

IMPROVED SOFTWARE FOR DESIGN OF LONG-THROATED FLUMES

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ABSTRACT

Long-throated flumes have received increased emphasis in recent years as a practical, low-cost, flexible means of measuring open-channel flows in new and existing canal systems (Reclamation, 1997). MS-DOS based software to aid in the design of long-throated flumes has been available for several years from the International Institute for Land Reclamation and Improvement, and was documented by Clemmens et al. (1993). To facilitate the future use of long-throated flume technology, the Bureau of Reclamation and the Agricultural Research Service are presently rewriting this software to operate in a Windows-based computing environment. The updated software will include significant user-interface improvements and new features, and will overcome an incompatibility between Windows 95 and the copy-protection system used on the current software. Some of the new features will include an improved design optimization scheme, integrated printing of full-scale wall gauges, improved graphics and units system support, a simplified system for saving, retrieving, and sharing flume designs with other users, and an online help system. At this time most of the new features are in place and the software is in a beta-testing phase. The completed software will be released at the end of the beta-test program along with updated printed documentation.

INTRODUCTION

The term *long-throated flume* describes a broad class of critical-flow flumes and broad-crested weir devices used to measure flow in open channels. These devices are adaptable to a variety of measurement applications in both natural and man-made channels, and both new and existing canal systems. Bos et al., (1984) describe the theory for determining discharge through these flumes, which has been well-developed over the course of the late 19th and 20th centuries. Procedures for determining head loss and developing flume designs for specific applications have been developed in the last two decades, and with the advent of relatively low-cost personal computers, these have become accessible through interactive computer programs (Clemmens et al., 1993).

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Figure 1 shows the components of a typical long-throated flume. Primary features are an approach channel and water level measurement device, a converging transition, the control (throat) section in which critical flow occurs, and an optional diverging transition to the tailwater channel.

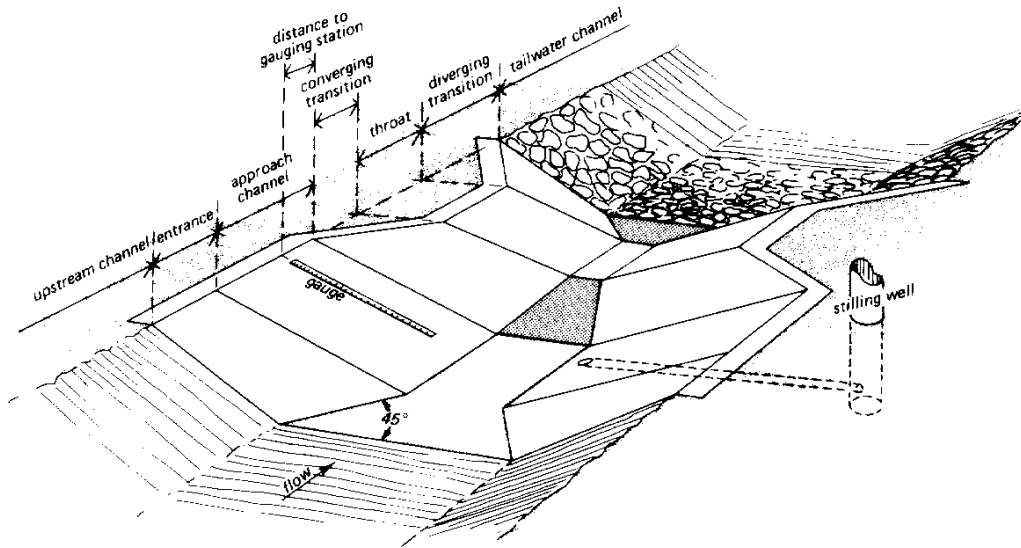


Figure 1. — Components of a Long-Throated Flume (Bos et al., 1984).

In recent years long-throated flumes have become the measurement device of choice for many applications (Reclamation, 1997), superseding Parshall flumes and other well-known standard measurement devices. To briefly review, significant advantages of long-throated flumes include:

- Assuming critical flow occurs in the throat, a rating table specifying the flow rate as a function of the upstream head can be determined with an error of less than 2% in the computed discharge. Rating tables can be computed for any combination of a prismatic control section and an arbitrarily shaped approach channel.
- The throat must be horizontal in the direction parallel to the flow, but can be any shape in the direction perpendicular to the flow, allowing the complete range of discharges to be measured with good precision.
- The required head loss across the flume is minimal to ensure a unique relationship between the upstream sill-referenced head and the discharge.
- Long-throated flumes can be operated with partial submergence (i.e., downstream water level above the sill elevation), and the submergence limit

and associated head loss requirement can be estimated for any structure placed in an arbitrary channel.

- With a properly constructed gradual converging transition, the flumes have virtually no problem passing floating debris.
- Long-throated flumes can be designed to pass sediment transported by channels having subcritical flow. Sedimentation only becomes a problem when sediment loads become excessive, or if the flume causes a significant reduction in flow velocity in the approach channel.
- If the throat is horizontal in the direction parallel to the flow, an accurate rating table can be computed using as-built dimensions. The throat section may also be modified as necessary to accommodate changing site conditions, and a new rating can be computed using the modified dimensions.
- Long-throated flumes are typically the most economical weirs or flumes for measuring open-channel flows, especially in larger sizes. For example, the construction of a large Parshall flume requires considerable care and construction expense to properly construct the sloped floor of the throat and diverging sections and maintain design dimensions within required tolerances. In contrast, long-throated flumes require only an arbitrary gradual transition into the throat section, and can be calibrated using as-built dimensions.
- Because long-throated flumes can be designed for installation into any arbitrary channel, they are very adaptable to installation in existing canals.

The design calculations needed to properly size and locate flumes are iterative; as a result, several generations of computer codes to assist in the design of long-throated flumes have been developed in recent years, primarily by the Agricultural Research Service (ARS) Water Conservation Laboratory in Phoenix, Arizona, USA. Most of these programs operated in a batch mode and were written in FORTRAN. In the early 1990's the International Institute for Land Reclamation and Improvement (ILRI) and ARS contracted the development of an interactive computer program for long-throated flume design. This program was written in the Clipper language and operated in an MS-DOS computing environment. The program included: on-screen graphic displays of flume geometry; a design optimization routine; features to assist in calibration of existing flumes; and printed output of rating tables, rating equations, wall gauge data and discharge-head curves. The program is distributed with the 1993 publication by Clemmens et al., titled FLUME: Design and Calibration of Long-Throated Measuring Flumes. Through the remainder of this paper the Clipper-based program will be referred to as FLUME 3.0.

FLUME 3.0 suffers from several shortcomings that have become more critical with the release and widespread adoption of the Windows 95 operating system. These include:

- A copy-protection system that is incompatible with Windows 95
- The need for a large amount of free DOS memory, which is most critical on DOS and Windows 3.1 systems connected to networks
- A text-based menu system and user interface that does not use a mouse, and in which keystroke sequences required to navigate the menus are tedious and non-intuitive
- Bugs in discharge curve graphics and flume geometry displays
- Lack of support for modern printers and poor management of printed output to modern page-type printers
- Problems in design optimization routines for some complex channel and throat section shapes
- A method of storing flume designs that makes it tedious to transfer individual flume designs among users

Several of these problems could be corrected by making relatively minor modifications to the Clipper source code, but others would require major revisions or simply are not possible within the framework of the existing program. Clipper is also no longer a widely used programming language, so making revisions to the Clipper-based program is not a good long-term strategy for maintaining and improving the software.

For these reasons, the Bureau of Reclamation (Reclamation) and ARS began in mid-1997 to work cooperatively on the development of an updated version of the flume design software. The new program is titled *WinFlume* and is being programmed for the Windows 95 and Windows NT environment using the Visual Basic language. The program will also be compatible with Windows 3.x systems, although this is not the target platform for the software. The new program will make use of the same hydraulic theory used in the previous FORTRAN- and Clipper-based programs, but will have an improved user interface, a new design optimization/analysis routine, and several additional features not contained in any of the previous programs. Programming work is being performed in-house by the Bureau of Reclamation to facilitate future maintenance and improvement of the software.

THE WINFLUME APPLICATION

The WinFlume program is being developed as a native Windows 95 and Windows NT application, using the Visual Basic programming language. The application will be compiled into a 32-bit executable for Windows 95/NT systems and a 16-bit executable for Windows 3.x systems. Graphical output from the program (e.g., head-discharge curves, plots of rating equations, comparisons to measured flows)

is provided using an integrated third-party graphics library that is distributed with the application.

Operation of the program is centered around an editable graphic display of the flume dimensions (Fig. 2), auxiliary data screens used to specify non-geometric properties of the flume and approach and tailwater channels, and several screens devoted to providing output, analysis, and review of flume designs. Flume bottom-profile dimensions are edited from the screen shown in Fig. 2, while cross-section dimensions are edited in a separate screen that shows additional cross-section detail (Fig. 3). Internally, the program uses an object-oriented programming approach in which the complete definition of the flume and associated channel and hydraulic properties are contained within a single structured data type. This simplifies storage and retrieval of flume designs and internal manipulation of multiple “virtual” flumes in the design optimization and analysis routines.

The WinFlume program shares essentially all of the basic features of the FLUME 3.0 program described earlier. These include:

- Ability to design flumes for specific head loss objectives, while verifying that the design meets criteria for maximum approach flow Froude number, adequate freeboard, maximum allowable tailwater, and desired discharge measurement precision
- Support for both fixed- and movable-crest flumes

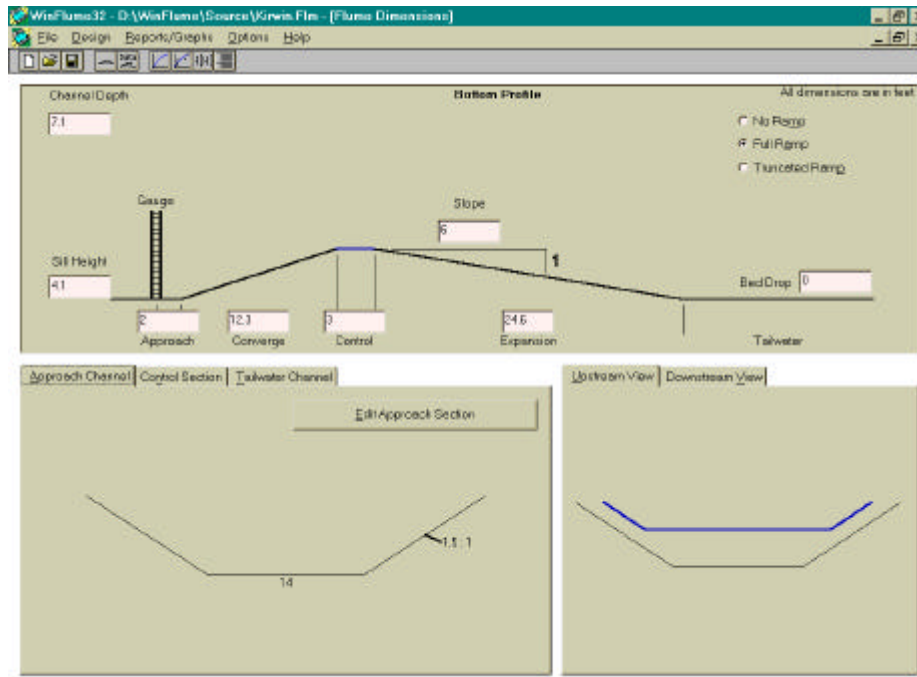


Figure 2. —WinFlume Display of Flume and Canal Geometry.

- Support for seven possible approach and tailwater channel cross-section shapes, and 14 possible control-section shapes including circular, parabolic, and trapezoidal sections, and complex sections containing trapezoids within simpler sections
- Ability to produce rating tables of discharge versus upstream head for direct field use and for use in constructing customized staff gauges graduated in head or discharge units for field installation
- A curve-fitting module to develop power-law rating equations for use in automated data collection systems

New Features

The WinFlume program contains a number of new and improved features. The most dramatic improvements are in the user interface, which takes full advantage of the Windows environment and includes such features as a standard Windows-style top menu bar, toolbars with tool tip help tags, tabbed dialog boxes to organize program features, grids to display rating table data, standard Windows common dialogs for loading and saving files, and support for exporting data and graphics to the system clipboard. All program output can be directed to a file, to the system clipboard, or to any printing device installed in the user's Windows system.

A key component of the improved interface will be an integrated online help system that will provide the user with both flume-design guidance and assistance with the details of program usage. The online help system will be constructed in

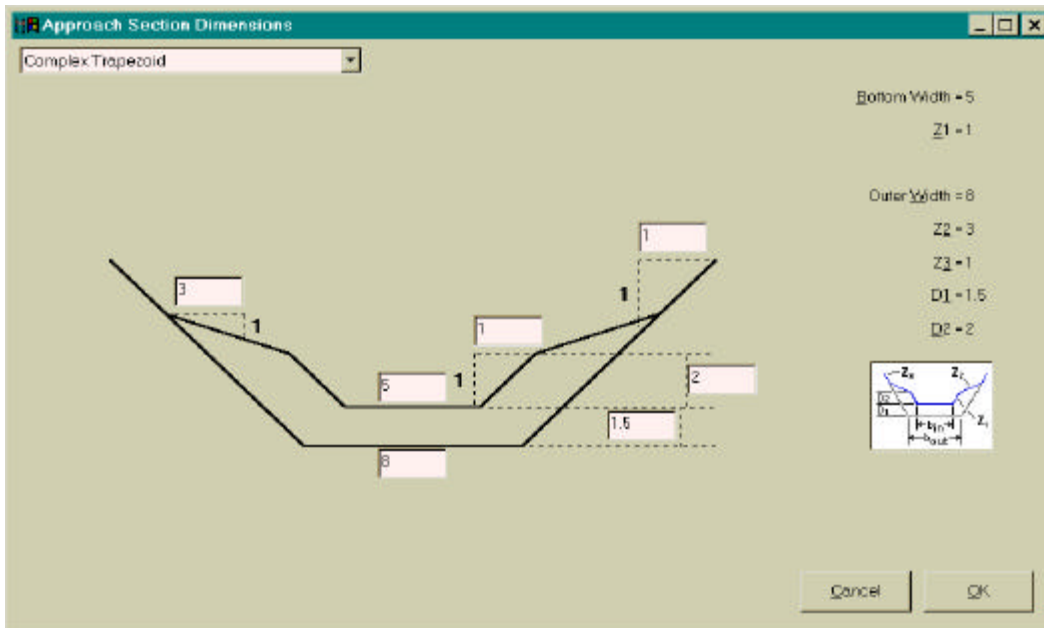


Figure 3. — Editing a Complex Trapezoid Cross-Section.

combination with the preparation of printed documentation for the new software.

New File Format: WinFlume now saves each flume design into an individual data file with the default extension of .FLM. This is in contrast to FLUME 3.0, which stored all flume designs collectively in a single dBase file. The use of individual data files makes transfer of flume designs among different users more convenient. For backward compatibility, WinFlume is able to load designs from the FLUME 3.0 dBase file format and then save them to new individual files in the WinFlume format. WinFlume and FLUME 3.0 both work internally and save all data in metric units, but WinFlume saves the user's units-system preferences for program input and output with each flume design, rather than as a program-wide preference as was done by FLUME 3.0. This simplifies working on multiple flumes in a variety of units systems. Data are also stored with better precision than was possible in the dBase file format, reducing problems with round-off errors that occasionally occurred in FLUME 3.0.

Rating Table Improvements: Several improvements have been made to the flume rating tables (Fig. 4). Tables can still be generated for either fixed-head or fixed-discharge increments, and a new Smart Range feature has been added that assists the user to find a reasonable range over which to generate the rating table. Tables can now include the estimated actual tailwater levels and submergence ratios for each flow rate shown in the table, whereas FLUME 3.0 only reported actual tailwater levels at the minimum and maximum design discharge.

The interactive display of rating table data has been improved in WinFlume by using a scrollable grid control. This presents the rating table data in a spreadsheet format that can be browsed by the user (Fig. 4). For each line of the rating table (corresponding to a single flow), any errors or warnings associated with the hydraulic calculations for that line are displayed in a text box below the table. This is in contrast to FLUME 3.0, which displayed only a summary of all errors or warnings for the entire table. The ability to associate individual error messages with specific lines in the rating table helps the user understand the cause of the error; they can then determine the modifications to the design or design criteria that may be needed to correct the problem, or whether the error can be ignored.

Rating table data can also be plotted, and the graphs then printed, copied to the clipboard, or saved to a Windows Metafile format. Graphs can display up to 3 parameters at a time, chosen from the 14 possible parameters that can be included in a rating table. Figure 5 shows a typical graph produced by WinFlume.

Ditchrider's Rating Table: A new type of rating table is included in WinFlume, specifically designed for field use. This rating table shows only the discharge as a function of upstream head, and is organized to fit a large amount of data onto one or two sheets of paper. Each row of the rating table displays the discharge for 10 increments of head, as shown in Table 1. This table can display the flow as a function of either vertical head or the slope distance for users who wish to install standard staff gauges on the sloped bank of the upstream channel.

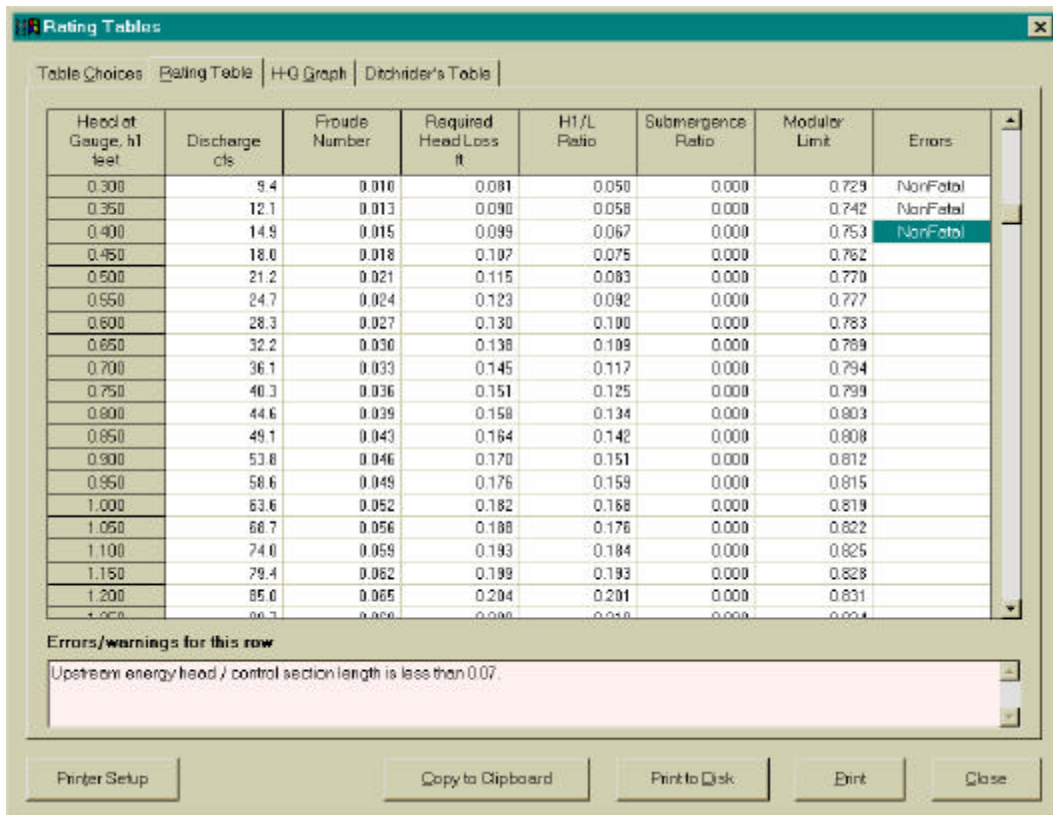


Figure 4. — Flume Rating Table Displayed in a Scrollable Grid.

Table 1. — Typical Ditchrider's Rating Table.

User: Tony L. Wahl WinFlume32 - Version 0.32										
D:\WinFlume\Source\Kirwin.Flm - Revision 2										
Flume at head of Kirwin Canal										
Ditchrider's Rating Table, Printed: 4/1/98										
Head, h1	Discharges in cu. ft/s									
ft	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.2	--	--	--	--	--	9.7	10.3	10.9	11.6	12.2
0.3	12.9	13.5	14.2	14.9	15.6	16.4	17.1	17.8	18.6	19.4
0.4	20.1	20.9	21.7	22.5	23.4	24.2	25.0	25.9	26.7	27.6
0.5	28.5	29.4	30.3	31.2	32.1	33.0	34.0	34.9	35.9	36.9
0.6	37.8	38.8	39.8	40.8	41.8	42.9	43.9	44.9	46.0	47.0
0.7	48.1	49.2	50.3	51.4	52.5	53.6	--	--	--	--

Rating Equation Curve-Fitting: The curve-fitting module in WinFlume is substantially the same as that used in FLUME 3.0. The user specifies a range and increment of heads for which rating table data are generated, and the program then uses a non-linear curve-fitting algorithm to determine a single equation fitting the data of the form:

$$Q = K_1(h_1 + K_2)^U$$

in which Q is the discharge, h_1 is the upstream sill-referenced head, and K_1 , K_2 , and U are all fitted parameters. The coefficient of determination is also reported to the user. A new feature of WinFlume is the option to force the value of K_2 to zero. This option was included to accommodate dataloggers that only support an equation of the form:

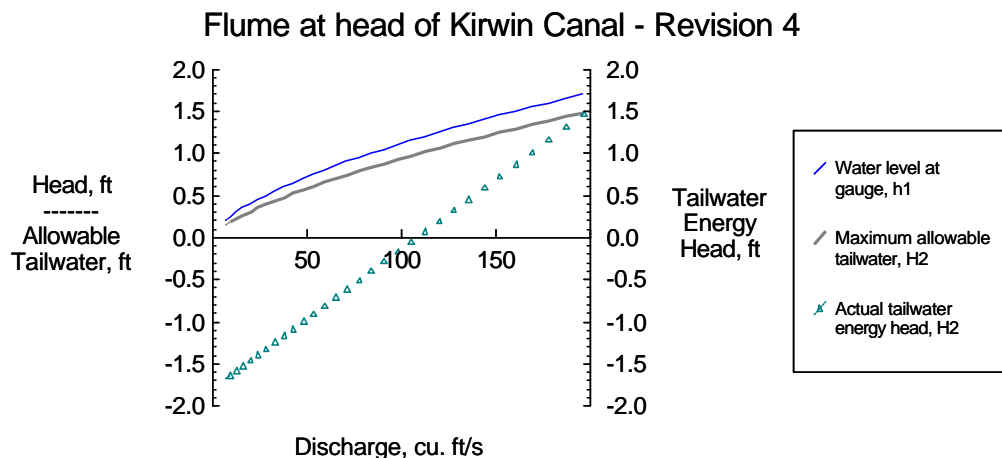


Figure 5. — Rating Table Graph Produced by WinFlume. Heads Are Shown Relative to the Flume Crest.

$$Q = K_1 h_1^U$$

Plotting Full-Scale Wall Gauges: A major new feature of WinFlume is the integrated printout of full-size flume wall gauges. Both FLUME 3.0 and WinFlume generate rating table data needed to construct a full-size wall gauge graduated in either head or discharge units, that can be installed vertically in the upstream pool or on the sloped bank of the approach channel. WinFlume also provides an on-screen preview (Fig. 6) of the wall gauge and can then print it at full-scale to a Windows printer driver. Controls are provided that permit adjustment of label sizes, labeling intervals, and number format. With a roll-feed plotter, large wall gauges can be printed on a continuous sheet of paper. With smaller page printers, WinFlume will split the gauge into several sections and print each on a separate sheet of paper with the match marks needed to reconstruct the continuous gauge. These full-size paper gauges can then be taken to a fabricator for construction of a durable baked enamel gauge.

New Design Routines: The design routines in WinFlume are still under development at this time, but it is expected that WinFlume will use a different approach to flume design than that used by FLUME 3.0. This approach is made possible by the tremendous advances in computing speed since the development of FLUME 3.0.

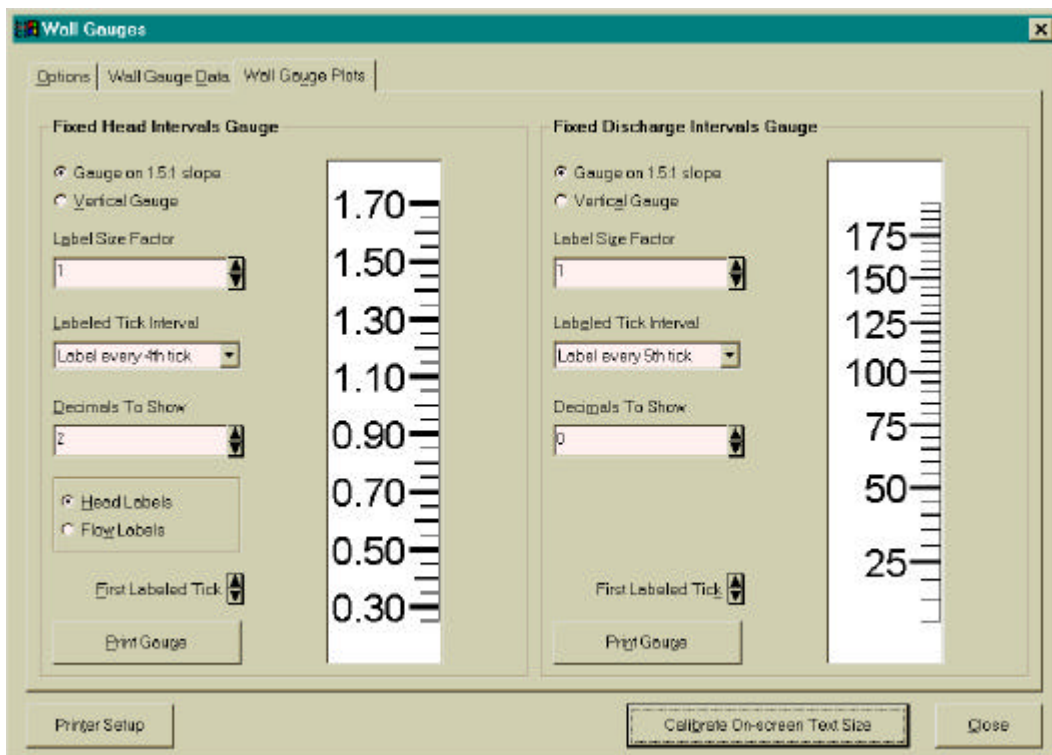


Figure 6. — On-Screen Preview of Flume Wall Gauges.

FLUME 3.0 used an iterative scheme to adjust the throat section geometry until a suitable design was found that satisfied the user-specified criteria for discharge range and measurement precision, while still meeting necessary hydraulic criteria for acceptable flume performance. Six design criteria were evaluated in the design optimization routine:

- User-specified freeboard required at maximum flow
- Minimum head necessary to satisfy user-specified flow measurement precision requirement at maximum flow, based on precision of upstream water level measurement device
- Minimum head needed to satisfy measurement precision requirement at minimum flow
- Maximum allowable tailwater level at maximum flow
- Maximum allowable tailwater level at minimum flow
- Froude number at maximum discharge < 0.5

To begin the computations the user specified a starting throat section shape and sill height, a method for adjusting the contraction, and a design objective. Four methods of contraction change and four possible design objectives were available, shown in Table 2.

Table 2. — User-Specified Design Methods and Objectives

Methods of Contraction Change	Design Objectives
<ul style="list-style-type: none"> • Raise sill height • Raise entire throat section • Raise inner section of throat (used with complex cross-sections) • Adjust lateral contraction by changing bottom width of throat section or changing diameter or focal distance of circular or parabolic sections 	<ul style="list-style-type: none"> • Minimum head loss • Maximum head loss • Intermediate head loss • Match head loss to drop in canal invert at site

The FLUME 3.0 design algorithm attempted to minimize the number of computations by determining at a given iteration both the direction and amount of contraction change needed to resolve any unsatisfied design criteria and meet the design objective. For straightforward cross-section shapes the technique was effective, but for complex throat sections having compound shapes or circular components there were some situations in which it was difficult to determine the proper direction of contraction change needed to satisfy the design criteria. In

these cases FLUME 3.0 would sometimes fail to find an acceptable design, even though one did exist.

To address these problems, WinFlume will use a more direct, brute-force method for finding an acceptable design. The user will still specify one of the four methods of contraction change listed above, and the same 6 design criteria will be evaluated. The design algorithm will begin by bracketing the range of possible designs using a subroutine that can determine the contraction required to produce a given upstream water level at maximum discharge. The maximum possible throat-section contraction will be that needed to produce a maximum upstream water level equal to the channel depth. The minimum allowable contraction will be that which produces either an upstream Froude number of 0.5 at maximum discharge, or an upstream water level that is at least as high as the downstream tailwater at maximum discharge. Once the range of contractions is determined, WinFlume will evaluate possible designs between the lower and upper contraction limits at an interval specified by the user. This interval might be chosen based on a minimum convenient dimensional increment for construction. The results of the design evaluations will be presented to the user, who may choose to accept one of the designs or discard the results of the analysis. This method will not directly produce a single design meeting a specific head loss objective. Instead, designs that have minimum head loss, maximum head loss, intermediate head loss, and head loss matching the bed drop at the site will all be listed in the output, along with the other acceptable designs. The user will be able to evaluate the different head loss characteristics of the possible designs and then choose the design that best meets their needs.

It is possible that if the contraction increment specified by the user is too large, or if design criteria are too limiting, no acceptable design will be found. If this occurs WinFlume will try to determine if an acceptable design might be found by searching with a smaller increment of contraction change. WinFlume searches for two adjacent designs for which all unsatisfied criteria in each of the designs are satisfied in the adjacent design. If such a situation can be found, then an acceptable design may exist between those two designs, and the analysis can be repeated using a smaller increment of contraction change within that range. If no region of possible acceptable designs is found, then the results of the analysis would be presented to the user, perhaps with suggestions of ways to relax the design criteria or change the initial design so that an acceptable design can be found.

Online Help: The WinFlume program will feature an integrated online help system that will provide the user with both flume-design guidance and assistance with the details of program usage. The online help system will be constructed in combination with the preparation of printed documentation for the new software.

In addition, the release version of WinFlume will include a step-by-step flume wizard that leads the user through the process of defining all critical properties of a

flume design. This will help ensure that the user does not omit crucial details, such as specification of tailwater levels and discharge ranges.

Possible Additional Features

Several additional features are being considered for future incorporation into the WinFlume program. These include:

- Support for determining proper setting of commercially available pre-fabricated flumes. These flumes can be analyzed with the program as it currently exists, but the user must manually enter the dimensions of each flume. Working with these flumes could be simplified by including a database of dimensions for available flumes.
- A more sophisticated backwater analysis module for determining tailwater levels. Presently the user can specify tailwater levels at minimum and maximum flow using either field data or the results of an independent backwater analysis, or by using the Manning equation and assuming flow is at normal depth in the downstream channel.

HOW TO OBTAIN WINFLUME

At this time the WinFlume program is in a beta-test state. The majority of the new features are in place. A demonstration version of the program is available on the World Wide Web at <http://ogee.do.usbr.gov/twahl/>. Because the program has not yet been thoroughly tested and verified, this demonstration version does not support printed output. Users are still urged to use FLUME 3.0 for production design work. If you are interested in beta-testing a fully functional version of the program, you may do so by contacting the authors of this paper.

Once the beta-test program is complete, the software will be made available to the public, in combination with updated printed documentation.

ACKNOWLEDGMENTS

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