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Bed Non-uniformity Effects on the Flow Resistance Equations in High-gradient Streams

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Co-PREPARE
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ABSTRACT

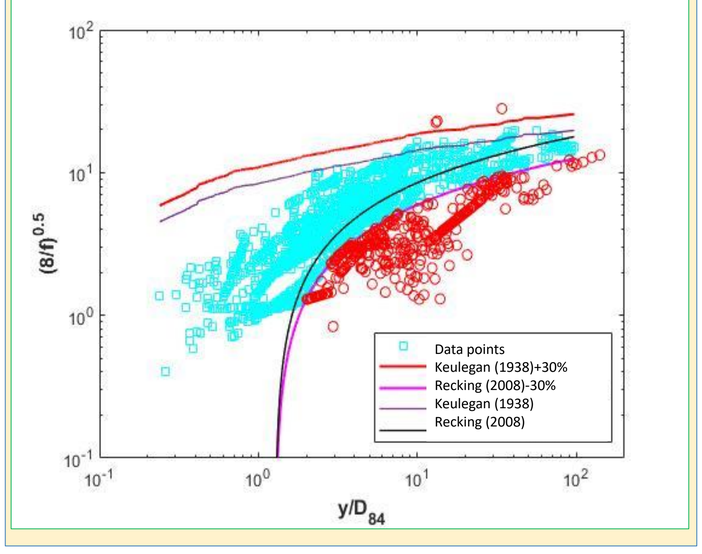
Reach averaged flow velocity estimates in high-gradient streams vary as sediment becomes poorly sorted, probably due to sediment clustering or armoring. Here we present a semi-empirical approach using the ***geometric standard deviation of bed material to calculate the flow velocity***. The high-gradient streams usually contain large clasts, but when particles of size range D_{50}-D_{84} are in a large proportion (poorly sorted), the conventional flow resistance equations must be used with caution to estimate the flow velocity, which is an important hydrometric variable.

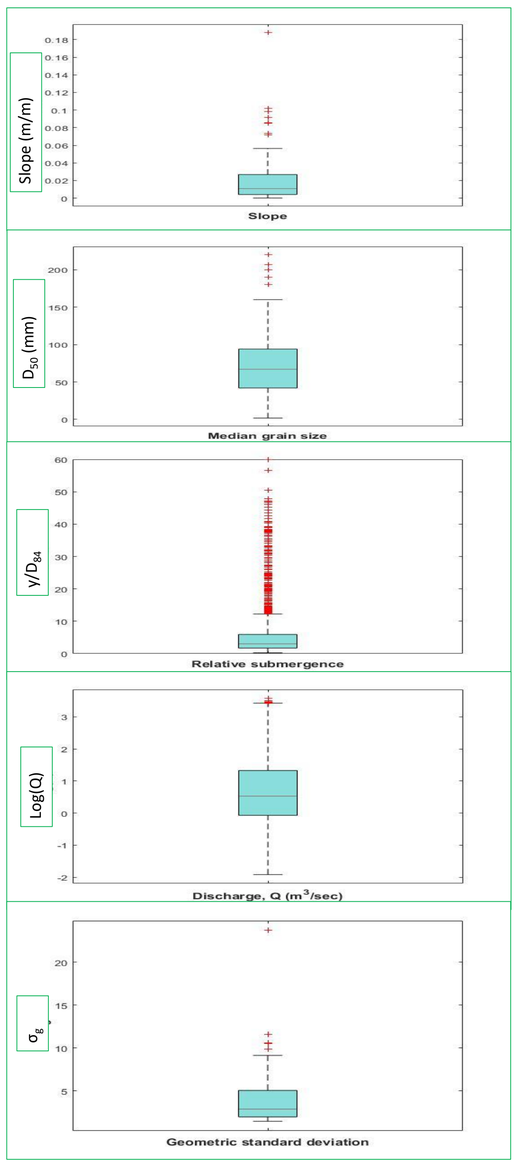
OBJECTIVES

1. **Sediment Sorting**
   To evaluate performances of conventional flow resistance equations for sediment non-uniformity (σ_g)
2. **Active Sediment Transport**
   To test the effects of sediment transport on flow resistance
3. **New Semi-empirical Approach**
   To improve the performances of conventional equations using geometric standard deviation, σ_g as an additional term

DATASET

- **2184 measurements** (Mendicino and Colosimo, 2019; Misset et al., 2019)
- Data shortlisted as per criteria suggested by Rickenmann and Recking (2011)
- Calibration dataset -1530 measurements (~70%)
- Validation dataset- 654 measurements (~30%)





FLOW RESISTANCE EQUATIONS

Strickler (1923) $\sqrt{\frac{8}{f}} = \frac{u}{u_*} = 8.3\left(\frac{y}{D_{90}}\right)^{1/6}$

Keulegan (1938) $\sqrt{\frac{8}{f}} = \frac{u}{u_*} = 6.25 + 5.75\log\frac{y}{D_{50}}$

Hey (1979) $\sqrt{\frac{8}{f}} = \frac{u}{u_*} = 6.25 + 5.75\log\left(\frac{y}{3.5D_{84}}\right)$

Smart and Jäggi (1983) $\sqrt{\frac{8}{f}} = \frac{u}{u_*} = 5.75\left[1 - exp\left(-0.05\frac{y}{D_{90}}.\frac{1}{\sqrt{S}}\right)\right]^{0.5}\log\left(8.2\frac{y}{D_{90}}\right)$

Bathurst (1985) $\sqrt{\frac{8}{f}} = \frac{u}{u_*} = 4 + 5.62\,log\frac{y}{D_{84}}$

Ferguson (2007) $\sqrt{\frac{8}{f}} = \frac{u}{u_*} = \frac{a_1 a_2\left(\frac{y}{D_{84}}\right)}{\sqrt{a_1^2 + a_2^2\left(\frac{y}{D_{84}}\right)^{5/3}}}$

Recking et al. (2008) $\sqrt{\frac{8}{f}} = \frac{u}{u_*} = -1 + 9.5\log\frac{y}{D_{84}}$

Rickenmann and Recking (2011) $\sqrt{\frac{8}{f}} = \frac{u}{u_*} = \frac{4.416\left(\frac{y}{D_{84}}\right)^{1.904}}{\left[1+\left(\frac{y}{1.283D_{84}}\right)^{1.618}\right]^{1.083}}$

BEDLOAD EFFECTS

The measurements characterized by bed load were identified by Shield's stress, Y, with its critical value, Y_{CR}=0.029 (Ackers and White, 1973)

$$Y = \frac{u_*^2}{gD_{84}(G-1)}$$

Equations	Statistical indices	Conventional equations using the whole dataset	
		(Y/Y_c<1) N=1597	(Y/Y_c≥1) N=587
Smart and Jaggi (1983)	RMSE	0.37	0.51
	RMSPE	4.79	7.70
Bathurst (1985)	RMSE	0.45	0.94
	RMSPE	7.39	18.43

NEW MODIFIED EQUATIONS

Modified equation = Conventional equation + $\boldsymbol{f(\sigma_g)}$

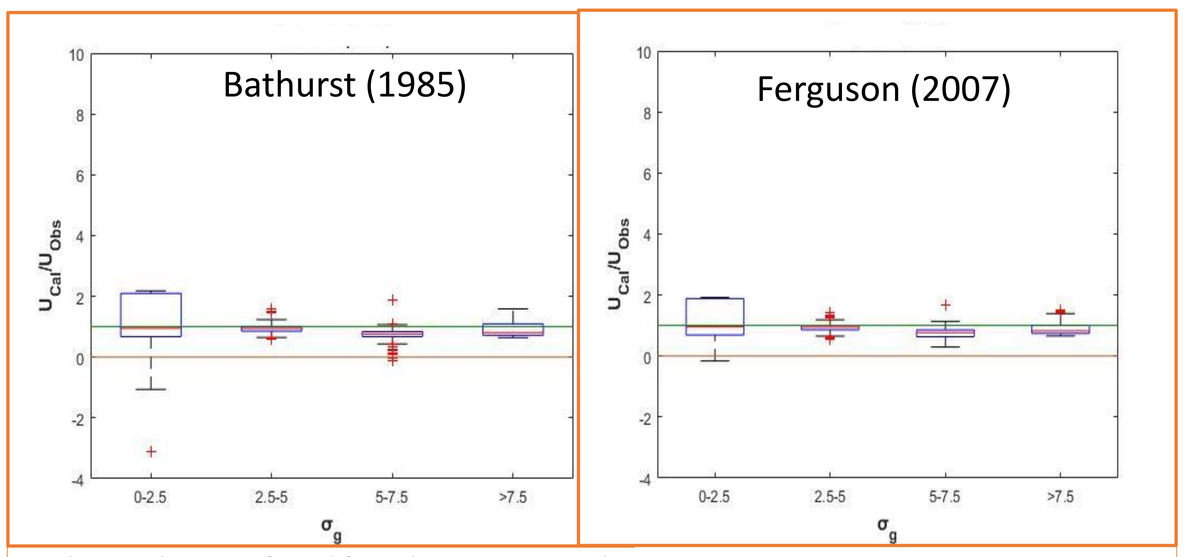
$$\boldsymbol{f(\sigma_g) = a_1(\sigma_g)^{a_2} + a_3}$$

Modified Ferguson (2007) equation would be expressed as:

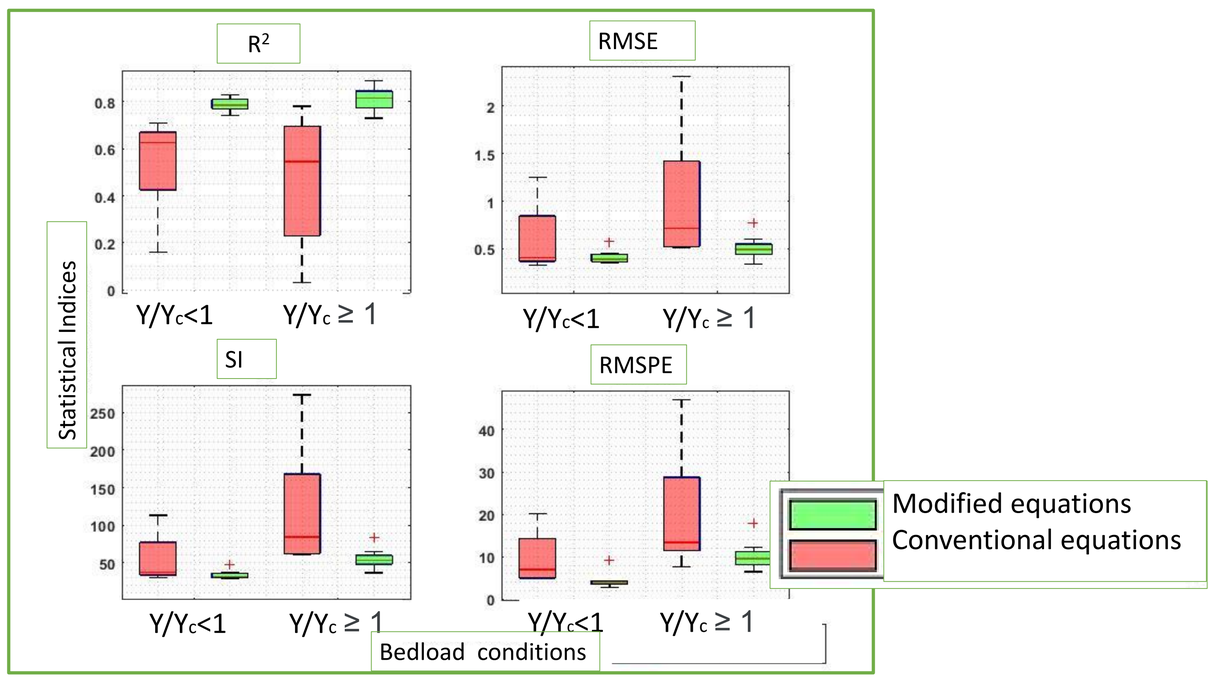
$$\sqrt{\frac{8}{f}} = \frac{u}{u_*} = \frac{a_1 a_2\left(\frac{y}{D_{84}}\right)}{\sqrt{a_1^2 + a_2^2\left(\frac{y}{D_{84}}\right)^{5/3}}} + a_1(\sigma_g)^{a_2} + a_3$$

Minimizing the difference between observed and calculated values ➔ a_1=8.94 , a_2=0.04, a_3= -10

VALIDATION



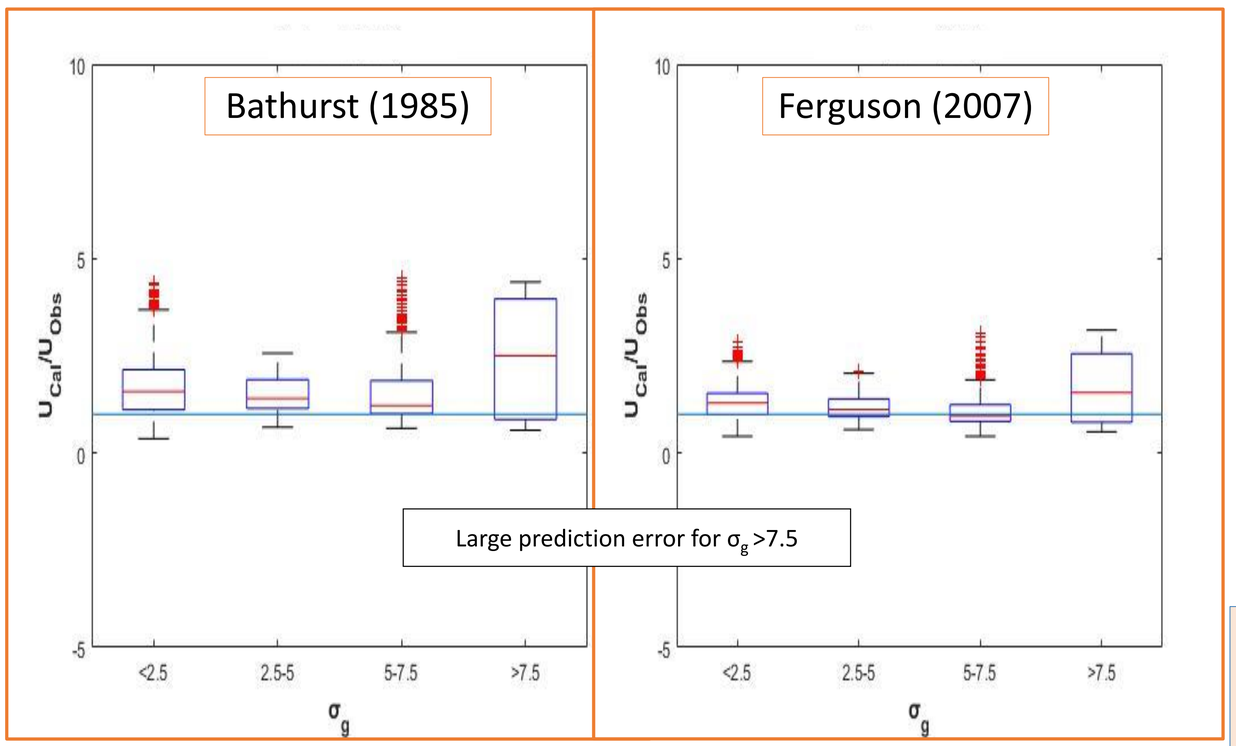
Similar results were found for other equations also



Equation	Conventional Equations		Modified Equations		Δ AIC	Δ BIC
	AIC	BIC	AIC	BIC		
Ferguson (2007)	1179.9	1202.3	1156.1	1191.9	23.8	10.4

Similar results were found for other equations also

SEDIMENT SORTING EFFECTS



Similar results were found for other equations also

CONCLUSIONS

- The conventional equations are **reliable in case of large submergence, uniform bed material and no sediment transport conditions**.
- The modified equations are **capable to consider the additional losses** occurring in case of poorly sorted sediments during bedload transport
- The inclusion of bed statistics, particle arrangement and microtopography of the bed might improve the predictive capability of conventional flow resistance equations.

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