | 5.56 | 5.55 | 5.53 | 5.38 | 5.36 | 5.33 | 5.30 | 5.12 | 5.06 | 4.97 | 4.82 | | |
| 1.67 | 5.75 | | | 5.67 | 5.66 | 5.65 | 5.64 | 5.63 | 5.62 | 5.46 | 5.44 | 5.42 | 5.39 | 5.20 | 5.15 | 5.07 | 4.94 | | |
| 1.68 | 5.83 | | | 5.75 | 5.74 | 5.73 | 5.72 | 5.71 | 5.70 | 5.68 | 5.52 | 5.50 | 5.47 | 5.43 | 5.24 | 5.17 | 5.06 | | |
| 1.69 | 5.91 | | | | 5.82 | 5.81 | 5.81 | 5.80 | 5.78 | 5.77 | 5.60 | 5.58 | 5.56 | 5.52 | 5.33 | 5.27 | 5.17 | 5.01 | |
| | | 1.19 | 1.22 | 1.25 | 1.28 | 1.31 | 1.34 | 1.37 | 1.40 | 1.43 | 1.46 | 1.49 | 1.52 | 1.55 | 1.58 | 1.61 | 1.64 | 1.67 | 1.70 |
| 1.70 | 5.99 | 5.91 | 5.90 | 5.89 | 5.89 | 5.87 | 5.86 | 5.85 | 5.68 | 5.66 | 5.63 | 5.60 | 5.40 | 5.34 | 5.24 | 5.08 | | | |
| 1.71 | 6.08 | | 5.99 | 5.98 | 5.97 | 5.96 | 5.95 | 5.93 | 5.76 | 5.74 | 5.72 | 5.69 | 5.49 | 5.43 | 5.35 | 5.21 | | | |
| 1.72 | 6.16 | | 6.07 | 6.06 | 6.05 | 6.04 | 6.03 | 6.02 | 5.85 | 5.83 | 5.80 | 5.77 | 5.73 | 5.53 | 6.45 | 5.33 | | | |
| 1.73 | 6.25 | | 6.15 | 6.15 | 6.14 | 6.13 | 6.12 | 6.10 | 6.09 | 5.91 | 5.89 | 5.86 | 5.83 | 5.62 | 5.55 | 5.45 | 5.28 | | |
| 1.74 | 6.33 | | 6.24 | 6.23 | 6.22 | 6.21 | 6.20 | 6.19 | 6.18 | 6.00 | 5.98 | 5.95 | 5.92 | 5.71 | 5.65 | 5.56 | 5.42 | | |
| 1.75 | 6.42 | | | 6.32 | 6.31 | 6.30 | 6.29 | 6.28 | 6.26 | 6.09 | 6.07 | 6.04 | 6.01 | 5.81 | 5.75 | 5.67 | 5.54 | | |
| 1.76 | 6.50 | | | 6.41 | 6.40 | 6.39 | 6.38 | 6.37 | 6.35 | 6.17 | 6.15 | 6.13 | 6.10 | 6.06 | 5.85 | 5.77 | 5.66 | 5.48 | |
| 1.77 | 6.59 | | | 6.49 | 6.49 | 6.48 | 6.47 | 6.45 | 6.44 | 6.43 | 6.24 | 6.22 | 6.19 | 6.15 | 5.94 | 5.88 | 5.78 | 5.63 | |
| 1.78 | 6.68 | | | 6.58 | 6.57 | 6.57 | 6.56 | 6.54 | 6.53 | 6.52 | 6.33 | 6.31 | 6.28 | 6.25 | 6.04 | 5.98 | 5.89 | 5.76 | |
| 1.79 | 6.77 | | | | 6.66 | 6.65 | 6.64 | 6.63 | 6.62 | 6.61 | 6.42 | 6.40 | 6.37 | 6.34 | 6.30 | 6.08 | 6.00 | 5.88 | 5.69 |

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