Factors Affecting Mean Flow Velocity of Overland Flow in a Flume

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1 Introduction

- Mean flow velocity (U_{mean}) of overland flow is determinant hydraulic parameter for hydrological routing and soil erosion modelling.
- Under shallow flow and low discharge estimation is problematic
  - Velocity measurement in general with dye or salt tracer (U_{dye})
  - Empirical correction factor $\alpha = \frac{U_{mean}}{U_{dye}}$ is applied
  - Wider range of α is found in literature for different experimental set-ups

2 Aims

- To assess the influence of
  - Flow rate (Q)
  - Substrate type (D_{50}), and
  - Slope (S)

  on α and on average flow velocity
- To develop a comprehensive equation for estimation of mean flow velocity from dye based estimations

3 Materials and Methods

1 Flume

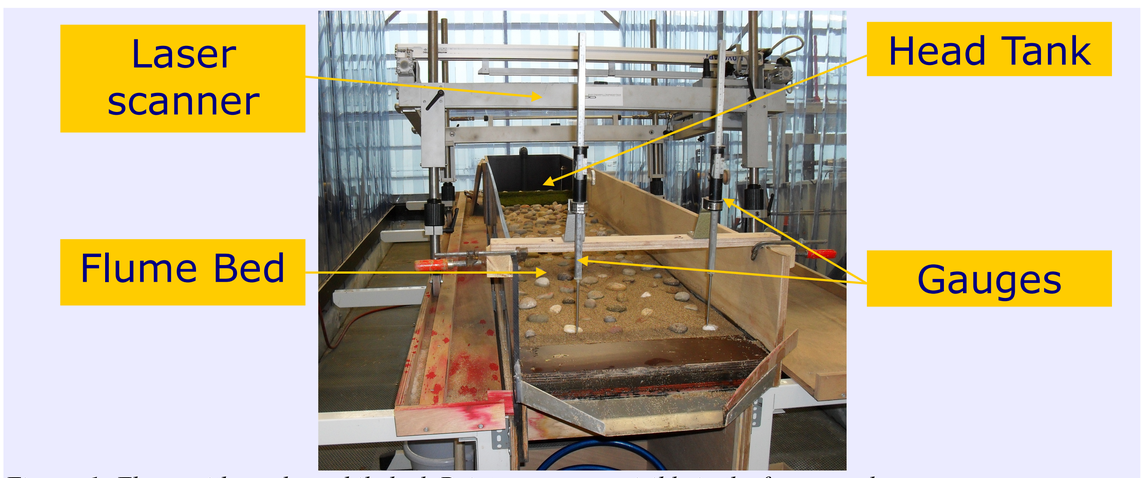

Figure. 1: Flume with sandy, mobile bed. Point gauges are visible in the foreground.

- L=3.0 m long and w=0.5 m wide rectangular (Fig. 1)
- Controlling variables:
  - Flow rates (Q): 33 – 1033 * 10^{-6} m^3 s^{-1}
  - Substrate: Sand (D_{50}) 0.230, 0.536, 0.719 and 1.022 mm
  - Slopes (S): 3°, 5°, 7.5° and 10°

2 Measurements and Data Analysis

- Flow velocity:
  - Lycopene dye tracing over a test length of 1.24 m, 5 replicates
- Average water depth (h):
  - 2 point gauges, 0.1 mm resolution (Fig. 1, right)
- Mean flow velocity (U_{mean}) estimated according to:

$$U_{mean} \approx U_{depth} = \frac{Q}{w * h}$$

- Bed form gathered by laser scanning (Fig. 1)
- Regression analysis with PASW between T_c and controlling variables or composite force predictors

4 Results and Discussion

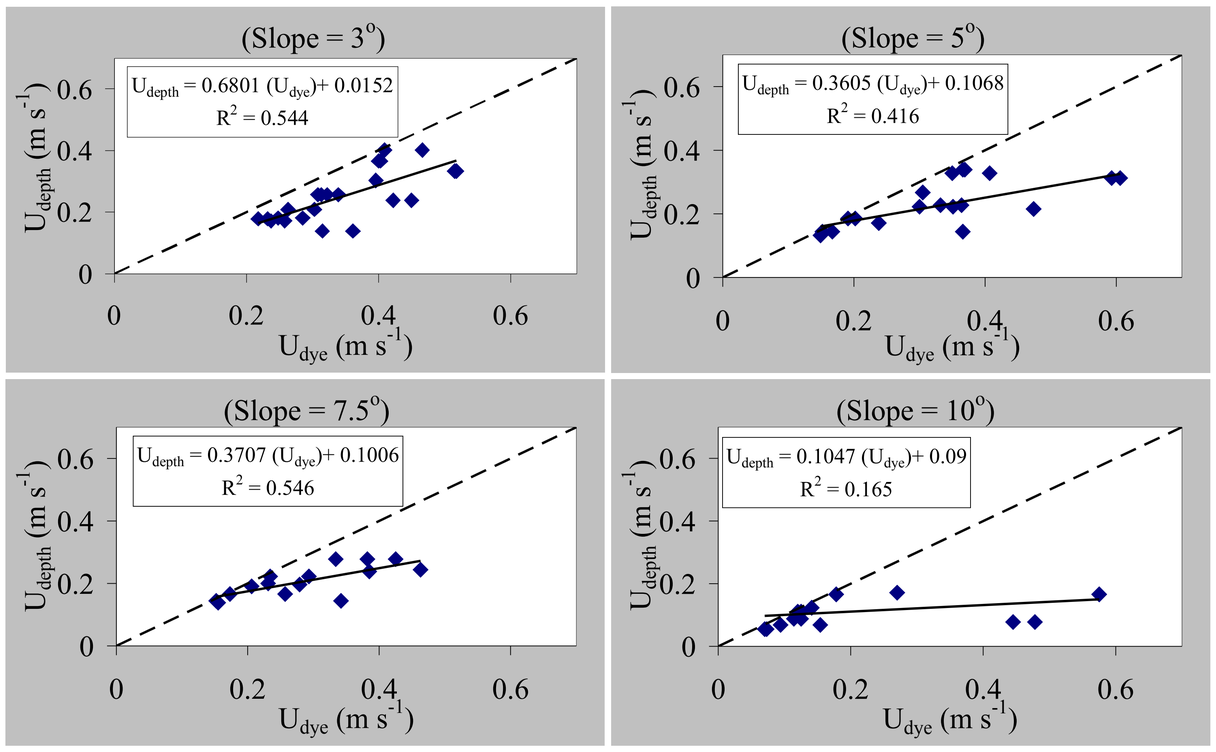

Figure 2a - 2d: Relationship between U_{depth} and U_{dye} for different slopes. (Upper left to lower right)

- Dye velocity (U_{dye}) always higher than estimated mean velocity (U_{mean})
- Effect highest for steep slopes and high velocities
- Effect of slope weak, no correlation with steep slopes

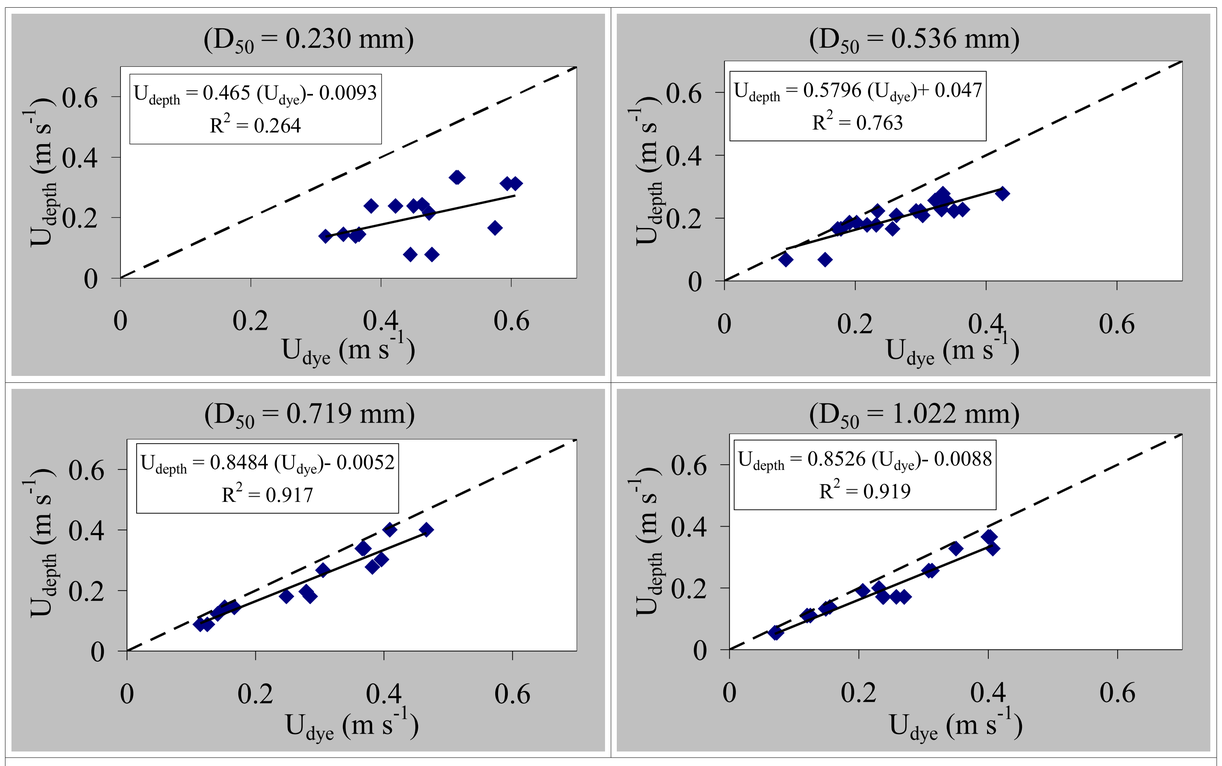

Figure. 3a – 3d:Relationship between U_{depth} and U_{dye} for different substrates (Upper left to lower right).

- Decreasing effect of grain size (Figure 3a – 3d, Table 1)

Table 1: Values for α depending on grain size.

Grain size [mm]	α
0.230	0.44
0.536	0.77
0.719	0.82
1.022	0.82

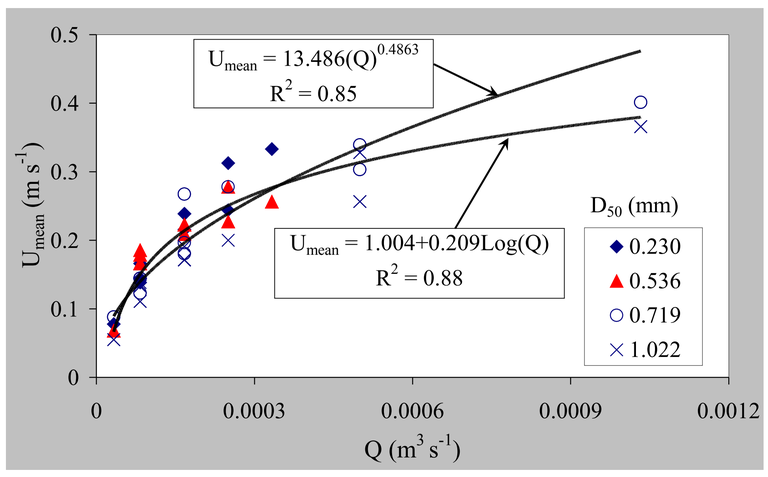

Figure 4: Relation between U_{mean} and Q.

- Good fit of logaritmic function depending for relation of U_{mean} with Q
- Trends towards maximum flow velocity U_{mean}

Table 2: Results from stepwise regression analysis for U_{mean} depending on Q, D_{50} and S

Eq. No.	Equation	R^2
1	$U_{mean} = 13.486 (Q)^{0.4863}$	0.85
2	$U_{mean} = 1.004 + 0.209\, Log(Q)$	0.88
3	$Log(U_{mean}) = 0.645 + 0.506\, Log(Q) - 0.172\, Log(D_{50})$	0.89
4	$U_{mean} = 1.072 + 0.217\, Log(Q) - 57.69 (D_{50})$	0.92
5	$Log(U_{mean}) = 0.646 + 0.502\, Log(Q) - 0.17\, Log(D_{50}) - 0.01 \log(S)$	0.89
6	$U_{mean} = 1.085 + 0.222\, Log(Q) - 59.21 (D_{50}) + 0.001 (S)$	0.92

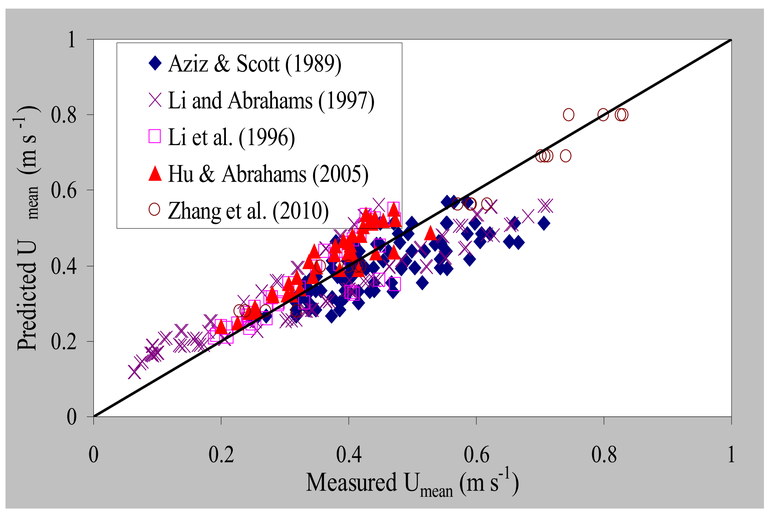

Figure 5: Application of eq. 3 to different data sets of literature.

- Best fit of functions including all variables
- Influence of S very small and can be neglected
- Validation with different datasets from literature shows best fit with eq. 3

5 Conclusions

- No constant relationship between dye tracer velocity (U_{dye}) and mean velocity (U_{mean})
- Clear impact of flow rate (Q) and grain size (D_{50}) on flow velocity
- In mobile beds, slope (S) has only a weak impact on flow velocity, especially as U_{mean} tends to reach a maximum value with increasing Q
- Reasons have to be found in complex interaction of sediment uptake, changes in flow characteristics etc.

6 References

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