A GUIDELINE FOR THE SELECTION AND INSTALLATION OF IRRIGATION FIELD SUPPLY CANAL FLOW MEASURING FLUMES FROM PREDESIGNED ALTERNATIVES FOR THE YUMA MESA IRRIGATION DISTRICTS

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Chapter 1. Introduction

Accurate flow measurement is essential for efficient irrigation management. In the Yuma Mesa Irrigation Districts many of the irrigation field supply canals are not fitted with accurate flow measuring structures.

Because long throated flumes are inexpensive, highly adaptable, and accurate canal flow measuring structures, they have been used in the field supply canals of the Yuma Mesa Irrigation Districts.

This document presents a simple procedure for field evaluation and selection of flow measuring flumes from predesigned alternatives. It also describes procedures for flume installation site selection and survey, flume and gage installation, and as-built calibration of flumes. In addition, an Excel worksheet designed to be used as a quick reference tool during flume field evaluation and selection is presented.

The presentation here is divided into seven chapters and six appendices. *Chapter2* presents the basic principles of flow measurement with long throated flumes and design considerations and measurement errors. In *Chapter 3* field procedure for flume installation site selection and survey is discussed. Flume selection from predesigned flumes is described in *Chapter 4*. Discussion on flume construction, field evaluation, and installation is presented in *Chapter 5*. A procedure for as-built calibration of flumes with WinFlume is presented in *Chapter 6*. *Chapter 7* describes an Excel spreadsheet designed to be a quick reference tool for flume field evaluation and selection in the Yuma Mesa Irrigation Districts. *Appendix 1* discusses a guideline for field measurement. A brief introduction to the WinFlume program is presented in *Appendix 2*. *Appendix 3* presents a procedure for measuring sill referenced upstream depth during field evaluation of flumes. *Appendices* 4, 5, and 6 present design and construction drawings for flume sill heights of 1.0ft, 1.25ft, and 1.5ft, respectively.

The objective in this document is to present the essential practical aspects of canal flow measurement with long-throated flumes with minimal technical details. Hence, the presentation of some of the materials in this document is theoretically less rigorous and sometimes approximate.

Chapter 2. Review of basic principles of flow measurement with long-throated flumes

Description

The type of flow measuring device that is to be used in the field supply canals of the Yuma Mesa is the long-throated flume. The flume considered here is a light-weight structure constructed in an off-site work shop and assembled on site. These structures measure flow by forcing water to pass through a state of flow known as critical flow, thereby allowing canal discharges to be measured accurately with inexpensive and simple device. The flume selected for use in the Yuma Mesa Irrigation Districts has four components (Figures 1a-1e): (1) The approach canal segment has a uniform cross-section over distance and is characterized by a stable and tranquil water surface, allowing accurate gaging of flow depth (hence discharge) – flow depth will be measured with a staff gage mounted directly on the canal wall. (2) The converging transition is a region of accelerated flow in which the canal cross-section tappers over distance from the approach cross-section to the throat cross-section. In contrast to structures with abrupt upstream transition, such as broad crested weirs, this feature gives these flumes the advantage of allowing the passage of sediment and suspended debris over the flume. (3) The throat section of the flume is the segment with the maximum contraction, it has a constant cross-section, and a level floor (sill). It has sufficiently small cross-section and is long enough to ensure accurate measurement of discharge over the entire range to be measured. (4) The tailwater canal section is part of the downstream canal segment and the depth-discharge relationship in the tailwater section is an important flume design input.

From the perspective of flume design the throat section is perhaps the most important part of the structure and the determination of its dimension and shape is an important element of the flume design process. The dimensions of other sections can be selected based on the relative dimensions of the throat and the approach canal section in such a way that a set of constraints, to be defined latter, are satisfied. Note that here the canal forms both the approach and tailwater sections. The contraction in the throat section of flumes can be provided by a vertical hump or a side contraction or both. However, for reasons of construction simplicity, installation convenience, and portability, the flume considered here will have vertical contraction only and no side contraction (Figure 1a, 1b, and 1d).

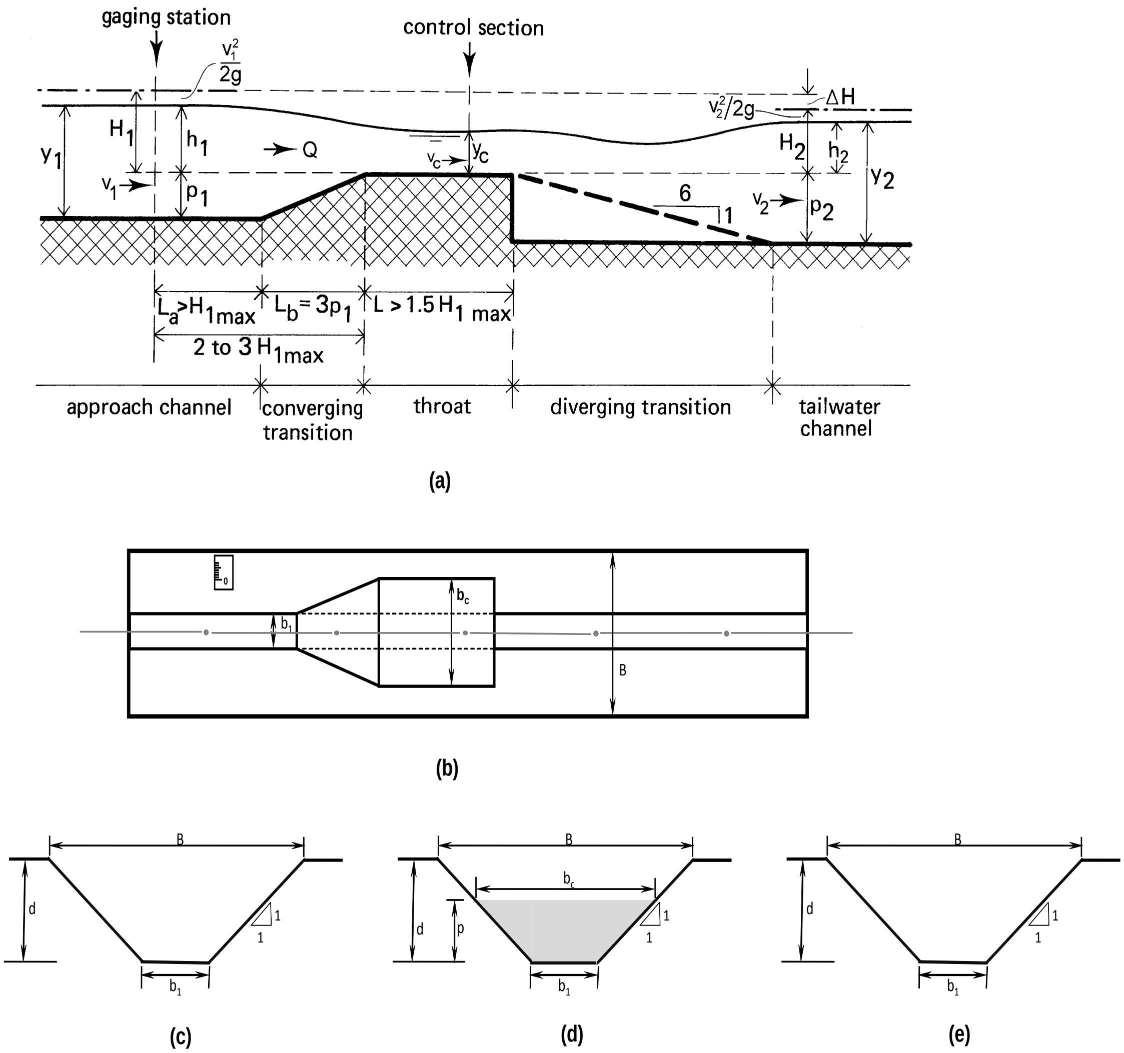


Figure 1 A sketch of long-throated flume for the Yuma-Mesa: (a) a longitudinal section along the centre line of flume, (b) Plan view, (c) Approach canal cross-section, (d) Cross-section at control section, and (e) Tailwater canal cross-section (b = canal bottom width, B = canal top width, b_c = flume crest width, and $p = p_1 = p_2$ is flume sill height)

Basic principles:

Given a discharge, canal shape and dimensions, longitudinal slope, there are two important flow depths in characterizing flow conditions in irrigation canals: (1) normal depth, h_n, and (2) critical depth, h_c. Given a canal of constant shape, dimensions and slope, as well as discharge, the normal depth is the depth that the water surface approaches over a sufficiently long distance within which the canal does not contain a structure that imposes a higher or lower depth. It is a condition in which water surface slope, the rate of energy loss due to friction per unit weight of water and the longitudinal slope of the canal are all the same (a condition in which gravity is balanced by friction). On the other hand, for a canal of constant shape, dimensions and slope, and a known discharge, its critical depth is the depth at which the energy per unit weight of water is minimum. This depth occurs if a canal is discharging freely into a drainage canal, passing over a critical flow measuring structure, or if water is flowing from a reservoir into a canal and an adjustable structure, such as a gate, does not set a lower depth than the critical depth. However, in some special cases, where the canal slope is steep enough, critical depth can occur over a finite segment of the canal not close to the type of canal boundaries described above.

The relative magnitudes of h_n and h_c depend on the combination of discharge, canal geometry, and longitudinal slope. Based on whether flow depth is greater than h_c or smaller than h_c, a flow is described as subcritical, critical, or super-critical flow. If the flow depth, h, is such that $h > h_c$, then the flow is termed as subcritical. If, on the other hand, $h = h_c$, it is called critical flow and for $h < h_c$ the flow is described as super-critical. When flow is subcritical, the discharge at any given cross-section is a function of conditions (flow disturbances – changes in discharge, depth, etc.) both upstream and downstream of it. When flow is critical or super critical these disturbances can travel only in downstream direction, hence discharge at a cross-section is a function of only upstream conditions. Irrigation canals typically have relatively flat (mild) slopes, thus $h_n > h_c$ and except in close vicinity of flow measuring and control structures flow is subcritical, i.e., $h > h_c$. Under such flow conditions, if a structure is introduced into a canal such that the state of flow transitions from subcritical to super-critical as it passes over the structure, it then follows that the flow upstream of the critical section (section at which critical depth occurs) is, hydraulically speaking, separated from the flow downstream of it. Hence, the canal discharge is uniquely related to flow conditions upstream of the critical section. Flow measuring devices that are based on this hydraulic principle are known as critical flow measuring devices, which include a wide variety of flumes and weirs commonly used for measuring discharge in irrigation canals.

These structures operate by introducing a contraction into the canal cross-section thereby forcing the water to accelerate and pass through the critical state of flow. Hence, canal discharge can be expressed as a function of sill referenced upstream depth, h_1, only (Figure 1a).

$$Q = C_d h_1^u \qquad (1)$$

where Q = constant canal discharge (*cfs*), h_1 = upstream depth measured from the flume sill (*ft*), C_d = discharge coefficient (ft^{3-u}/s) and u = empirical constants *(-)*.

There are different ways of measuring h_1, the most commonly used approach for small irrigation canals being staff gauges mounted on canal side walls. Values of the discharge coefficient (C_d) and the exponent (u) in Eq. 1 can be determined through curve fitting based on measured Q and h_1 data or in case of long-throated flumes, given the range of h_1 the corresponding Q values can be computed with a mathematical model derived based on hydraulic theory. Equation 1 is commonly known as the rating curve of the flow measuring structure, in this case a flume, and the process of determining the constants in Eq. 1 is known as calibration of the structure.

Equation 1 assumes that flow conditions downstream from the flume do not have an effect on flow conditions upstream. This condition will be satisfied if there is sufficient flow depth differential over the flume - between the gauging station in the approach canal and the tailwater section (Figure 1a). Otherwise, the flume will become submerged (discharge is a function of both upstream and downstream sill-referenced depths – h_1 and h_2) and Q computed with Eq. 1 becomes inaccurate. The ratio h_2/h_1 can be used as an approximate indicator of the effect of downstream flow depth on conditions upstream of the flume. The ratio h_2/h_1 can be referred to as approximate submergence ratio. When this ratio exceeds a threshold (approximate modular limit), which can be as high as 90% for long-throated flumes, then Eq. 1 may no longer be considered accurate. This implies that for proper functioning of a flume the approximate submergence ratio should not exceed the approximate modular limit. For a flume to be accurate it should be operated under modular flow conditions (approximately $h_2/h_1 < 0.9$) over the discharge range to be measured.

Given a canal and the range of flow rate to be measured, in general modular limit requirements of a flume can be met by increasing flume sill height, p, (Figures 1a and 1d). However, as the flume sill height increases the water surface elevation in the approach canal will also increase. Increasing p eventually leads to a condition in which the freeboard could become smaller than the minimum freeboard required to prevent canal overtopping. In addition, if the flume is sufficiently close to the main canal turnout, too high a flume sill may lead to a condition in which water backs up to the main canal turnout and to a reduction in the flow rate into the canal. The flume sill should have sufficient height: (1) to ensure modular flow over the range of flow rate to be measured and (2) to form a stable and tranquil water surface in the approach canal for accurate gage reading. On the other hand, the flume sill height should be low enough: (1) to satisfy freeboard requirements at maximum discharge and (2) to prevent upstream inundation from reaching canal inlet. For the type of control section shape considered here (a flume with a raised sill only and no contraction, hence trapezoidal cross-section), given a range of canal discharge to be measured by a flume and the depth measuring method, measurement accuracy is inversely related to sill height.

The design of new flumes or the selection of flumes from predesigned alternatives is an exercise in defining the shape and size of the flume throat section that best balances these conflicting requirements. The dimensions of other components of the flume can be proportioned in line with standard guidelines to be briefly outlined subsequently (see also Figure 1a). In addition to the factors listed above the range of sill-referenced upstream depth to be measured, the maximum depth relative to flume sill length, and flume sill width relative to its length are important factors in determining the accuracy of flow measurement. Noting that the flumes considered here will have only vertical contractions and that a typical cross-section of a field supply canal in the Yuma Mesa is trapezoidal, the shape of the throat section of the flumes will also be trapezoidal. Consequently, important design variables in selecting the flume control section are the height of the flume sill and its length.

Design considerations and measurement error

To ensure modular flow over the entire range of canal discharge variation, it is sufficient, for practical purposes, to evaluate the approximate submergence ratio, h_2/h_1, at the maximum and minimum discharges. Freeboard requirements, occurrence/absence of excessive upstream inundation, and the requirement to have a stable tranquil flow in the approach canal are to be checked at maximum canal discharges. Accuracy (which depends on depth measurement method, shape of control section, and range of depth measured) requirements need to be checked at maximum and minimum discharges.

In addition to the design criteria described in the preceding paragraph, there are requirements that the dimensions of the flume components need to meet so as to ensure calibration accuracy. The approach canal length (the distance between the upstream end of the converging section and the gaging station) should be at least approximately equal to the sill referenced upstream depth, h_{1max} (where h_{1max} = sill referenced upstream depth at the minimum discharge), Figure 1a. The sum of the approach canal length and the length of the converging section should be between $2h_{1max}$ and $3h_{1max}$. The length of the flume crest, L, should be between $14.3h_{1min}$ (where h_{1min} = sill referenced upstream depth at the minimum discharge) and $1.43h_{1max}$. As mentioned above the flumes considered here have only vertical contraction, defined in terms of flume sill height, p (Figures 1a, 1b, and 1d). Given p, the length of the upstream ramp can be calculated such that it is slope (horizontal:vertical) is in the range of 2.5 to 4.5, preferably 3.0. Ideally the throat section has uniform cross-section and level sill. However, because of the slope in the canal, the flume sill will have a longitudinal slope about the same as the canal bottom. In the Yuma Mesa Irrigation Districts, typical bed slope is 0.00025, which is nearly flat, hence flume crest can be considered level. For any given field, specific bottom slopes need to be determined and flume sill longitudinal slopes exceeding 2-3 degrees need to be avoided to minimize measurement errors. Pertinent dimensional constraints are shown in Figure 1a.

There are uncertainties in measured canal discharges, the sources of error are: (1) rating curve uncertainty (with ±2%), (2) gage reading error (up to 15mm or 0.0492ft for wall mounted direct read-out gages), and (3) imprecision in flume construction and installation. In general for a given condition, larger depths can be measured with higher accuracy than smaller depths. Rating curve is generated based on design specifications. However, the flume may have construction imprecision, less than ideal installations, and may undergo minor deformations. Hence, post-construction (as-built) calibration is needed to improve accuracy. These points will be discussed in subsequent sections.

Chapter 3. Field procedure for flume installation site selection and survey

Although the predesigned flumes are for a standard field supply canal size (2ft bottom, 1:1 side slope, and 3ft depth), common in the Yuma Mesa irrigation districts; field measurements may be needed to confirm that canal dimensions are either not altered due to soil settlement or are in fact of the standard size, thus the predesigned flumes are applicable to them. The following is an outline of the field procedure for flume installation site selection and survey, which is to be performed prior to flume construction.

Select a flume installation site:

(i) For a distance of at least 10 times the average canal width (sum of canal top width and bottom width divided by two) upstream of the potential flume installation site, the canal:

- Should be straight,
- Should have a uniform cross-section, and
- Should not contain a structure or any source of turbulence

(ii) Should not be too close to the upstream off-take structure to cause water to backup to the point of reducing flow into the canal.

(iii) If canal depth is variable, it should be placed in a cross-section where there could be adequate freeboard provided the site satisfies the other requirements.

(iv) If there is a drop in the canal bottom and if the location of the drop satisfies above listed requirements, then it could present some advantage (less susceptible to submergence) as potential flume installation site.

(v) Canal bottom is stable – typically canals in the Yuma Mesa are lined, hence this is not an issue here.

Flume installation site survey: The following need to be determined for the flume installation site: *(1)* canal shape and dimensions, *(2)* hydraulic characteristics (Manning's roughness coefficient, hydraulic gradient, hydraulic drops, boundary conditions), *(3)* the range of flow rate to be measured, and *(4)* the method for characterizing head-discharge relationships in the tailwater canal and the field measurement of pertinent *Q-h* data. A form for recording information on flume installation site survey is shown in Table 1.1. Table 1.1 summarizes the design input data for the test canal in the UA Yuma Mesa research farm obtained with a flume installation site selection and survey procedure outlined below:

(i) Flume installation site survey data is to be summarized in Table 1.1.

(ii) Measure canal dimensions (in the Yuma Mesa irrigation districts a typical canal has trapezoidal shape and is concrete lined) :

- Canal bottom width (b_1) in *ft* or *in*
- Canal top width (B) in *ft* or *in*

- Canal depth (*d*) in *ft* or *in*
- Drop in canal bottom at site, Δp, in *ft* or i*n*, if there is one.

A guideline on field measurement of these quantities is presented in *Appendix 1*. Note that in relatively new canals these may be obtained form design documents. In relatively older canals soil settlement and other factors may have changed the dimensions. In any case, field measurements can be used to establish current dimensions.

(iii) Conduct a profile survey of the canal bottom over a distance of $100b_1$ *(see Appendix 1).* Since typical irrigation field supply canals in the Yuma Mesa have a constant slope, two elevation measurements along the center line of the canal and the horizontal distance between those two points is sufficient to calculate canal bottom slope.

(iv) Determine maximum and minimum flow rates (Q_{max} and Q_{min}):

- If the canal is relatively new, Q_{max} and Q_{min} can be obtained from design documents.
- In well maintained, but relatively older canals, where hydraulic parameters assumed at design are no longer valid, the following steps can be used to verify discharge range:
  - Consult with growers/irrigators about gate (off-take from main canal) settings for maximum and minimum flows.
  - Obtain irrigators'/growers' estimates of corresponding maximum and minimum discharges.
  - Set gate for maximum and minimum flows (as described by irrigator) and measure discharges, Q_{max} and Q_{min}, using indirect flow measuring devices (see *Appendix* 1 for further discussion).

(v) Determine tailwater characteristic – measure a single canal discharge and flow depth pair.

a. Set gate at the turnout from main canal at a regular operating height
b. Wait until the canal fills
c. Open gate in one of the irrigation basins (it is assumed here that only one basins is irrigated at a time under normal operating conditions)
d. Measure discharge using the velocity area method (see *Appendix 1*).

e. Measure flow depth sometime after one of the sluice gates (basin inlet) are opened at a far enough distance from the basin inlet to minimize the effect of the drawdown on measured flow depth.

The above assumes that flow measurement may not be performed when all gates (basin inlets) are closed and that a calibrated indirect flow measuring device is available for discharge measurement. To ensure that these devices are not out of calibration, they need to be checked regularly and if necessary be recalibrated. Note that regular checking and recalibration of these devices may require assistance from manufacturers and additional service fee. Follow manufacturer's recommendations in measuring flow rate with indirect flow measurement devices. Some additional points are outlined in *Appendix 1*.

(vi) Considering a rough canal (i.e., not a new smooth concrete surface) as a typical field supply canal in the Yuma Mesa Irrigation Districts, a Manning *n* of 0.014 can be used. Given the geometry of the canal, the hydraulic gradient (friction slope), S_f , can then be calculated with the Manning equation (Table 1.1).

Chapter 4. Flume selection from predesigned alternatives

The predesigned flumes are for a standard canal geometry (shape and size) and hydraulic characteristics typical of the irrigation field supply canals in the Yuma Mesa irrigation districts. The following is a description of the standard canal dimensions considered in this study, canal discharge ranges, and field evaluation and selection of the flumes.

Canal dimensions and discharge ranges:

Table 1 and 1.1 summarize the data and design constraints used in the development of the predesigned alternative flumes for the Yuma Mesa Irrigation Districts. The standard field supply canal geometry commonly used in the Yuma Mesa irrigation districts is a trapezoidal cross-section with bed width of 2.0ft, a side slope of 1:1, and a canal depth of 3.0ft (Table 1). The flow rate supplied to individual farms is generally constant, but varies from farm to farm, approximately in the range *7.0cfs* to *25.0cfs* (Table 1). The canal discharge and the corresponding depth used in the characterization of tailwater for the purpose of flume design are *16cfs* and *19in*. This discharge is about the average value used in the Yuma Mesa Irrigation

Districts. The sensitivity of the designs were tested against larger tailwater conditions and the designs were found to be robust. Field measurement and flume installation site selection procedure is described in *Chapter 3*, *Chapter 5*, and *Appendices 1-3*.

Flume selections:

Based on standard canal dimensions, typical discharge range, measured canal depth-discharge data in the University of Arizona (UA) Yuma Mesa research farm, and design criteria summarized in Table 1, three alternative flume designs with sill heights of 1.0ft, 1.25ft, and 1.5ft were selected for use in the Yuma Mesa irrigation districts. WinFlume (see *Appendix 2*) is used to evaluate the alternative flumes for meeting the design and dimensional requirements described in *Chapter 2* and summarized in Table 1. In addition, field evaluation of the flumes were conducted at the Maricopa and Yuma Mesa research farms of the UA. A summary of the dimensions, discharge ranges, and rating equations and tables of the selected alternative flume designs are presented in Tables 2, 3, 4, 5, and 6. Note that design dimensions of flumes were revised taking into account dimensions of available standard construction material sizes.

Structural grade plastic-lumber is used as a construction material – it is light hence highly portable and also strong and inexpensive. Figures 4.1 and 4.2, in *Appendix 4*, show the longitudinal section and cross-section as well as the construction drawings for a flume with sill height of 1.0ft. Figures 5.1 and 5.2 (*Appendix 5*) depict the longitudinal section, cross-sections, and design drawings for flume sill height of 1.25ft. The longitudinal section, cross-sections, and design drawings for a flume sill height of 1.5ft are presented in Figures 6.1 and 6.2 (*Appendix 6*).

In theory, any of the three flumes can be used to measure discharge accurately in a typical irrigation field supply canal (standard canal size and a discharge in the range 7*cfs* to 25*cfs* in a well maintained canal with longitudinal slope of 0.00025) in the Yuma Mesa irrigations districts. However, selection of the most appropriate flume from the alternatives for use in any given canal requires field evaluation under actual hydraulic conditions. Considering standard canal geometry and the same hydraulic characteristics as the UA farm, a comparison of the performance of the three flume sill heights for three discharge ranges obtained with WinFlume is summarized in Table 7. As shown in Table 7, the three discharge ranges are 7-12*cfs*, 12-18*cfs*, and 18-25*cfs*, representing subintervals of the range of discharge in a typical irrigation field supply canal in the Yuma Mesa irrigation districts (7.0cfs-25.0cfs). The results show that submergence could be an issue to monitor in the field when a flume sill height of 1.0ft is evaluated in the highest discharge range. When evaluating a flume with a sill height of 1.5ft in the discharge range of 18-25cfs, canal over topping need to be a concern. The midsized flume (flume sill height of 1.25ft) provides acceptable performance over three discharge ranges. However, canals may have different tailwater characteristics due to differences in canal age (which affects the roughness characteristics of the canal), changes in canal cross-section (for instance because of sediment accumulation or settlement), differences in canal bed slope, and boundary conditions. Thus, as hydraulic conditions may vary from canal to canal, these results are to be used only as a rough guide to assist in actual field evaluation of the flumes.

Table 1 Design input for the UA research farm

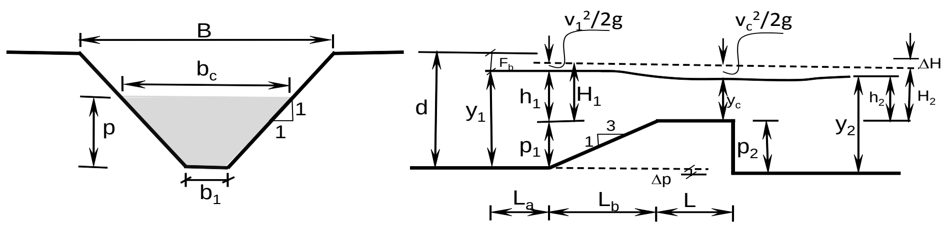
Design input	Unit	Value
Canal bed width, b_1,	*ft*	2.0
Side slope, z,	-	1.0
Canal depth, d,	*ft*	3.0
Depth for tailwater characterization, Y[1],	*ft*	1.58
Canal discharge for tailwater characterization, Q[1],	*cfs*	16.0
Q_{min}	*cfs*	7.0
Q_{max}	*cfs*	25.0
Maximum Froude number at Q_{max}[2]	-	0.5
Discharge measurement error at Q_{max}	%	8.0
Discharge measurement error at Q_{min}	%	15.0
Minimum freeboard requirement[2]	-	$0.2h_{1max}$
Roughness height for plastic-lumber	*ft*	In WinFlume, the hydraulic roughness characteristics of plastic-lumber is approximated by concrete-smooth, custom
Head measurement error (considering head measurement method -- staff gage without a stilling well with Fr < 0.5[2])	*ft*	0.0492

[1]The tailwater specification option used is single flow depth-discharge data based on Manning equation. All flumes considered here have a raised sill, with no side contractions, thus noting that the field supply canals are trapezoidal, the throat sections of the flumes considered here are also trapezoidal. [2]Corresponding values are based on recommendations by Clemmens et al. (2001).

Table 2 Flumes for lined trapezoidal irrigation field supply canals in the Yuma Mesa Irrigation Districts, predesigned alternatives[a]

Canal dimensions			Range of canal capacities		Flume shape		Minimum headloss ΔH (ft)
Side slope, Z	Bottom width, b_1 (ft)	Maximum canal depth[b], (ft)	Lower[c] Q_{min} (ft³/s)	Upper Q_{max} (ft³/s)	Crest width b_c (ft)	Sill height p (ft)	
1	2.0	3.0	6.2	40	4.0	1.00	0.12
			6.8	33	4.5	1.25	0.14
			7.4	27	5.0	1.50	0.15

Notes: [a] $L_a \geq \Delta H_{1max}$; $L_b = 3p_1$; $L_a + L_b > 2$ to $3H_{1max}$, $L > 1{:}5H_{1max}$, $d > 1{:}2\ h_{1max} + p_1$, $\Delta H > 0.1H_1$.
[b] Maximum recommended canal depth, [c] Limited by sensitivity.



B = Canal top width, b_1 = canal bottom width, d = canal depth, b_c = flume crest width, p_1 = flume sill height upstream end, p_2 = flume sill height downstream end, p = for the portable flumes considered in this study $p_1 = p_2 = p$ = flume sill height, y_1 = flow depth in approach canal, y_2 = flow depth in tailwater canal, F_b = freeboard in approach canal (gaging station), ΔH = headloss over the flume, Δp = hydraulic drop, L_a = length of approach channel, L_b = length of converging transition, and L = length of the flume throat section.

Table 3 Rating equations based on construction dimensions of the selected designs (See Table 2)

Flume type, dimensions and location of gaging station					*Range of Q[a] (ft)*	Calibration equation, $Q = K_1(h_1 + K_2)^u$		
Flume type	b_c *(ft)*	L_a *(ft)*	L_b *(ft)*	L *(ft)*		K_1 *(ft$^{(3-u)}$/s)*	K_2 *(ft)*	u *(-)*
E_e	4.0	3.0	3.00	2.666	$6.2 \leq Q \leq 40$	14.65	0.04359	1.830
F_e	4.5	3.0	3.54	2.33	$6.8 \leq Q \leq 33$	16.19	0.03624	1.781
G_e	5.0	3.0	3.71	2.0	$7.4 \leq Q \leq 27$	17.74	0.03003	1.741

[a]Discharge ranges are those indicated in Table 2. Upper limits of the discharge ranges pertinent to Yuma Mesa Irrigation Districts are given in the rating tables (Tables 4-6)

Table 4 Rating table and equation, flume sill height of 1.0ft - constructed dimensions

h1 Sill Referenced Head at Gage feet	Q Theoretical Discharge cu. ft/s	Q_fit Curve Fit Equation Discharge cu. ft/s	D=Q_fit-Q Difference cu. ft/s	(D/Q)*100% Difference %	Warnings
0.188	1.00	1.01	+0.011	+1.08	
0.291	2.00	1.98	-0.023	-1.13	
0.374	3.00	2.97	-0.033	-1.09	
0.446	4.00	3.97	-0.030	-0.75	
0.511	5.00	4.98	-0.020	-0.41	
0.570	6.00	5.99	-0.007	-0.11	
0.625	7.00	7.01	+0.008	+0.12	
0.676	8.00	8.02	+0.023	+0.29	
0.724	9.00	9.04	+0.038	+0.43	
0.770	10.00	10.05	+0.051	+0.51	
0.814	11.00	11.06	+0.061	+0.56	
0.856	12.00	12.07	+0.069	+0.58	
0.896	13.00	13.07	+0.075	+0.58	
0.935	14.00	14.08	+0.078	+0.55	
0.972	15.00	15.08	+0.077	+0.52	
1.008	16.00	16.07	+0.074	+0.46	
1.043	17.00	17.07	+0.068	+0.40	
1.077	18.00	18.06	+0.058	+0.32	
1.111	19.00	19.05	+0.048	+0.25	
1.143	20.00	20.03	+0.032	+0.16	
1.174	21.00	21.01	+0.014	+0.06	
1.205	22.00	21.99	-0.008	-0.04	
1.235	23.00	22.97	-0.033	-0.15	
1.264	24.00	23.94	-0.056	-0.23	
1.293	25.00	24.91	-0.086	-0.35	
1.321	26.00	25.88	-0.120	-0.46	
1.349	27.00	26.84	-0.156	-0.58	
1.376	28.00	27.80	-0.196	-0.70	
1.402	29.00	28.76	-0.238	-0.82	

Equation: Q_fit = K1 * (h1 + K2) ^ u
Parameters: K1 = 14.65, K2 = 0.04359, and u = 1.830, Coefficient of determination: 0.99995540

Theoretical discharge (Q) is determined by the WinFlume model, using hydraulic theory and empirical relationships determined from laboratory testing. It is the most accurate estimate of discharge. Curve fit discharge (Q_fit) is computed with the equation above, which was fitted to the theoretical discharge values. The 'difference' columns show the difference between the flow rates computed from the simplified equation and those obtained from the theoretical WinFlume model.

Summary of Warning Messages

No warnings.

Table 5 Rating table and equation, flume sill height of 1.25ft – construction dimensions

h1 Sill Referenced Head at Gage feet	Q Theoretical Discharge cu. ft/s	Q_fit Curve Fit Equation Discharge cu. ft/s	D=Q_fit-Q Difference cu. ft/s	(D/Q)*100% Difference %	Warnings
0.174	1.00	1.01	+0.010	+0.99	
0.271	2.00	1.98	-0.022	-1.08	
0.350	3.00	2.97	-0.032	-1.06	
0.418	4.00	3.97	-0.029	-0.74	
0.480	5.00	4.98	-0.020	-0.40	
0.536	6.00	5.99	-0.007	-0.11	
0.589	7.00	7.01	+0.008	+0.11	
0.638	8.00	8.02	+0.024	+0.30	
0.685	9.00	9.04	+0.038	+0.43	
0.729	10.00	10.05	+0.051	+0.51	
0.771	11.00	11.06	+0.062	+0.56	
0.812	12.00	12.07	+0.070	+0.58	
0.851	13.00	13.08	+0.076	+0.58	
0.888	14.00	14.08	+0.079	+0.56	
0.925	15.00	15.08	+0.079	+0.53	
0.960	16.00	16.08	+0.076	+0.47	
0.994	17.00	17.07	+0.072	+0.42	
1.027	18.00	18.06	+0.062	+0.35	
1.060	19.00	19.05	+0.050	+0.26	
1.091	20.00	20.03	+0.034	+0.17	
1.122	21.00	21.02	+0.015	+0.07	
1.152	22.00	21.99	-0.007	-0.03	
1.181	23.00	22.97	-0.032	-0.14	
1.210	24.00	23.94	-0.060	-0.25	
1.238	25.00	24.91	-0.092	-0.37	
1.265	26.00	25.87	-0.126	-0.48	
1.292	27.00	26.84	-0.164	-0.61	
1.318	28.00	27.80	-0.204	-0.73	
1.344	29.00	28.75	-0.248	-0.85	

Equation: Q_fit = K1 * (h1 + K2) ^ u
Parameters: K1 = 16.19, K2 = 0.03624, and u = 1.781, Coefficient of determination: 0.99995601

Theoretical discharge (Q) is determined by the WinFlume model, using hydraulic theory and empirical relationships determined from laboratory testing. It is the most accurate estimate of discharge. Curve fit discharge (Q_fit) is computed with the equation above, which was fitted to the theoretical discharge values. The 'difference' columns show the difference between the flow rates computed from the simplified equation and those obtained from the theoretical WinFlume model.

Summary of Warning Messages

No warnings.

Table 6 Rating table and equation, flume sill height of 1.5ft – construction dimensions

h1 Sill Referenced Head at Gage feet	Q Theoretical Discharge cu. ft/s	Q_fit Curve Fit Equation Discharge cu. ft/s	D=Q_fit-Q Difference cu. ft/s	(D/Q)*100% Difference %	Warnings
0.163	1.00	1.01	+0.011	+1.15	10
0.254	2.00	1.98	-0.023	-1.13	10
0.328	3.00	2.97	-0.032	-1.08	10
0.393	4.00	3.97	-0.030	-0.76	10
0.452	5.00	4.98	-0.022	-0.43	10
0.506	6.00	5.99	-0.009	-0.15	10
0.556	7.00	7.01	+0.006	+0.09	10
0.604	8.00	8.02	+0.021	+0.26	10
0.649	9.00	9.04	+0.035	+0.39	10
0.691	10.00	10.05	+0.048	+0.48	10
0.732	11.00	11.06	+0.059	+0.53	10
0.771	12.00	12.07	+0.067	+0.56	10
0.809	13.00	13.07	+0.073	+0.56	10
0.846	14.00	14.08	+0.077	+0.55	10
0.881	15.00	15.08	+0.079	+0.53	10
0.915	16.00	16.08	+0.076	+0.48	10
0.948	17.00	17.07	+0.071	+0.42	10
0.980	18.00	18.06	+0.062	+0.35	10
1.012	19.00	19.05	+0.051	+0.27	10
1.042	20.00	20.04	+0.036	+0.18	10
1.072	21.00	21.02	+0.018	+0.08	10
1.101	22.00	22.00	-0.003	-0.02	10
1.130	23.00	22.97	-0.028	-0.12	10
1.158	24.00	23.94	-0.055	-0.23	10
1.185	25.00	24.91	-0.086	-0.34	10
1.212	26.00	25.88	-0.119	-0.46	10
1.238	27.00	26.84	-0.156	-0.58	10
1.264	28.00	27.80	-0.196	-0.70	10
1.290	29.00	28.76	-0.238	-0.82	10

Equation: Q_fit = K1 * (h1 + K2) ^ u;
Parameters: K1 = 17.74, K2 = 0.03003, and u = 1.741, Coefficient of determination: 0.99995497

Theoretical discharge (Q) is determined by the WinFlume model, using hydraulic theory and empirical relationships determined from laboratory testing. It is the most accurate estimate of discharge. Curve fit discharge (Q_fit) is computed with the equation above, which was fitted to the theoretical discharge values. The 'difference' columns show the difference between the flow rates computed from the simplified equation and those obtained from the theoretical WinFlume model.

Summary of Warning Messages

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10 - Converging section is too short (ramp is too steep). Considering standard dimensions of available construction material, flume ramp length is set to 48in, this results in a ramp slope of about 2.47:1. Modeling with WinFlume and field evaluation showed that discharge measurement error because of the steeper ramp is negligible.

Table 7 Comparison of the three selected flume designs for three different discharge ranges

Flume sill height 1.0ft				
	Unit	*Ranges of Q*		
		7- 12 cfs	*12-18cfs*	*18-25cfs*
Fr (Q_{max})	-	0.264	0.319	0.366
Freeboard (Q_{max})*/minimum*	*ft*	1.144/0.171	0.923/0.215	0.707/0.259
Submergence protection at Q_{max}	*ft*	0.373	0.269	0.176
Submergence protection at Q_{min}	*ft*	0.495	0.373	0.269
Sill referenced upstream depth at Q_{max}*/ minimum for accuracy/error*	*ft/ft/%*	0.856/1.035/9.59*	1.077/1.055/7.85	1.293/1.074/6.73
Sill referenced upstream depth at Q_{min}*/ minimum for accuracy/error*	*ft/ft/%*	0.625/0.529/12.74	0.856/0.541/9.59	1.077/0.551/7.85
Flume sill height 1.25ft				
	Unit	*Ranges of Q*		
		7- 12 cfs	*12-18cfs*	*18-25cfs*
Fr (Q_{max})	-	*0.216*	*0.267*	*0.312*
Freeboard (Q_{max})*/minimum*	*ft*	*0.939/0.162*	*0.723/0.205*	*0.514/0.247*
Submergence protection at Q_{max}	*ft*	*0.571*	*0.459*	*0.359*
Submergence protection at Q_{min}	*ft*	*0.704*	*0.571*	*0.458*
Sill referenced upstream depth at Q_{max}*/ minimum for accuracy/error*	*ft/ft/%*	*0.812/ 1.022/ 9.97**	*1.027/1.040/8.09**	*1.236/1.057/6.91*
Sill referenced upstream depth at Q_{min}*/ minimum for accuracy/error*	*ft/ft/%*	0.589/ 0.524/ 13.37	0.812/0.534/9.97	1.026/0.543/8.1
Flume sill height 1.5ft				
	Unit	*Ranges of Q*		
		7- 12 cfs	*12-18cfs*	*18-25cfs*
Fr (Q_{max})	-	*0.179*	*0.226*	*0.268*
Freeboard (Q_{max})*/minimum*	*ft*	0.729/0.154	0.520/0.196	0.315/0.237
Submergence protection at Q_{max}	*ft*	0.772	0.651	0.545
Submergence protection at Q_{min}	*ft*	0.916	0.772	0.651
Sill referenced upstream depth at Q_{max}*/ minimum for accuracy/error*	*ft/ft/%*	0.771/1.012/10.37*	0.980/1.028/8.37*	1.185/1.043/7.10
Sill referenced upstream depth at Q_{min}*/ minimum for accuracy/error*	*ft/ft/%*	0.556/0.520/14.03	0.771/0.529/10.37	0.980/0.537/8.37

* = error exceeds the expected discharge measurement uncertainty at Q_{max}, which is 8.0%

Chapter 5. Flume construction, field evaluation, and installation

Flume construction: The construction dimensions and the corresponding rating equations for the three alternative flumes are presented in Table 3. It is assumed here that the canal reach in which the flume is to be installed makes up both the approach and tailwater canal sections. The flume will have only vertical contraction, *p*, where b_c is the corresponding crest width (Figures 1a, 1b, and 1d). The flume sill height and converging transitions are to be constructed in accord with construction specifications given in Figures 4.1 and 4.2 *(Appendix 4)* for flume sill height of 1.0ft; Figures 5.1 and 5.2 *(Appendix 5)* for flume sill height of 1.25ft; and Figures 6.1 and 6.2 for the 1.5ft sill height *(Appendix 6)*.

As can be seen from Figures 4.1, 4.2, 5.1, 5.2, 6.1, and 6.2, the crest section needs to have a 1:1 slope along its edges that fit into the canal side walls. The converging section of the flume needs to be beveled at a 1:3 (horizontal:vertical) slope along its edge at the joint with the flume sill. Along the edges that fits into the canal wall the converging section needs to have a 1.05:1 slope. This is based on the assumption that the upstream ramp has 3:1 (horizontal:vertical) slope, hence steeper/flatter slopes may require slight changes. However, in practice the error in using this value is negligible.

Construction tolerance for long-throated flumes and associated discharge measurement errors were discussed in the preceding section. In general, measured discharge is most sensitive to errors in constructed flume crest. Construction imprecision in flume sill height, *p*, and length, *L*, are generally less critical. However, in a trapezoidal canal with a flume that has vertical contraction only, b_c is a function of *p* as well, hence significant error in constructed flume sill height can have a significant effect on discharge measurement accuracy.

The flume will be pre-cast to construction specifications from plastic lumber in an off-site workshop in two parts – the upstream ramp and the throat section. The sections will then be transported to the installation site and assembled. The structure needs to be sufficiently sturdy so as to minimize deformation during installation or subsequent operation, hence both flume crest and upstream ramp are reinforced by 2”×4” and 2”×6” beams (Figures 4.1 and 4.2, 5.1 and 5.2, and 6.1 and 6.2). The joint between the upstream ramp and the crest of the flume sill needs to be smooth and perhaps beveled to prevent flow separation. The ramp may need to have a hole near the canal bottom to allow water to drain freely once the tailwater canal section is drained, so as to prevent water stagnation upstream of the flume. In addition, since plastic lumber is light, clips riveted or screwed to the canal wall are to be used to secure it in place, especially during the canal filling phases in which the backwater may lift the flume sill and ramp.

Installation of flumes: The following is an outline of a field procedure for installation of flumes:

(1) First place the upstream ramp in a dry canal such that it fits tightly into the canal;

(2) Place the flume crest in a dry canal and make sure that it fits tightly into the canal and check if crest is level using a spirit level;

(3) If flume is to be installed permanently (i.e., not for evaluation purpose), after the ramp and sill are fitted tightly into the canal, they should be firmly secured using clips riveted or screwed into the canal walls.

Design and installation of staff gage: The predesigned flumes are to be used along with a direct read-out gage mounted on the sides of the canal and labeled directly with discharge (in place of the sill referenced upstream depth) to measure canal discharges. The staff gage can be made from different materials: steel, aluminum, baked enamel. WinFlume can be used to design the wall gage taking into account the side slope of the canal on which the gage is to be placed. For details see discussion on *Appendix 2*.

Accurate zero-setting of the staff gage is necessary to minimize systematic error. The following procedure can be used for installing the gaging station:

1 Determine the location of the gaging station in accord with specifications in Figure 1a.

2 Using surveyor's level take a back sight on a selected benchmark. The benchmark can be any relatively permanent feature around the site of installation of the structure and its elevation can be assumed or measured. By adding the back sight to the elevation of the benchmark, the elevation of the line of sight is calculated.

3 Take a foresight at the sill crest to determine the elevation of the sill crest.

4 Determine the most common discharge, Q, to be measured by the flume and read the corresponding h_1 value from the appropriate rating table.

5 Subtract h_1 from the foresight reading taken at the sill crest to find the reading on the leveling staff if it were to be placed on the mark for h_1, or corresponding Q, value on the scale.

6 Place the gage on the sidewall at the correct location (Figure 1a).

7 Place the leveling staff on the side wall next to the gage and slide it slowly up and down the wall until the reading in the leveling staff equals the difference between the foresight taken at the sill crest and h_1.

8 Slide the gage such that the mark for the most common discharge is aligned with the leveling staff.

9 Mark the gage holes or slots and the gage top and bottom on the side wall. Drill the holes, secure the anchors, and tentatively attach the gage to the canal wall. Check the rod reading on the gage and if necessary adjust the gage to correct location and fasten securely.

Field procedure for flume evaluation: In general the field evaluation of the three flumes presented above is conducted in the following steps:

(1) Install flume in accord with procedure outlined above,

(2) Take a typical discharge used under normal operating conditions and add to it ±20% to 30% variations as estimates of the possible ranges of variation of flow (note that discharge in a given irrigation field supply canal in the Yuma Mesa is constant, hence this range is meant to take into account normal variations about the typical discharge due to, for instance, flow fluctuations in the main canal),

(3) Adjust gate for maximum and minimum discharges and in each case, measure upstream and downstream sill-referenced depth and check the following:

- Flow should be modular over the range of discharge variation. Hence, the ratio of h_2/h_1 must be less than 0.9 for both the maximum and the minimum discharges (where h_1 = sill referenced upstream depth and h_2 = sill referenced downstream depth);
- Freeboard at the maximum discharge should be at least $0.2h_1$;
- A stable water surface should be formed at the gaging station at the maximum discharge;
- Discharge measurement errors should be less than 8% at maximum discharge and below 15% at the minimum discharge. Compare discharges measured by different flumes as a way of checking accuracy of flume measurements. However, it is also possible to check flume measurement accuracy by comparing flume discharge measurements with discharge measured using other methods – such as the velocity

area method. Note that this is just a check as the accuracy of these devices is not the same. A brief discussion on velocity-area method is presented in *Appendix 1*.

(4) Among the flumes that provide stable water surface at the gaging station, acceptable accuracy, and sufficient freeboard at the maximum flow, select the flume with maximum approximate submergence protection (h_1-h_2) at the maximum and minimum flows.

Chapter 6. As-built calibration

Due to imprecision in the construction and installation of flumes the actual flume dimensions may be slightly different from design specifications. Hence, new rating tables may need to be developed based on as-built dimensions of the flume. Two approaches can be used to perform as-built calibration of flumes: (1) to measure discharge using a velocity area method along with sill-referenced upstream depth and use the array of depth discharge data as an input to WinFlume to generate a rating curve and (2) to measure as-built dimensions of the flume and use that as an input to generate a rating curve.

The following steps can be used in as-built calibration of flumes with WinFlume:

(1) Start the WinFlume program

(2) Open an existing flume file

Specify data on tailwater characteristics (flow depth and corresponding canal discharge) using the menu command *Design* and the submenu option *Flume Properties, Canal Data, &Design Requirements*

(3) Specify as-built dimensions of the flume in the bottom profile window

(4) Using the menu command *Report/Graphs* and the submenu *Rating Equation*, the rating table and equation generated by WinFlume for as-built flume dimensions can be viewed, printed, and copied to a word document or excel worksheet

A brief summary of the WinFlume program features and capabilities is presented in *Appendix 2*.

Chapter 7. Excel worksheet - a quick reference tool for flume field evaluation and selection in the Yuma Mesa Irrigation Districts

The Excel spreadsheet accompanying this document is designed to be used as a quick reference tool for flume field evaluation, selection, and installation. It presents the canal geometry and hydraulic data for which the predesigned alternative flumes are developed. It also presents the design and construction drawings for each of the flumes and help information on field measurement procedures, flume installation site selection criteria, rating tables/equations, and links to training materials.

The spreadsheet is stored in a flash memory and is available along with this document. It is stored in the folder *Yuma Flume*, which contains the main Excel file: *Flume selection tool for irrigation field supply canals in the Yuma Mesa Irrigation Districts* and two subfolders: (1) *Yuma flume selection*, which contains four spreadsheet files and two power point files and (2) *Flow measurement video*, which contains flow measurement video and a video player. To install the spread sheet program just copy the entire content of the *Yuma Flume* folder to the hard drive of your computer.

To start the flume selection spreadsheet, go to the folder *Yuma Flume* and click on the Excel file: *Flume selection tool for irrigation field supply canals in the Yuma Mesa Irrigation Districts*. This leads to a window with four options: *Canal Geometry and Hydraulic Data*, *Flume Data*, *Flume Drawings*, and *Help*.

Selection of the option *Canal Geometry and Hydraulic Data* leads to a Window with data on canal shape and dimensions and hydraulic data set for which the flume designs were developed.

Selection of the option *Flume Data* leads to a workbook with three worksheets, each for one of the predesigned flumes (12”, 15”, and 18”). Each worksheet presents the dimensions and shapes of the flume components.

Selection of the option *Flume Drawings* leads to a workbook with nine worksheets, a group of three worksheets each for one of the predesigned flumes (12”, 15”, and 18”). In each group, one worksheet presents the bottom profile of the flume, a second worksheet presents the design drawings, and a third worksheet presents the construction drawings.

Selection of the *Help* menu option opens a workbook with three worksheets, each for one of the alternative flume sill heights. Although much of the help information is common for all the three flumes, the rating tables and suitability information are different for each alternative flume sill height.

Acknowledgements: The guideline for flume field evaluation and installation compiled in this document is based on the work of Dr. John A. Replogle and Dr. Albert J. Clemmens of the USDA-ARS Water Conservation Laboratory, Phoenix, AZ, and Dr. Marinus G. Bos of the ILRI, Wagenningen, The Netherlands.

Appendix 1. Field measurement guidelines

(i) Profile survey

- Equipment needed: (surveyor's level, measuring tape, and chalk)
- Determine the points, along the center line of canal, at which elevation readings are to be taken and mark the points with a chalk or a marker, etc.
- Setup surveyor's level in working order, if possible at a point where all readings can be taken from the same point.
- Take a back sight reading from a bench mark and calculate elevation of line of sight as the sum of the elevation of bench mark and back sight reading. Bench mark can be any relatively permanent feature near the potential flume installation site with an assumed or measured elevation.
- At each of the points along the center line of the canal take a foresight reading and determine the elevation of the point by subtracting the foresight reading from the elevation of the line of sight.
- If at some point during the survey it becomes necessary to move the instrument to continue the survey, the following steps are to be followed to determine the new height of instrument:
    - Setup the instrument in a suitable location.
    - Take a back sight reading in one of the points whose elevation has already been determined and use that reading to determine the new elevation of the line of sight.
    - Complete the remaining survey by taking foresight readings at each of the remaining points and subtracting them from the elevation of the line of sight.

(ii) Measurement of canal dimensions

- Materials and equipment required (surveyor's level, leveling staff/rod, plum-bob, measuring tape, chalk/marker, spirit level, a relatively wide telescopic rod).
- Use a suitable equipment to establish the cross-section at which measurements of canal dimensions are to be made. Make sure that measurements are made on a section that is perpendicular to the center line of the canal. A simple field approach is outlined here:

  - Hold a telescopic rod (which can be a leveling rod, if available) across the width of the canal (Figures 1.1a and 1.1b). Assuming the rod is sufficiently wide it fits into the canal only if it is placed perpendicular to the center line of the canal.
  - Use a spirit level to ensure that the telescopic rod is level and mark the end points on the edge of the canal (points 1 and 2, Figures 1.1a and 1.1b).
  - Drop a plum-bob to locate two points (points 3 and 4, Figures 1.1a and 1.1b) on the cross-section and at the canal bottom and mark the two points.
  - Measure canal top width (horizontal distance between points 1 and 2) and canal bottom width (distance between points 3 and 4) with a measuring tape (Figures 1.1a and 1.1b).
- Depth measurements can be made using surveyors level:
  - Set the surveyor’s level in proper operational order.
  - Take a back sight on a bench mark.
  - Elevation of the line of sight is calculated as the sum of the back sight and elevation of bench mark from datum.
  - Move the leveling staff to one of the points (point 1 or 2, Figures 1.1a and 1.1b) on the edge of the canal at the selected canal cross-section and make sure that it is vertical.
  - Take a foresight reading and subtract it from the elevation of the line of sight to obtain the elevation of the point on the edge of the canal.
  - Move the leveling staff and set it in the canal bottom at the selected cross-section (on either point 3 or 4, Figures 1.1a and 1.1b) and take another foresight reading. Calculate the elevation of the canal bottom at the selected cross-section by subtracting the foresight reading from the elevation of the line of sight.
  - Canal depth is the difference between the elevation of the canal edge and the elevation of the canal bottom at the selected cross-section.

Note that it is assumed here that there is no differential settlement between the two sides of the canal and hence corresponding points on the two side walls of the canal are at the same elevation.

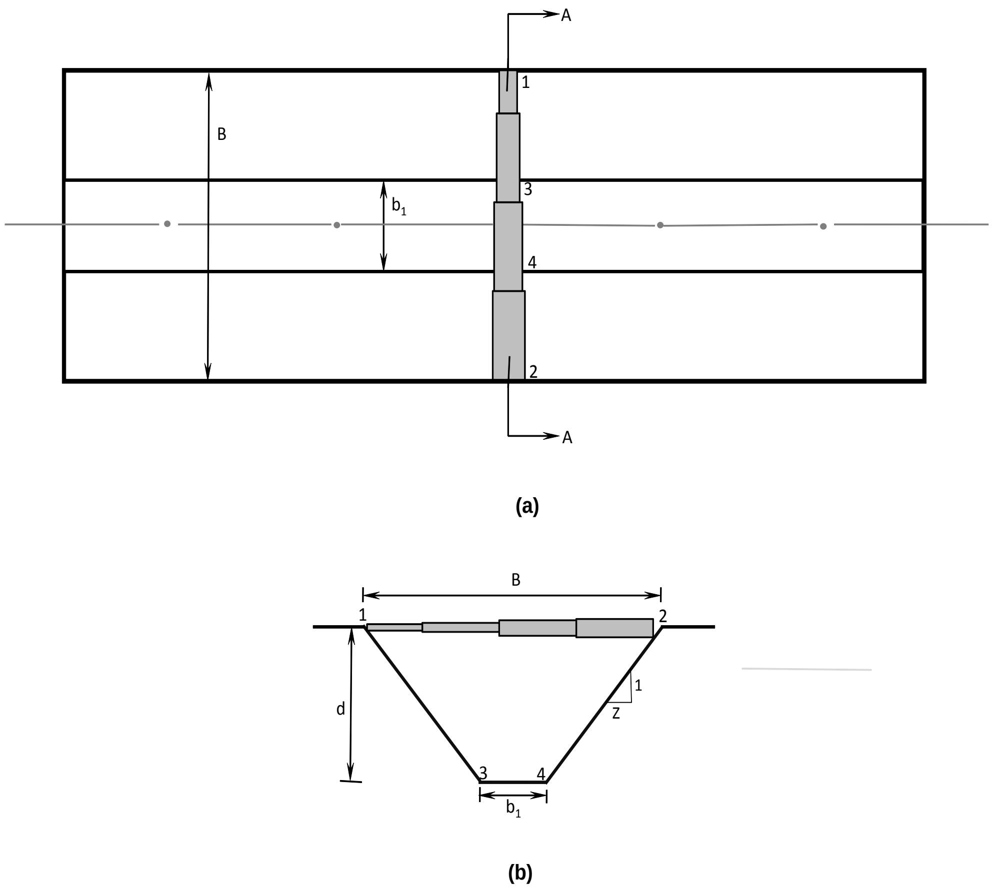


Figure 1.1 A sketch of field method for determining the canal cross-section at which canal dimensions are to be measured with a telescopic rod: (a) Plan view and (b) Cross-section along A-A

(30 Determine side slope as the ratio of half the difference between canal top width and bottom width to canal depth.

(iv) Indirect flow measuring devices generally use what is known as the velocity area method: measure velocity and multiply it by the flow cross-sectional area to determine corresponding discharge.

- Flow velocities vary over a cross-section. Hence, to determine an average velocity for a cross-section, measurements of velocity need to be made at a number of points in the cross-section and averaged over the cross-sectional area.
- There are also calibration errors, which may generally be smaller at high flows and larger at low flows. To minimize calibration errors, it is advisable to make a couple of average velocity measurements over a cross-section.

- Hence, the average velocity in a cross-section is the average of the average cross-sectional velocities determined in a couple of measurements.

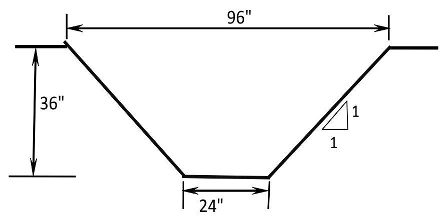
Table 1.1 Flume installation site survey data form (Bos et al., 1986, Clemmens et al., 2001)

Name of site: University of Arizona Yuma Mesa farm		Date: 03/27/09
HYDRAULIC DEMANDS		
Range of flow, *Q*, to be measured	Present water depth in canal, y_2	Maximum permissible error in flow measurement
$*Q_{min}$ = *8.0*	y_{2min} = *1.33* *ft*	X_{Qmin} = *15.0* *%*
$*Q_{max}$ = *26.0*	y_{2max} = *1.92* *ft*	X_{Qmax} = *8.0* *%*

HYDRAULIC DESCRIPTION

Canal bottom width	b_1	=	2.0	ft
Canal side slope	z	=	1.0	-
Canal depth	d	=	3.0	ft
Maximum allowable Water depth	y_{1max}	=	1.92	ft
Manning's *n*	*n*	=	0.014	-
Hydraulic gradient	S_f	=	0.00186	-
Available drop in Water depth at site	Δh	=	0.0	ft
Drop in channel bottom at site	Δp	=	0.0	ft

Sketch of canal cross-section:



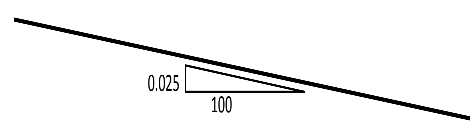
Concrete lined: × ☐

Earthen channel: ☐

FUNCTION OF STRUCTURE

Flow measurement only

Bottom profile of canal over a distance of *100*b_1



PERIOD OF STRUCTURE SRVICE

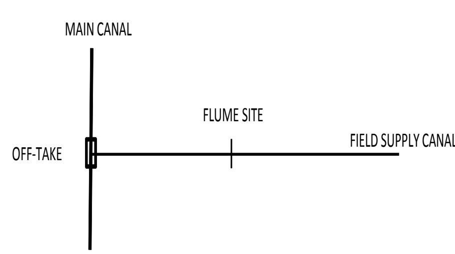
Day	☐	Season	☐
Month	☐	Permanent	× ☐

DESCRIPITION OF ENVIRONMENT

Irrigation system		Drainage system	
Main	☐	From irrigated area	☐
Lateral	☐	Artificial drain	☐
Farm ditch	× ☐	Natural drain	☐
In field	☐		

FURTHER DESCRIPTION (attach photo)

Plan of site:



**= these are field measured flow depth and discharge values, however, the discharge range used in design is 7-25cfs,* S_f *is calculated based on the discharge and depth pair of 16cfs-19in*

Appendix 2. A brief introduction to the WinFlume program

WinFlume is public domain computer program developed, through years of collaborative efforts, by the United States Department of Agriculture Water Conservation Laboratory, Phoenix; the United States Bureau of Reclamation, Denver; and the International Institute for Land Reclamation and Improvement, Wagenningen, The Netherlands. Detailed description of the program, availability, theoretical basis, and usage of program in design, calibration, and evaluation of long-throated flumes (broad crested weirs) is provided in the website: *http://www.usbr.gov/pmts/hydraulics_lab/winflume/32bitwinflumedownload.html*.

WinFlume has a well developed Graphical User Interface. When starting the WinFlume program the menu bar contains three commands: *File*, *Options*, and *Help*. The *Help* command provides the access to help info on WinFlume capabilities, definition and description of technical terms, etc. With the *Options* menu item the user can specify the units for variables, user name, and select default options for file saving, display of water surface profiles. In general, design of flumes with WinFlume begins by making selections, using the *File* command, whether a new flume is to be designed, or a flume definition file from a previous WinFlume session is to be loaded for refinement/ modification, or a file created with earlier version of WinFlume (Flume 3.0) is to be opened for modification. The selection of any one of these three options from the pull-down menu under the *File* command leads to the main design window with three smaller widows, displaying:

(1) The upper half of the window shows the bottom profile along the center line of the canal, between the approach and the tailwater sections. This window can be used to edit the dimensions of the various sections of the flume: the length of the approach section (L_a), the length of the converging transition (L_b), and length of the flume crest (L), length of downstream diverging transition, flume sill height, and canal depth.

(2) The window in the lower left-hand quarter displays cross-sections at the gaging station, control section, and tailwater section. This window can be used to edit the cross-sectional dimensions at the gaging station, control section, and tailwater section.

(3) The window on the lower right hand corner provides the elevation view of the control section from the upstream and downstream ends of the flume and a brief design report based on the six design criteria.

In this window, the menu bar provides three more commands in addition to the three described above: *Flume&Canal*, *Design*, and *Reports/Graphs*. With a pull-down menu under the menu command *Flume&Canal,* the user can access the option *Flume Properties&Canal Data*. Selection of this menu item opens a tabbed dialog box that allows the specification of flume crest type, construction material, and related hydraulic roughness properties. In addition, this dialog box allows the user to select the range of discharge to be measured by the flume, the option for characterizing tailwater from the five alternatives available in WinFlume, and to specify the pertinent input data on flow depth and discharge.

Selection of the menu command *Design* opens a pull-down menu with a couple of menu items, including:

Site Selection Tips, which provides brief descriptions of criteria to be considered in the selection of an appropriate site for flume installation;

Flume Wizard, this option provides access to a dialog box that guides the user through a step-by-step input of the data on canal and flume properties data and design requirements;

Flume Properties, Canal Data, &Design Requirements: This command provides access through tabbed dialog box to four windows in which the user can specify: (1) flume crest type, construction material, and related hydraulic roughness properties, (2) the range of discharge to be measured by the flume, the option for characterizing tailwater from the five alternatives available in WinFlume, and the pertinent input data on flow depth and discharge, (3) the sill-referenced upstream head measurement method, related uncertainty, and allowable floe measurement uncertainty, and (4) freeboard requirements.

Review of Current Design: This option allows review of current design for the specific fume definition. The report contains a comparison of design requirements and actual conditions for the six design criteria described in the preceding sections. It also contains a summary of the input data.

Evaluate Alternative Designs: This option provides access to a dialog box in which an evaluation report on a range of control section sizes and corresponding flow conditions using the design criteria described in preceding sections.

Selection of the third menu command, *Reports/Graphs*, in the menu bar leads to a pull-down menu with the options: *Rating Tables*, *Rating Equations*, *Wall Gage*, *Flume Data Report*, *Flume Drawing Printout*, and *Copy Flume Drawing to Clipboard*. Clicking on the option *Rating Tables* leads to a tabbed dialog box that can be used to view rating tables and graphs. Selection of the option *Rating Equations* opens another tabbed dialog box that provides access to rating equation, rating table, and rating curve.

The menu option *Wall Gage* provides access to wall gage data report which is a rating table that takes into account the canal side slope on which the gage is installed. It also provides access to wall gage design capability of WinFlume to generate a full-scale wall gage paper, labeled with depth or discharge, for use in the construction of the gage. The following procedure is to be used to design a full-scale wall gage paper that can be used to construct the actual wall gage from steel, or aluminum, or baked enamel:

1. Selecting the menu option *Wall Gage* opens a tabbed dialog box with three tabs: *Options*, *Wall Gage Data*, and *Wall Gage Plots*
2. In the *Options* tab, the depth and discharge range expected to be measured can be specified, selection can be made whether gage is referenced from flume sill or upstream channel bottom, and the side slope of the canal can be set.
3. The *Wall Gage Data* tab provides the rating table with vertical gage and with a gage laid on the canal wall (taking into account the side slope).
4. The *Wall Gage Plots* tab provides access to the WinFlume functionality for designing a full-scale wall gage paper with head or discharge labels. In this study, the wall gage paper is to be labeled directly with discharge. There are options to specify the size of thick marks on the gage, the font size, label spacing, decimal places to show on the gage. In addition, the specific printer that is to be used to printout the wall gage paper need to be calibrated. To do so, click on the option *Calibrate Printer* and print a trial page. The test line on the print out should be 24cm long, if not specify the actual measurement in centimeters and WinFlume calculates a *Scale Ratio* to be used to calibrate the printer. Figure 2.1 shows wall gage paper printed in three segments, which can be used to construct the actual wall gage from an appropriate material.

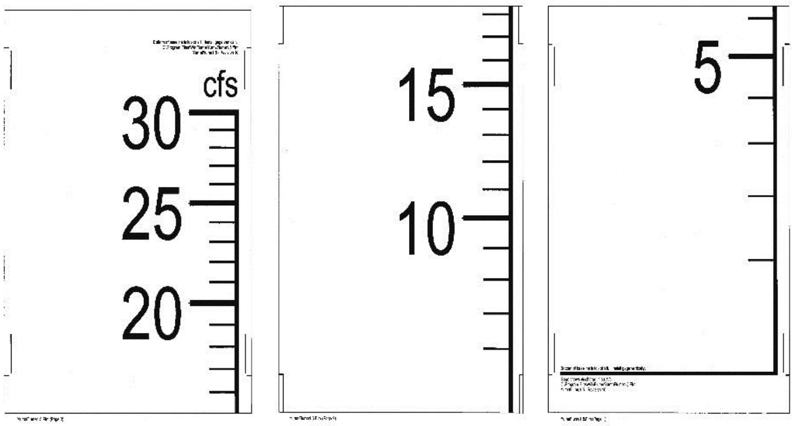


Figure 2.1. Example wall gage paper printed in three segments

Selection of the menu option *Flume Data Report* from the *Reports/Graphs* menu opens a tabbed dialog box that provides access to the WinFlume design report for the specific flume definition. The report contains a comparison of design requirements and actual conditions for the six design criteria described in the preceding sections. It also contains a summary of the input data. The menu options *Flume Drawing Printout* and *Copy Flume Drawing to Clipboard* allows printing flume drawings to disk or to printer or to copy to clipboard so that it can be copied to a design report (for instance an MS WORD document).

Appendix 3. Procedure for measuring sill-referenced upstream head during field evaluation of flumes

A portable point gage apparatus can be used as a quick and reliable method to field test portable structures in irrigation field supply canals. The apparatus required is shown in Figure 3.1. It includes: (1) a depth sensing pipe with perforations, the upstream end of which is plugged with a rubber stopper and rough-ground to a rounded point (not shown in Figure 3.1, because it is under water), (2) a cup used as a stilling well, (3) a point gage, and (4) a support beam to span the canal. The sensing pipe and hose can be any practical size. The point gage is commercially available through laboratory supply houses.

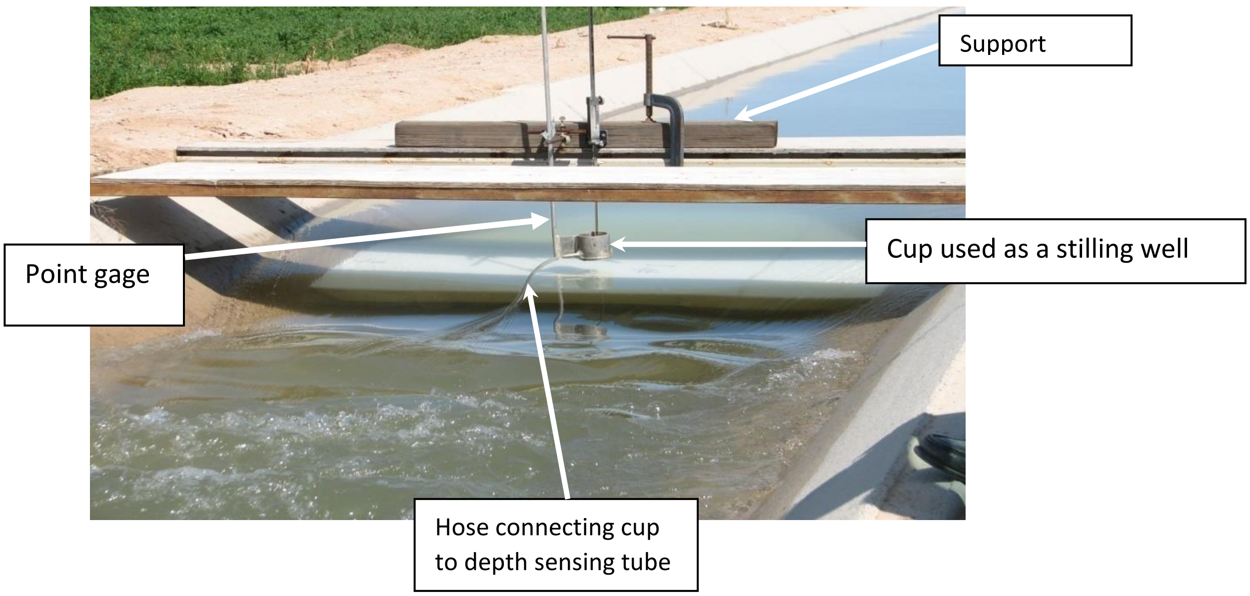


Figure 3.1. Point-gage apparatus for measuring sill-referenced upstream depth - during field evaluation of a flume in the UA Yuma Mesa farm

The following is a procedure, for using the point gage apparatus for measuring sill-referenced upstream head during field testing of portable flumes:

1. Attach the point gage and the cup to a rigid support that can span the flow of water. Attach a transparent hose to the perforated sensing pipe (Figure 3.1). The perforation are about 0.3m from the closed nose of the sensing pipe.

2. Place the support of with the point gage across canal. Place the sensing pipe in the flowing stream, point the rounded nose directly into the direction of flow and locate the pipe sidewall sensing holes at the gaging station.
3. With the point gage, take a reading with the point resting on the weir sill or flume throat bottom on the control section (sill-reference point). Read to ±1mm (0.003ft) or more precisely. Do not lean on the support for the point gage. Deflection will change the point gage readings.
4. Raise the point gage sufficiently high so that the funnel or cup can be placed below the point gage. (Do not move the point-gage setup between these readings)
5. Lower cup below water level to purge air from transparent hose and then attach the cup so that the water level is several centimeters deep in the bottom of the cup and the cup is above the flowing water level.
6. Lower the point gage and read the water level in the cup. Repeat this step as a check. It may take a minute or so for the water level in the cup to stabilize. Compute the sill-referenced upstream head as the difference between the two point-gage readings, which is then used in the rating table to determine discharge.

Appendix 4. Construction drawing (sill height 1.0ft)

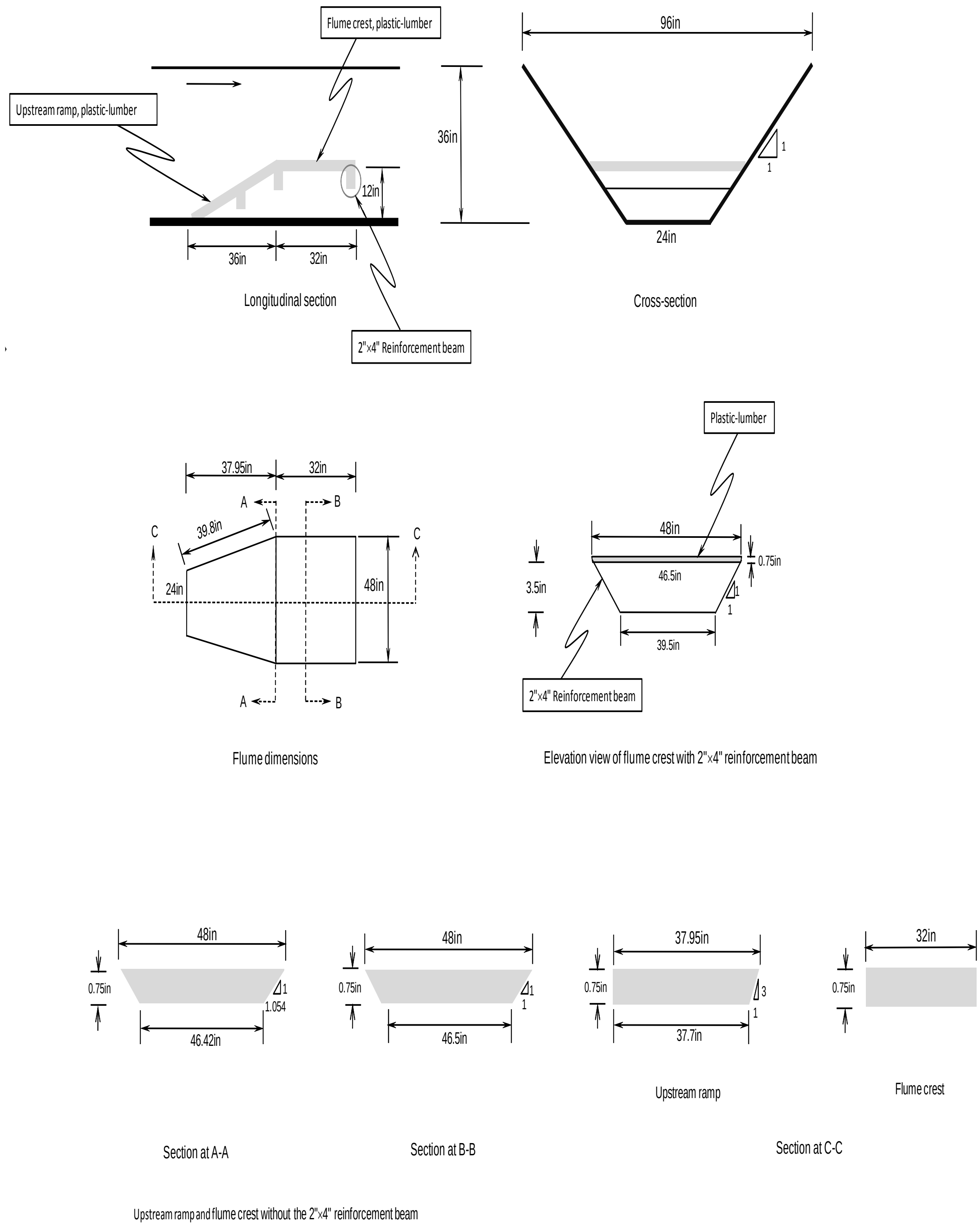


Figure 4.1 Flume construction dimensions for 1.0ft (12in) sill height

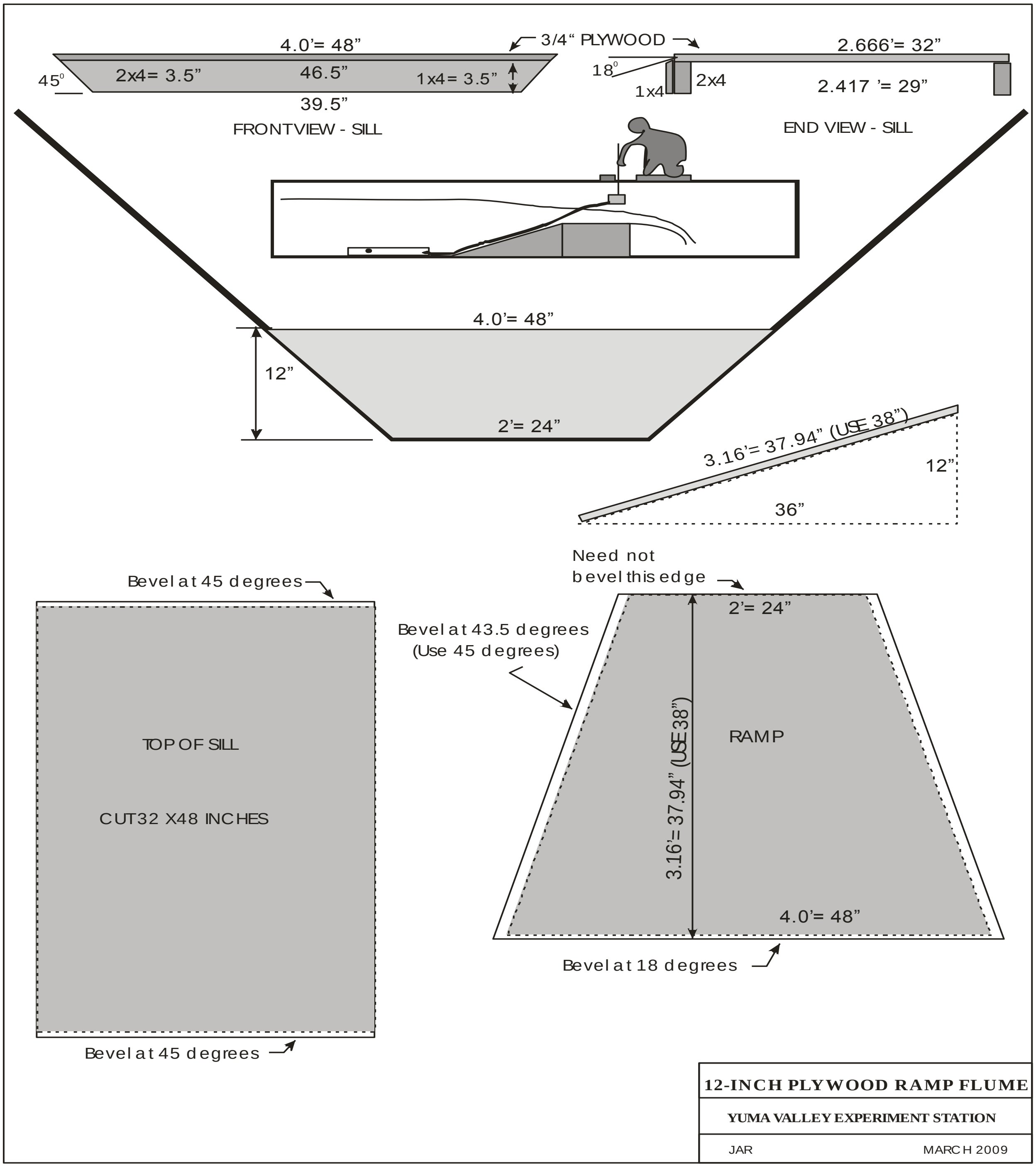
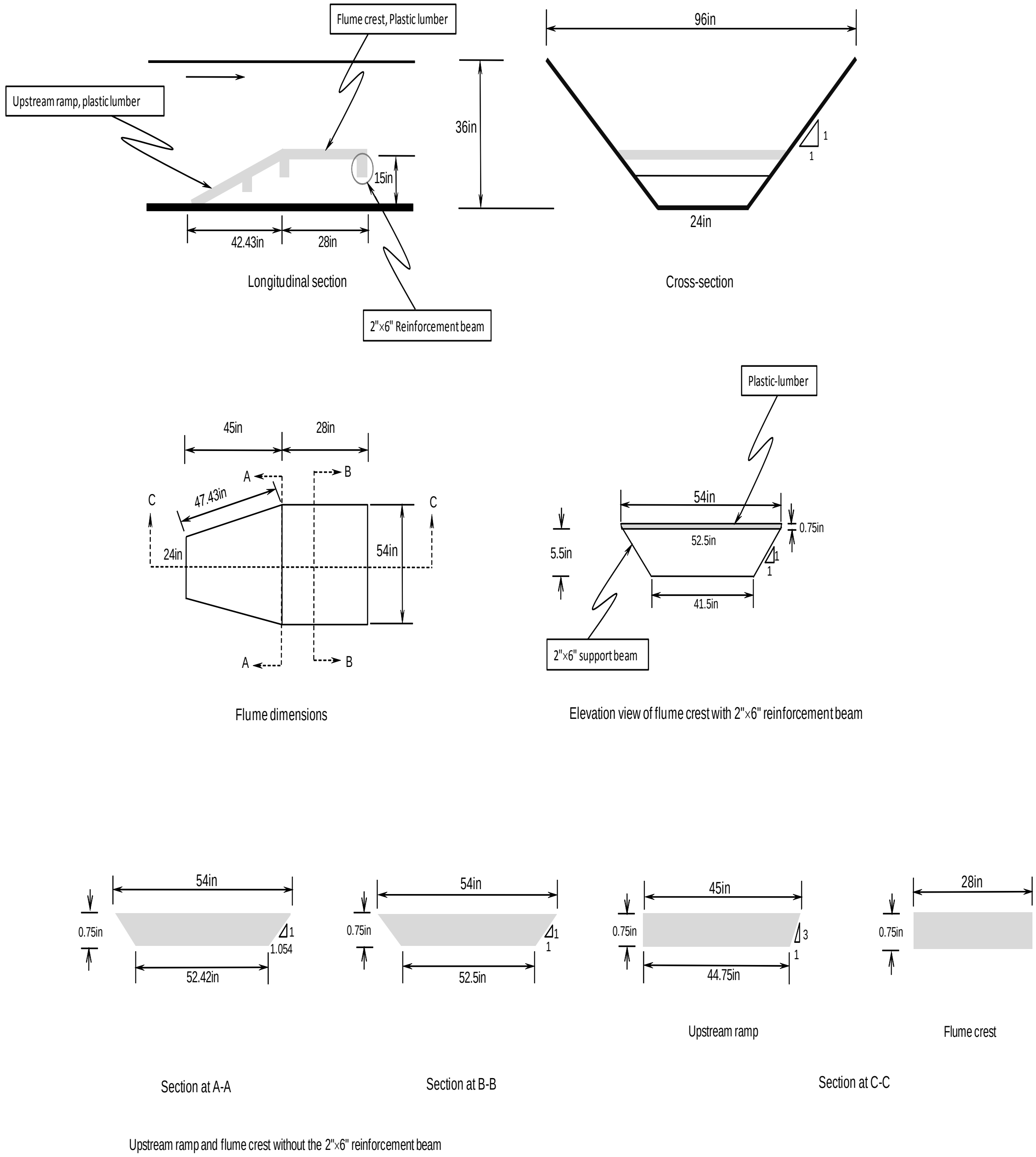


Figure 4.2 Flume construction drawings – 1.0ft (12in) sill height

Appendix 5. Construction drawing (sill height 1.25ft)



Flume design drawings for flume sill height 15in (1.25ft)

Figure 5.1 Flume construction dimensions for 1.25ft (15in) sill height

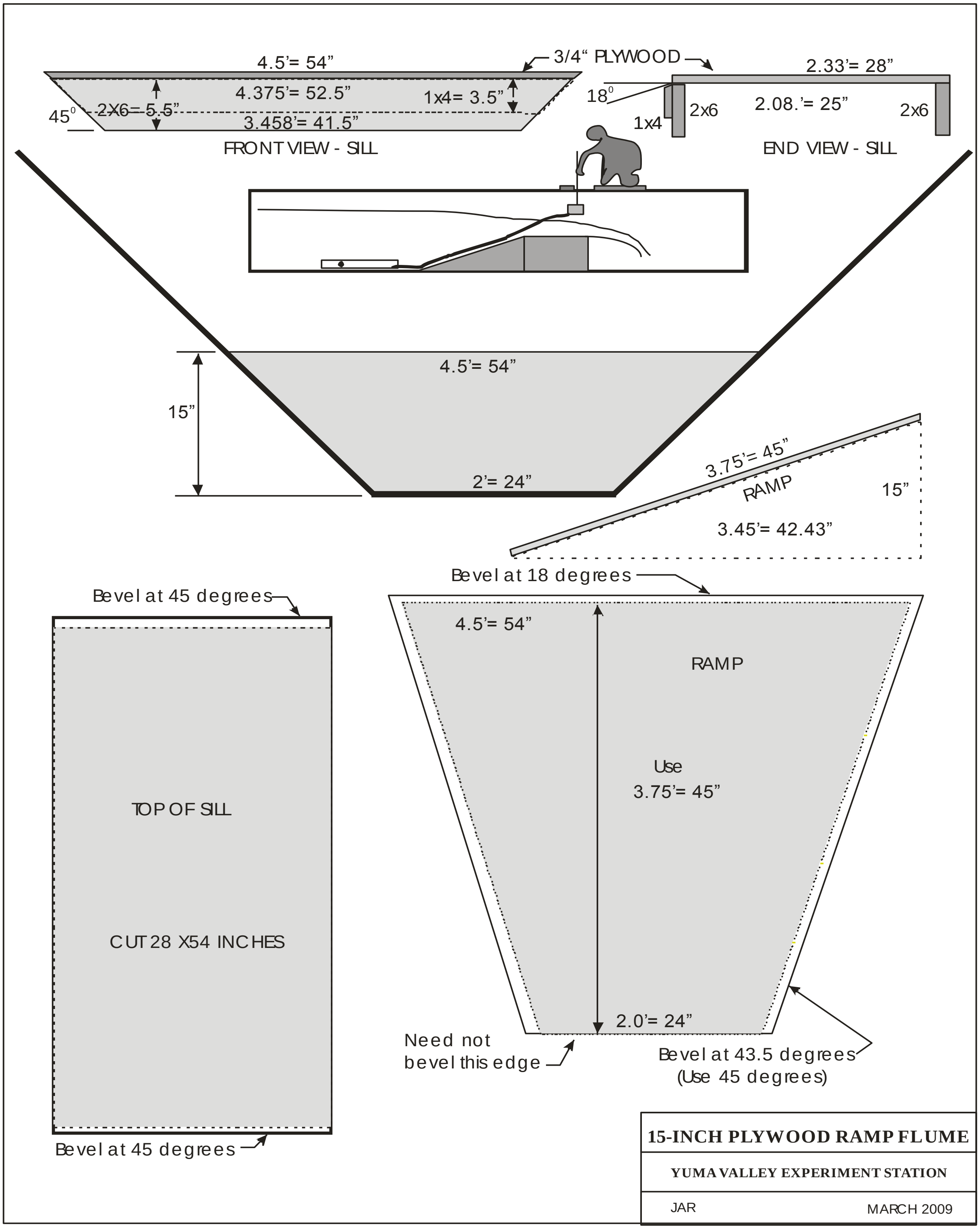


Figure 5.2 Flume construction drawings – 1.25ft (15in) sill height

Appendix 6. Construction drawing (sill height 1.5ft)

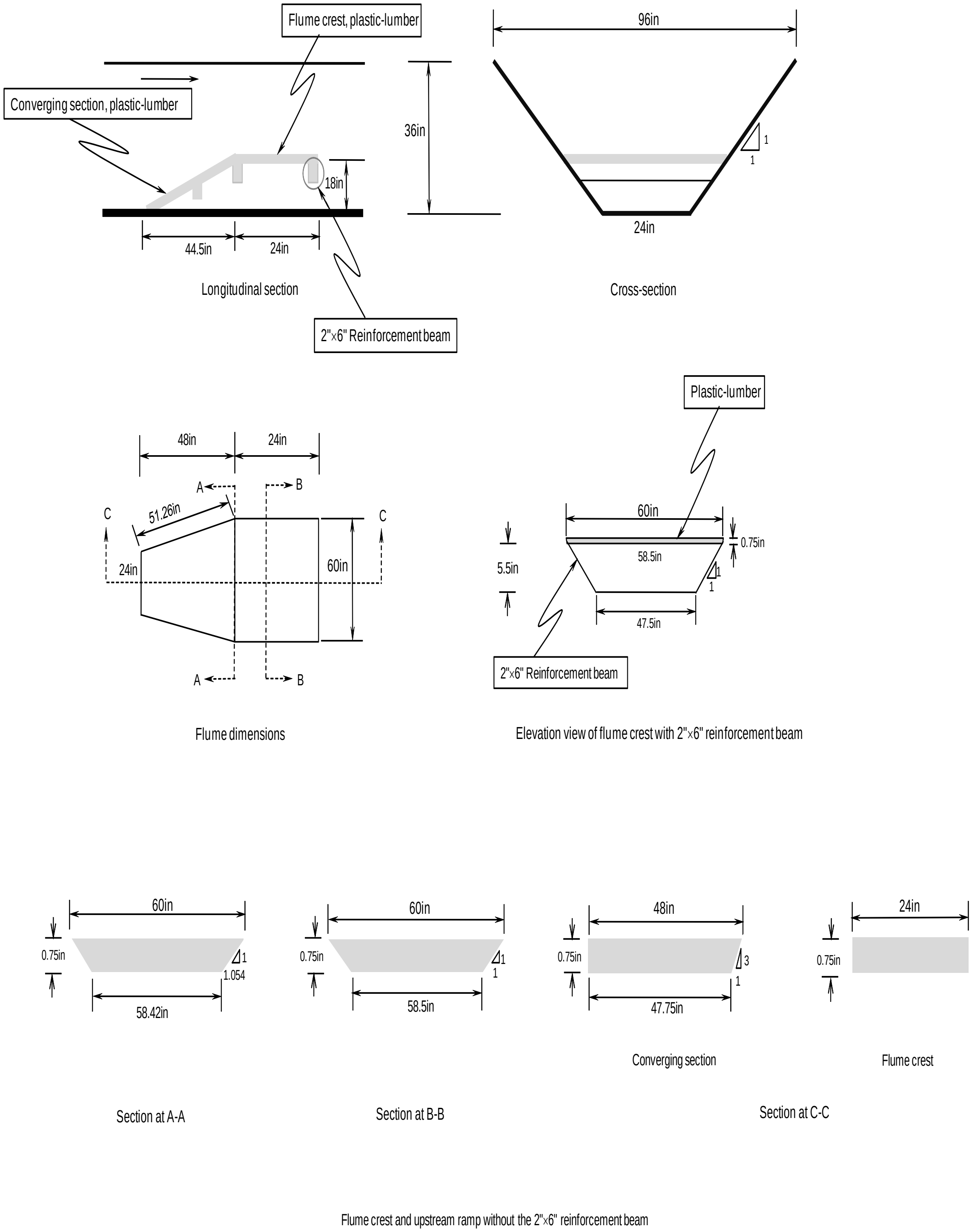


Figure 6.1 Flume construction dimensions for 1.5ft (18in) sill height

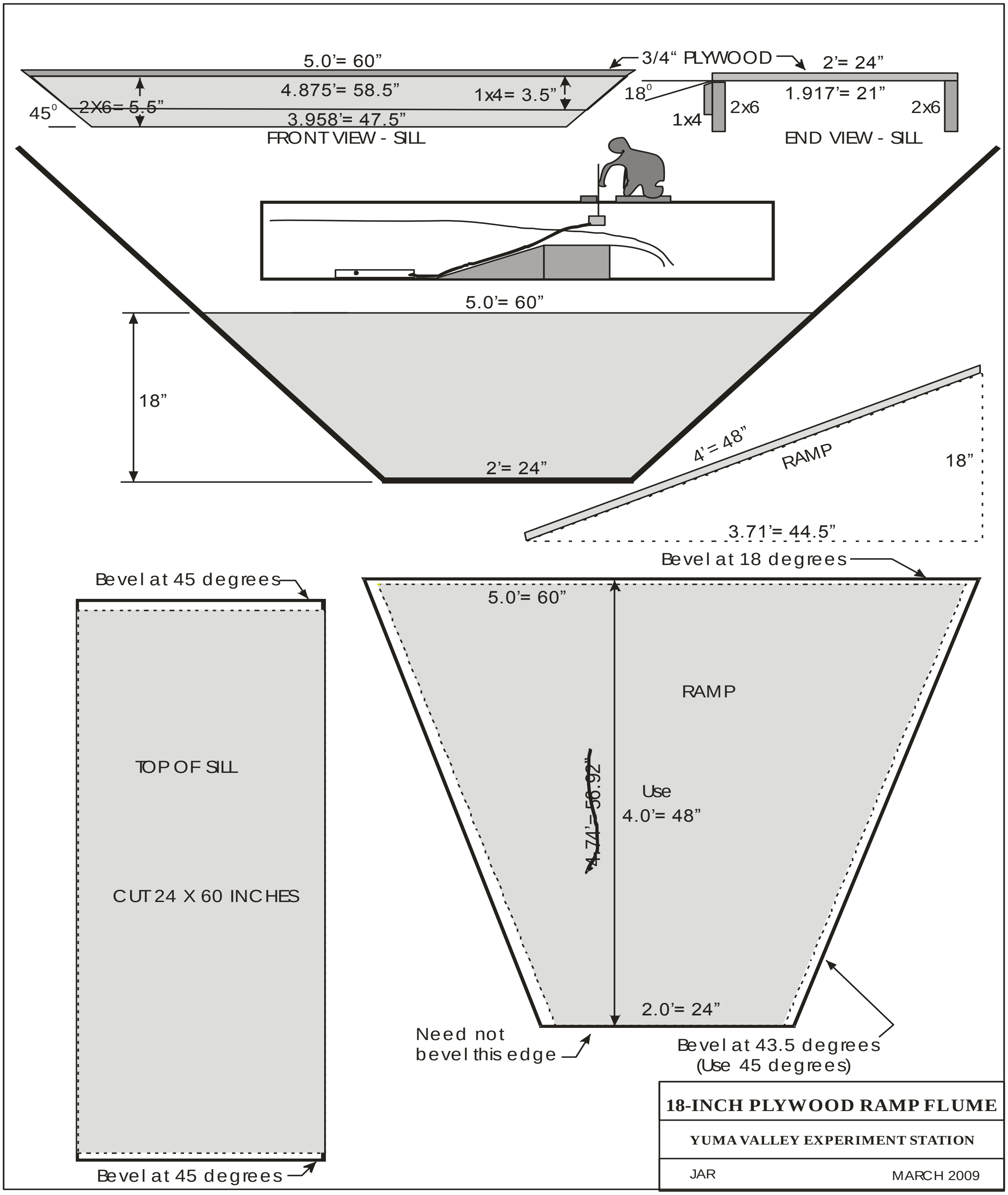


Figure 6.2 Flume construction drawings – 1.5ft (18in) sill height