Simplified procedure for design of long-throated flumes and weirs

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\begin{abstract}
An appropriate critical-depth measuring device should match the flume to approach channel conditions to provide a suitable Froude number in the approach channel to pass the sediment and for producing a stable and readable water surface at the gauging station. In current research, area ratio is explicitly expressed via an elegant equation. This equation is used to design the rectangular-throated flumes and weirs based on the upstream Froude number (upstream flow conditions). Introducing a correction factor, $C_f$, the proposed equation can be also used with high accuracy for nonrectangular control sections such as triangular ($C_f = 0.979$) and parabolic/trapezoidal ($C_f = 0.987$) sections. Moreover explicit equations for approach velocity coefficient of the long broad-crested weirs (long-throated flumes) are also presented. These relationships facilitate the discharge computation of the broad-crested weirs and long-throated flumes. The relations presented in this study will be useful in the design and analysis of the long-throated flumes and weirs, and reduce computation time and effort.
\end{abstract}

\section{1. Introduction}
Water discharge measurement in open channels is very important from the water conservation viewpoint [1]. Flow-measuring structures are used for continuous measurement of discharges in open channels [2]. The discharge in open channels can be measured by a wide variety of structures. As mentioned by Boiten [3] gates, weirs and flumes have been used for a long time to determine flow discharges in open channels. Parshall flumes were developed in the early 1900 s as simple and inexpensive devices for flow measurement in open channels [4]. A broad-crested weir is considered as a flat-crested structure with a crest length large compared to the flow thickness [5]. Long-throated flumes and broad-crested weirs have been accepted as standards for flow measurement during the past two decades [6]. Long-throated flumes and weirs provide a cost-effective, practical and flexible tool for measuring discharge in open irrigation systems. Broad-crested weirs are also used in circular sewers and pipes [7]. WinFlume is one of the computer programs used to design and calibrate flumes [8]. Hydraulic theory and the design procedure for these water structures has been extensively presented by \textit{Water Measurement with Flumes and Weirs} [9]. However, any effort for presenting a simple solution with reasonable accuracy would be of practical importance. The current study is mainly based on the mentioned work and previous studies by Clemmens et al. [10,11] but further manipulations based on the algebraic analysis has made the final results much more efficient to use for design engineers.

This research intends to propose direct equations for the design procedure of rectangular and nonrectangular broad control sections based on the upstream Froude number. The approach is valid for all long-throated flumes, regardless of the shape of their throat cross-sections. Moreover an explicit equation for discharge equation in terms of the upstream sill referenced water level is analytically derived.

\section{2. Rectangular long-throated flumes and weirs}
Fig. 1 depicts a typical long-throated flume with a rectangular control section. The subscript ‘1’ refers to the cross section in the approach channel at the gauging station where the head above the crest, $h_1$, is to be measured for discharge determination and subscript ‘c’ refers to the critical flow conditions at control/contracted section. Water flows in an approach channel at a depth, $y_1$, and velocity $V_1$. The channel is contracted to a rectangular-throated weir and the bed is raised by a sill. Sill height relative to the approach channel is $P_1$ and sill length (throat length) is $L$. The flow velocity is increased by the sill (contracted section). The contraction should be adequate to result in critical flow conditions. Because of the non-uniform distribution of the velocities over the cross sections, a velocity distribution