Does discharge variability control alluvial stratigraphy?

The deposits of large sand-bed rivers were simulated using a physics-based numerical model of hydraulics, sediment transport, bank erosion and floodplain formation. This model is described in detail in Nicholas *et al*. (2013). Forty four model simulations were carried out in this study. All simulations use initial conditions consisting of a straight channel that is 2.4 km wide, with a constant downstream slope (S) that has small (0.1 m) white noise elevation perturbations superimposed on the bed. In the current simulations, the model uses two sediment fractions: A sand fraction with a diameter (D) that was varied between simulations, and a silt fraction with a settling velocity of $2x10^{-4}$ ms^{-1} that was held constant between simulations. Sand supply rates at the inlet to the model domain were assumed to be at capacity. Silt concentrations (L) at the inlet were held constant throughout simulations (i.e. they did not vary over the course of hydrographs). Other model parameters that were varied between simulations are the Chezy roughness coefficient (C) of the river bed used in hydrodynamic calculations, the dimensionless bank erodibility (E), and the time (T_{veg}) over which flow must not exceed a critical water depth (H_{cr}) in order for vegetation to become established on sand bars. In 26 of the simulations the hydrologic regime of the river was represented as a series of flood hydrographs (of duration two years) with a minimum discharge of 10,000 m^3s^{-1}, and peak discharges that varied between 15,000 m^3s^{-1} and 30,000 m^3s^{-1} between individual floods. In the case of six simulations that produced low sinuosity anabranching rivers similar in form to the Río Paraná, Argentina, additional simulations were carried out using three alternative hydrologic regimes: (i) Flood hydrographs of four years duration; (ii) Flood hydrographs of eight years duration; and (iii) A constant inflow discharge of 22,500 m^3s^{-1}.

It should be noted that rates of morphological change vary significantly between large sand-bed rivers. For example, the Amazon experiences lower rates of change than rates observed in model simulations, while the Jamuna experiences rates of morphological change that are more rapid (Rozo *et al*., 2012; Nicholas *et al*., 2103). The duration of model simulations (350 years) should thus be considered a nominal time period, in that the amount of simulated morphological change during this time could be less than or greater than the amount experienced in some natural rivers. The duration of model simulations is set here to ensure that modeled deposits are reworked multiple times during simulations, and that the resulting bedset characteristics are independent of model duration (as illustrated in Fig. 1E, and in Table DR2 below).

Modeled deposits were reconstructed from channel topography and flow conditions at 700 points in time over the course of simulations. Bedsets, defined as depositional elements bounded by erosional surfaces, were identified from vertical profiles in each model grid cell (80 m by 40 m in size). Mean set thickness values reported below represent average values for the whole model domain.

References:

Nicholas, A.P., Ashworth, P.J., Sambrook Smith, G.H. and Sandbach, S.D., 2013, Numerical simulation of bar and island morphodynamics in anabranching megarivers: Journal of Geophysical Research: Earth Surface, v. 118, p. 2019-2044, doi:10.1002/jgrf.20132.

Rozo, M.G., Nogueira, A.C.R. and Truckenbrodt, W., 2012, The anastomosing pattern and the extensively distributed scroll bars in the middle Amazon River: Earth Surface Processes and Landforms, v. 37, p. 1471-1488, doi:10.1002/esp.3249.

Table DR1: Model parameter values and deposit characteristics for full the set of 44 model simulations. These are the data plotted in Figures 2A, 2C and 2D.

S	C	D	H_i	L	E	T_{veg}	H_{cr}	Q	T_{flood}	H_0	λ	$\sigma_{\Delta z}$
0.00005	55	0.4	8.34	150	1	10	0.1	Variable	2	6.84	1.70	2.40
0.00005	55	0.4	8.34	150	3	10	0.1	Variable	2	6.50	1.67	2.05
0.00005	55	0.4	8.34	150	10	10	0.1	Variable	2	6.29	1.37	1.92
0.00005	55	0.4	8.34	450	1	6	0.3	Variable	2	6.92	1.65	2.57
0.00005	55	0.4	8.34	450	3	6	0.3	Variable	2	6.60	1.67	2.19
0.00005	55	0.4	8.34	450	10	6	0.3	Variable	2	6.26	1.31	1.81
0.0001	40	0.4	8.19	150	3	10	0.1	Variable	2	8.53	1.69	2.93
0.0001	40	0.4	8.19	150	10	10	0.1	Variable	2	7.57	1.81	2.77
0.0001	40	0.4	8.19	450	3	6	0.3	Variable	2	8.30	1.63	2.70
0.0001	40	0.4	8.19	450	10	6	0.3	Variable	2	7.62	1.94	3.04
0.00005	55	0.2	8.34	150	3	10	0.1	Variable	2	9.94	1.92	2.86
0.00005	55	0.2	8.34	150	10	10	0.1	Variable	2	8.80	2.28	3.17
0.00005	55	0.2	8.34	450	3	6	0.3	Variable	2	9.50	2.04	2.87
0.00005	55	0.2	8.34	450	10	6	0.3	Variable	2	8.36	2.08	2.72
0.0001	40	0.2	8.19	150	3	10	0.1	Variable	2	11.15	2.33	3.65
0.0001	40	0.2	8.19	150	10	10	0.1	Variable	2	9.83	2.40	3.50
0.0001	40	0.2	8.19	450	3	6	0.3	Variable	2	11.09	2.20	3.58
0.0001	40	0.2	8.19	450	10	6	0.3	Variable	2	9.52	2.15	3.00
0.00005	55	0.4	8.34	150	3	10	0.01	Variable	2	6.57	1.47	2.41
0.00005	55	0.4	8.34	150	10	10	0.01	Variable	2	6.20	1.47	2.08
0.0001	40	0.4	8.19	150	10	10	0.01	Variable	2	7.79	1.93	3.56
0.00005	55	0.2	8.34	150	10	10	0.01	Variable	2	8.34	2.18	2.60
0.0001	40	0.3	8.19	450	10	6	0.3	Variable	2	8.90	2.27	3.26
0.00005	55	0.3	8.34	450	3	6	0.3	Variable	2	6.92	1.60	2.29
0.0001	40	0.3	8.19	150	10	10	0.1	Variable	2	7.87	1.97	3.19
0.0001	40	0.2	8.19	450	3	4	0.5	Variable	2	11.52	2.54	3.55
0.00005	55	0.4	8.34	150	1	10	0.1	Constant	~	8.10	2.73	4.99
0.00005	55	0.4	8.34	150	3	10	0.1	Constant	~	7.57	2.34	4.24
0.00005	55	0.4	8.34	150	10	10	0.1	Constant	~	6.70	2.43	3.20
0.00005	55	0.4	8.34	450	1	6	0.3	Constant	~	8.13	2.93	4.96
0.00005	55	0.4	8.34	450	3	6	0.3	Constant	~	7.56	2.66	4.21

0.00005	55	0.4	8.34	450	10	6	0.3	Constant	~	7.10	2.22	3.14
0.00005	55	0.4	8.34	150	1	10	0.1	Variable	4	6.80	1.91	2.72
0.00005	55	0.4	8.34	150	3	10	0.1	Variable	4	6.53	1.69	2.55
0.00005	55	0.4	8.34	150	10	10	0.1	Variable	4	6.29	1.54	2.25
0.00005	55	0.4	8.34	450	1	6	0.3	Variable	4	6.95	1.78	2.49
0.00005	55	0.4	8.34	450	3	6	0.3	Variable	4	6.69	1.70	2.29
0.00005	55	0.4	8.34	450	10	6	0.3	Variable	4	6.22	1.39	1.97
0.00005	55	0.4	8.34	150	1	10	0.1	Variable	8	6.67	2.14	3.19
0.00005	55	0.4	8.34	150	3	10	0.1	Variable	8	6.47	1.89	3.01
0.00005	55	0.4	8.34	150	10	10	0.1	Variable	8	6.08	1.80	2.46
0.00005	55	0.4	8.34	450	1	6	0.3	Variable	8	6.86	2.02	3.02
0.00005	55	0.4	8.34	450	3	6	0.3	Variable	8	6.62	1.81	2.84
0.00005	55	0.4	8.34	450	10	6	0.3	Variable	8	6.08	1.57	2.34

S is the initial channel slope (m m^{-1}), C is the Chezy roughness (m$^{1/2}$s^{-1}), D is the bed sediment sand diameter (mm), H_i is the initial water depth (m) at the start of the simulation (given for a discharge of 22,500 m^{3}s^{-1}), L is the inlet silt concentration (mg l^{-1}), E is the dimensionless bank erodibility, T_{veg} is the time (years) that flow depths must not exceed H_{cr} (m) for channel to be converted to floodplain, Q is the discharge regime (either variable or constant discharge, as describe above), T_{flood} is the flood duration (years), H_0 is the mean channel flow depth averaged over all locations and times, λ is the mean set thickness (m) in all individual model grid cells at the end of the simulation, $\sigma_{\Delta z}$ is the standard deviation (m) of the thickness (Δz) of packages of continuous erosion or deposition in all individual model grid cells throughout each simulation. Rows 2 to 7 (the first six rows of data) contain parameter values for model simulations that produce low sinuosity anabranching channels similar in form to the Río Paraná, Argentina. Rows 28 to 45 contain data for simulations that use the same values of S, C, D, L, E, T_{veg} and H_{cr} as these six simulations, but with different hydrologic regimes.

Table DR2: Mean set thickness for observed and modeled bedsets as a function of set depth below the bar surface. These are the data plotted in Figure 1E.

d	λ: Paraná	λ: E=3 (at 350 y)	λ: E=3 (at 400 y)	λ: E=3 (at 450 y)	λ: E=10 (at 350 y)	λ: E=10 (at 400 y)	λ: E=10 (at 450 y)
0 – 1	1.02	1.88	2.07	1.82	1.18	1.20	1.15
1 – 2	1.68	2.10	1.96	1.89	1.27	1.18	1.13
2 – 3	1.60	2.03	2.10	2.01	1.38	1.26	1.22
3 – 4	1.45	2.27	2.21	2.19	1.52	1.40	1.40
4 – 5	1.78	2.27	2.26	2.24	1.67	1.56	1.58
5 – 6	2.65	2.32	2.15	2.28	1.97	1.85	1.94
6 – 7	2.50	2.47	2.44	2.44	2.46	2.38	2.41
7 – 8	2.57	2.58	2.20	2.31	2.32	2.46	2.43

Column 1 (*d*) is depth below the bar surface (m). Column 2 (λ:Paraná) contains values of mean bedset thickness derived from Ground Penetrating Radar data collected at the sites on the Río Paraná, Argentina, that are shown in the white boxes in Figure 1B. Columns 3 to 7 contain values of mean bedset thickness (λ) for two model simulations that generate low sinuosity, anabranching channels similar in form to the Río Paraná. These two simulations use different values of the dimensionless bank erodibility parameter (*E*=3 and *E*=10). Model results are presented at three points in time during these simulations (after 350 y, 400 y and 450 y).

Table DR3: Characteristics of simulated deposits (these are the data shown in Table 1, with additional data included in columns 4 and 5)

Channel pattern	Meandering	Sinuous braided	Low sinuosity anabranching	Low sinuosity anabranching
Discharge	Variable (T = 2y)	Variable (T = 2y)	Variable (T = 2y)	Constant
λ (m)	2.33	1.97	1.56 (1.31 – 1.67)	2.55 (2.22 – 2.93)
Lxy (Dune)	1.89	1.83	2.51 (2.38 – 2.70)	2.95 (2.68 – 3.10)
Lxy (Ripple)	2.01	1.91	2.71 (2.49 – 2.85)	3.22 (2.81 – 3.33)
Lxy (Large sets)	1.99	1.89	2.56 (2.33 – 2.71)	3.21 (2.94 – 3.61)
σ_{V90} (rad)	1.03	0.92	0.61 (0.53 – 0.74)	0.45 (0.42 – 0.51)
ψ (Dune)	7.54	3.80	2.26 (1.82 – 2.62)	5.37 (4.78 – 6.15)
ψ (Ripple)	0.44	0.66	0.75 (0.57 – 0.84)	1.69 (1.50 – 1.85)
ψ (Slackwater)	0.19	0.11	0.13 (0.08 – 0.16)	0.22 (0.18 – 0.27)

Columns 2 and 3 show results for two simulations with contrasting morphology. Columns 4 and 5 show results for six simulations of low sinuosity anabranching channels that use variable discharge (hydrograph duration, T = 2 yr) and constant discharge. Values in columns 4 and 5 represent the mean and range (in brackets) for these six simulations. λ is the mean set thickness. Lxy is the ratio of the average downstream and cross-stream lengths of contiguous model grid cells classified by deposit type as: Dunes (cells where >90% of sediment is classed as dunes); Ripples (cells where >10% of sediment is classed as ripples); and Large sets (cells where >50% of sediment comprises sets thicker than twice the mean set thickness). σ_{V90} is the 90th percentile of the probability density function of the standard deviation of paleocurrent direction. ψ is the mean thickness of contiguous vertical packages of each deposit type.