Chute Channel Dynamics in Large, Sand-Bed Meandering Rivers

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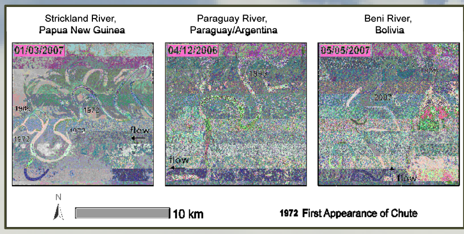
Introduction

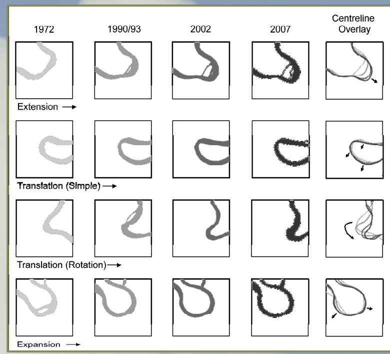
Meander bends of large, sand-bed meandering rivers are commonly partitioned by chute channels that convey permanent flow, and co-evolve with the mainstem for decades. These 'bifurcate meander bends' are an intellectually alluring phenomenon; their initiation in large, tropical meandering rivers appears contrary to the findings of experimental studies that suggest that chute formation should be suppressed in rivers with cohesive, well-vegetated channel banks (Schumm and Khan, 1972; Smith, 1998; Gran and Paola, 2001; Tal and Paola, 2007) and a high suspended sediment load (Ashmore, 1991; Braudrick et al., 2009), and their stability (longevity) defies any preconception that bend cutoff is an inevitable outcome of chute channel initiation. As a first step toward understanding the dynamics and morphodynamic implications of bifurcate meander bends, this work aims to determine whether it is possible to predict chute channel initiation in sand-bed meandering rivers based on attributes of channel planform character and dynamics, and examines controls on chute initiation and stability.

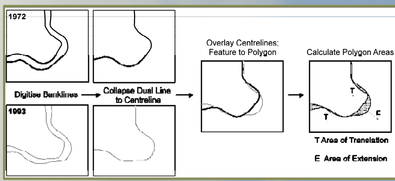


Bifurcate meander bends in large, sand-bed meandering rivers.

Methods

Several attributes of planform character (e.g. curvature) and dynamics (e.g. migration rates) were quantified for 54 Strickland bends, 45 Paraguay bends, and 114 Beni bends. Primarily interested in effects of bend migration style on chute channel dynamics.





Binary Logistic Regression Analysis

Categorical Outcome Variable	
Whether a Chute Forms at a Bend or Not, During the Full Analysis Period	
Continuous Predictor Variables (Bend Attributes)	
1	Average Curvature (R:w)
2	Minimum Curvature (R:w)
3	Maximum Curvature (R:w)
4	Average Entrance Angle (°)
5	Minimum Entrance Angle (°)
6	Maximum Entrance Angle (°)
7	Average Sinuosity
8	Minimum Sinuosity
9	Maximum Sinuosity
10	Average Rate of Extension (Channel Widths.a^{-1})
11	Average Rate of Translation (Channel Widths.a^{-1})
12	Average Rate of Expansion (Channel Widths.a^{-1})
13	Average Rate of Total Migration, All Styles Combined (Channel Widths.a^{-1})

Only one predictor had a statistically significant effect for each river....

River Name	R^2 (Cox and Snell, 1989)	R^2 (Nagelkerke, 1991)	Odds Ratio
Strickland	0.37	0.54	1.07
Paraguay	0.36	0.58	8.12
Beni	0.30	0.44	1.33
Predictor: Average Rate of Extension			$p < .01$

...but other planform attributes should not be disregarded entirely:

	Curvature (R:w)	Entrance Angle (°)	Sinuosity
Strickland			
Single-Thread Cases (n = 142)			
Mean	2.78	52.61	1.52
StDev	1.41	23.15	0.40
Bifurcate Cases (n = 66)			
Mean	2.55	63.71	1.66
StDev	0.78	20.09	0.29
Paraguay			
Single-Thread Cases (n = 130)			
Mean	3.02	53.64	1.52
StDev	1.71	20.41	0.33
Bifurcate Cases (n = 50)			
Mean	2.95	61.12	1.54
StDev	0.92	12.34	0.27
Beni			
Single-Thread Cases (n = 338)			
Mean	2.63	56.08	1.74
StDev	1.31	24.77	0.73
Bifurcate Cases (n = 69)			
Mean	2.16	71.30	2.24
StDev	0.74	27.01	1.29
Note: 'case' refers to one bend in one image.			

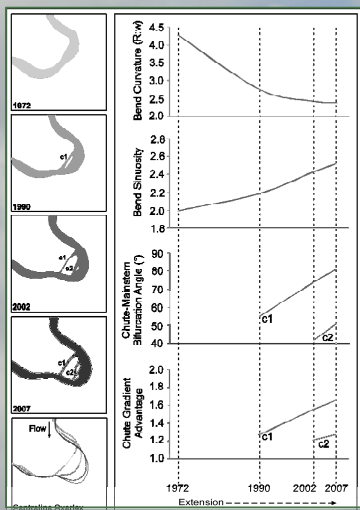
In terms of predicting chute initiation at a meander bend, the average rate of extension of a bend alone accounts for 37-54 % of the variation in the Strickland data, 36-58 % of the variation in the Paraguay data, and 30-44 % of the variation in the Beni data. Odds ratios >1 indicate that as the extension rate of a bend increases, the likelihood of chute initiation at the bend increases.

Bends with chutes have lower curvature (R:w), but higher sinuosity and entrance angle than single-thread bends (consistent with the results of Micheli and Larsen, 2010).

Stable chutes have greater chute-mainstem bifurcation angles and gradient advantages than chutes that infill.

	Chute Statistics	Strickland	Paraguay	Beni
1	Total number of chute channels observed	32	21 (5)	42 (30)
2	Chute:bend ratio	0.59	0.47 (0.71)	0.37 (0.50)
3	Chute:bend ratio (initiation only)	0.26	0.20 (0.57)	0.25 (0.42)
4	Percentage stable chute-mainstem bifurcations	63	67 (40)	33 (33)
5	Percentage chute infills	28	24 (40)	57 (80)
6	Number of chute cutoffs	1	0	1
7	Average chute-mainstem bifurcation angle for stable bifurcations (°)	71.77	62.13	50.28
8	Average chute-mainstem bifurcation angle for chute infills (°)	43.92	45.48	39.73
9	Average chute gradient advantage for stable bifurcations	1.67	1.41	1.56
10	Average chute gradient advantage for chute infills	1.17	1.13	1.27
Beni: values in brackets represent foredeep.				
Paraguay: values in brackets represent reach downstream of Bermejo confluence.				

Why is rapid extension important?



Typical developmental pathway of bends subject to rapid extension.

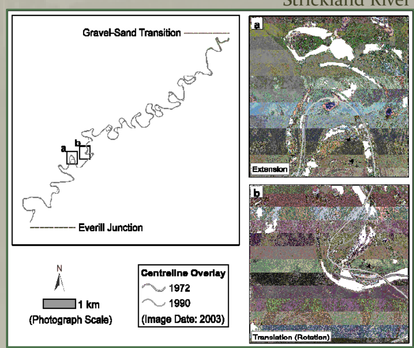
Why is rapid extension important?

1. More than 95 % of all chutes that formed during the imagery analysis period initiated at chord locations (close to the inner-bend apex, terminology after Lewis and Lewin, 1983), mostly at points of bend widening – chute formation in sand-bed meandering rivers may be intimately related to morphodynamic effects of bend widening on point bar development (after Seminara, 2006; Bolla Pittaluga et al., 2009), which result in the locus of maximum deposition occurring toward the channel centre, leaving a gap between the point bar and inner bank (Braudrick et al., 2009). Widening occurs to the greatest extent at rapidly migrating bends (Brice, 1975).

2. Extension favours positive alignment of ridge/slough topography with the downstream direction of flow diversion across the developing point bar; sloughs form parallel to the bend apex, providing a direct flow path between bend limbs. Thus, rapidly extending bends of sand-bed meandering rivers are vulnerable to dissection by chute channels because point bar development and associated thalweg shoaling of bedload sheets and unit bars (Carson, 1986; Ashmore, 1991; Peakall et al., 2007) diverts flow into prominent, positively-aligned sloughs. These sloughs also break the continuity of channel-ward vegetation encroachment on point bars.

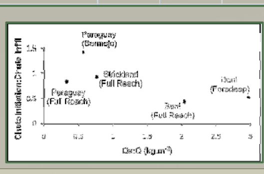
3. Immediately after initiation, chute channels in sandy point bars are vulnerable to infill due to the low bifurcation angle and low gradient advantage associated with their chord location, conditions which favour aggradation at the chute entrance. With bend extension, the chute adopts a more axial location (mid-bend, terminology after Lewis and Lewin, 1983), and there is a concomitant tendency for the chute-mainstem bifurcation angle and chute gradient advantage to increase, thereby reducing chute vulnerability to infill, depending on the suspended sediment load of the river.

Strickland River



Decadal-scale interplay between chute initiation and chute infill on the Paraguay, Strickland and Beni defines a continuum mediated by sediment load (Qs/Q). The Paraguay occupies one extreme, with low sediment load, bend extension rate, and chute initiation rate, while the Beni occupies the other, with the extremely high sediment load reducing net chute presence through chute infill. The Strickland, where stable bifurcate bends are most common, has an intermediate sediment load (Qs/Q approaching 1 kg.m^{-3}), greatest frequency of bends subject to rapid extension, and a chute initiation to infill ratio ~1.

Strickland	Reach Average		
Slope	0.0001		
Water Discharge, Q ($Mm^3.a^{-1}$)	98144		
Suspended Sediment Discharge, Qs ($Mt.a^{-1}$)	70 - 80		
Ratio Qs:Q ($kg.m^{-3}$)	0.71 - 0.82		
Paraguay	**Upstream of Bermejo**	**Downstream of Bermejo**	
Slope	0.000006	0.00005	
Water Discharge, Q ($Mm^3.a^{-1}$)	101836	122633	
Suspended Sediment Discharge, Qs ($Mt.a^{-1}$)	9	70	
Ratio Qs:Q ($kg.m^{-3}$)	0.09	0.57	
Beni	**Foredeep**	**Forebulge**	**Back-Bulge**
Slope	0.0002	0.00007	0.0001
	Rurrenabaque		**Riberalta**
Water Discharge, Q ($Mm^3.a^{-1}$)	64693		90570
Suspended Sediment Discharge, Qs ($Mt.a^{-1}$)	192		100
Ratio Qs:Q ($kg.m^{-3}$)	2.97		1.10



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