Discharge Estimation in An Adverse Slope Condition Using Entropy Concept: An Experimental Analysis

Gurpinder Singh, Rakesh Khosa

Indian Institute of Technology Delhi, India.

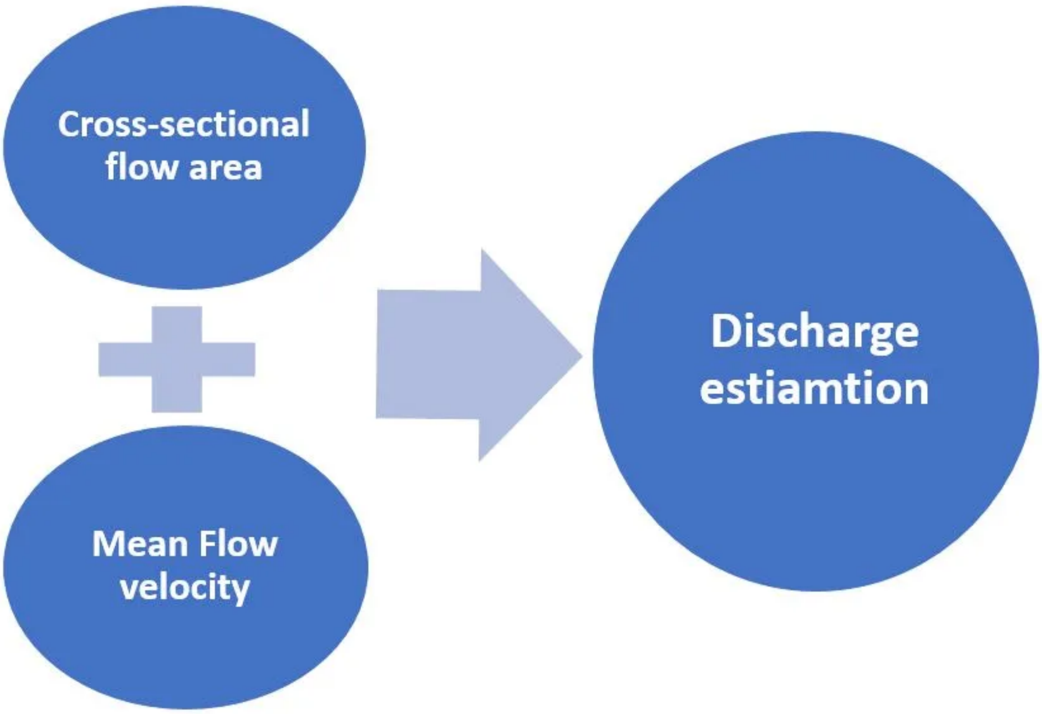
PRESENTED AT:

INTRODUCTION

The knowledge of flow data is a very fundamental step in hydraulic Engineering as it is needed for:

- Designing of hydraulic structures.
- Evaluation of the present operations such as reservoir releases and hydropower.
- oInvestigation of new criteria for the effective management of the reservoir.
- Development of an effective real-time flood control system.
- Hydraulic modeling of the river.
- River training works and so on.

For streamflow measurement at a particular cross-section in a natural open channel, two primary parameters are required,



SHANNON ENTROPY-BASED VELOCITY DISTRIBUTION

Chiu (1987) used the Shannon entropy to develop the entropy-based velocity distribution for the open channel flows.

$$\frac{u}{u_{max}} = \frac{1}{M} ln[1 + (e^M - 1)F(u)]$$

Derived a relationship between mean and maximum velocity,

$$\frac{u_{mean}}{u_{max}} = \frac{e^M}{(e^M - 1)} - \frac{1}{M} = \phi(M)$$

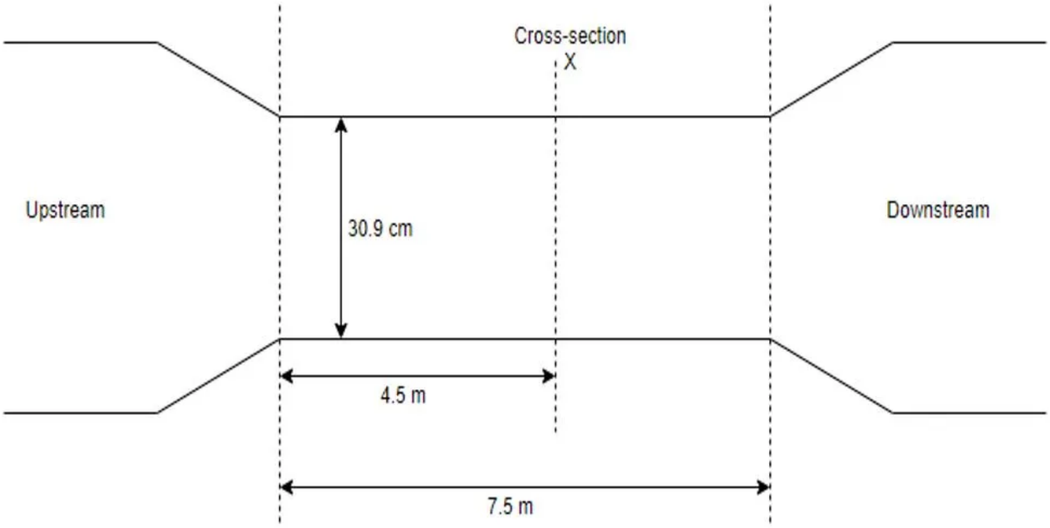
where,

- F(u) = Cumulative distribution function,
- ϕ(M) = State equilibrium constant,
- M = Entropy parameter.

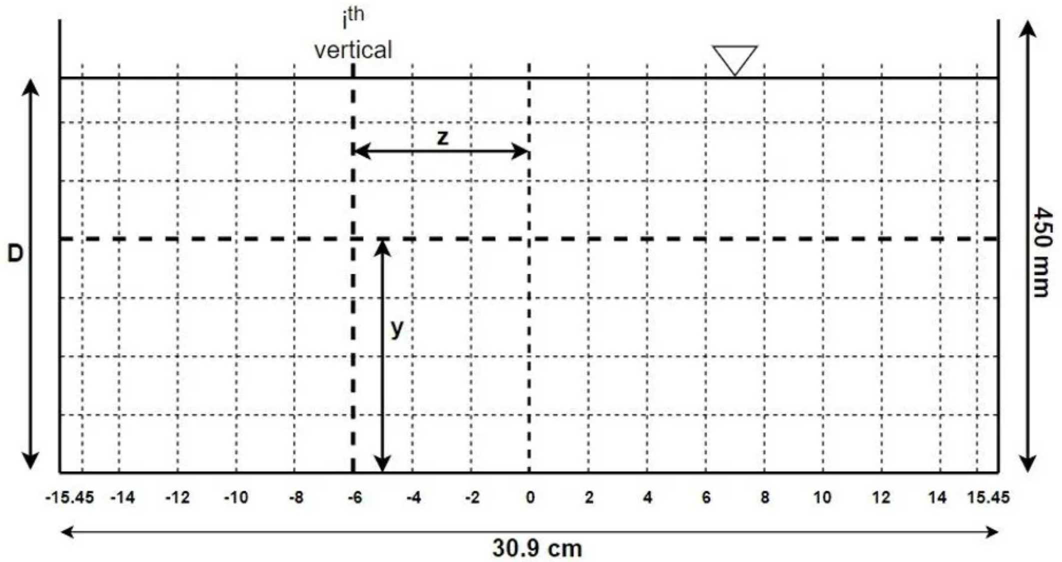
The variation of the parameter M is checked using the collected velocity data.

MATERIALS AND METHODOLOGY

- Velocity data was collected by performing experiments on a Laboratory Flume.



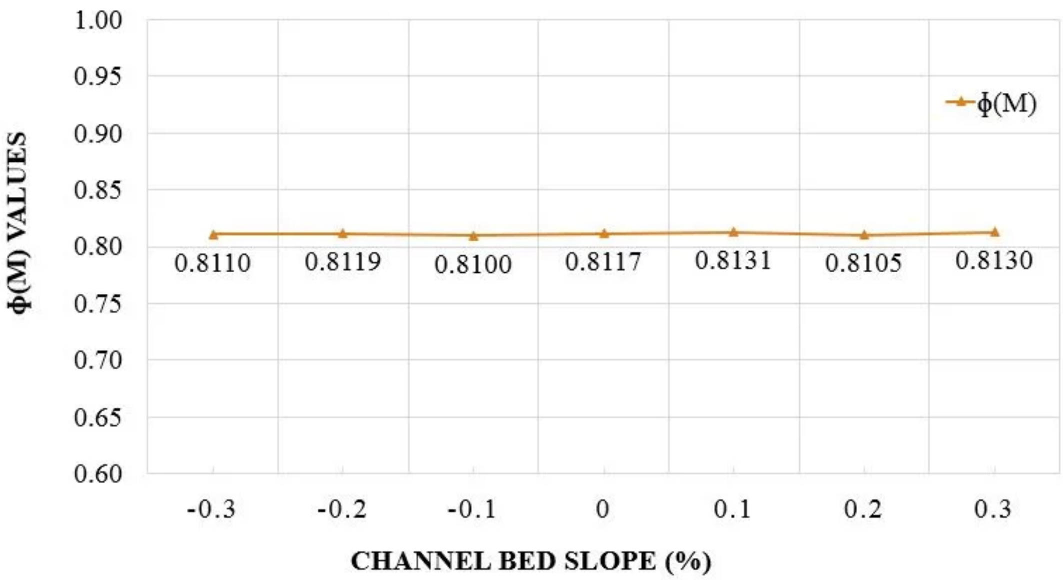
- A particular cross-section at a distance of 4.5m from upstream was fixed for all the observations.



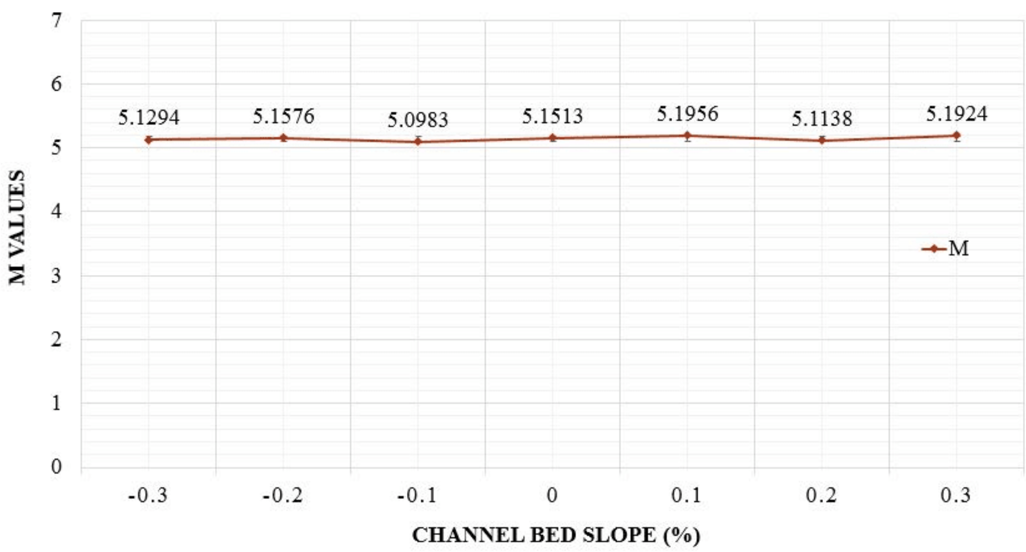
- Point velocities were measured at seven different values of Channel bed slopes (-0.3%:0.1%:+0.3%).
- For each bed slope value, five different discharge rates were considered, summing to 35 velocity profiles.
- All 35 velocity profiles rendered 35 pairs of mean and maximum velocity, which were used to check the influence of the channel bed slope on the entropy parameter (M).

ANALYSIS OF ENTROPY PARAMETER (M) AND DISCHARGE ESTIMATION

Variation of State Equilibrium Constant [ϕ(M] with channel bed slope.

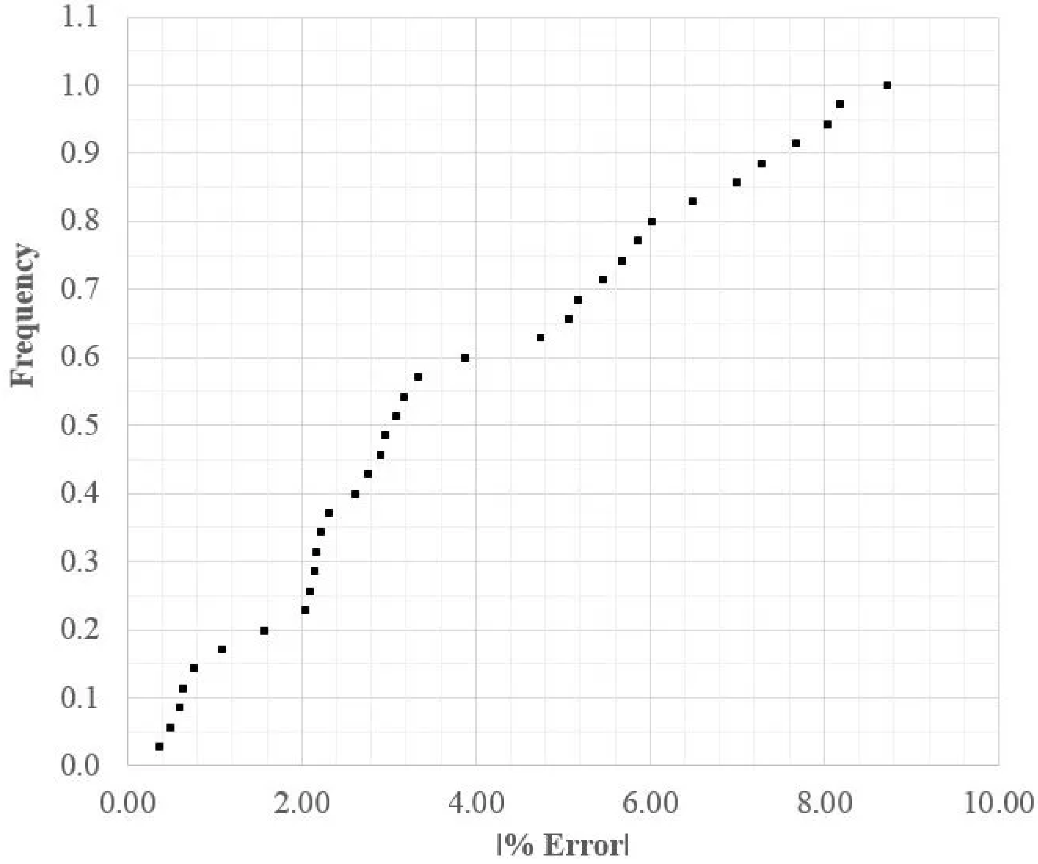


Variation of Entropy Parameter (M) with channel bed slope.



Analysis of error in discharge estimation.

- The absolute percentage error between estimated using the entropy method and observed values were calculated and plotted as shown below.

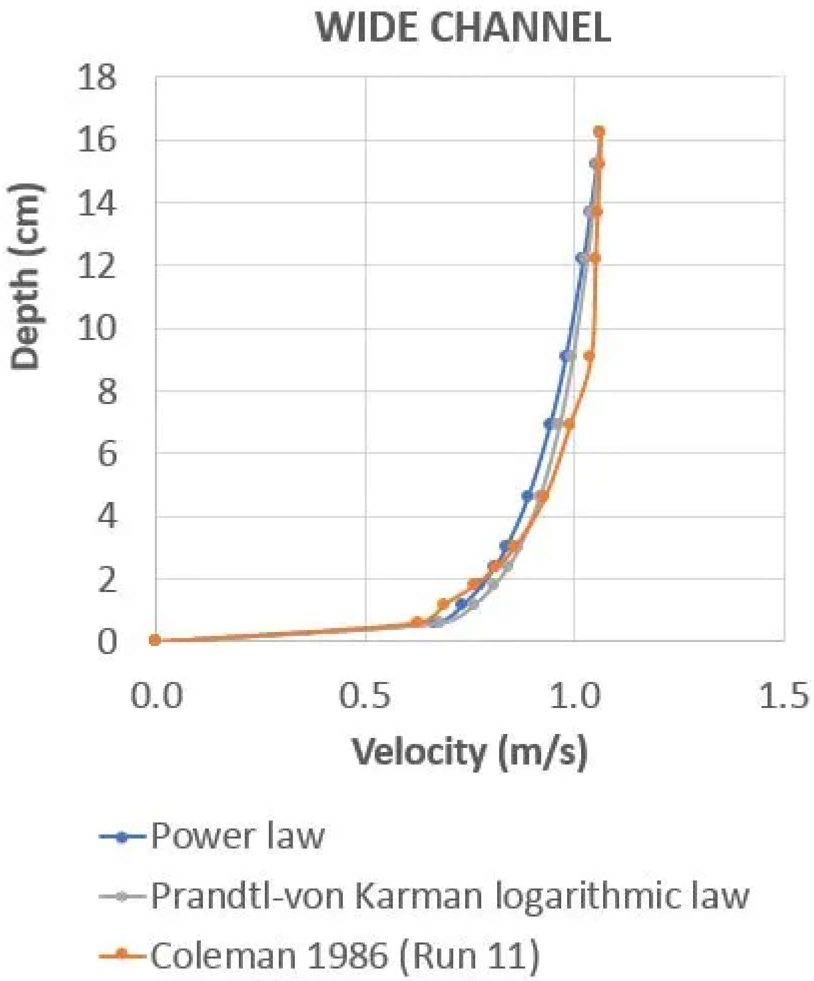


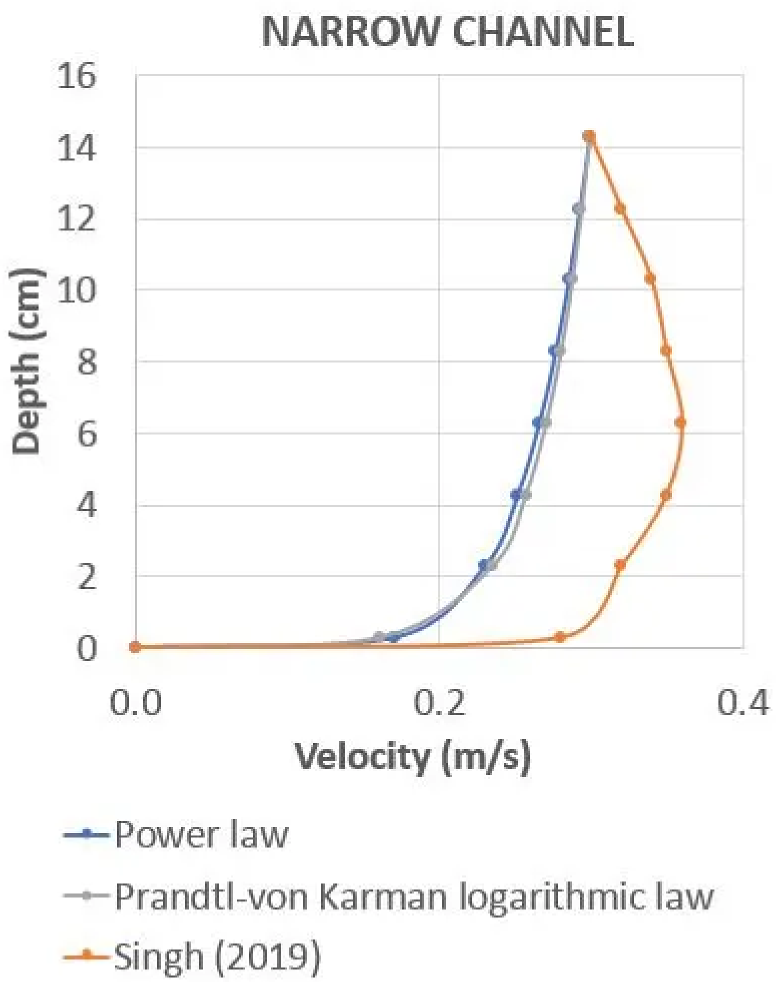
- The above graph depicted the good accuracy of the Shannon entropy-based model as the absolute percentage error was less than 10% for all the samples.

VELOCITY DISTRIBUTIONS

Classical approaches (such as Power law and Prandtl-Von Karman logarithmic law) have limited accuracy (i.e., only applicable for wide channels) due to the inherent system randomness and uncertainties associated with the estimation of the parameters such as,

- n= Power-law parameter
- k= Prandtl von-Karman constant.





Hence, velocity is statistically regarded as a random variable, and associated uncertainties can be accounted for probabilistically using Information theory.

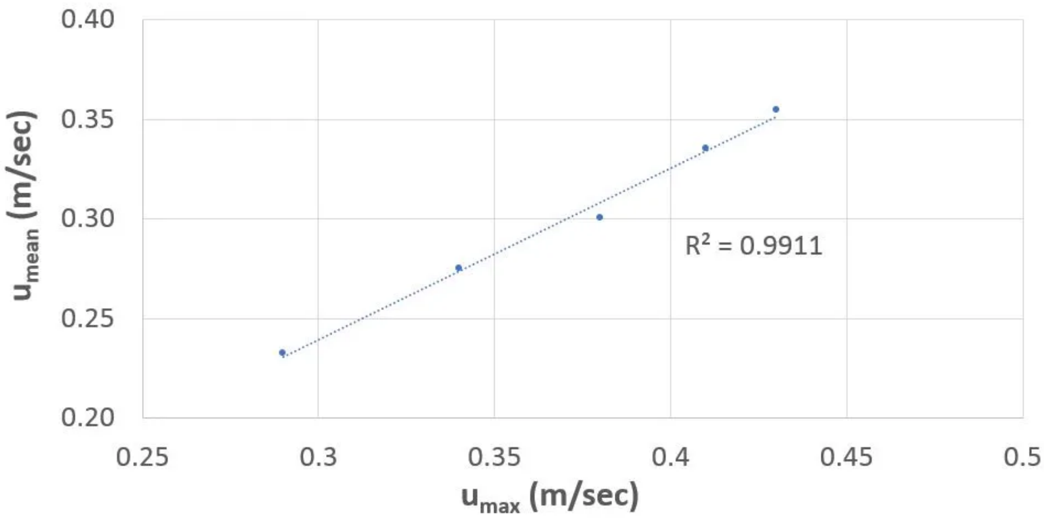
Entropy-based velocity distributions are derived probabilistically and applicable for both wide and narrow channels (Chiu, 1987).

RESULTS AND DISCUSSIONS

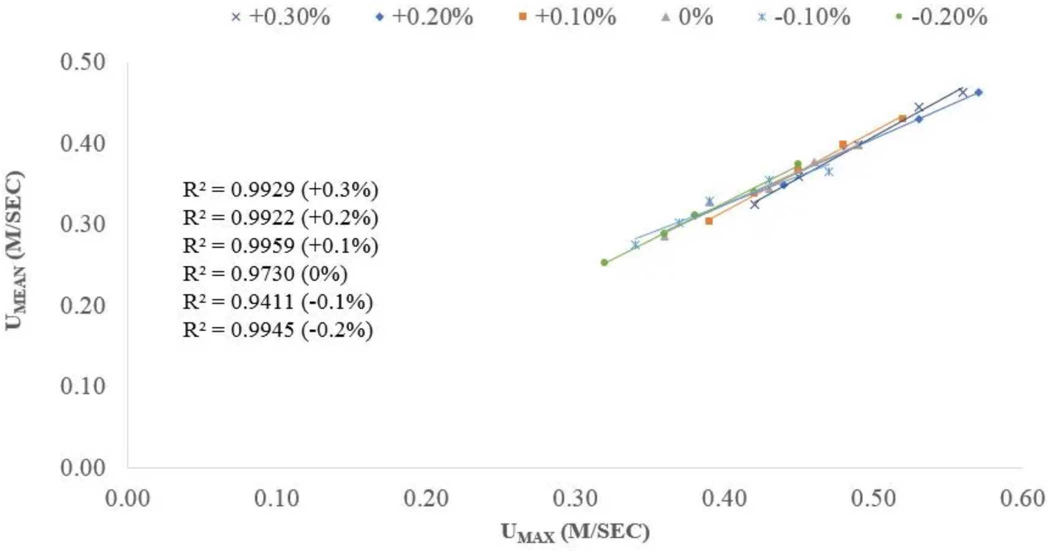
- Sampled pairs of mean and maximum velocity for bed slope -0.3%.

Run	U_{max} (m/sec)	U_{mean} (m/sec)	ϕ(M)	M
1	0.29	0.2328	0.8110	5.1294
2	0.34	0.2753		
3	0.38	0.3003		
4	0.41	0.3355		
5	0.43	0.3548		

- Mean and maximum velocity plot for bed slope -0.3%.



- Similarly, pairs of mean and maximum velocity for all slopes were plotted on a simple graph.


× +0.30% ◆ +0.20% ■ +0.10% ▲ 0% ✳ -0.10% ● -0.20%
R² = 0.9929 (+0.3%)
R² = 0.9922 (+0.2%)
R² = 0.9959 (+0.1%)
R² = 0.9730 (0%)
R² = 0.9411 (-0.1%)
R² = 0.9945 (-0.2%)
U_MEAN (M/SEC)
U_MAX (M/SEC)
0.00
0.10
0.20
0.30
0.40
0.50
0.60

CONCLUSIONS

- State equilibrium constant, ϕ(M), and entropy parameter remain almost constant with the variation of channel bed slope keeping all other parameters constant. Thus, indicating that the channel tries to maintain its entropy.

- Mean cross-sectional velocity can be calculated directly from the observed maximum velocity using the Entropy theory.

- Discharge estimated using the entropy concept depicted good agreement with the measured values.

ABSTRACT

Flow measurement is critical in hydraulic engineering for developing and managing water resources. The mean flow velocity and cross-sectional flow area at the measurement location are two major metrics required for discharge estimation. River bathymetric surveys or advanced technologies such as the Acoustic Doppler Current Profiler (ADCP) might be used to determine the cross-sectional area. The mean flow velocity can be measured using different techniques depending on whether the measurements are taken from a distance (non-contact) or a contact method (traditional approach). Non-contact velocity measuring techniques are becoming increasingly common in recent years since they are less time-consuming and easier to utilize while dealing with heavy flows and inclement weather. One such modern approach is the entropy-based concepts (such as Shannon entropy, Tsallis entropy and Renyi entropy) used to calculate the discharge from non-contact observations, yielding superior results to classic approaches such as the velocity area method. Entropy-based velocity distribution depends on the crucial parameter called entropy parameter (a function of the ratio of the mean and maximum velocity), which is linked to the channel and flow characteristics. Its value is surmised to be constant for a particular river reach. Due to this fact, the entropy-based approach was used in this study to evaluate the discharge in case of the adverse bed slope condition that may arise due to several reasons, and one among them is the excessive mining in the particular river reach. This study collected the experimental velocity data for the mild, horizontal and adverse bed slope conditions from a rectangular flume fitted with a mechanical apparatus to change the bed slope. Results concluded that the mild and horizontal slope conditions depicted only a slight variation in entropy parameter value, i.e., almost constant. The same was adopted for finding the mean velocity for the adverse bed slope condition to calculate the discharge. Furthermore, the discharge error analysis presented a substantial justification for the utilized single constant value of the entropy parameter for the whole cross-section, and the same can be employed for future explorations on the same channel stretch.

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