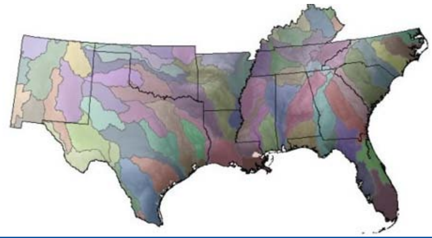
SR-IWM-6

Applying knowledge to improve water quality

Southern Regional Water Program

A Partnership of USDA CSREES & Land Grant Colleges and Universities



AUBURN UNIVERSITY
ALABAMA A&M UNIVERSITY
UNIVERSITY OF ARKANSAS
UNIVERSITY OF ARKANSAS – PINE BLUFF
UNIVERSITY OF FLORIDA
FLORIDA A&M UNIVERSITY
UNIVERSITY OF GEORGIA
UNIVERSITY OF KENTUCKY
LOUISIANA STATE UNIVERSITY
MISSISSIPPI STATE UNIVERSITY
ALCORN STATE UNIVERSITY
NEW MEXICO STATE UNIVERSITY
NORTH CAROLINA STATE UNIVERSITY
NORTH CAROLINA A&T STATE UNIVERSITY
OKLAHOMA STATE UNIVERSITY
CLEMSON UNIVERSITY
UNIVERSITY OF TENNESSEE
TENNESSEE STATE UNIVERSITY
TEXAS A&M UNIVERSITY
PRAIRIE VIEW A&M UNIVERSITY

A Simple Flow Measuring Device for Farms

By

Zohrab Samani[1], Henry Magallanez[2], Rhonda Skaggs[3]

1. Professor, NMSU Department of Civil and Geological Engineering
2. Chief Engineer, Elephant Butte Irrigation District, Las Cruces, New Mexico
3. Professor, NMSU Agricultural Economics and Agricultural Business Department

for

The Irrigation Water Management Program Team

Craig Runyan, New Mexico State Univ., Chair
Tom Obreza, Univ. of Florida, Co-Chair
Sam Dennis, Tennessee State Univ.
Bob Goodman, Auburn Univ.
Kerry Harrison, Univ. of Georgia
Garry Grabow, North Carolina State Univ.
Alton Johnson, Alcorn State Univ.
Jeff Koch, Prairie View A&M Univ.
Joseph Massey, Mississippi State Univ.
Bryan Smith, Clemson Univ.
Phil Tacker, Univ. of Arkansas
Jim Thomas, Mississippi State Univ.
Ted Tyson, Auburn Univ.

of the

Southern Regional Water Program

This guide was adapted from Water Task Force Report #3 "A Simple Flow Measuring Device for Farms" by Zohrab Samani, et al. New Mexico State University

CSREES EDUCATION USDA RESEARCH • EXTENSION

A Simple Flow Measuring Device for Farms

Introduction

This publication provides a guideline for construction and operation of a simple water measuring device for water flow in open channels and small streams. Many states have faced serious drought and water shortages in recent years. Farm managers that use flood irrigation from either surface or ground water recognize the need for irrigation water measurement. An effective irrigation water management plan which includes water measurement makes the best use of limited water supplies and can help improve efficiency.

The first step in developing an on-farm water management plan is to establish how much water is being delivered to fields. When water is over applied, the excess water leaches below the root zone of the crop without additional benefit to the crop. A small amount of excess water is needed as a leaching fraction to remove salts. Excess water can also reduce yield, due to leaching of nutrients and waterlogging of fields with heavy clay soils. On the other hand, under application of water, especially during critical growth periods, can result in yield losses.

This publication describes the design, construction, installation and operation of a simple and inexpensive flume device for measurement of channel flow. The flume can be constructed using metal or plywood and a short piece of PVC or metal pipe.

When the flume is built, installed and operated correctly, it provides a very accurate measurement of channel flow. The accuracy is comparable to other flow-measuring devices such as the Parshall Flume (U.S. Bureau of Reclamation, 1984) or RBC (Bos et al., 1984) with the added advantages of low cost and simple construction.

Description of the of the flume

The device is an S-M flume design (Samani and Magallanez, 2000). The flume consists of a rectangular section of channel constricted in the middle by vertically positioned PVC or metal pipe contracting both sides. The cross section of the device is thereby constricted using lengthwise half sections of PVC or metal pipe as shown in fig. 1 (top view). The side view of the flume is shown in fig. 2.

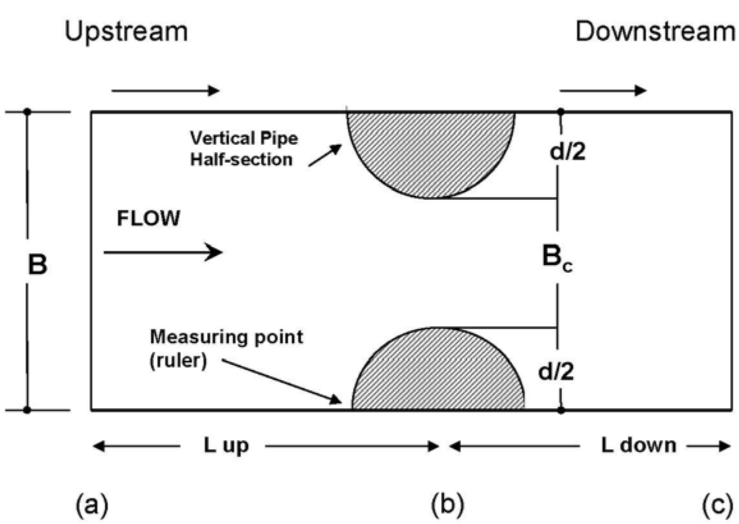


Fig. 1. Top view of S-M flume

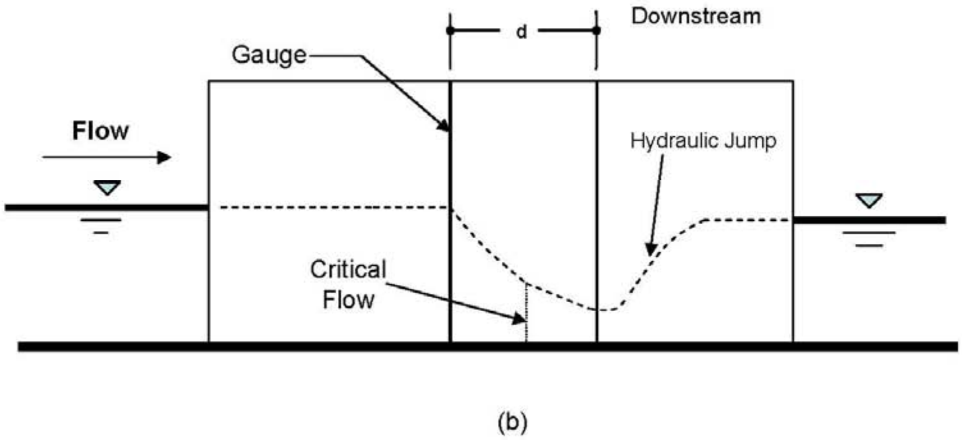


Fig. 2. Side view of S-M flume

The central, narrow section of the flume (Bc) is the throat. The ratio of the throat width to the width of the rectangular channel (B) is the contraction ratio. The contraction ratio (Bc/B) should be between 0.40-0.60. The contraction creates a critical flow, making it possible to calculate the water flow by simply measuring the water depth at the upstream corner of the PVC pipe (as indicated in fig. 1). Instructions for design, construction, installation and operation of the flume follow.

Designing the Flume

To design a flume, one should start with a range of flow which is to be measured. Once the range of flow is known, table 1 can be used to identify the dimensions of flume. The following two examples describe how table 1 is used to design a flume.

Example 1:

Suppose that we want to design a flume which can measure flow rates between 0.4 to 10 cubic feet per second (cfs). Table 1 shows that a flume with dimensions of (B = 2 feet, Bc/B = 0.50 and height of 2 feet will measure between 0.3 to 11 cfs. The Bc/B ratio of 0.50 in this example means that the throat width Bc should be equal to 0.50(2) = 1 foot and the vertical column sections should have a width of 0.50 feet each (d/2=0.50). If the appropriate pipe size is not available to accomplish a throat width (Bc) of 1 ft and the throat width ratio (Bc/B) becomes equal to 0.55 for example, then the range of flow can be calculated by interpolating between (Bc/B) of 0.5 and 0.6. Using the interpolation, the flow range that the flume can measure will be between 0.40 to 12.50 cfs. This flow is still within the desired range.

Table 1 is for a flume height of 2 ft. If flow rates higher than those shown in table 1 are desired, then table 1 can be used to identify the dimensions based on minimum flow and the flume height can be adjusted accordingly to accommodate the maximum flow.

Example 2.

Suppose that we want to design a flume to measure a flow rate between 0.40 and 20 cfs. Table 1 shows that a flume with dimensions (B=3 ft, Bc/B = 0.50) will measure between 0.40 to 17 cfs. In order to measure a maximum flow of 20 cfs, we can use equation 1 to calculate the required height for a flow rate of 20 cfs.

Using equation 1 with B =3 ft, Bc =1.5 ft, the height H can be calculated as:

$$Q = 0.701(\sqrt{g})(1.5)^{0.91}(H^{1.59})$$

This equation gives an H value of 2.12 feet. An additional two inches of freeboard is recommended.

Table 1. Range of Flow for Various Flume Sizes. Flow is in cubic feet per second (cfs). The height of flume =2 feet. For conversion from cfs to gpm multiply the values by 448.8312.

B_c/B*	B, Width of Flume in feet					
	1	2	3	4	5	6
0.40	0.04-5.00	0.20-9.00	0.30-14.00	0.30-18.00	0.40-22.00	0.40-26.00
0.50	0.05-6.00	0.30-11.00	0.40-17.00	0.50-22.00	0.60-27.00	0.70-32.00
0.60	0.08-7.00	0.50-14.00	1.0-20.00	1.30-26.00	1.50-32.00	2.00-38.00

*B_c/B is the ratio of the throat width (B_c) to the width of the rectangular channel (B). Typical widths ranging from 1 to 6 feet are shown in the table. A flume height (H) of 2 feet is assumed for the data presented in table 1.

Building the Flume

- Estimate the maximum depth of the water in the channel or stream to be metered. The height of the flume should be sufficient to measure the high flow as described in the previous section (Designing the Flume) and should be equal or greater than the anticipated maximum depth of the water in the channel.

- Calculate the required minimum length of the flume (L) (a-c, fig. 1) to be equal to 1.5 times the height of the flume (H).
- Install the half sections of PVC or metal pipes so the vertical center is 2/3 of the distance from the upstream entrance of water into the flume. For example, if the expected maximum depth of the water is 2 feet, the minimum height of the flume (H) is 2 feet, and the length (L) would be 3 feet (2 x 1.5). The distance from the center of the vertical contraction pipe to the upstream entrance (L up) (a-b, fig. 1) would be 2 ft, (2/3 x 3). The distance from the center of the vertical contraction pipe to the downstream end (L down) (b-c, fig. 1) would be 1 foot. The length values given here are minimum requirements. If the lengths are longer, it will not affect the measurement results.
- Cut the pipe into equal halves lengthwise. In fig. 1, the measurement d is the diameter of the PVC or metal pipe, and d/2 illustrates two equal half sections of the pipe.
- The rectangular section of the flume can be constructed from plywood, steel or aluminum. Plywood construction is useful for short-term flow measurement, but will not last long. Steel would be more appropriate for permanent measurement. If the flume is to be moved, aluminum construction is best since it provides a light device that can be easily transported.
- A water-measuring ruler (gauge) is installed upstream in the corner where the edge of the pipe meets the flume wall as shown in fig. 1.

- The vertically positioned PVC or metal pipe can also function as a stilling well. A hole can be drilled at the upstream corner of the pipe to convert the vertical pipe into a stilling well. A water depth in the stilling well can be measured manually or electronically by using a pressure transducer and data logger.
- The vertical pipe is attached to the wall using a strip of metal which is wrapped around the pipe and bolted to the wall in both ends. The ruler (depth gauge) is attached to the pipe using epoxy glue.
- Metal cross-bars can be placed across top of the flume in order to stabilize the walls.

Installing the Flume

- The flume should be leveled both laterally and lengthwise within the channel where it is installed.
- The area surrounding the flume and underneath the flume needs to be sealed with soil or other material such as concrete, such that the entire water flow will pass through the flume and not around or under the flume's leveled position in the channel. Aprons on the upstream and downstream ends of the flume may also be added to help prevent flow from undermining the flume. Angled wings on either end of the flume will also add to its efficiency and stability.

Operating the Flume

- The depth of water (H) is measured in the flume at the point indicated in fig.1 in order to calculate water flow through the flume.

- The relationship between the depth of the water (H) and the flow rate of water is as follows:

$$Q = 0.701(\sqrt{g})(Bc)^{0.91}(H)^{1.59} \qquad (1)$$

- Variables in the equation above are defined as:

Q = flow rate in m^3/sec or ft^3/sec (m = meter, ft = feet, sec = seconds)

g = acceleration of gravity, 9.81 m/sec^2 (SI unit) or 32.2 ft/sec^2 in English units.

Bc = flume throat width in meters (SI unit) or feet in English units

H = depth of the water flow at the gauge, in meters (SI unit) or feet in English units.

- The flow rate can be calculated in SI unit or in English unit. For example, if H is measured as 0.5 ft, in a flume with (Bc) equal to 2 ft, then the flow rate from the above equation is calculated as:

$$Q = 0.701 * (\sqrt{32.2}) * (2^{0.91}) * (0.5^{1.59}) = 2.483 \text{ cfs}$$

Where: cfs = cubic feet per second

- Once the flume is built and Bc is determined, the flume equation can be used to generate a Flow Rate table with two columns, showing the relationship between H and Q.
- The flume has to have a free flow condition to operate correctly. This requires that the water depth at the downstream end of the flume (point c in fig. 1) divided

by the water depth at the measuring gauge be less than 0.85 (85%). If the ratio is more than 0.85, the bottom of the flume must be raised in order to reduce the depth ratio. This adjustment is normally done only once, when the flume is installed.

- The side view of the flume in fig. 2 illustrates the movement of water as it flows through the flume. The ruler (depth gauge) is positioned so as to measure the water depth at the upstream junction of the flume wall and the vertical pipe. The water depth at the depth gauge (H) which is the same as the depth of water inside the stilling well is used in equation 1 to calculate the flow. There is normally enough turbulence to cause the depth to move up and down at the depth gauge. Therefore, an average depth should be used to calculate the flow. It is recommended to measure the depth inside the stilling well to avoid error caused by water level fluctuations. Distance d is the diameter of the vertically positioned pipe. The hydraulic jump is a temporary turbulence in the water as it moves out of the flume and goes back to the normal depth in the channel.

An Installed S-M Flume

Figs. 3 and 4 below are pictures of S-M flumes currently being used to measure flows. Fig. 3 shows a S-M flume installed in an open channel in a dirt ditch in a Northern New Mexico ditch. The flume is made of aluminum and is 2 feet wide and 3 feet long. The S-M flume in fig. 4 is installed at a turnout from a concrete lined ditch. This flume is constructed of steel (including the vertical pipe halves) and is 1.5 feet wide and 4 feet long. Concrete has been poured at the junction of the flume and the canal in order to stabilize the flume and prevent the water from bypassing the flume. The flume in figure 4, serves as a measuring device as well as a large turnout for a pecan orchard in La Union, NM.

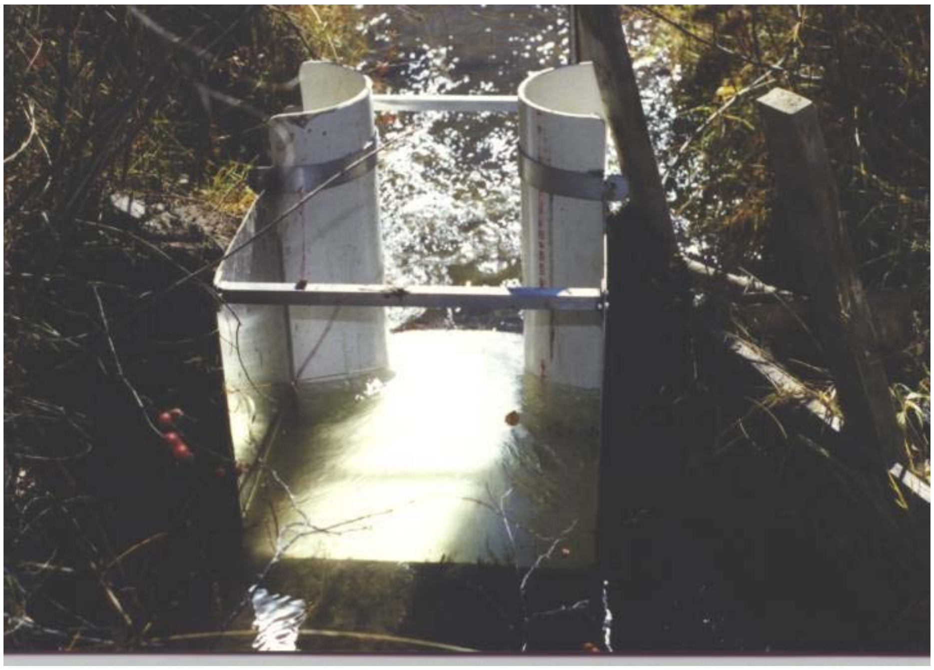


Fig. 3. S-M flume installed in a Northern New Mexico ditch.

Fig. 4. S-M flume installed in turnout on a pecan farm in Southern New Mexico.

References

Bos, M.G, J.A. Replogle, A.J. Clemens. 1984. *Flow Measuring Flumes for Open Channel Systems*. John Wiley & Sons, Inc., New York, New York.

Magallanez, H., 2003. District Engineer, Elephant Butte Irrigation District. Personal communication.

Samani, Z. and Magallanez, H. 2000. Simple Flume for Flow Measurement in Open Channel. *American Society of Civil Engineers (ASCE) Journal of Irrigation and Drainage* 126(2):127-129.

United States Bureau of Reclamation. 1984. *Water Measurement Manual*. U.S. Dept. of Interior, Denver, Colorado.

Publication date: November 2006. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture under Agreements No. 2004-51130-03114 and 2005-45049-03209. The U.S. Department of Agriculture prohibits discrimination in all its programs and activities on the basis of race, color, national origin, sex, religion, age, disability, political beliefs, sexual orientation, and marital or family status. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the U.S. Department of Agriculture.