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Morphologic Quantification of River Traversability

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LONG-TERM GOALS

This effort is designed to provide both a database and methodology for the implementation of an expert system for the evaluation of river traversability in denied areas. In such areas, decisions concerning the ability to both navigate and cross rivers may require only a limited set of data that can be obtained remotely. Experience based on existing river systems can help provide rules and guidelines for making traversability decisions based on remotely-sensed data.

OBJECTIVES

The research has two objectives. The first of these is the compilation and digestion of data pertaining to bankfull hydraulic geometry of rivers into a format that can be used for traversability decisions. The second of these is the development of "statistical" hydraulic relations that allow for estimates of the variation of depth etc. in terms of probability of exceedance.

APPROACH

The research approach consists of statistical analysis of available data, combined with a comparison with numerical simulation.

WORK COMPLETED

The work completed to date includes a) the assembly of a large database for the bankfull hydraulic geometry of river, b) the organization of this data into a set of dimensionless graphs delineating hydraulic geometry, and c) the identification of several sets of field data collected with multibeam, which should allow extension of the research to "statistical" hydraulic relations. Parameters in the database include bankfull depth H_{bf}, bankfull width B_{bf}, bankfull discharge Q_{bf} channel slope S and characteristic bed material grain size D.

The database is divided into five subsets below according to characteristic bed material size D in the table below. The set "Parker et al." corresponds to the set for gravel-bed rivers compiled by Parker et al. (2007). The sets "D < 0.062 mm", "0.062 < D < 0.5 mm" and "D > 0.5 mm" were collected for use

in Wilkerson and Parker (in press). The data set "0.062 < D < 0.5 mm, Latrubesse," which pertains to large, tropical rivers, was obtained from Edgardo Latrubesse.

All of the data in Table 1 except "0.062 < D < 0.5 mm, Latrubesse" pertain to bankfull flow in single-channel rivers, for which bankfull discharge has been obtained independenty (e.g. from direct measurement or rating curves, rather than applying a Manning-type equation to measured values of H_{bf}, B_{bf} and S. The Latrubesse data refers to large tropical rivers, which usually show low bend sinuosity and at least some degree of island formation,

Table 1

Data set name	No. of points	Minimum D (mm)	Maximum D (mm)
D < 0.062 mm	6	0.02	0.062
0.062 < D < 0.5 mm	47	0.094	0.50
0.062 < D < 0.5 mm Latrubesse	15	0.20	0.40
D > 0.5 mm	84	0.52	25
Parker et al.	72	27	168

RESULTS

The primary parameters governing bankfull geometry are characteristic bed sediment size D, bankfull depth H_{bf}, bankfull width B_{bf}, channel bed slope S and bankfull discharge Q_{bf}. The following parameters also play roles: kinematic viscosity of water ν, acceleration of gravity g and sediment submerged specific gravity R, where $R = (\rho_s/\rho) - 1$, ρ_s is sediment density and ρ is water density. Dimensionless bankfull depth $\widetilde{H}$, bankfull width $\widetilde{B}$, bankfull discharge $\hat{Q}$ and grain size D^* are defined as follows:

$$\widetilde{H} = \frac{g^{1/5} H_{bw}}{Q_{bw}^{2/5}} \quad , \quad \widetilde{B} = \frac{g^{1/5} H_{bw}}{Q_{bw}^{2/5}} \quad , \quad \widetilde{Q} = \frac{Q_{bf}}{\sqrt{RgD}\, D^2} \quad , \quad D^* = \left(\frac{\sqrt{RgD}\, D}{\nu} \right)^{2/3} \qquad (1a,b,c,d)$$

The above parameters and bed slope S constitute the relevant dimensionless parameters.

In addition, it is useful to define an estimate of a dimensionless Shields τ_{bf}^* number characterizing the mobility of bed sediment at bankfull flows. To do this, the bed shear stress at bankfull flow τ_{bbf} is estimated from the applicable relation for steady, uniform normal flow:

$$\tau_{bbf} = \rho g H_{bf} S \qquad (2)$$

The bankfull Shields number is then given as

$$\tau_{bf}^* = \frac{\tau_{bbf}}{\rho R g D} = \frac{H_{bf} S}{RD} \qquad (3)$$

Here we choose $\hat{Q}$ and D^* as independent variables, and seek relations of the form

$$\tilde{H} = f_H\left(\hat{Q}, D^*\right) \quad , \quad \tilde{B} = f_H\left(\hat{Q}, D^*\right) \quad , \quad S = f_H\left(\hat{Q}, D^*\right) \quad , \quad \tau^*_{bf} = f_H\left(\hat{Q}, D^*\right) \qquad \text{(4a,b,c,d)}$$

The above relations cannot be expected to be complete. For example, direct account is given neither of supply of bed material supply and the supply of washload; both are necessary in order to construct the channel-floodplain necessary to define channel geometry. In addition, significant scatter can also be expected due to varying measurement techniques.

Relations of the form of (4) are best expressed in 3D graphics. Here that has been done using Matlab, While the plots in Matlab can be freely rotated by the user, only screenshots given here. The respective plots for $\tilde{H}$, $\tilde{B}$, S and τ^*_{bf} are given in Figures 1a ~ 1d below.

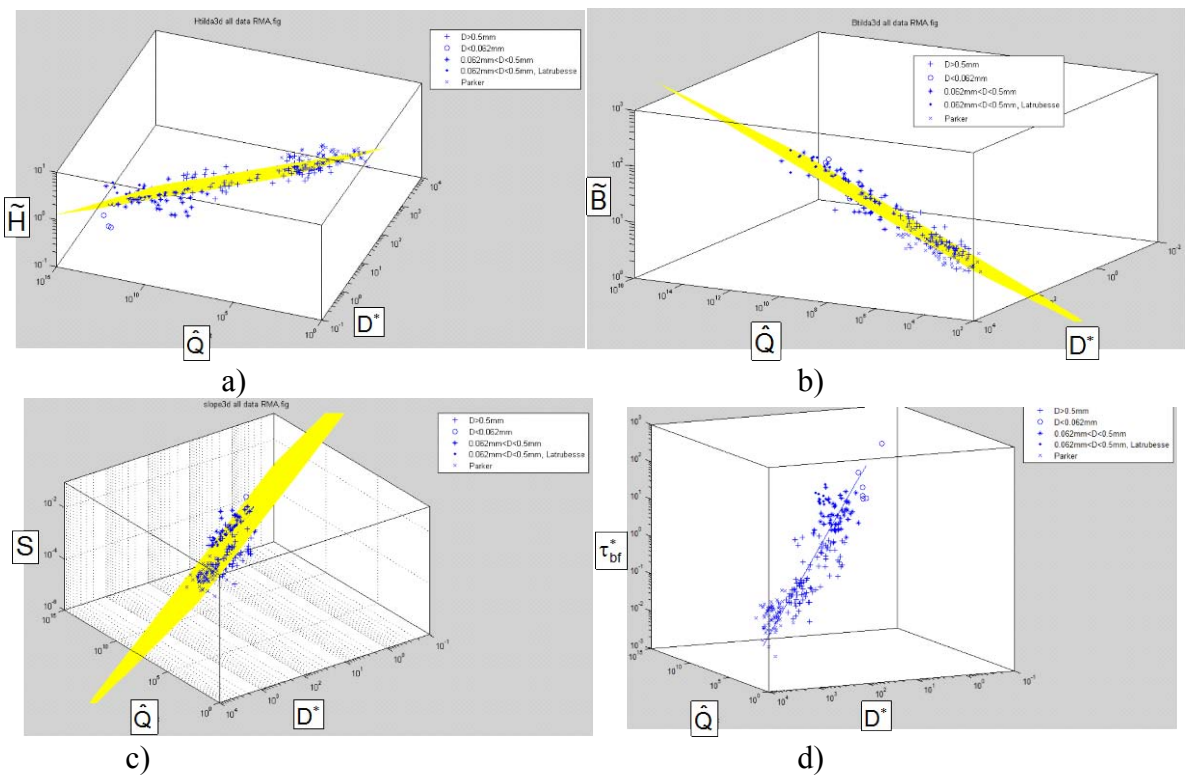

Figure 1: Bankfull hydraulic relations for a) depth, b) width, c) bed slope and d) Shields number.

In all cases, Reduced Major Axis regression is being used to determine the best-fit regression forms for the data as a whole, and for subsets defined according to e.g. grain size ranges. The yellow planes shown in Figures 1a, b and c and the line in Figure 1d denote the results of regression.

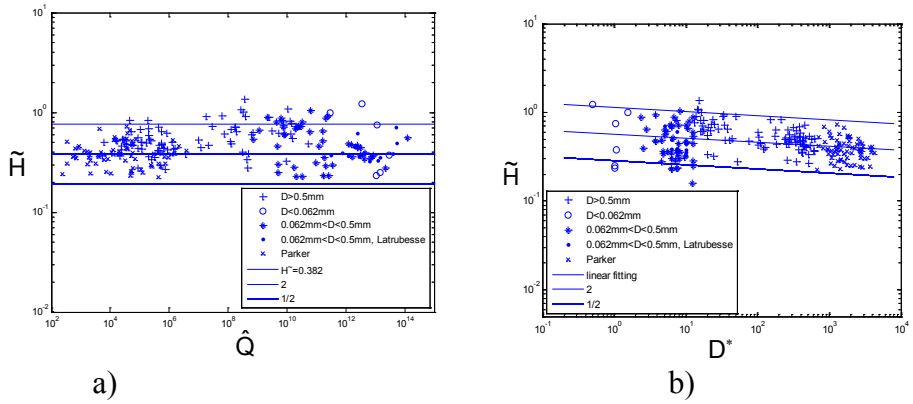

Figure 2. a) Projection of Figure 1a onto the $\widetilde{H} - \hat{Q}$ ***plane. b) Projection of Figure 1a onto the*** $\widetilde{H} - D^*$

Figure 2 shows some relatively simple behavior. Within the substantial scatter of the data. $\widetilde{H}$ shows little dependence on $\hat{Q}$, implying that $H_{bf} \sim Q_{bf}^{2/5}$. In addition, over 5 decades of D^*, the parameter $\widetilde{H}$ shows a tendency to decline only weakly in D^*.

IMPACT/APPLICATIONS

The results obtained in Figures 1a and 2a,b are of particular interest to riverine traversability, as they pertain to channel depth. The author is working with N. Plant to incorporate this information into an expert system.

RELATED PROJECTS

The author is presently collecting detailed data on bed topograpy from D. Parsons, D. Mohrig, J. Best obtained with multibeam applied to large rivers. In addition, he is working with M. Hicks to obtain similar data for smaller, gravel-bed rivers. The goal is to go one step beyond, and predict statistical quantities related to traversability of rivers at a variety of flows.

REFERENCES

Parker, G., P. R. Wilcock, C. Paola, W. E. Dietrich, and J. Pitlick (2007), Physical basis for quasi-universal relations describing bankfull hydraulic geometry of single-thread gravel bed rivers, *J. Geophys. Res.*, *112*, F04005, doi:10.1029/2006JF000549.

Wilkerson, G. V. and Parker, G. (in press), "Physical basis for quasi-universal relations describing bankfull hydraulic geometry of sand-bed rivers, *J. Hydraul. Engrg.*