Portable, Adjustable Flow-Measuring Flume for Small Canals

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ABSTRACT

A portable flume capable of throat height adjustment above a canal bottom and special stilling well and depth sensing arrangements is being used as a field-survey device before casting low-cost concrete throat sections. This "caliper-flume" can be installed and removed from a flowing canal by two persons.

INTRODUCTION

Attempts to improve water management on existing farm irrigation systems are frequently frustrated by lack of practical water measurement devices. Even though good measuring systems are available, they are often insensitive, inconvenient, or inappropriate to the operator's needs because of improper location or installation.

With few exceptions, critical flow devices, like weirs or flumes, can be installed to adequately measure canal flow to within the ± 5 percent accuracy, usually ascribed to field installations, if the site and the device are carefully selected, i.e., a detailed engineering survey, using estimated canal roughness, calculated backwater curves, and estimated checkgate and water outlet influence, can be made that could establish the depth-discharge relations for a particular site. With this information, a flume or weir could be proportioned to operate between the margins of backwater and tailwater limits. The mass of detailed data necessary and time-consuming computations make this process prohibitive, except for singular cases.

A more practical and economical method was required to implement flow measurement in several field ditches near Yuma, Arizona, in the Wellton-Mohawk Irrigation and Drainage District. To meet the need for quickly, accurately, and economically sizing and setting permanent flumes in existing field canals, a portable flume was designed that could be placed into a flowing canal and adjusted so as to produce the minimum backwater needed to avoid submerged flow under typical operational conditions. Submerged flow operation usually occurs when the flume discharges into water deeper than about 75 percent of the upstream flow depth. The depths are referenced to the elevation of the flume floor in the throat section (Fig. 1). Measurement at submerged conditions is inconvenient (requiring knowledge of water depths at two locations) and insensitive (leading to inaccuracies) and generally should be avoided.

FIG. 1 Schematic of typical permanent flume installation.

Placing a portable flume in a canal provides most of the information. The effects of backwater can be immediately observed; the flow rate can be accurately determined for at least one discharge; extrapolation of canal depths at other discharges is immediately possible, and the effects quickly judged; downstream limitations can be estimated with high assurance of being accurate; and canal roughness effects are automatically incorporated into the observations.

DESIGN REQUIREMENTS

A portable device suitable for use as a canal-flow, field-survey instrument should cause no more than 3- to 4-in. (7 to 10-cm) head loss in the canal, be accurate to ± 2 to 3 percent, and preferably be somewhat similar to the permanent measuring device that may be installed at the survey site, although this is not absolutely necessary. Weirs usually cause excessive head loss, if they are to be accurate. Propeller meters are impractical for permanent settings in open ditches because of debris. Parshall flumes and Cutthroat rectangular flumes (Skogerboe and Hyatt, 1967) while quite usable as permanent devices, are not readily adaptable to a wide-flow-range, portable system. Long-throated critical-flow-flume devices (Replogle, 1971, 1975) were chosen for adaptation to the portable system. The design flexibility offered by computer-calibrated, long-throated flumes is well suited for the development of a portable survey device and the subsequent permanent flow-measuring installation.

Other design criteria relative to the Wellton-Mohawk project can be summarized as follows:

1. The flume-throat contraction relative to the channel cross section, called the contraction ratio, should be adjustable. This allows the flume stage-discharge relation to be manipulated during flow to determine the smallest practical margin between submergence, caused by downstream restrictions, and backwater effects on other structures upstream—an important consideration on many farms with nearly level ditches and limited freeboard.

2. The flume should be usable in slip-formed canals with both 1-ft (30.5-cm) and 2-ft (61-cm) bottom widths, and also adaptable to small unlined canals. The capacity

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should range from about 0.5 to 25 cfs (0.01 to 0.7 m³/s).

3 The portable flume should be constructed in sections capable of being handled by two persons without special equipment, because some sites are not accessible from field roads.

4 The flow-depth sensing device must be easily references to the elevation of the flume throat and, yet, be capable of sensing the water depth at a predetermined distance upstream, relative to the throat elevation.

FLUME DESIGN

Several techniques were examined in the process of choosing a method to change the contraction ratio. Closing-angle or moving-side systems were discarded as too complex. A single, basic, trapezoidal-throat section designed to be raised and lowered was finally chosen. The throat section had a 1-ft bottom width (30.48 cm) and 1:1 sideslopes, and was raised and lowered with four jackscrews that also provided a means to approximately level the flume, as indicated by a circular level bubble mounted on the flume.

Previous studies with flumes (Reploge, 1975) have shown that flume throat dimensions should be accurate to the same degree as that desired for the measured discharge. However, the canal section may be used as the upstream flume section. Therefore, a portable flume needs only two basic sections: a converging inlet section and a throat section. These two sections were made from aluminum sheeting and structural angles and channels, and were constructed so that they could be detached from each other for convenience of transport and installation. The converging section was purposely made somewhat flexible to aid in conforming to the concrete lining of the canal. A sufficiently good water seal at the upstream edge could usually be obtained, except in crudely-formed concrete ditches. The converging section was hooked to the throat section, at the bottom only, with a hinge-like mechanism, made from a piece of channel, welded to the upstream and of the throat section, into which a round piece of rod, attached to the converging section, was cradled (Fig. 2, also see the construction drawings). This arrangement made a hinge with close enough tolerances to limit leakage through the hinge parts. The hinge allowed free angle-change movement between the converging section and the throat section, when the throat was raised or lowered. This movement caused variable gaps on either side of the flume between the two sections, ranging from no gap near the bottom to about 8 in. (20 cm) at the top. These were covered by triangular pieces that were attached to the throat section, but could slide over the converging section. These pieces were also made of sheet aluminum which was flexible and formed a sufficiently tight seal under flow conditions.

The flume throat was suspended from four jackscrews made from 3/4-in. (1.9-cm) steel-threaded rod attached to an outer frame, or cradle, that was built to conform to the size being measured. The vertical travel was from a low-jack position, with the flume throat floor about 0.2 ft (6 cm) above the canal bottom, to a high-jack position of 0.9 ft (27 cm). The trapezoidal throat section itself was 4 ft long (1.22 m) with 1:1 sideslopes and 1-ft (30.48-cm) bottom width. Two converging sections were furnished, one each for 1:1 slumped canals with 1-ft (30.5-cm) and 2-ft (62-cm) bottom widths. Small irregular earthen canals can be accommodated with either approach section combined with a chain-weighted canvas blanket.

Since the most crucial dimensions on critical flow flumes are those of the contracted, or throat section, the flow-area-to-depth relationship must be accurate to a precision approximating the desired flow accuracy of ±2 to 3 percent. This means that in practice, the flume floor in the throat must be used as the primary point of elevation reference. To attempt to use the upstream floor depth as the primary reference could introduce depth errors of nearly 0.5 in. (1.3 cm) at the throat of the flume.

Normally, when a permanent flume is built, a pipe is installed through the canal wall to a stilling well equipped with a depth-measuring gage or recorder (Fig. 1). The zero reference is obtained by ponding water in the ditch using temporary dams upstream and downstream from the flume (Reploge, 1971). The ponded water depth, at about the flume throat center, is transferred to the stilling-well gage. Thus, the flume zero is accurately determined. Surveying techniques also can be used to set the gage zero.

The ponding technique is not usable for a portable flume designed to be placed into flowing canals. In fact, conventional stilling wells and stilling-well taps are not usable. Zeroing the flume by using surveying equipment would not be convenient. Thus, the portable flume system should provide easy and accurate zeroing with water flowing, and provide accurate depth-sensing, equivalent to the conventional stilling-well and point-gage systems of permanent flumes.

The depth-sensing problem of zero-referencing the surface of an upstream water depth to a moving floor was solved by mounting a stilling well, or rather, a shallow substitute for a stilling well, above the center of the flume throat itself. The depth-measuring point-gage was also attached above the flume throat center. Thus, the point gage maintains the same zero reference with respect to the throat section floor, regardless of the elevation chosen with the jack screws, and is relatively insensitive to whether the flume is carefully leveled.

Since it is impractical to drill stilling-well tap holes
in the canal wall for each canal setting, an alternate depth-sensing element was substituted. This consisted of an 18-in. (45-cm) piece of 1-in. (2.54-cm) diameter pipe with one end closed with a hemispherical cap. The pipe had several 1/8-in. (3-mm) holes drilled around its girth about 10 in. (25 cm) from the capped end. Plastic tubing, attached to the open end, was connected to the shallow stilling well. The pipe, with a handle attached, was laid in the canal bottom parallel to the stream flow. The cap was pointed upstream with the sensing holes placed about 1 ft (30 cm) from the beginning of the converging flume section. The shallow stilling-well was manually adjusted up or down to keep its usable depth of about 2 in. (5 cm) within the flow-depth range being used. This is not difficult, since changes in flow depth of this magnitude occur slowly. The depth of this stilling-well is limited by the drawdown between the upstream canal depth and the flume throat, since it should remain above the water surface to avoid interfering with the flow. In this flume, the drawdown is about 4 in. (10 cm) at 15 cfs (0.4 m³/s) and about 1.5 in. (3.8 cm) at 1 cfs (0.028 m³/s).

A summary of the operating principles for the portable flume is diagrammed in Fig. 2.

Calibration

The calibration tables were developed using computer techniques described previously (Replogle, 1975). A separate calibration table was provided for each 0.1-ft (0.03-m) change in sill height; i.e., change in throat floor elevation with respect to the channel bottom. Since this elevation difference needs to be only approximated, marks on the jack frame were used as indicators. Thus, the table used for a particular flow was that corresponding to the nearest 0.1-ft (0.03-m) sill height.

The actual field tables were printed for values of 0.005-ft (1.527-mm) intervals of flow depth. Appendix I shows examples of the printout at 0.03-m intervals for a mid-range sill height of 0.6 ft (0.15 m) based on a slipform-lined ditch with a bottom width of 2 ft (0.61 m). Appendix II shows general construction details for the flume.

FIELD NOTES AND OBSERVATIONS ON OPERATION

Frequently, the flume can be placed in the ditch to be measured while it is dry. However, this is not necessary. On several occasions, the flume has been placed into flowing water. Removal from flowing water can be difficult if the flume is flowing nearly full with low tailwater elevation, which develops large down-

forces. However, a wooden plank (1.5 in. x 3.5 in. (38 mm x 89 mm)) fitted with short lengths of chain near each end was used to lift the approach section from the canal. The sides were flexed together by the lifting action, breaking the water seal, which permitted removal of the section (Fig. 3).

Once in place, the device is more readily raised than lowered by the loosely-socketed jack screws which can easily provide lifting force, but not down force, to overcome the friction of the flume against the downstream side of the jacking frame. It quickly became standard practice to start with the flume in the down-most position and progress upward the required amount to overcome submergence effects.

Field Measurement Examples

Example I. Field canal A has a bottom width of 2 ft (0.610 m), and 1:1 sideslopes. The flume was placed in the canal before flow began, was leveled and set to its lowest position. The flume was raised to a sill height of 0.5 ft (0.15 m) shortly after the run began, to avoid an intermittent high-tailwater situation. Fig. 4 shows the canal with the portable flume in position. A depth-above-sill-height of 1.588 ft (0.484 m) corresponds to 13.60 cfs (0.385 m³/s), for a total water depth of about 2.1 ft (0.63 m). The upstream canal banks would be overtopped at a total depth of 2.5 ft (0.762 m) with a flow
The symbols and names on the printout table are as follows:

**SILL HEIGHT** = Elevation of the throat bottom with respect to the flume bottom of the approach section where depth Y1 is detected. Value may be positive (raised) or negative (depressed).

**B1** = Bottom width of the approach section, Section 1.

**B3** = Bottom width of the throat section, Section 3.

**K** = Absolute roughness height of material in flume throat.

**X1** = Distance from point-of-depth sensing to transition section; i.e., that length of Section 1 that contributes to friction loss, starting at the point of depth sensing.

**L2** = Length of the transition section, Section 2.

**L3** = Length of the throat section, Section 3.

The program prints out nine columns of information:

<table>
<thead>
<tr>
<th>Column 1: Y1 (m)</th>
<th>Column 2: Q (m³/s)</th>
<th>Column 3: CRITICAL-DEPTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth detected in Section 1 referenced to floor elevation of Section 3.</td>
<td>Computed discharge rate for depth Y1 and the other geometrical data.</td>
<td>Depth of flow in flume throat, also approximate limiting depth for backwater on flume before submergence effects begin.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Column 4: FROUDE No. at Y</th>
<th>Column 5: IDEAL-Q</th>
<th>Column 6: DISC.C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Froude number in Section 1, indicates stability of depth reading; should be less than 0.6 for a stable water surface but greater than 0.3 to aid sediment movement.</td>
<td>Computed discharge for an ideal fluid, which ignores frictional effects and velocity distribution effects.</td>
<td>Discharge coefficient, comparing the ideal Q, Column 5, with the computed discharge in Column 2.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Column 7: V1 (ft/sec)</th>
<th>Column 8: ALF3</th>
<th>Column 9: V3 (ft/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average velocity in Section 1.</td>
<td>Velocity distribution coefficient, aₚ, for the throat section, in Section 3.</td>
<td>Average velocity in Section 3.</td>
</tr>
</tbody>
</table>

**APPENDIX II.—GENERAL CONSTRUCTION DETAILS FOR PORTABLE FLUME**

No attempt to present shop drawings has been made on the following pages. With the exception of the steel 3/4-in. (19-mm) threaded jack screws made from standard threaded rod and the 1/4-in. (6-mm) plated bolts used for assembly, all parts of the flume are made of aluminum sheeting 0.050 in. (1.25 mm) thick, and aluminum structural angles and channels. As shown in the diagrams, although not specifically dimensioned, the throat section fits with liberal clearances of about 1/4 in. (6 mm) inside the cradle-frame portion. The frame members that are used for the 2-ft (61-cm) canals are removed to accommodate 1-ft (30.5-cm) canals. The leveling bubble is attached to the movable throat section, as is the point gage and stilling well. The overhead portion of the frame provides both frame bracing and support for a bridge that allows easy access to both sides of the canal and to the point gage.
of 22.5 cfs (0.637 m³/s) using this shape of flume; however, the flow at this site was limited to about 17 cfs (0.48 m³/s) due to entrance conditions at the canal head. Because of this built-in limit, the permanent concrete flume chosen for this site was shaped similar to the portable flume but had a sill height of 0.6 ft (18.3 cm). The permanent flume, being installed, is shown in Fig. 5.

Example II. Field Canal B was similar to Canal A. The flume was placed, and raised to a sill height of 0.4 ft (12.2 cm). This produced a depth reading of 1.702 ft (0.326 m), corresponding to 16.0 cfs (0.453 m³/s). The observed normal depth in the ditch downstream from the flume was about 1.6 ft (0.49 m). Combining the sill height with the flume-depth reading meant that the upstream ditch was flowing about 2.1 ft (0.63 m) deep. This left 0.4 ft (0.12 m) of upstream freeboard on the 2.5-ft (75-cm) deep ditch, which would be overtopped at 25.3 cfs (0.716 m³/s). This was an unlikely flow in this situation because a 30-in. (76-cm) pipe under a road, leading from the main canal, limited the flow to only about 17 cfs (0.48 m³/s) with the available head. The effects of backwater on this pipe, about 500 ft (150 m) upstream from the flume, were observed to be about 3/4 in. (20 mm) with the flume in place. The theoretical downstream maximum depth for free flow was 1.32 ft (0.40 m) plus the sill height of 0.4 ft (0.12 m) or 1.72 ft (0.52 m). The observed depth of 1.6 ft (0.49 m) was less than this; therefore, the flume was not submerged.

Field Canal A and another ditch similar to it were fitted with concrete flumes (Fig. 5) selected from a family of possible throat sections, which differed only in the height of installation from the canal floor. The construction was accomplished in two phases. First, forms were made to define the ends of the throat section, which was 4 ft (1.22 m) long. The tops of the forms were used to control the strike-off elevation of the wet concrete. A low-slung mix did not sag on the 1:1 side-slope of this ditch. Reinforcing bars were placed in the concrete primarily to hold the forms in place. Wire ties and spacers should have worked equally well. Two lengths of 2-in. (5-cm) plastic pipe about 10 ft (3 m) long were laid through the flume-floor area parallel with the ditch before pouring the concrete, to allow for complete draining of the canal if desired. The pipes were plugged during canal operation. Second, as soon as the upstream form could be removed, usually in 1 hr, the converging section was poured. Since the tolerances on this section are very liberal, hand-plastering techniques, instead of forms, were used. The taper of the converging section was carried on a slope that would have terminated about one throat length (4 ft (1.21 m)) upstream, but was rounded off abruptly when the tapering caused the concrete thickness to be less than 1.5 to 2 in. (3 to 5 cm) thick to discourage chipping. The rounded edge does not affect flume performance. For the mass-produced flumes, complete inside forming techniques, as described by Bondurant et al. (1969), have subsequently been used by ditch contractors on about fifty other installations.

SUMMARY AND CONCLUSIONS

A portable, field-site, survey flume was constructed and used to verify placement and design of permanent metering flumes. The portable system consists of a trapezoidal throat that can be raised and lowered in a flowing field ditch to establish limits of free-flow operation and backwater effects on upstream structures. Mechanical solutions to problems of maintaining gage-zero on a movable-throated flume, stilling-well readout, and movable seals between ditch and flume, were presented. A family of concrete throat sections, differing only in height of installation from the canal floor, were recommended for the permanent installations.

Flows between about 0.5 cfs (0.01 m³/s) and 25 cfs (0.7 m³/s) can be measured with the portable system. Satisfactory operation can be achieved with less than 4-in. (10-cm) head loss to the canal system. Permanent structures can be installed with high assurance that they will operate as intended, be convenient enough to be used routinely, and rugged enough to remain reliable and accurate, well with the ± 5 percent tolerance usually ascribed to field installations.

References

1 American Society of Agricultural Engineers. 1976. ASAE Standard ASAE S559.1-Trapezoidal flumes for irrigation flow measurement. AGRICULTURAL ENGINEERS YEARBOOK 56:567.

APPENDIX I.—COMPUTER PROGRAM AND NUMERICAL EXAMPLE

A listing of a BASIC program suitable for simple shapes like trapezoidal throats (and the limiting cases of triangular and rectangular throats), is available from the author. The program is also suitable for broaderest weirs with rounded upstream edge. The approach channels, Section 1, need not be the same shape as the throat section, Section 3. For example, the approach ditch may be trapezoidal but the flume throat may be rectangular.