HYDRAULIC GEOMETRY EXPLAINS INACCURACIES IN EMPIRICAL CORRELATION FOR ESTIMATING FLUVIAL DISCHARGE ON MARS. R. E. Jacobsen[1] and D. M. Burr[1], [1]University of Tennessee, Knoxville, TN USA 37996 (RJacobse@vols.utk.edu and dburr1@vols.utk.edu).

Summary: Fluvial discharge (Q, m^3s^{-1}) is used in martian landscape erosion models, some with implications for ancient climate [e.g., 1], and in landing site evaluations [2]. On Earth, river discharge data from the Missouri River Basin (MRB) have been empirically correlated to channel widths (W, m) yielding Correlation 1a in Table 1 [3]. This empirical correlation has been scaled for the putative effect of gravity [4,5] yielding Correlation 1b, which has been repeatedly used to estimate discharge on Mars [e.g., 2,4-7].

Table 1: Form-discharge correlations

1a	Missouri River Basin [3]	Q = 1.8W^1.22
1b	Martian correlation [4]	Q = 1.37W^1.22

Table 2: Hydraulic geometry relationships

2a	Konsoer et al. 2013 [8]	W = 3.73Q^0.524
2b	algebraic inverse of 2a	Q = 0.08W^1.908
3a	Eaton 2013 [9]	W = 3.35Q^0.536
3b	algebraic inverse of 3a	Q = 0.10W^1.866

Submarine channels flowing in reduced-gravity follow similar width-discharge trends as terrestrial channels [8], suggesting that gravitational scaling of empirical correlations may be unnecessary. Here, we examine Correlation 1a from the MRB and compare it with hydraulic geometry relationships (2a and 3a in Table 2). We find differences that lead us to doubt the suitability of Correlation 1a for estimating discharge outside the MRB. Using a Martian-terrestrial analog river, we continue [10] to compare discharge estimates from Correlation 1a and algebraically manipulated versions of Relationships 2a & 3a. Our findings suggest empirical relationships from hydraulic geometry, instead of from form-discharge correlations, are more suitable for estimating paleodischarge on Mars.

Hydraulic Geometry: Hydraulic geometry studies the cause-effect relationships between fluvial discharge (i.e., independent variable) and channel width, depth, and flow velocity (i.e., dependent variables) [11]. Fluvial channels of various sizes and sediment characteristics are empirically compared by their channel-forming discharges. In general, the best approximation of the channel-forming discharge is the bankfull discharge, or flow filling the channel [12, p. 167]. Flows larger than bankfull expand across the floodplain and do not substantially increase shear stress, which works to shape the channel [9,12]. Bankfull channel width is measured between levee crests on opposing channel banks [8,11].

Figure 1 shows two hydraulic geometry datasets [from 8 & 9] and the form-discharge dataset from the MRB [3]. Hydraulic geometry data are bankfull widths and discharges from channels with a wide range of median grain sizes (<0.062 mm to >25 mm), located throughout the US and Canada, and some in Europe, S. America, and Asia [8,9]. Linear regression derives power-law relationships with remarkably similar exponents (2a & 3a, Table 2). Empirical relationships derived from samples with low variation may be manipulated algebraically [13] into relationships that estimate discharge from channel width, such as 2b & 3b.

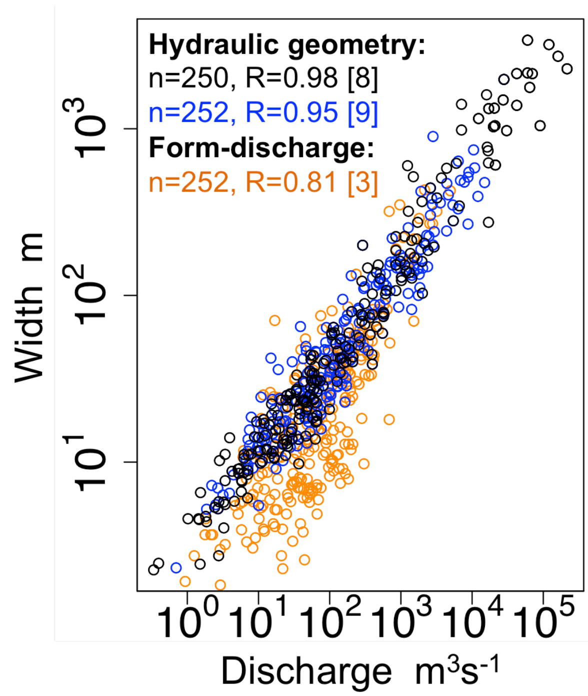

Figure 1: Hydraulic geometry data (black and blue circles) represent bankfull discharges and widths. Form-discharge data (orange cirlces) represent Q2yrs and active channel widths.

Form-discharge: The form-discharge data differ from those of hydraulic geometry in several ways.

(1) The form-discharge data are more geospatially limited (i.e., MRB) and sample fewer orders of magnitude of width and discharge than the hydraulic geometry data (Figure 1).

(2) The form-discharge data have greater variation relative to a linear trend (R values in Fig. 1) and appear below the trend of hydraulic geometry data. We attribute this offset to two differences in sampling. (i) Discharge data are flows with a recurrence interval of

2 years (Q2yr) rather than bankfull discharges used in hydraulic geometry. The Q2yr may be *greater than* the bankfull discharge [e.g., 14], causing form-discharge data to plot to the right of hydraulic geomtery data in Figure 1. (ii) Width data are active channel widths rather than bankfull widths used in hydraulic geometry. Active channel width is the distance between opposing breaks in bank slope and the edges of permanent vegetation [3]. As described in the original analysis [3], active channel width is *less than* bankfull width [Figure 1 in 3], causing form-discharge data to plot lower than the hydraulic geometry data in Figure 1.

(3) Form-discharge analysis of MRB data is purely correlation and not based on caustion because the dependent variable (width) was used to explain the independent variable (discharge) [3].

(4) The form-discharge exponent (1.22) is unusual, in that, when algebraically manipulated by taking the inverse (1.22^-1 = 0.82), this exponent implies changes in discharge are accommodated, nearly entirely, by changes in width, rather than also by depth and velocity. This manipulated exponent is unlike many exponents of hydraulic geometry (~0.5) [cf. 8,9,11,12].

Quinn River, NV: Morphology and discharge data from the Quinn River, NV – a Martian-terrestrial analog river [15] – provide opportunities to examine the accuracy of the form-discharge correlation (1a). The Quinn River is a suitable analog because its banks generally lack rooted vegetation, but are stabilized by Late Pleistocene lacustrine silt and clay [15]. Table 3 compares bankfull conditions from *in-situ* measurements and modeling [16] with our remote estimates.

Table 3: Bankfull conditions of Quinn River, NV

Variable	[from 16]	this study
Discharge, Q	11.9 m^3s^{-1}	31.6 m^3s^{-1}
Width, W	20.1 m	19.7 m
Cross-sectional Area, *A*	25.78 m^2	25.15 m^2
Hydraulic radius, *R*	1.32 m	1.27 m
Mean velocity, *U*	0.46 ms^{-1}	1.26 ms^{-1}
Roughness coef. *f*	0.008	[from 16]
Slope, *S*	[see 16]	0.00014

Analysis: We measure bankfull width by measuring the distance between the cut bank and the crest of the point bar on the inner bank, as it appears in 1-m airborne LiDAR topography [from 16]. Then, we estimate bankfull discharge by multiplying (i) the channel cross-sectional area and (ii) flow velocity, as estimated from the Darcy-Weisbach equation, $U=(8gRS/f)^{½}$. Finally, we compare discharge estimates from the form-discharge correlation (1a) and the manipulated hydraulic geometry relationships (2b & 3b).

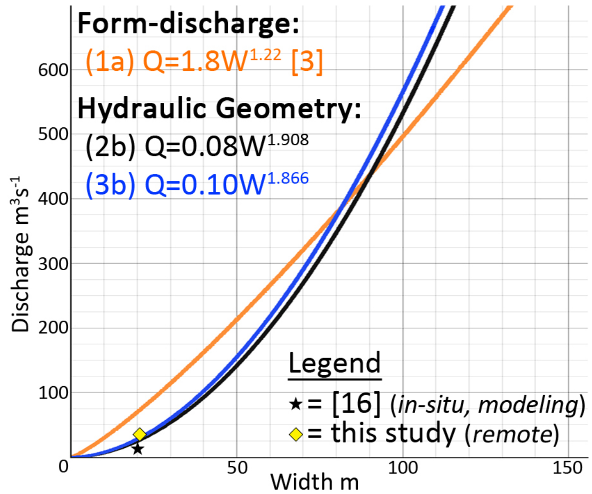

Figure 2: Bankfull width and discharge data (Table 3) for the Quinn R. are compared to the form-discharge correlation (1a) and hydraulic geometery relationships (2b & 3b).

Results: Remote measurements of bankfull width and discharge are 19.7 m and 31.6 m^3s^{-1}, respectively. When width is coupled with the form-discharge correlation, it yields a discharge of 68.3 m^3s^{-1}, and the manipulated hydraulic geometry relationships 2b & 3b give discharges of 24 m^3s^{-1} & 27.3 m^3s^{-1}, respectively.

Discussion: The form-discharge relationship, often scaled and applied to Mars, *over-estimates* discharge in the Martian-terrestrial analog channel. Hydraulic geometry relationships also *over-estimate* dischare but are more consistent with *in-situ* & modeling estimates [16]. The inaccuracy of the form-discharge relationship may be from differences in sampling compared to hydraulic geometry. Based on these findings, we conclude that manipulated hydraulic geometry relationships (2b & 3b) provide more accurate estimates of paleodischarge on Mars.

Acknowledgements: We thank Brett Eaton, Kory Konsoer, and Gary Parker for hydraulic geometry data.

References: [1] Barnhart et al. (2009) *JGR: Planets, 114*(E1). [2] Irwin et al. (2015) *Geomorph.*, 240. [3] Osterkamp & Hedman (1982) *USGS Prof. paper* 1242.[4] Irwin et al. (2005) *Geology, 33*. [5] Burr et al. (2010) *JGR: Planets, 115*(E7). [6] Howard & Moore (2011) *JGR: Planets, 116*(E5). [7] Williams & Weitz (2014) *Icarus, 242*. [8] Konsoer et al. (2013) *JGR: Earth, 118*(E1). [9] Eaton (2013) *Treatise Geomorphology*, 9. [10] Jacobsen & Burr (2015) *GSA Mtg*, Abs. 190-9. [11] Leopold & Maddock (1953) *USGS Prof. paper* 252. [12] Knighton (1998) *Fluvial form & process*. [13] Williams (1983) *Geology*, 11. [14] Williams (1978) *WRR*, 14. [15] Matsubara et al. (2015) *Geomorph.*, 240. [16] Matsubara & Howard (2014) *EPSL*, 39.