

PRACTICAL IRRIGATION FLOW MEASUREMENT AND CONTROL — AN UPDATE

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ABSTRACT

Previous discussions concerning practical technologies that can encourage farmers to adopt practices supporting sustainable irrigated agriculture are updated. Important among these are convenient water measurement and control techniques. These techniques need to be available not only to the farmers, but also to the delivery system operators that make the system responsive to the on-farm needs. Improved irrigation planning and management techniques depend heavily on accurately controlling and quantifying water deliveries. Automation places a further burden on reliable operation of primary water measuring and flow control equipment. Many simple constructions and operating procedures can be provided to farmers and irrigation-delivery-system operators that offer considerable convenience at small expense and can be included in automation upgrades to improve reliability. Problems of reliability are aggravated if equipment is not easily field checked for proper functioning. Many observable clues, when they do exist, go unrecognized by inadequately trained personnel. This compilation of practices and design suggestions should help the operator assure valid measurement data and control functions. These suggestions are intended to make these devices easier to use, easier to verify, and more economical to construct and install. The techniques and devices discussed included: (a) accurate and convenient zero setting for weirs and flumes; (b) pressure-transducer field checks; (c) easy-to-use scales for orifice and Venturi meters; (d) wave suppressors for canals that flow at variable depths; (e) method for measuring Manning n values; and (f) flow-profile visualization using rising-bubble techniques to evaluate canal flow conditioning. Also included is a discussion of some pipe flow conditioning ideas used in field practice for devices installed in adverse conditions.

INTRODUCTION

Improved irrigation planning and management techniques depend heavily on accurately controlling and quantifying water deliveries. Modernization of systems involving mechanization and automation place a further burden on reliable operation of water measurement and control equipment. Irrigation control and measurement can potentially be done in this age of technology with so-called “high tech” methodology. Many of these methods may be difficult to support both technically and economically in an agricultural environment. However, several low-cost and practical technologies exist that can encourage adoption of practices supporting effective water use, modernization and sustainable agriculture. User understanding of the proper application, installation, use, and maintenance of control and measuring devices is generally less than desirable. Many observable clues, when they do exist, go unrecognized by inadequately

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trained field personnel. Not all of the problems can be traced to the user. Reliability problems arise because much of the equipment is not readily field checked for proper function.

This paper deals with a compilation of practices and design suggestions to assist measurement personnel to recognize valid measurements and control functions. Thus, discussed herein, are some useful procedures and designs to make these devices economical, easier to use, and more readily verified.

REDUCING ERRORS AND MISTAKES

Flow Measurement Errors For Canal Deliveries

Measurement errors can be systematic (bias), random, or mistakes. Random errors can be treated statistically and affect the level of assurance that can be placed on a reading or group of readings. Systematic, or bias, error, if discovered, can often be used to correct past records. Mistakes do not lend themselves to any particular method of recovering or correcting data. Wahlin, et al, 2000, discusses treatment of errors usually appropriate to canal measurements. They review methods of checking for bias errors and the statistical knowledge that random errors tend to zero with large samplings. Thus, rather large flow-rate variations in individual readings may still render relatively accurate volume results over long time periods of record, once systematic errors are satisfactorily laid to rest. This knowledge will be referred to in the following discussions of flow meters and their uses.

Zero settings Inaccurate zero settings for flume and weir wall-type gages and recording devices are a primary source of systematic error. Eliminating the need for precise leveling is among conveniences that make a flume easily portable. Previous work showed that long-throated flumes are very forgiving. That is, they can be sloped upward slightly in the direction of flow without changing the discharge equation significantly (Replogle et al. 1987). However the upstream depth gage must be referenced always to the elevation of the throat floor near the out-fall end. A point on the centerline of the flume about one-quarter of the throat, or crest, length from the outlet end, works well for the zero-reference elevation. For portable flumes, if a wall gage is used at the usual upstream measuring point in the approach section, then the gage will not remain properly “zeroed” to the reference elevation in the throat if the flume is not level both longitudinally and laterally. To avoid this, an offset stilling well is useful. With it, the water surface from the upstream gage location is siphoned to a point above the zero reference, where the distance to the throat floor is then observed and small slopes are largely compensated. This general method will also be discussed below for its additional utility with non-portable flumes.

Sidewall gages marked directly in flow rate usually produce readings accurate enough for irrigation purposes and reduce the chance of using the wrong flow table or equation.

If a stilling well and recording instrument are to be used, then convenient and accurate zero setting is needed to properly reference the instrument. Avoid the so-called “drain-down-to-zero” method commonly found to be used in field practice, because it is not accurate enough for most

small field channel installation due to surface tension effects that introduce a systematic error (Bos et al, 1991).

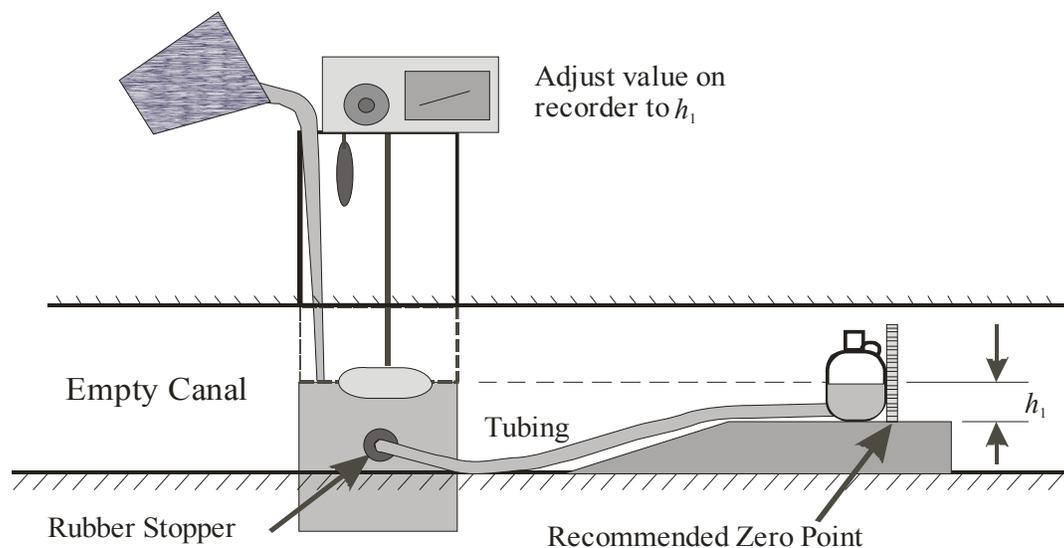


Figure 1. Method to Zero-Reference a Flume or Weir in a Dry Channel for Portable and Permanent Flumes

A simple and accurate scheme to zero-reference a portable or permanently installed flume is a slightly modified version of that described in Bos et al, 1991. Referring to Figure 1, use plastic tubing and a rubber stopper to connect the bottle container to the stilling-well tap hole. Fill the stilling well with water and allow it to partly fill the container, which is placed at the sill-zero location. Check for bubbles in the line to make sure the water level in the container accurately reproduces the water level in the stilling well. Measure the distance, h_1 , from the sill surface to the water level in the container and adjust the value on recorder to h_1 . If possible, check another flow level to assure that mistakes are eliminated. A common mistake with chart recorders is that the technician may set the physical reading of h_1 on the chart instead of the gear-reduced chart value of h_1 .

This procedure is usually more convenient than using surveying methods that require trying to determine the stilling well water surface with a surveying rod. This procedure should be adaptable to most weirs and flumes. It allows the stilling well to be detached from a portable flume and readily re-zeroed after movement. This makes installation convenient and flexible because the stilling well can be located upstream, downstream, or in the canal bank. The primary requirement is that the pressure sensing (stilling well tap) is at the prescribed upstream location and connected by tubing to the stilling well, wherever it is placed.

A static-pressure probe, Figure 2 can conveniently be used to achieve a correct instrument zero in a flowing canal. The probe is placed in the flowing canal upstream of the flume or weir in the designated cross-channel plane for depth sensing, Figure 3. The static-pressure probe should be oriented parallel to the approach flow, but can be on the channel bottom, sidewalls or midstream at any depth below the surface.

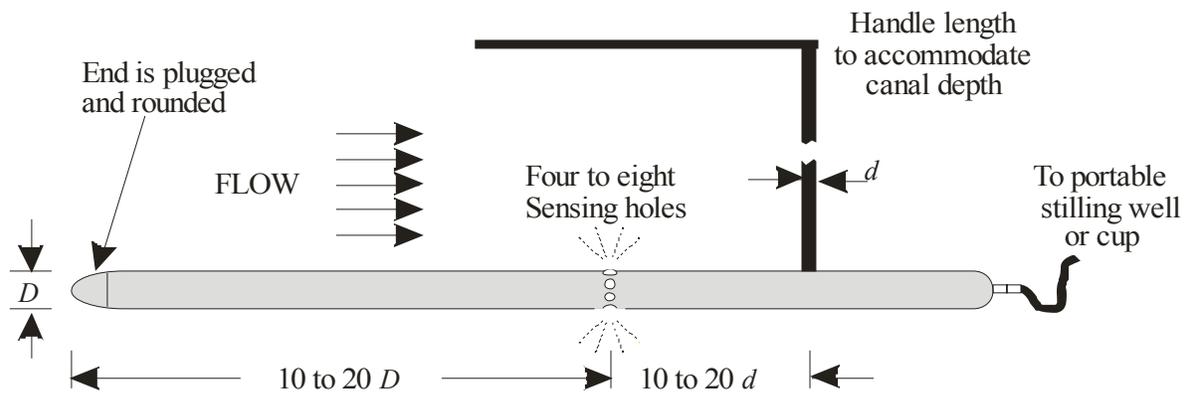


Figure 2. Static-Pressure Tube has Several Useful Functions in Canal Operations and Management

Staff Gages Staff gages, usually wall mounted, are recommended at all depth sensing locations regardless of the attending electronic detection and transmission because it provides immediate field data validation to reduce mistakes and detect malfunctions.

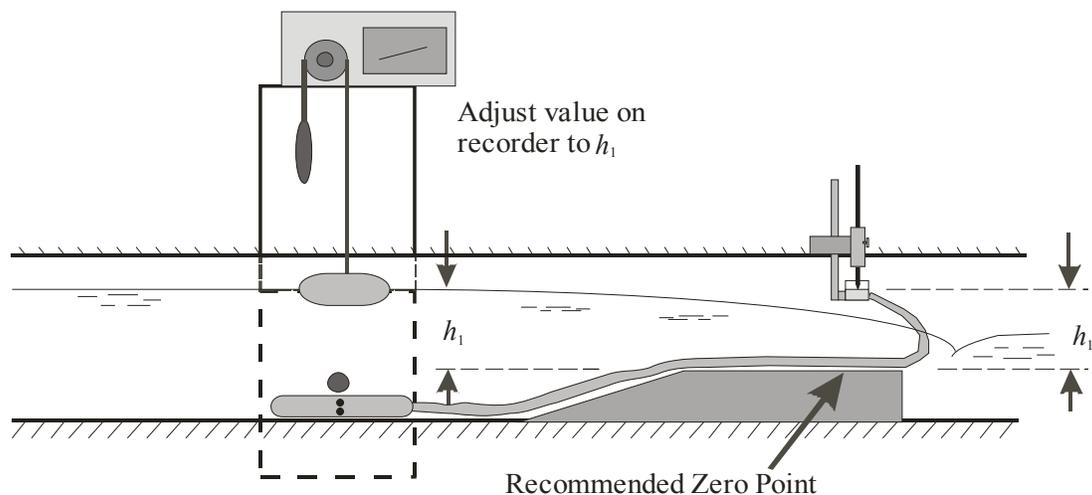


Figure 3. Method to Zero-Reference a Flume or Weir in Flowing Water

Installation Precautions for Flumes and Weirs Stilling wells used with weirs and flumes, or to simply detect canal depth, often do not indicate the correct water depth. Figure 4 illustrates a common problem and suggested corrections. For a pipe protruding into the flow, such as might be encountered in an earthen channel, a round or rectangular plate large enough to provide smooth flow past the pipe entry, usually with an approach length of 10 to 20 pipe diameters upstream and 3 to 5 diameters downstream will suffice. A plate that is longer in the upstream direction, and with the upstream edge tapering into the stream bank at not more than a 3:1 angle, may be needed to avoid catching debris. An alternate is to use a static-pressure probe (Figure 2).

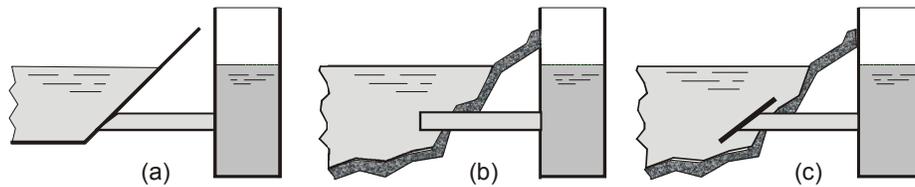


Figure 4. Stilling Well Installations: (a) Pipe Correctly Cut Smooth at Channel Boundary Wall; (b) Pipe Incorrectly Protrudes into Flow; (c) Correction Using a Plate Added to Pipe to Simulate a Channel Wall

Pressure-Transducer Field Checks Water-submersible, temperature-compensated pressure transducers are increasingly being used for detecting water depth in canal systems. These pressure transducers can typically detect depth to an accuracy of ± 3 mm. For depths in small canals, this random error represents an uncertainty of 6% for a 150 mm instantaneous depth reading, and even more for shallower depths. However, if total delivered volume is more important than instantaneous readings, the many readings involved for the volume tend to reduce this random uncertainty to zero, even for the shallow flows, and volume records can be expected to be well within $\pm 5\%$.

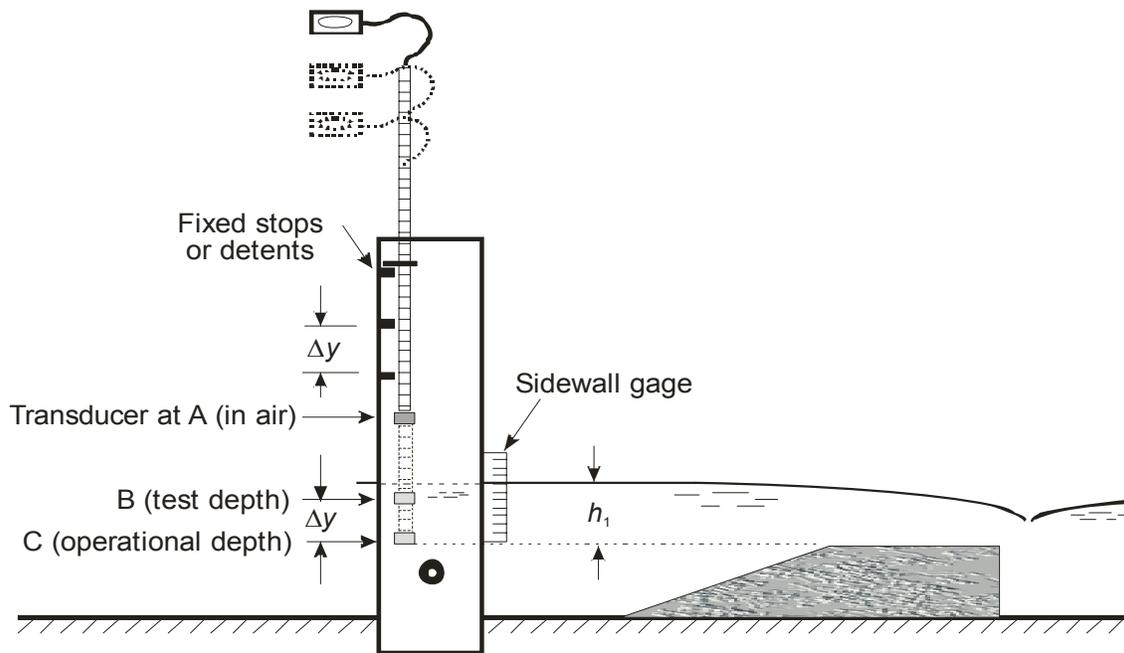


Figure 5. Pressure Transducer on Movable Rack

To render submersed transducers conveniently field checkable, the device can be mounted on a rigid, but movable rack with detents, or stops, at the operating depth, some known other depth, and in the air. These mounting detents can be as simple as “eye” bolts on the wall and screws on a sliding rod. To check the installation, the transducer output is read in the stilling well while:

- In the air, where the zero-pressure reading, e_0 , is noted:
- At operating depth, where an output reading, e_1 , is noted in any scale units without particular regard to span or zero setting; and
- At a known distance, Δy , above or below the operating depth position, where another output, e_2 is noted.

$$h_1 = \frac{e_1 - e_0}{\left(\frac{e_2 - e_1}{\Delta y} \right)}$$

This value of h_1 can be referenced to the zero elevation of the flume, weir, or other depth-indicating device, such as a permanently mounted wall gage. Thus the field technician can quickly verify proper function and can calibrate the pressure transducer in the field environment. For convenience of description, the operating position of the transducer is shown at the zero elevation reference in Figure 5. This is not necessary as long as the transducer-zero offset is determined, perhaps by surveying methods, and is applied to the value of h_1 .

Float Activated Recorders Float operated recorders have a long history and are well established (Bos, 1989; Bos et al, 1991). Inappropriately small diameter floats may introduce unacceptable errors of recording and may have variable responses during depth reversals due primarily to instrument friction. The main design feature for floats is the float diameter. Usually 15 cm or larger diameter is selected to overcome most instrument friction effects. It should be pointed out that float weight does not influence the operation except as it might cause more bearing friction. The cross-sectional area, usually a diameter of the float, is the important dimension. Thus, in concept, counter-weighted concrete blocks could be used if they are suitably coated to reduce variable water absorption. Usually cylindrical floats serve as well or better than ball floats. Glass jugs, partly filled with rocks to assure that they stay upright, can be used. Plastic jugs are to be avoided, because they may change shape and introduce a systematic zero shift. Rounded or conical tops discourage a resting place for frogs, mice, and accumulated dust and dirt that can introduce systematic error.

PRACTICAL FIELD EQUIPMENT AND PROCEDURES

Special Applications To Canal Operations

Wave suppression in canals Excessive waves in small canals are usually caused by a jet entry from a sluice gate or by a waterfall situation. The unstable surface can be 10 to 20 cm high and extend for tens of meters downstream, making the reading of sidewall gages on flumes and weirs difficult. For canals that usually flow at a fixed level, a firmly fixed, roof-like structure that penetrates the flow by as little as 10% of the flow depth, used in conjunction with a floor and wall projections of about the same proportions, have been effective in reducing the wave height to as little as 10 % of the original wave problem. The length in the flow direction of the roof-like structure has not been well established, but two or three surface wavelengths are recommended. Field observations would suggest that this length would be about equal to the flow depth, Figure 6 (Replogle, 1997).



Figure 6. Wave Suppression in Small Canal.

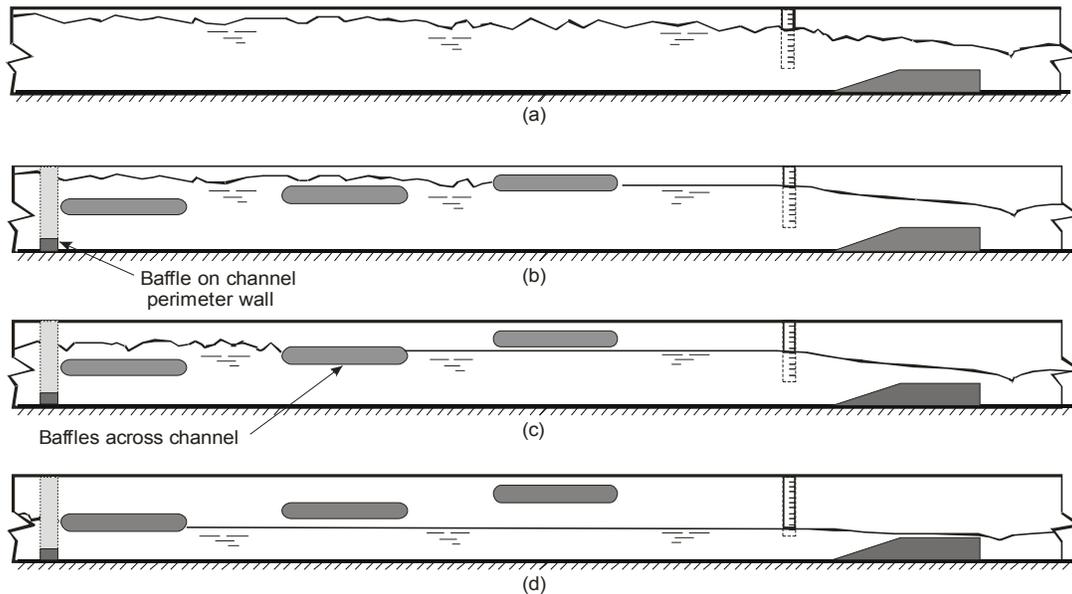


Figure 7. Wave Suppression for Variable Depth Flow. Top (a): Untreated Canal. (b),(c),(d): Typical Behavior at Various Flow Depths

To suppress waves in canals that do not always flow at the same depth, a staggered set of baffles, Figure 7, has been successfully used in a rectangular laboratory channel (1.25 m wide flowing up to 0.5 m deep). The original channel with no baffles is represented in Figure 7(a). Typically a perimeter baffle is added that may have dimensions of about one-tenth the channel depth. This may be made of a row of bricks or an angle iron. The thickness in the flow direction is not critical. The cross-channel baffles are rounded on at least the upstream end to help shed floating

debris. Each baffle thickness should not exceed about 25% of the channel depth and should be placed in elevation to slightly overlap the previous baffle. The baffles should proceed in increasing elevation in the direction of flow, as shown, otherwise flow would go over the baffle and the resulting waterfall would recreate new waves.

Flow conditioning to improve meter performance Frequently, water is discharged through a partly open gate valve producing a jet along a pipe boundary. The jet effects may be aggravated by a pipe bend as depicted in Figure 8. The insertion of a large orifice on the order of $B = 0.9$, which is not well suited for use itself as a flow meter because it produces a small differential-head reading, will disperse the boundary jet across the flow. This results in an improved flow profile being presented to the downstream meter. A slightly larger gate opening compensates the slight increase in head loss. Although the resulting profile has reduced both flow jetting and spiraling, additional vanes protruding from the pipe walls may further improve the results, particularly for propeller meters.

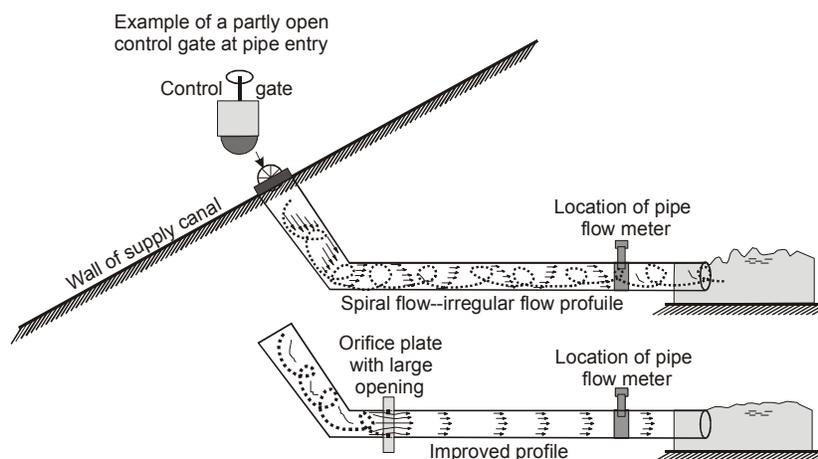


Figure 8. Orifice With Large Opening ($B = 0.9$) is used to Condition Flow for Downstream Meter

Simple Constructions

Several suggested special tools and procedures are described in following section. Most can be fabricated in farm shops.

Simplified Flume Constructions Low-cost, but accurate canal flow measurements are provided in the simplified construction methods illustrated in Figure 9. Most of the parts including the adjustable wall gage arrangement can be constructed in some farm shops or a local sheet-metal shop. The wall gage is in two parts as shown. The marked metal gage can be made by using WinFlume (Wahl, et al. 2005) first to print a direct-discharge, rate-indicating paper gage. This paper gage is then taped to a sheet metal strip that will fit into the holding bracket as shown. A chisel and punch is then used to make permanent markings on the sheet metal strip. This marked sheet metal strip can be easily adjusted to the correct zero elevation using surveying methods.

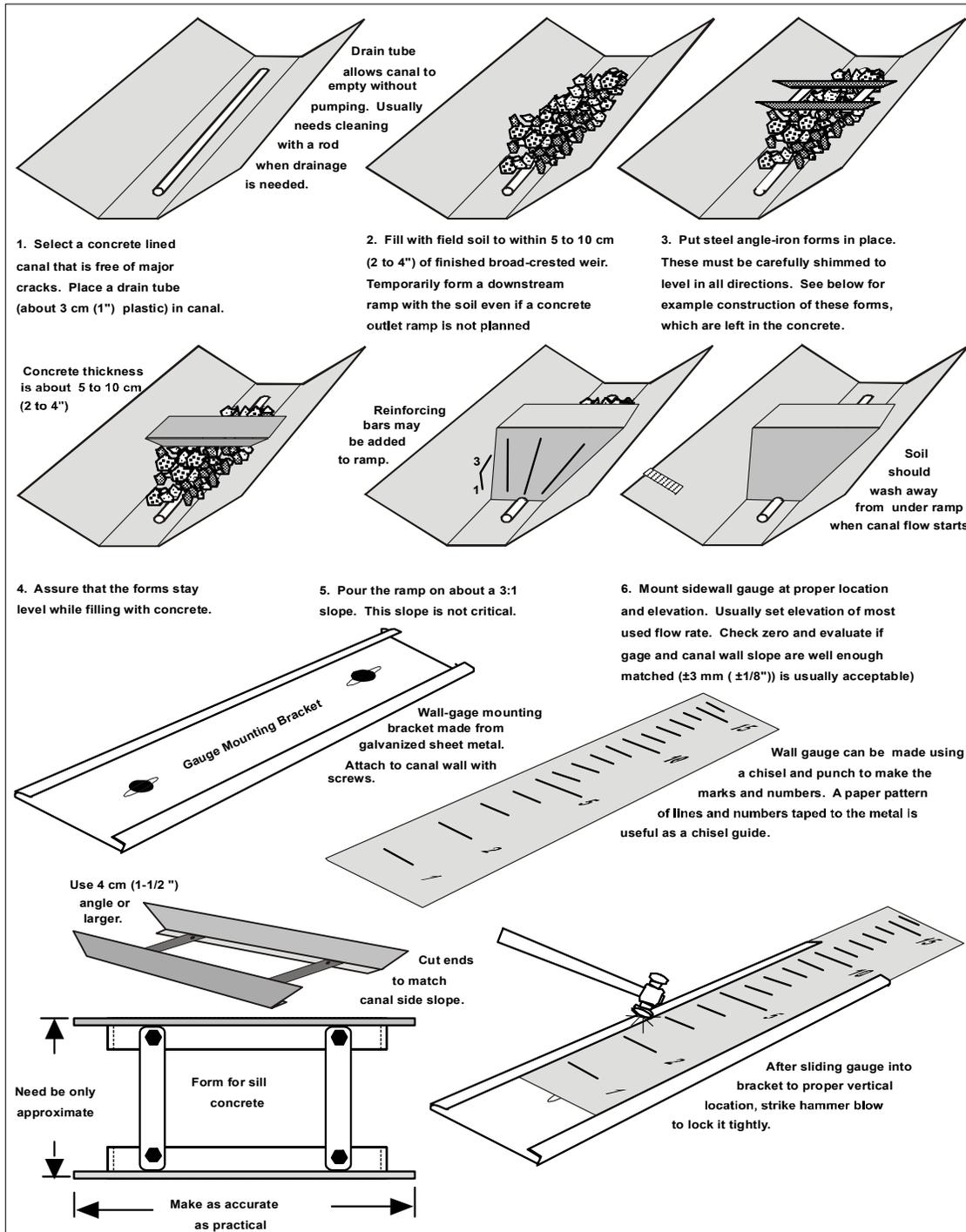


Figure 9. Simple Construction Method for Flumes in Small Farm Canals

Easy-To-Use Scales For Differential-Head Meters The common differential head meters are Venturi meters, orifice meters and Elbow meters. All are used in irrigated agriculture, and each is described in various common handbooks, such as Brater and King (1976). The Venturi meter, Figure 10, constructed from plastic pipe parts is described in detail in Replogle and Wahlin

(1998), and illustrates a simple readout method applicable to differential-head meters, using with a specially marked ruler stick. The Venturi design parameters should be selected to produce readings on the order of 0.3 to 1.5 m, so that the reading is large enough to minimize reading errors and yet small enough that a ladder is not required for the user.

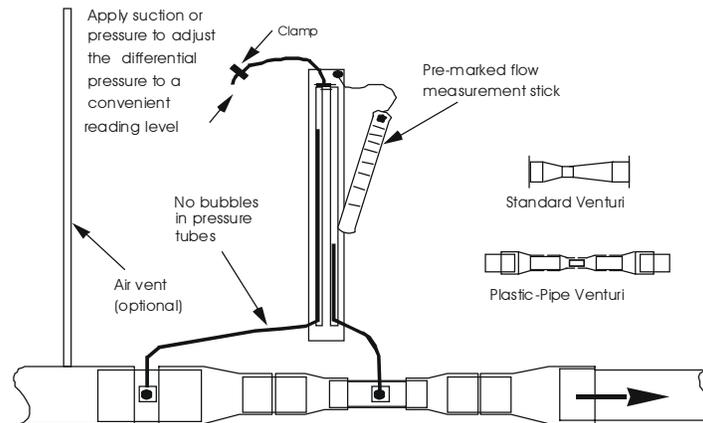


Figure 10. Marked Ruler Can Readily Indicate Direct Discharge Rate

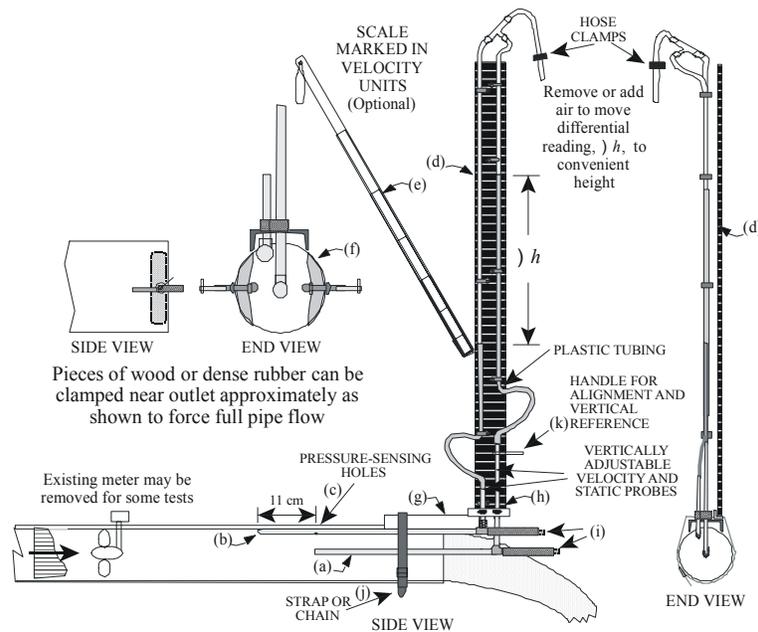


Figure 11. Pitot System for Irrigation Well Measurements

Pitot system for pipe outlets A pitot-tube combined with a static pressure tube can be used to measure discharges from free-discharging irrigation wells. Figure 11 shows the major components. Both the pitot tube (a) and static tube (b) are constructed from standard galvanized pipe of the smallest size available in most local hardware stores (nominal 1/8-inch). The use of the static tube allows the pipe pressure at the plane of the impact pitot to be obtained without drilling a hole in the pipe. The velocity profile is sampled at four points. These selected points

are determined by dividing the circular flow area into two concentric parts of equal area. The velocities at the centers of these two areas are sampled on opposite sides of the pipe and averaged. These four points compare well with the 10-point traverse detailed in Brater and King (1976). Note the pipe center point is not used, because that value is a strong function of the pipe roughness, which can vary widely. If a single point is used in a symmetrical velocity profile, a point on the division line between the concentric halves will produce the most reliable results that can tolerate a large range in pipe roughness. Replogle and Wahlin (2000) describe the system in more detail.

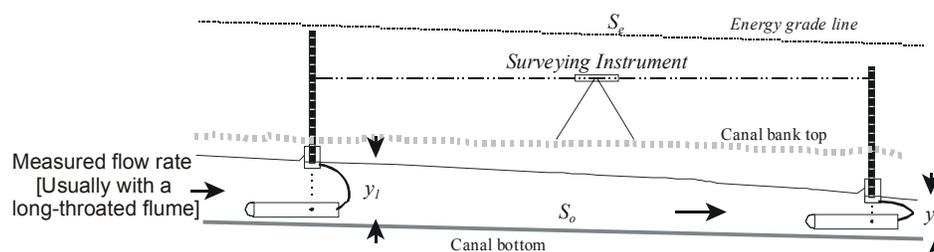


Figure 12. Method for Measuring Head Loss in a Channel

Manning n measurement Field measurement of Manning n values in prismatic canals can be determined to accuracies limited mostly by the accuracy of the known flow rate. If a long-throated flume is used with the depth detection similar to that shown in Figure 12, then the flow rate can be accurate to within about 2% or 3%. Static pressure tubes like those of Figure 2 are situated as shown in Figure 12 at distances of up to 400 m apart, somewhat depending on the surveying instrument available. By positioning the surveying instrument midway between the static-pressure tube stations, errors in instrument readings are minimized. Small cups are suspended into the surface of the flow and the water levels are read on the stable water levels in the cups with a point gage. The point gage elevations relative to each other are determined using the surveying instrument so that the elevation difference between the two cups can be accurately determined, usually within 1mm. The canal size and shape must also be accurately measured, because the flows in most canals are not uniform, that is, the water surface slope, the energy line slope and the canal slope are not parallel. Thus, a backwater curve computation such as the method in Chow (1959, Table 10.4) can be used to “back out” the Manning n value.

Under-Used Techniques

Stabilizing canal deliveries Often flow through an outlet from a supply canal is introduced into a farm canal where farm operations can vary the backwater levels against the outlet. Thus, the flow through the outlet varies and fluctuates both the farm delivery and the supply canal as in Figure 13a. If field elevations permit, a simple over-fall weir can isolate the supply canal from the farm system so that the farm operations cannot affect the operation of the supply canal. This will require a weir edge height that is at least 50 mm above the highest expected backwater elevation. This will usually require a large Δh , Figure 13b, unless the weir is impractically wide. The situation in Figure 13c uses a long-throated flume to isolate the supply and farm canals by exploiting the large submergence that can be tolerated, and requires a small Δh .

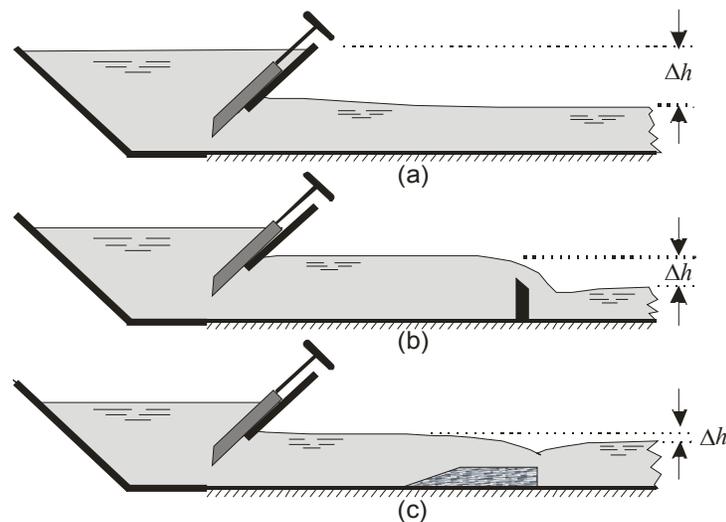


Figure 13. Use of a Flume or Weir to Stabilize Flow from a Main Canal Outlet.

Canal Level Control Long-Crested Weirs of either the “Duckbill” shape or diagonal style, Figure 14, are found to be underused, particularly in the United States. Their design-length versus head-change is adequately predicted using standard weir equations. They can be fitted with “flush-through” gates for periodic sediment management and canal maintenance. They can be combined with underflow gates to reduce the required labor of frequent gate adjustments during canal deliveries (Walker, 1997).

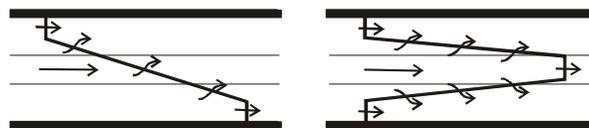


Figure 14. Plan View of Diagonal Weir and Duckbill Weir.

Checking a flow profile Sometimes it is desirable to verify that the approach flow to a channel flume or weir is not distorted to one side. One way to evaluate this is to attach perforated irrigation tubing, available from many sources with holes at about 15 cm and 30 cm spacing, to a heavy chain to hold it tightly to the channel floor and walls (Figure 15). Air is forced into the tube to form a bubble curtain that rises to the surface and makes a visible outline across the channel that is a function of both the channel shape and the velocity profile through which the bubbles pass on their relatively uniform velocity rise from the channel boundary to the surface. In the case of a prismatic channel, a non-symmetrical outline on the surface would indicate a distorted flow profile.

For irregular channel cross-sections, the picture is not so clear because the outline on the surface depends on both the point of bubble origin on the channel boundary and the flow profile. There is, however, a secondary use for the surface outline. The area in square units of measure, say m^2 , multiplied by the rise velocity of the bubbles, which is a fairly constant rate of about 0.218 m/s, gives the channel flow rate in m^3/s (Herschy, 1985). A limitation of the method is the

inconvenience of determining the area defined by the plane of bubble release and the bubble “froth line” on the surface. This line is fairly distinct, however, because the bubbles tend to break up into the optimum size to rise at the rate stated, thus leaving larger and smaller bubbles to drift downstream in sort of a “beard” effect.

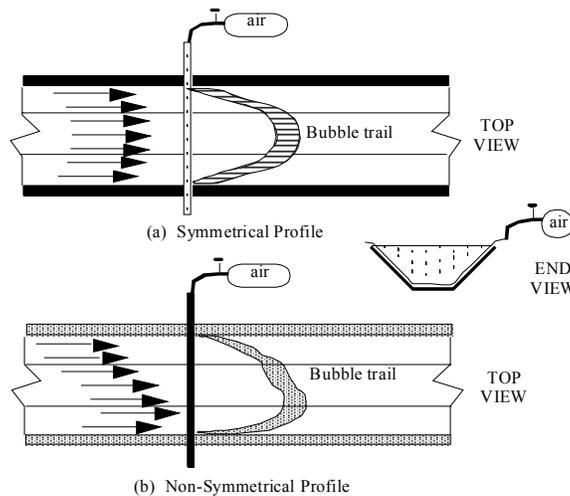


Figure 15. Bubble Curtain Used to check velocity profile.

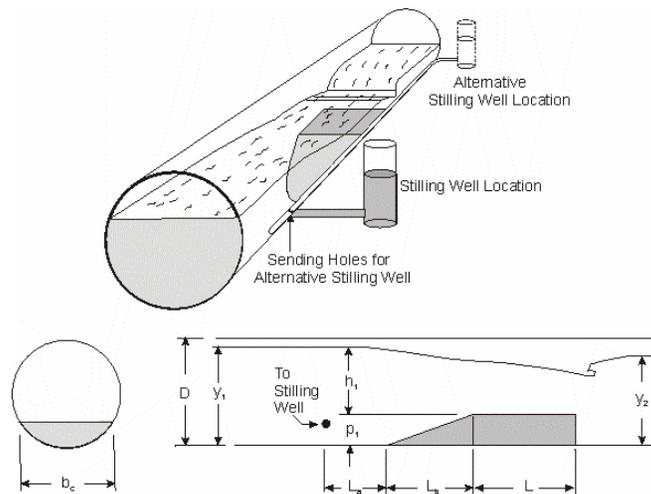


Figure 16. Suggestions for Using a Long-Throated Flume in a Culvert with Alternative Locations for the Stilling Well

Stilling well locations Often overlooked is that the stilling well to a flume or weir can frequently be at a location that is more convenient to service than when placed immediately beside the flume or weir in the cross-channel plane of the depth sending location. This technique, described earlier for portable flumes, can also apply to permanent flumes. Moving the stilling well is particularly useful when field culverts necessary for machinery movement over farm canals are fitted with long-throated flumes. Figure 16 shows a static pressure tube like that of Figure 2 being fastened to the wall of the culvert with the sensing holes at the location of

the upstream depth point. The conduit to the alternative stilling well can pass over the top of the flume if it is small enough to obstruct less than about 1% of the flow area at the lowest flow depth of interest. This would thus avoid digging on the outside of an existing culvert.

For portable flumes in circular pipes and culverts, a convenient method of laying out an ellipse for the ramp portion is illustrated in Figure 17. I was shown this method by a friend many years ago, but have not seen the method described elsewhere.

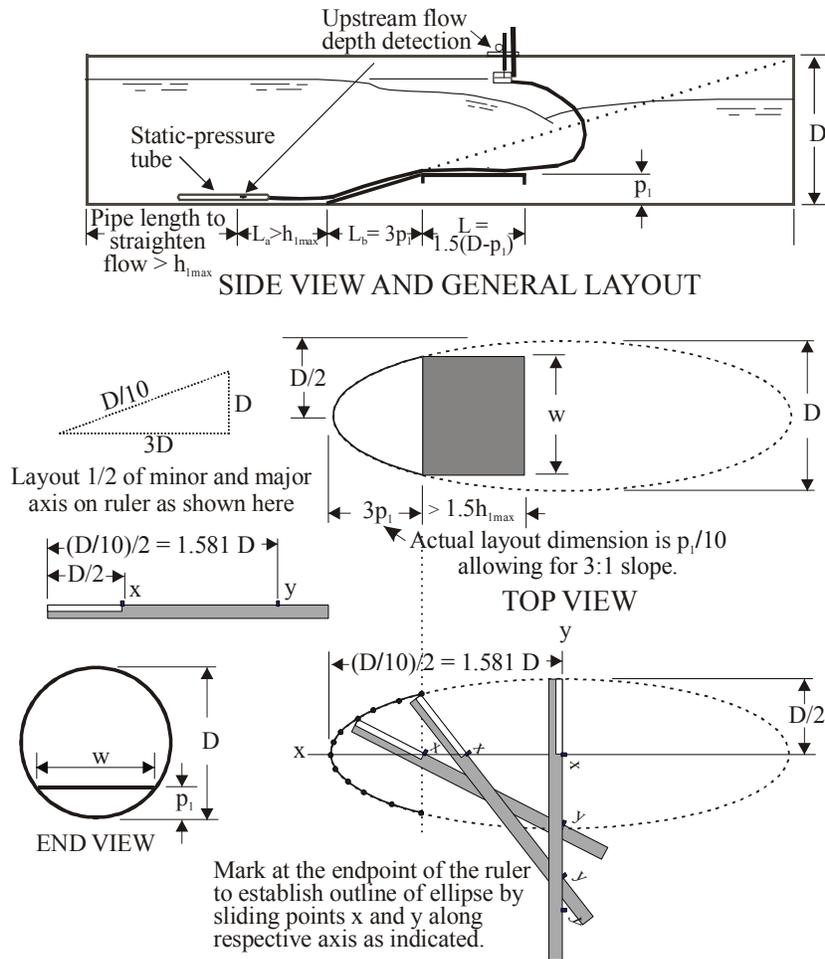


Figure 17. Ellipse Layout for Constructing Portable Flumes to Use in circular Pipes

SUMMARY

Several field techniques to help attain accurate flow measurements along with suggestions for performing convenient field constructions are discussed. Use of these suggestions is intended to make flow control and measurement practical at the field level.

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