Differences Between Effective and Physical Roughness Parameter- A Headwater Mountain River Experiment

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Abstract*— One-dimensional hydrodynamic models (HM) are widely used in the hydraulic modeling of rivers and channels. The result obtained with this type of model depends largely on correct estimation the roughness parameter. The value of the roughness parameter obtained through a HM calibration process differs from the one measured in the field. Hence, the objective of this research is focused on identifying the difference between physical and effective roughness for different morphologies present in Mountain Rivers. Physical roughness was indirectly measured with field data and Manning equation, while Effective roughness was found through GLUE experiments using water depth as validation data in one dimensional models in HEC RAS. Physical and effective roughness coefficients have shown differences depending on the morphology. In Cascade and Step-pool the physical roughness is higher than effective roughness, while in Plane-bed effective roughness is higher than physical roughness. The differences are attributed to the deviations that occur between the real conditions and the flow idealizations in an 1D - HD model. For any modelling application is important to research roughness values used previously and avoid formulations or tables which are based on field measurements.

***Keywords*— Effective roughness, physical roughness, Mountain river, 1D, HEC RAS**

I. Introduction

Hydraulic models (HM) are intended to replicate the flow of a fluid [1], but they make some assumptions to represent mathematically reality leading to structural errors [2]. Moreover, there are error in input data, model parameters and calibration data leading to model output uncertainties [3]. Thus, there is no a single set of optimal parameters, instead there is a set of parameters which has the same model performance which is called equifinality. HM require good estimation of resistance losses in order to obtain representative results [4].

One-dimensional models are still used and are considered a good predictor of river and canal hydraulic modeling when adequate topographic data is available. [5], [6]. These models are popular due to a low computational demand and low investment in data collecting since point measurements of flow and water depth are required [1],[5]. Furthermore, resistance estimation in these models is through a roughness parameter containing different processes playing an important effect on model results [5].

Several studies based on hydrodynamic models have been carried out. Reference [7] performed a GLUE experiment in a two-dimensional hydrodynamic model to test the performance of two types of likelihood functions: one based on a statistical framework and other in fuzzy-rules. The available data was limited and ambiguous. The one based on fuzzy rules provided the best results. Reference [8] use binary pattern for flood prediction in GLUE experiments. An approximation was developed to obtain information of global and distributed uncertainty, and the objective function provide a good calibration curve. Reference [3] use GLUE experiments to analyze the uncertainty arising from different variables such as flow, topography, and roughness: individually and in combination. Furthermore, GLUE experiments were used to analyze the effect of the likelihood function in the uncertainty quantification in flood inundation. Reference [9] run multiple times a two-dimensional hydrodynamic model to produce probability flooding maps. When comparing probability flooding map with deterministic flooding map some areas predicted as not flooded had a certain likelihood to be flooded. In the studies above there is no comparison of effective parameters with physical measures, so there is a gap in the knowledge.

In this manuscript, the difference between physical and effective roughness parameters for three different morphologies in Mountain Rivers are presented. Section II describes the study zone where three reaches were selected with different morphologies having different resistance phenomena. Furthermore, in this section the methodologies to obtain effective and physical roughness are described as well as a description of the study zone. The differences between effective and physical roughness are explained in Section III, where a possible explanation of the difference between both is provided. Section IV deals with the conclusions of the comparison performed.

II. MATERIALS AND METHODS

A. Study area

The study site is in a headwater mountain river called Quinuas (Fig. 1). The reach under study is 1500 m long, with a mean slope of 4%. In this site, there are multiple morphologies such as: cascades, step-pool, and plane bed. Three of them were chosen: Cascade 3, Step-pool 2, and Plane-bed 1.

B. Field data

Physical roughness was estimated through Manning's formula (1).

$$Q=A\,R^{2/3}\,Sf^{1/2}/n \quad (1)$$

Where: Q is flow m3/s, A cross sectional area m2, R hydraulic radius m, Sf is friction slope, and n is the Physical roughness. The uncertainty in Physical roughness was estimated to 22% based on the methodology described in Fornasini [10].

The topography data was obtained with the use of a total station and differential GPS. Flow and velocity were estimated with dilution-gauging method by using salt as tracer [11] and with the Harmonic methodology [12]. The friction slope was approximated with the water surface slope [13].

C. Numerical Scheme

HEC-RAS one dimensional hydrodynamic module was used in this research to estimate effective roughness. This HM was run under steady state conditions, so the energy equation is solved iteratively [14]. The mix flow regime was chosen since mountain rivers has transcritical flow. Two boundary conditions were given: at the upstream and downstream reach end where a normal depth was assigned.

The validation data consist of water levels measured with measuring tape at staff gauges in the studied reach.

D. The GLUE methodology

The GLUE experiment was performed varying the roughness parameter of the main channel only because the flow was inbank even for high flows. The GLUE methodology was coded in HEC RAS Controller in Visual Basic Excel ® taking as a base the code in [15].

The likelihood function was based on sum of Root mean square error (RMSE), Mean average error (MAE), and the standard deviation of residuals (SDR). All the metrics were normalized with the mean of the observations (O_m) as shown in (2).

$$Likelihood=1-RMSE/O_m-MAE/O_m-MSDR/O_m \quad (2)$$

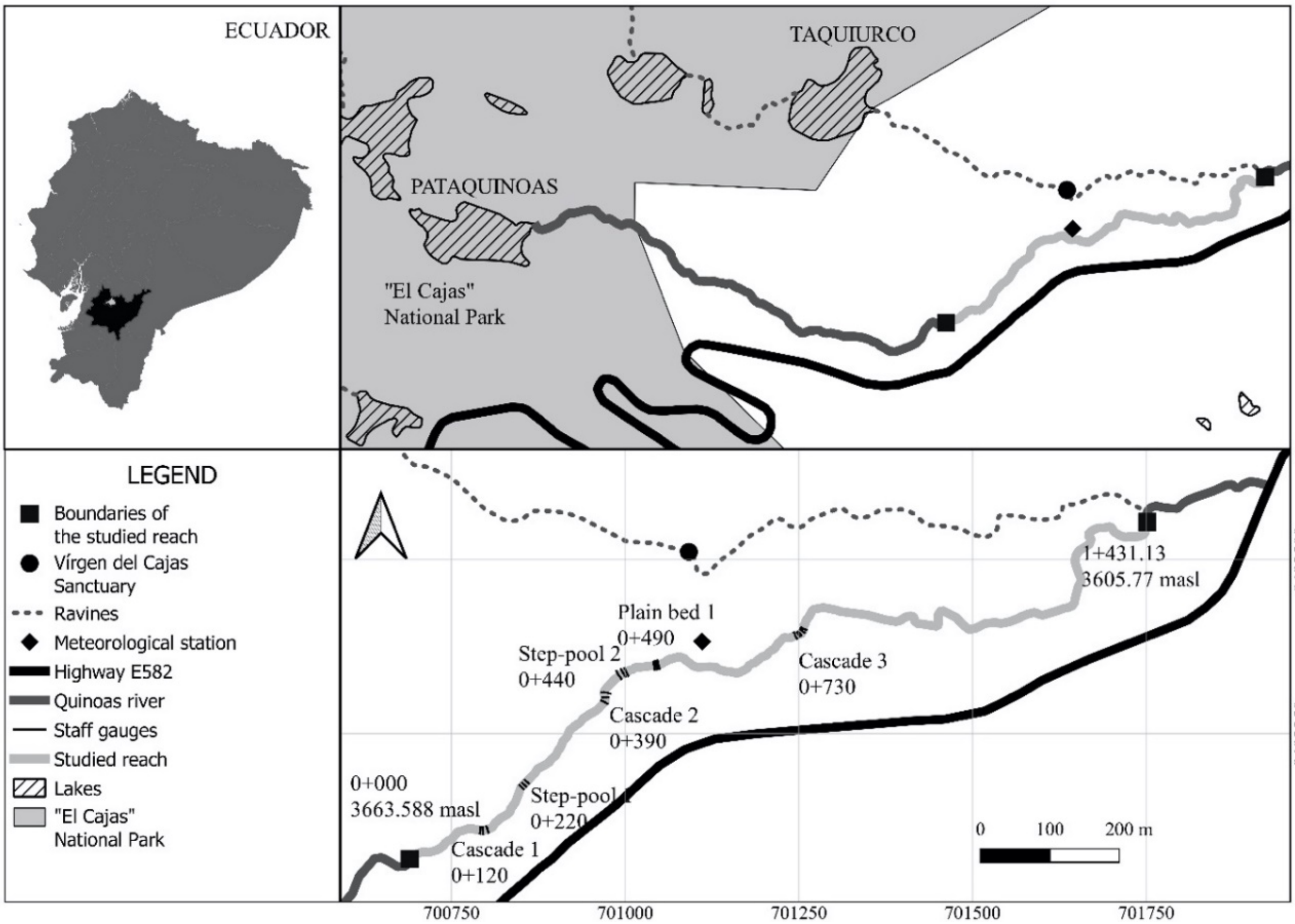

Fig. 1. Location of the 1.5 km studied reach with indication of the sequence of sub reaches.

E. *Statistical performance metrics*

Physical and Effective roughness are compared through RMSE and MAE. Both parameters are normalized with the mean of the physical roughness producing RMSEa and MAEa. Thus, if physical and effective roughness are equal RMSEa and MAEa are zero. Moreover, the difference between RMSEa and MAEa indicates the presence of outliers since RMSE provides more weight to higher residuals while MAE gives the same weight to any residual.

III. RESULTS AND DISCUSSION

Fig. 2 depicts a comparison between effective and physical roughness in the chosen morphologies. This figure clearly shows the difference between the values under study as well as the uncertainty of Physical roughness. A hydrodynamic model performs simplifications to model water flow resulting in structural errors. Those errors are compensated with roughness parameter variation [16], so this coefficient encompass different physical processes [5].

TABLE I. STATISTICAL PERFORMANCE METRICS, COMPARISON PHYSICAL AND EFFECTIVE ROUGHNESS

Site	RMSEa (%)	MAEa (%)
Step-pool	22.04	18.59
Plane-bed	58.63	51.56
Cascade	18.08	12.48

Hence, the difference between effective and physical roughness was expected.

In Cascade and Step-pool physical roughness is higher than effective roughness, and both values are close to each other being Effective roughness inside the uncertainty band of Physical roughness in most of the data present (Fig. 2 a and c). In Plane-bed morphology, effective roughness has the opposite behavior: effective roughness is higher than

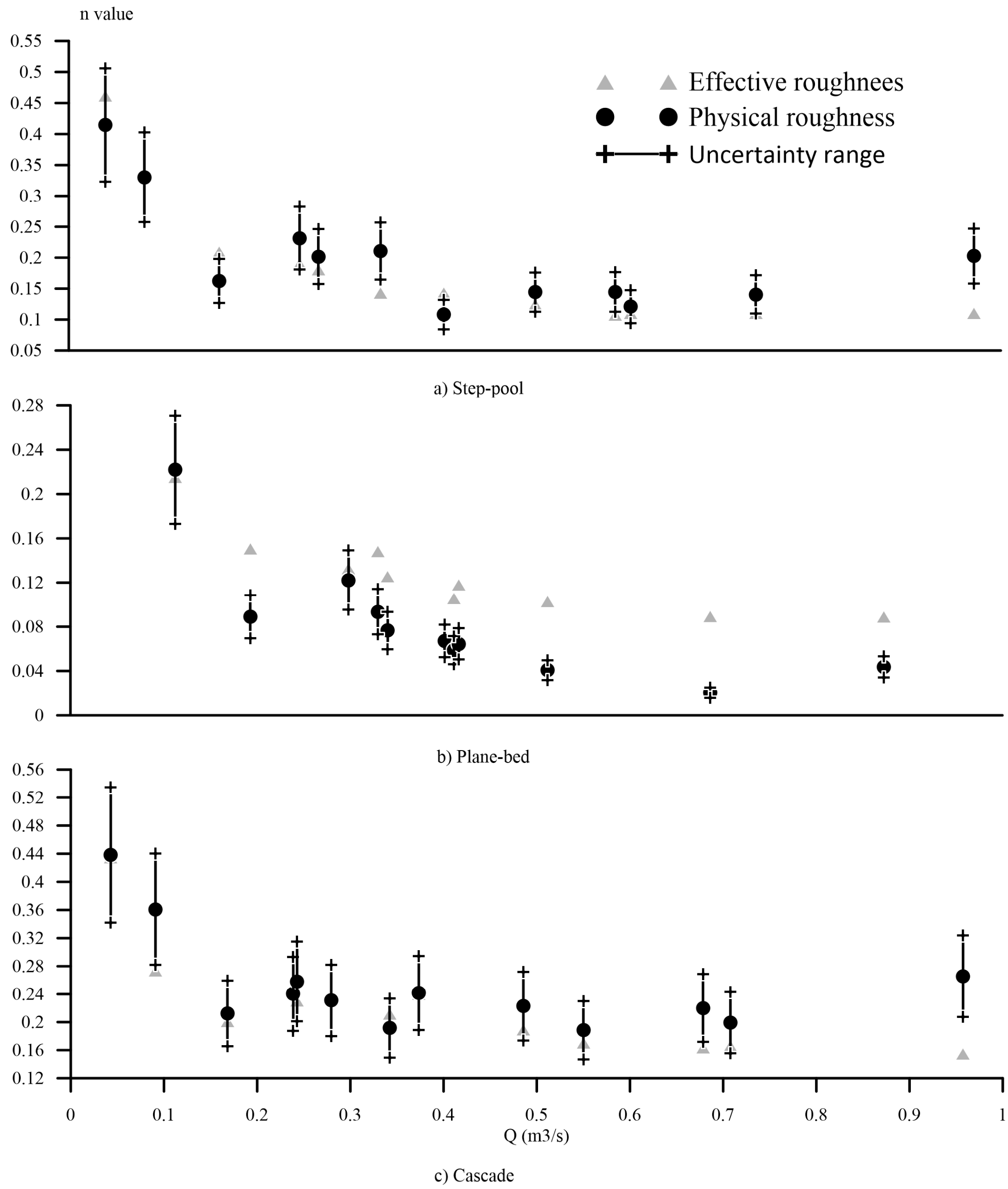

Fig. 2. Comparison between effective and physical roughness for different flows

physical roughness, and difference between both increases as flow increases. Effective roughness is outside the Physical roughness uncertainty range for most of the data (Fig. 2 b). The flow resistance in Cascade and Step-pool is higher than Plane-bed.

Table I presents that Physical and effective roughness are closer in Cascade and Step-pool than Plane-bed. Indeed, RMSEa and MAEa Plane-bed values twice those in Cascade and Step-pool. The difference between RMSEa and MAEa indicates the presence of outliers in residuals. The biggest difference is in Plane-bed being 7% while Cascade and Step-pool values were similar (5% and 4% respectively).

Cascade presents randomly distributed boulders and cobbles [17] whose interaction with water produce water division increasing resistance [13]. The former phenomena produces an alteration of water surface level which is far from being horizontal as the idealization of a 1D model is supposed. [14]. Step-pool has tumbling flow where the vertical component of velocity becomes important which is ignored in the HM [18]. Therefore, the difference between both parameters is due to the simplifications of the processes assumed in a 1D modeling. Indeed, effective roughness encompasses different levels of energy dissipation depending on the level of flow description e.g. 1D or 2D. According to Morvan [19] the effective roughness in 1D model is not necessarily the same as 2D model. On the other hand, Plane-bed is the morphology which is closer to simplifications in HM, however there is vegetation at the banks entering into the water at high flow. The authors believed effective roughness is higher than physical roughness to take into account these phenomena.

IV. CONCLUSIONS

In this study, the difference between effective and physical roughness parameter have been tested in a headwater Mountain river. Three different morphologies reaches have been tested: Cascade, Step-pool, and Plane-bed. Physical roughness was estimated with different field measurements: flow, mean velocity, and water depth. Flow and velocity were measured using salt as a tracer, while water depth was measured at staff gauges with a measuring tape. GLUE experiments were developed to estimate the effective roughness values. The likelihood function was a combination of two measures of mean error and a measure of the deviation of the residuals.

Effective and physical roughness parameter values have shown to be different due to simplifications in the hydrodynamic model. There are two main patterns; firstly, in Cascade and Step-pool physical roughness is higher than effective roughness, however both values are closer. Cascade do not meet the horizontal water level in the HM, while Step-pool does not meet the hydrostatic pressure distribution; secondly, in Plane-bed the difference between effective and physical roughness increases as flow increases. The reason may be the interaction of water with vegetation at banks.

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