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Tools for Design, Calibration, Construction and Use of Long-Throated Flumes and Broad-Crested Weirs

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ABSTRACT

Long-throated flumes and broad-crested weirs provide a practical, low-cost, flexible means of measuring open-channel flows in new and existing irrigation systems and have distinct advantages over other flume and weir devices. Application of these flumes and weirs has been greatly facilitated by the 1999 release of the WinFlume software used to design and calibrate these structures, and the recent publication of *Water Measurement with Flumes and Weirs*, a text providing comprehensive information on design, calibration, construction, and operation issues. The primary advantages of these flumes and weirs are that they can be custom-designed to satisfy unique operational and site requirements, and they can be computer calibrated without the need for laboratory testing. In addition, these devices are easily and economically constructed, and a number of commercially built, pre-calibrated devices are available. This paper and accompanying poster describe the use of the WinFlume software and present examples to illustrate application to a range of situations, including various flow rates, channel types, and construction techniques.

INTRODUCTION

The term *long-throated flume* describes a broad family of critical-flow flumes and broad-crested weirs used to measure open-channel flows. A variety of specific configurations are possible (Fig. 1). Bos et al. (1984) described the theory for determining discharge through these flumes. WinFlume is the most recent in a

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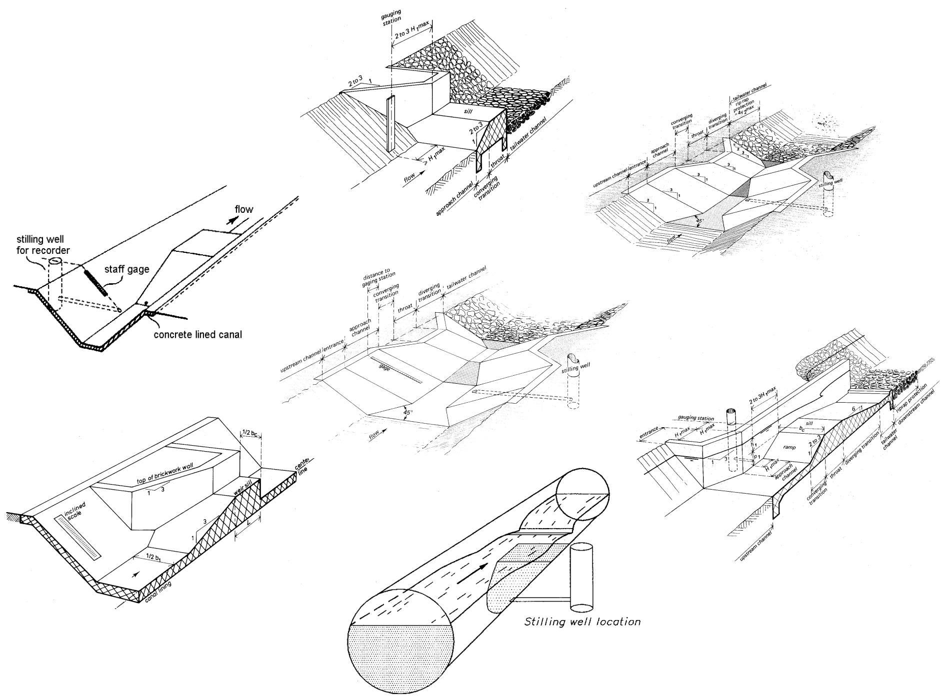

Figure 1. — Examples of Long-Throated Flumes and Broad-Crested Weirs.

series of computer programs used to design and calibrate these structures. *Water Measurement with Flumes and Weirs* (Clemmens et al. 2001) presents updated hydraulic theory, design procedures, application and construction examples, and detailed instructions for using the WinFlume software.

Long-throated flumes are the measurement device of choice for most open-channel applications, having significant advantages over Parshall flumes and other traditional devices. These older devices were laboratory-calibrated, because the flow through their control sections is curvilinear. In contrast, streamlines are essentially parallel in the control sections of long-throated flumes, making them ratable using straightforward hydraulic theory. Significant advantages of long-throated flumes include:

- Rating table uncertainty of ±2% or better in the computed discharge.
- Choice of throat shapes allows a wide range of discharges to be measured with good precision.
- Minimal head loss needed to maintain critical flow conditions in the throat of the flume.
- Ability to make field modifications and perform computer calibrations using as-built dimensions.
- Economical construction and adaptability to varying site conditions.

Adaptability of these structures is a primary advantage, with the range of applications demonstrated by design and construction examples provided in Clemmens et al. (2001). Structures meeting the criteria for analysis as long-throated flumes can be small or large, permanent or temporary, fixed or portable, and may serve as either simple flow measurement devices or as combined measurement and control or flow division structures.

PERMANENT STRUCTURES FOR FLOW MEASUREMENT

Permanent flumes and weirs form the backbone of many water measurement networks for open-channel irrigation and drainage systems. In concrete-lined canal sections the most common structures are of the broad-crested weir type, consisting essentially of a sill that spans the full width of the existing lined channel. The resulting shape of the throat section of the flume (the control section) may be trapezoidal, rectangular, or one of several complex shapes such as a sill in a circle or sill in a parabola. The side walls of the existing lined channel form the side walls of the throat section, so construction is generally straightforward.

Figures 2-4 illustrate several possible construction methods. In Figure 2 an earthfill core is constructed, and a concrete shell is then placed over the earthfill to form the converging ramp and the control section. Drain pipes through the structure eliminate undesirable standing water upstream from the flume during the off-season. When flow is initiated, the underlying earthfill is washed out, leaving a concrete shell structure.

Figure 2. — Construction of a Broad-Crested Weir in a Concrete-Lined Trapezoidal Channel.

Figure 3 shows the installation of pre-cast concrete sections of a broad-crested weir for a lined trapezoidal channel. This construction technique is useful when many weirs of exactly the same design are needed for installation at several locations in a canal system. Similar weirs can also be constructed with pre-fabricated metal ramp and sill sections.

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Figure 3. — Placing Pre-Cast Weir Sections in a Lined Trapezoidal Canal.

Figure 4 shows the construction of a large permanent flume with a trapezoidal throat section. In this case, a length of the existing earth canal was fully lined to create the sidewalls of the control section. The most important aspect of construction is maintaining a level sill in the throat section (level in the flow direction is most important).

Figure 4. — Construction of a Large Broad-Crested Weir in an Earthen Channel.

A common flume design used for earth-lined canals is illustrated in Figure 5. The throat section is rectangular, which often simplifies construction, since sloped side walls do not have to be constructed in the throat section. The vertical side walls are constructed from concrete block and mortar. Erosion protection is provided downstream from the flume in the channel bottom and on the side walls.

In natural channels where a very large range of flows may need to be measured, flumes with a triangular-shaped control section are often used. These flumes offer good measurement accuracy at low flows, while passing flood flows without an unacceptably large flow depth upstream from the structure. Figure 6 shows a triangular-shaped flume constructed in Florida.

Figure 5. — A Rectangular-Throated Flume in India.

Figure 6. — Triangular-Throated Flume in Florida.

PORTABLE AND TEMPORARY FLUMES

Long-throated flumes and broad-crested weirs are very useful for portable and temporary applications. Such devices can be very economical to build, while still providing highly accurate flow measurement capability. The RBC family of 5 small trapezoidal-throated flumes is suitable for flow survey work. These flumes can be constructed from sheet metal using drawings provided in Clemmens et al. (2001), or commercially pre-fabricated flumes are also available, such as the fiberglass models shown in the right hand photograph in Figure 7.

Figure 7. — Portable RBC Flumes Measure Flow in Drains and Furrows.

Portable flumes with rectangular throat sections are shown in Figure 8. These can be constructed from wood, metal, or fiberglass. Temporary flumes for lined trapezoidal canals can be constructed from plywood (Figure 9).

Figure 8. — Rectangular-Throated Portable Flumes.

Figure 9. — Temporary Flumes for Lined Trapezoidal Channels.

Portable flumes can also be constructed by installing a sill into a circular or semicircular pipe section. If the pipe section is small enough, these flumes can be easily transported to different measurement sites. Leveling bubbles shown on the flume in Figure 10 help the user to achieve a good installation.

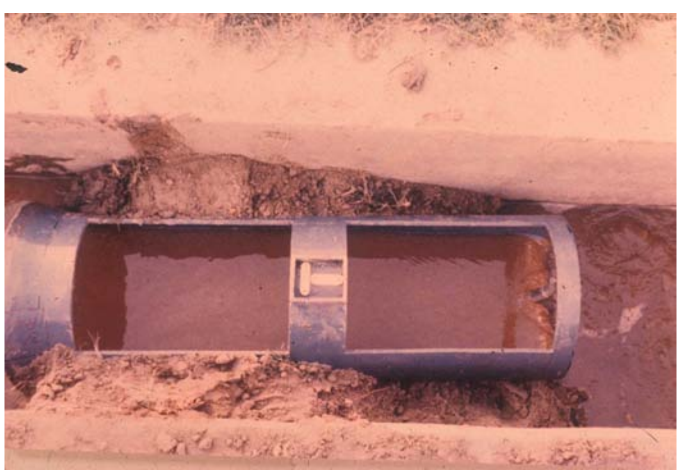

Figure 10. — Portable Flume Constructed in a Section of Circular Pipe.

FLUMES AND WEIRS FOR FLOW DIVISION AND CONTROL

In addition to flow measurement, flumes and weirs can facilitate regulation of deliveries and accurate division of flows. For regulation of deliveries, weirs with a vertically movable crest are used. Such weirs can be constructed in sizes up to about 4 m wide. These weirs are installed at offtakes where the supply water level is steady, and the weir elevation is varied to change the delivered flow rate. Figure 11 shows a pair of vertically movable weirs and the flow registration system used to directly indicate the flow rate.

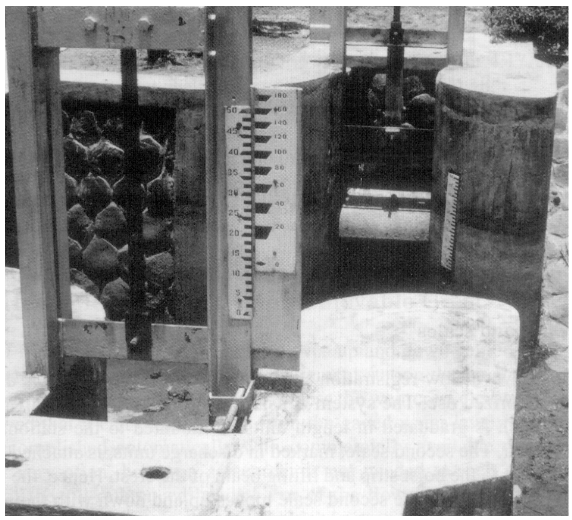

Figure 11. — Movable-Crest Weirs and Flow Registration Scales.

Broad-crested weirs with a rectangular throat section can be used to accurately divide flows among two downstream users or districts. A vertical division board is installed just downstream from the control section. The division board may be fixed or movable. Such structures are useful on projects where different users are entitled to a percentage of the available water supply, rather than a fixed quantity of water. Figure 12 shows an adjustable flow division structure in Argentina.

PRECOMPUTED FLUME DESIGNS AND RATINGS

Two basic approaches can be taken to the problem of flume design. Custom designs may be developed with the WinFlume software described later, or precomputed flume designs can be selected from tables provided in Clemmens et al. (2001). Precomputed designs are available for trapezoidal-throated structures to be installed in lined canals, rectangular-throated structures for installation in lined or earthen channels, triangular-throated structures for natural channels and drains experiencing a wide range of flows, and for sills installed in circular conduits. Tables provide discharge and head ranges, minimum head loss requirements, structure dimensions, and rating equation parameters. Precomputed designs are available for typical small to medium-size channels; for large structures, analysis with WinFlume is recommended to achieve an optimum design. Each precomputed design has been developed to satisfy criteria related to approach channel Froude number and flow measurement accuracy. The user is responsible for verifying that a selected design will satisfy upstream freeboard requirements and operate in a free flow condition (i.e., that enough head loss is available at the site to avoid submergence of the flume by the existing tailwater conditions). Clemmens et al. (2001) provides numerous design examples to illustrate the use of the tables.

Figure 12. — Flow Division Structure with a Movable Divisor.

WINFLUME SOFTWARE

Custom flume ratings and designs to satisfy nearly any application can be developed with the WinFlume software (Figure 13), available for free download on the Internet at www.usbr.gov/wrrl/winflume/. The software operates on all Windows-based computers. An online help system is integrated into the program, and a printable user's manual is distributed electronically with the software. A helpful flume wizard is available to assist new users with basic data entry.

Flume ratings for existing structures can be developed from as-built dimensions, provided that the throat section is horizontal in the flow direction and there is a smooth transition from the approach channel into the throat section. The software will generate head-discharge tables, rating curves, rating equations, and flow-graduated wall gages. Wall gages can be printed at full scale on Windows-compatible plotters and printers and provided to a fabricator for construction of durable field-quality staff gages (Figure 14). Additional optional parameters provided in WinFlume's rating tables include the required head loss and modular limit (i.e., maximum allowable submergence ratio).

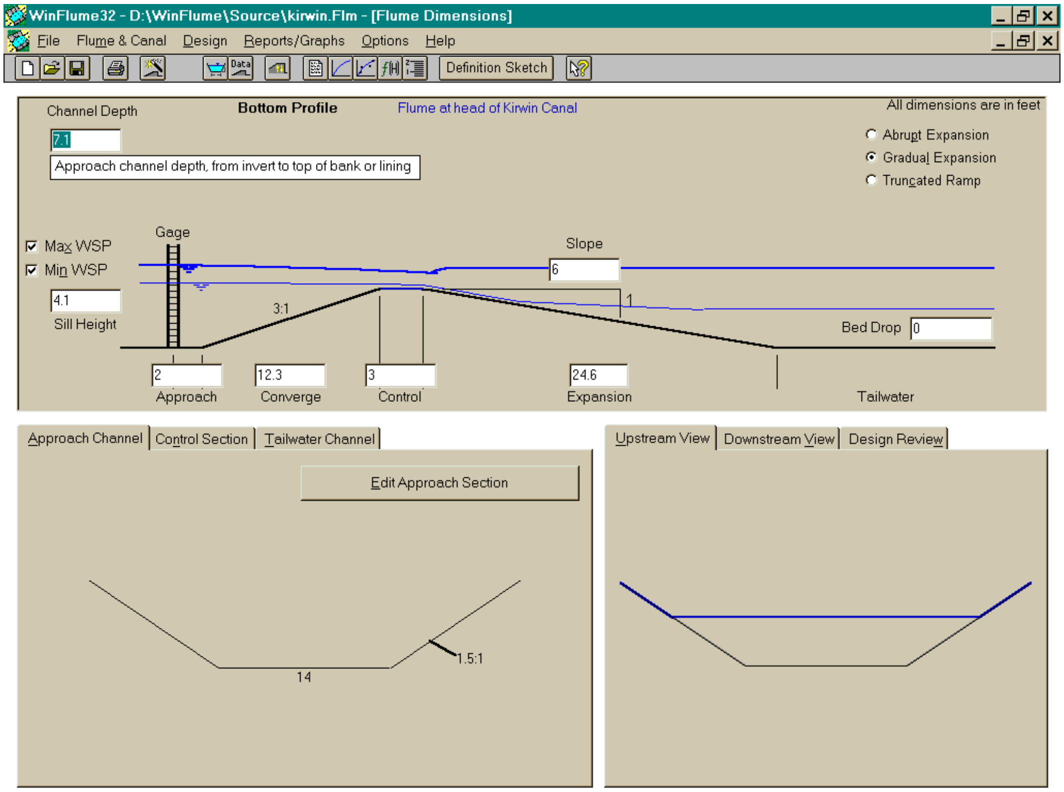

Figure 13. — Entering Flume Dimensions into the WinFlume Software.

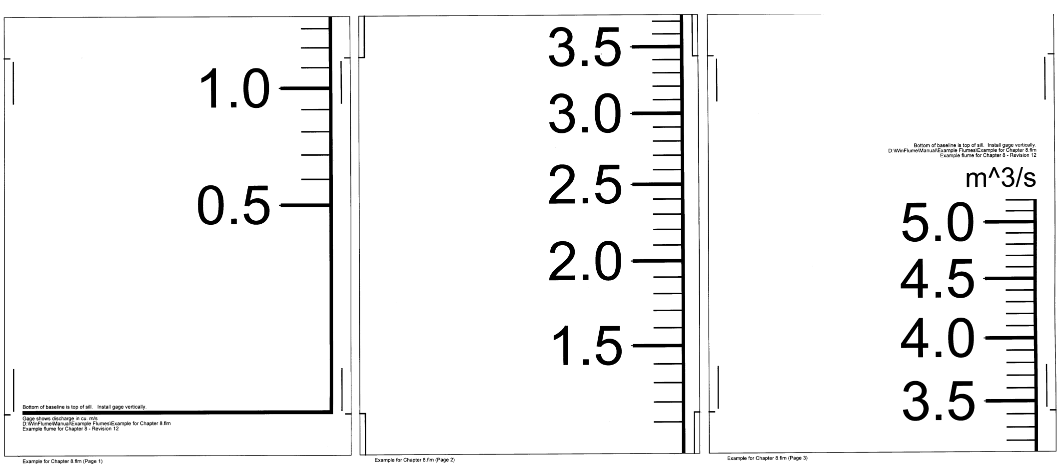

Figure 14. — A 3-Section Flume Wall Gage Produced by WinFlume.

Design of new flumes can be accomplished either by trial or with the assistance of WinFlume's automated design evaluation routines. To develop a design by trial, the user enters the flume dimensions and design requirements (e.g., desired freeboard, discharge range, tailwater conditions, accuracy requirements), and then performs a design review. The design review report will indicate deficiencies in the design and suggest alternatives to improve the design. The initial design task is to determine the proper amount of contraction in the throat section (narrowing of the channel width or raising of the sill) needed to produce critical depth flow over the full range of flows to be measured. Once this is accomplished, the length of flume components is fine-tuned so that the structure meets the requirements for performance as a long-throated flume.

To develop a design using the design evaluation routines, the user again provides starting flume dimensions and design requirements, then executes the design evaluation routine. WinFlume builds a family of virtual flume designs derived from the initial design and evaluates each against the primary design criteria. The alternative designs are created by changing the amount of contraction in the throat section of the structure, for example by raising or lowering the sill. Acceptable designs are listed in a report and the user can then select a design from the list. This approach allows the user to see the range of acceptable designs (since there is not normally just one acceptable design) and the performance tradeoffs to be considered in selecting a final design. These tradeoffs usually involve maintaining acceptable upstream freeboard while minimizing the possibility of flume submergence if tailwater levels should be higher than expected. An intermediate design that provides acceptable freeboard and operates somewhat above the modular limit condition is often the best final design choice.

CONCLUSION

The release of the WinFlume software and publication of *Water Measurement with Flumes and Weirs* has greatly advanced the application of long-throated flumes and broad-crested weirs for open-channel flow measurement. The flexibility of these structures and the simplicity of developing, calibrating, and constructing effective, economical designs make them the best structure for most open-channel flow measurement applications.

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