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Small profile concavity of a fine-bed alluvial channel

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θ Range of Natural Streams (Including Both Bedrock and Alluvial Channels)

We collected θ data from a wide range of literature covering both bedrock and alluvial channels. The range spans from 0.11 to 2.1, with mean and standard deviation as 0.63 and 0.33, respectively (TABLE DR1).

θ Range of Bedrock Channels at Equilibrium State under Spatially Uniform Uplift Rate Regions

We collected θ for bedrock channels, which are reported to be at steady-state under spatially uniform uplift rate region (Snyder et al., 2000; Kirby and Whipple, 2001). Mean and standard deviation are obtained as 0.43 and 0.08 (TABLE DR2).

Ranges and Two Moments of the Scaling Exponents

Two process parameters α and β are known to range mostly between 1 and 2 (Prosser and Rustomji, 2000; Peckham, 2003; Paik, 2012). For their distributions, we adopted μ_α=μ_β=1.5 and σ_α=σ_β=0.25. Recall that we have three geomorphic parameters (n, h, and p) originated from aforementioned scaling relationships. For n, we used μ_n=0.0667 and σ_n=0.0135, given by Parker et al. (2007). h is empirically found to be between 0.5 and 0.7 (Hack, 1957; Gray, 1961; Robert and Roy, 1990; Crave and Davy, 1997). Here, μ_h=0.6 and σ_h=0.05 were used. p varies between 0.3 and 0.9 (Brierley and Hickin, 1985) (TABLE DR3), and we adopted μ_p=0.6 and σ_p=0.2. Finally, the last parameter of γ is typically less than 1 but no less than 0.5 when it comes to the dominant discharge. We used μ_γ=0.77 and σ_γ=0.09, estimated from literature (TABLE DR4). Physically unrealistic parameter ranges, i.e., $\alpha < 0$, $\beta < 0$, $\gamma < 0$, $\gamma > 1$, $h < 0$, and $p < 0$, were truncated from the Gaussian distributions.

Analysis of Four Alluvial Rivers

Longitudinal profiles and area-slope relationships have been extracted from DEM for the Minnesota and the Sugar-Wabash Rivers in Midwest USA (Figure DR1). The same analysis was repeated for the Gwda-Noteć (Poland) and the Neman (Lithuania) Rivers in northern Europe (Figure DR2). The analysis was implemented using TopoToolbox (Schwanghart and Kuhn, 2010) software in the following procedure. Italic terms in parentheses are the name of functions in TopoToolbox.

(A) Preprocessing DEM

We first filled sinks (depression cells) in the DEM (*fillsinks*). Then flow directions were assigned based on the D8 algorithm (*FLOWobj*) and flow accumulation was calculated (*flowacc*) on the filled DEM, sequentially.

(B) Selection of channel reaches

In this analysis, we defined a DEM cell of which upslope area equals 100 cells (approximately 0.64 km^2) as channel head. This criterion has been consistently applied for four study rivers. Accordingly, flow paths extracted from DEM are pruned (*STREAMobj*) and specific reaches for which longitudinal profiles are extracted were selected (*modify*).

(C) Drawing longitudinal profiles

Longitudinal profiles were drawn for each selected reach (*plotdz*). Raw DEM was used in the drawing and hence sinks are shown in profiles (Figure 3). The sink-filled DEM was only used for flow direction extraction.

(D) Plotting area-slope relationships

Local slope at each cell was calculated with the distance to the downstream cell of 30 m vertical drop (*slopearea* with ‘drop’ option). After a couple of trial-and-error, this criterion was found appropriate to prevent negative slope due to sinks in DEM. This criterion was consistently used for all four study rivers.

Figure

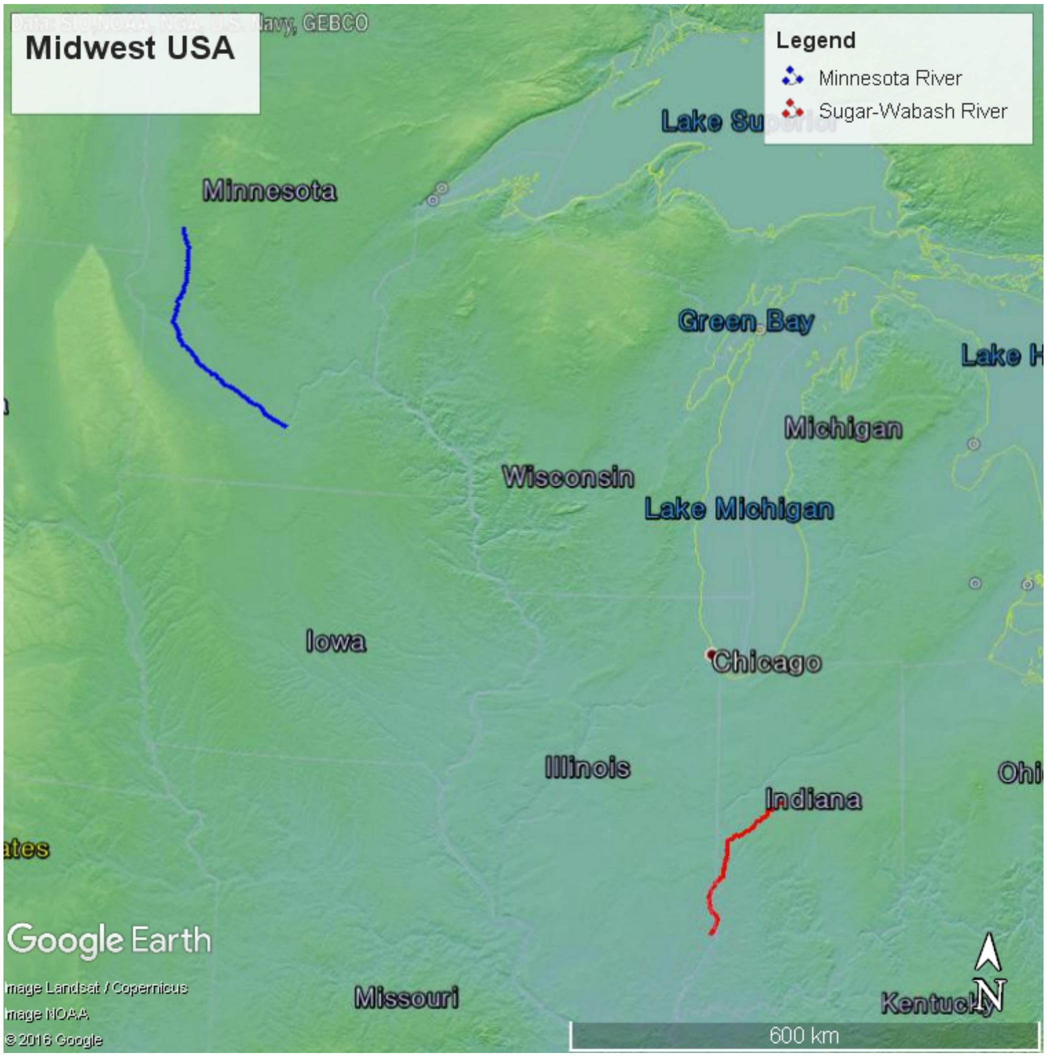

Figure DR1. Location of the Minnesota and the Sugar-Wabash Rivers in Midwest USA

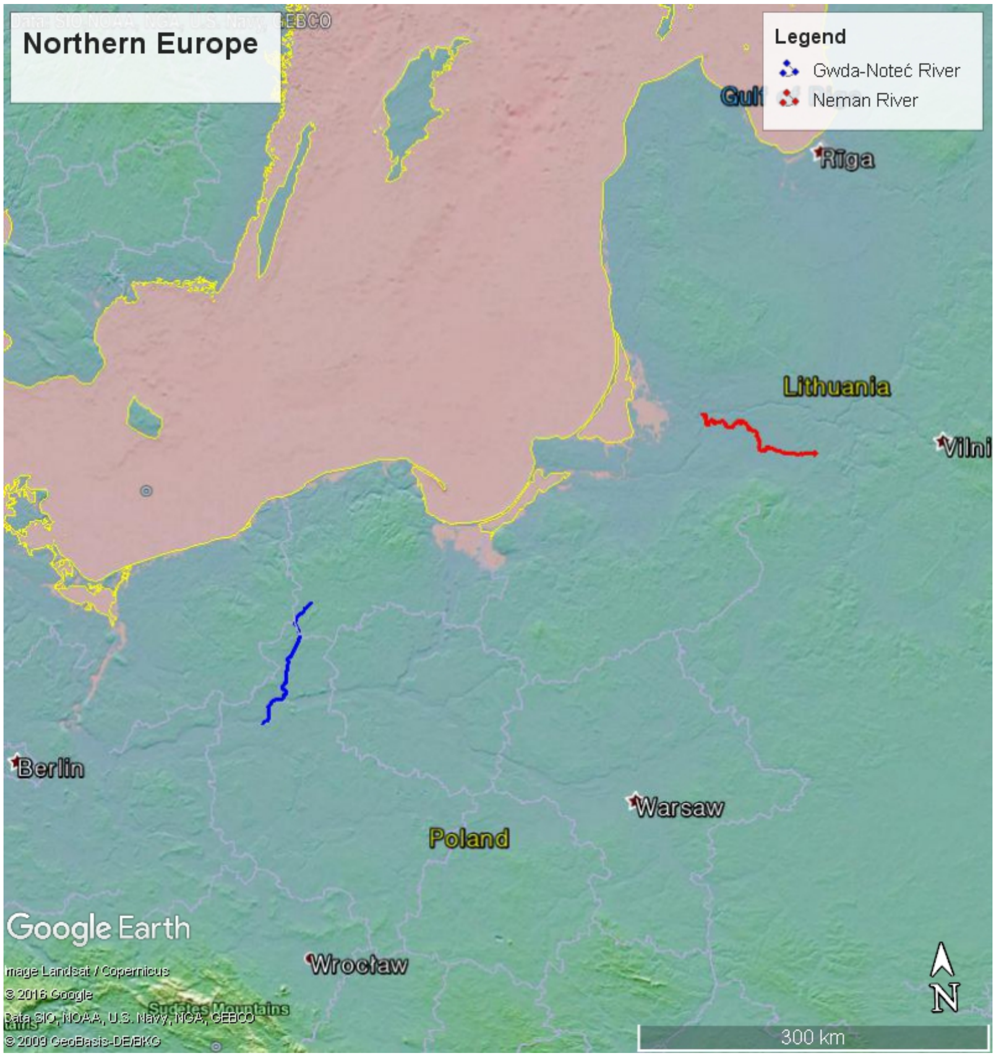

Figure DR2. Location of the Gwda-Noteć (Poland) and the Neman (Lithuania) Rivers in northern Europe

TABLE

TABLE DR1. PROFILE CONCAVITY DATA FROM LITERATURE.

Location	θ
Middle River, Appalachians, Virginia (three branches)[*]	0.64, 0.59, 0.49
North River, Appalachians, Virginia (four branches)[*]	0.43, 0.47, 0.56, 0.52
Montgomery Fork, Tennessee[†]	0.37
Watson Creek, Ohio[†]	0.58
Left Fork, Washington and Virginia[†]	0.78
Grovers Creek, Kentucky[†]	0.52
Bear Branch, Kentucky[†]	0.65
Cooks Run, Pennsylvania[†]	0.56
Hawes Fork, Kentucky[†]	0.83
West Bays Fork, Kentucky[†]	0.40
Flat Creek, Kentucky[†]	0.63
McGills Creek, Kentucky[†]	0.59
Brush Run, Pennsylvania[†]	0.70
Virginia Badlands[§]	0.15
Utah Badlands[§]	0.19
Great Plains[§]	0.20
Ephemeral, New Mexico (two channels)[§]	0.15, 0.11
Walnut Gulch, Arizona (three sub-basins)[#]	0.30, 0.29, 0.25
Big Creek, Idaho (two sub-basins)[#]	0.51, 0.48
North Fork Cour d'Alene River, Idaho[#]	0.47
St. Joe River, Idaho (two sub-basins)[#]	0.47, 0.56
St. Regis River, Montana (two sub-basins)[#]	0.55, 0.55
Schoharie Creek, New York (three sub-basins)[#]	0.48, 0.42, 0.43
East Delaware River, New York[#]	0.55
Racoon Creek, Pennsylvania (two sub-basins)[#]	0.51, 0.34
Beaver Creek, Pennsylvania and Ohio[#]	0.34
Buck Creek, northern California[#]	0.48
Brushy Creek, Alabama[#]	0.53
Moshannon Creek, Pennsylvania[#]	0.58
Montgomery Fork, Tennessee[#]	0.85
Siuslaw, Umpqua, and Alsea River basins, southern coastal Oregon[**]	1.00
Mahantango Creek, Pennsylvania[††]	0.49
Central Zagros Mountains, Iran[††]	0.42
Upper Noyo River, California (seven sub-basins)[§§]	0.89, 0.56, 0.65, 0.83, 1.13, 0.59, 0.67
Coastal basins, northern California (21 basins)[##]	0.37, 0.29, 0.58, 0.43, 0.45, 0.44, 0.41, 0.40, 0.58, 0.25, 0.36, 0.39, 0.31, 0.47, 0.42, 0.37, 0.52, 0.48, 0.46, 0.59, 0.36
Waipaoa River, New Zealand (five sub-basins)[***]	0.61, 0.53, 0.49, 0.55, 0.57
Southern Sierra Madre Occidental, Mexico (11 rivers)[†††]	0.24, 0.52, 0.63, 0.35, 0.74, 0.53, 0.42, 0.53, 0.35, 0.85, 0.19
Santa Ynez Mountains, coastal California (50 channels)[§§§]	0.58, 0.35, 0.48, 0.41, 0.67, 0.53, 0.40, 0.34, 0.97, 0.51, 1.60, 0.65, 0.62, 1.10, 0.87, 0.85, 0.74, 0.87, 1.80, 2.10, 0.89, 0.72, 0.86, 0.92, 0.54, 0.60, 0.55, 0.38, 1.20, 0.71,

	0.40, 1.90, 1.60, 1.20, 0.90, 0.76, 0.58, 0.97, 0.81, 0.77, 0.88, 0.69, 0.54, 0.55, 0.37, 0.56, 0.54, 0.55, 0.58, 1.00
Eastern Central Range, Taiwan (16 rivers)[###]	0.77, 0.78, 0.72, 1.54, 1.41, 1.30, 0.54, 1.01, 0.96, 0.78, 0.94, 0.90, 0.65, 0.95, 0.95, 0.52

[*] Hack (1957). For the calculated θ values, refer to Tucker and Whipple (2002).
[†] Flint (1974).
[§] Howard (1980). Each θ was calculated assuming that Hack's exponent is 0.6.
[#] Tarboton et al. (1991).
[**] Seidl and Dietrich (1992).
[††] Tucker (1996). Refer to Tucker and Whipple (2002).
[§§] Sklar and Dietrich (1998)
[##] Snyder et al. (2000).
[***] Whipple and Tucker (2002).
[†††] Montgomery and López-Blanco (2003)
[§§§] Duvall et al. (2004).
[###] Stolar et al. (2007).

TABLE DR2. PROFILE CONCAVITY DATA FOR BEDROCK CHANNES AT EQUILIBRIUM STATE UNDER THE SPATIALLY UNIFORM UPLIFT AREAS.

Location and Reference	Fitted θ
Basin names of the measured channels in the Mendocino triple junction region, northern California (Snyder et al., 2000)	
Singley	0.37
Davis	0.29
Fourmile	0.58
Cooskie	0.43
Randall	0.45
Spanish	0.44
Oat	0.41
Kinsey	0.40
Big	0.58
Big Flat	0.25
Shipman	0.36
Buck	0.39
Gitchell	0.31
Horse Mtn.	0.47
Telegraph	0.42
Whale	0.37
Jackass	0.52
Hardy	0.48
Juan	0.46
Howard	0.59
Dehaven	0.36
Davis	0.43
Channels in the Siwalik Hills in central Nepal[*] (Kirby and Whipple, 2001)	
14	0.50
15	0.47
16	0.48
17	0.51
18	0.44
19	0.34
20	0.51
Averaged θ value	
	0.43±0.08

[*] Data for only the bedrock channels flowing parallel to the strike of the anticline, thereby under the spatially uniform uplift rate regions. Numbers refer to channels in Kirby and Whipple (2001)'s Data Repository Table DR1 and Figure DR1.

TABLE DR3. REPORTED p VALUES FOR THE POWER FUNCTIONAL DOWNSTREAM FINING EQUATION (THE SQUAMISH RIVER, CANADA, FITTED WITH MEDIAN GRAIN SIZE) (Brierley and Hickin, 1985)

Location and Type	p
Braided Reach	0.79
Meandering Section	0.76
Within the Canyon	0.38

TABLE DR4. REVIEWED RELATIONS BETWEEN DISCHARGE OF A GIVEN FREQENCY OF OCCURRENCE AND UPSTREAM CONTRIBUTING AREA ($Q \propto A^{\gamma}$)

γ	Corresponding flow frequency	Location and Reference
~1	Average annual discharge	Potomac River basin, USA (Hack, 1957)
0.895	Bankfull discharge	High-elevation basins in Colorado, USA (Segura and Pitlick, 2010)
0.85	Mean annual flood discharge ($Q_{2.33}$)	New England, USA (Benson, 1962)[*]
0.80	Mean annual flood discharge ($Q_{2.33}$)	Pennsylvania, USA (Brush, 1961)
0.78	Mean annual flood discharge ($Q_{2.33}$)	River Trent, England (Knighton, 1987)[*]
0.77	Mean annual flood discharge ($Q_{2.33}$)	British Isles, (NERC, 1975)[*]
0.74	Mean annual flood discharge ($Q_{2.33}$)	Great Britain, (Nash and Shaw, 1966)[*]
0.70	Annual maximum flood peak discharge	Pennsylvania and New Jersey, USA (Aron and Miller, 1978)[†]
0.62	Average annual peak discharge	Kentucky, USA (Sólyom and Tucker, 2004)
0.57	~90th Percentile unit discharge[§]	USA and Puerto Rico, (O'Connor and Costa, 2004)
0.53	~99th Percentile unit discharge[§]	USA and Puerto Rico, (O'Connor and Costa, 2004)

[*] Cited in Knighton (1999).

[†] Cited in Snow and Slingerland (1987).

[§] Peak discharge divided by drainage area.

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