

Benchmarking fluvial geomorphic processes for river restoration and monitoring

Analyse comparative des processus géomorphologiques fluviaux pour la restauration et la surveillance des rivières Peter W. Downs¹², Derek B. Booth¹ and Colm M. Casserly² peterwdowns@ucsb.edu

ABSTRACT

River restoration generally implies efforts to return the integrity and resilience of river forms, processes and connectivity in the hope of a significant and sustained uplift in biodiversity. While there are various means of characterising changes in river forms and river connectivity, there have been few methods for benchmarking fluvial geomorphic processes as a channel evolves. We showcase a rapid assessment protocol developed to quantify the mode and intensity of river channel adjustments and to assess whether the channel is functionally stable. Of note, we separate field observations from their interpretative conversion into 'adjustment indices' to reduce inter-surveyor bias and allow for post-survey interpretative improvement. The approach was tested in relatively undisturbed high elevation meadow channels in California and highly modified lowland channels of Ireland. The method estimates 14 indices representing modes of channel adjustment, categorised into 4 levels of apparent intensity, and with integrative outcomes summarising the channel's sensitivity to change, lateral activity and relative instability. As a rapid assessment, the approach is well-suited to pre- and post-project monitoring to judge the evolutionary trajectory of channel adjustment processes and relative stability as part of benchmarking fluvial geomorphic processes for river management and restoration.





Introduction

- River restoration usually aims to restore the ecological (i.e., physical and biological) integrity of river systems.
- Evaluating the success of restoration activities ideally requires monitoring the evolution of forms, processes and connectivity and over a sufficient time period to determine that the restoration actions have created a resilient and self-sustaining river environment.
- Lack of effort/resources for establishing pre-project baseline conditions has seen the gradual development of self-referencing (i.e., benchmarked) methods scoring from low to high, whereby the good score implies conditions that are near-natural or fully-functional. Examples: habitat inventory: Gurnell et al., 2020; river connectivity van de Bund et al., 2024.
- For river processes, multiple modes of river adjustment, operating at different intensities, prevent a singular score from low-to-high. In response, we have developed an approach to codify and combine field observations to identify different modes of channel adjustment, the relative intensity of such processes, and summary outcomes reflecting whether a channel appears functionally stable or instead displays signs of instability (Booth and Downs, 2025; Downs et al., in prep.)
- Results demonstrate the conversion of field observations into 14 modes of channel adjustment, 4 levels of apparent adjustment intensity, and summary judgments about channel's relative stability.

Method

Steps:

- 1. Assemble indicator set (~40) diagnostic of potential channel adjustment,
- 2. Make structured observations ('read the river') over a representative river reach (width-scaled), using non-linear extensiveness values (DAFOR variation, per Gurnell et al., 2020)
- 3. Assemble individual observations (i.e., indicators of change) into suites of observations (equations) indicative of one particular mode of channel adjustment. 14 modes identified, with equations utilizing 1-9 indicators
- 4. Convert Indicators to Values to Scores, taking care that Values in each equation are comparable and do not create an inherent weighting towards certain indicators. Values are banded into Scores to allow comparability between equations. Scores ranges from 0-3 according to negligible (0), some (1), moderate (2) or considerable (3) evidence for change. Can revisit without jeopardizing field surveys.
- 5. Group equations according to whether they could be interpreted as reflecting the channel's inherent sensitivity to change, evidence for lateral activity (e.g., as part of natural meander migration processes) or whether the adjustments seemed indicative of prevailing channel instability.



3.Estimates of Adjustment

2. Structured Data Collection

Date/time	Surveyor(s)		Su	rvey bank(s) l	/ R / Both	BED AND BANK STRUCTURE	S				
Weather conditions	Dry / rain / snow	Flow conditio	ns	Low / elevated	/ flood	Damage to bed protection ³⁵		A/T/	P/E Plu	inge pool ¹⁵	_
Representative photos (des	cribe)					Erosion around bank structu	res ¹² LI	Yes /	No	RB	
						Widening d/s structure ¹³	LI	Yes /	No	RB	
NOTES						ned14	Ye	/No	Structure buried/infi	illed ¹⁶	
						Banks					
							LB A/T/	P/E	Mature trees at bar	nktop⁴ LB	3
							RB A/T/	P/E		RB	3
						Adjusted bank top/face	LB A/T/	Р/Е	Dominant 1	type LB	3
Reach charc	icter –					trees ³	RB A/T/	P/E	and see to Dad a second	RB	3
Unstream GPS Coords		Downstream	GPS Coords			Trees protruding into	IB A/T/	ареа), ек = ехр Р / F	oosea roots, kivi = overn	ianging root ma	515
Unstream water surface		Downstream	water surface			channel ⁶	RB A/T/	P/F			
elevation (m)		elevation (m)			Bank erosion ⁷	LB A/T/	P/E	Erosion of op	posite banks ⁹	9
Dominant reach typology ¹⁷	BoBedr BoBedr	UnCon	PC Cob PC Gr	av Con CobBo	Con Cob		RB A/T/	P/E			_
Byrne/Lane/Pasternack clas	sn Lrg Con Head Co	Grav Low (Grav Unif Cob R	iPo StepP	Bo Uni	Type/s of failure ⁸	Fluvia	I A/T/	P / E Rot	tational slump)
Valley width confinement (c	hannel widths) <	1/1-5/5-10/>1	0			See Key sheet	Sla	A/T/	P / E	Sheet	t
Weirs count	Bridges count	Н	langing tributaries ¹	31 count		U	ndercutting/Cantileve	A/T/	P/E	Other	r
Knickpoints ²⁹	Count		Total drop (m)			Damage to hard bank	L	3 A/T/	P/E		
Hard bank protection ¹⁰	LB extent A /	Т/Р/Е	Dominant	type		protection ¹¹	R	3 A/T/	P/E		
	RB extent A /	T/P/E	Dominant	type		River corridor features ³²		Fea	atures indicative of recei	nt change; Key:	: NV
Key: COncrete, BRick,	Sheet Piling, Wood Piling, Wa	iste Materials, Rip-F	Rap, GAbions, Willow	Spiling, Biotextiles,	/Coir	Meander cut-offs	/oxbow lakes	Y/N		Chutes	5
Hard had protection ³⁵	A/-	T/P/E	Flood embankm	nents A/	Г/Р/Е	ank sed	imentation ³³	A/T/P/E/N	NV Backw	rater infilling ³⁴	•
Module char	acter 🗖	r each sampled	module			Bed —		- /			_
		Primary Key: A	A = 0%, T				A/T/	P/E Alg	al layer/biofilm on se	diments ²⁰	+
Bankfull width (m)		Avera	ge bankt ME	easurem	ents	Clean coarse sediments ove		P/E AIT	nouring .: N – none IM – Imbrici	nted I – loose	
Active channel width (m)		C	hannel r			Red Ciltation ⁴³	Extensiveness	17 L KCy	Dominant matoria	1	
Bed materials ²⁴ Do	minant		Subdomina	ant		bed Sittation			SA / SI / CI / OR / DE /		+
Key: ARtifica	l, BEdrock, BOulder, CObble, G	GravelPebble, SAnd,	Silt, CLay, ORganic, F	PEat, NotVisible		Vegetation encroachment ³⁰	Left bank to	A/T/	P/F	Type	-
Representative D50 (mm)						regetation eneroderment	Right bank to	A/T/I	P/F	Type	÷
Bedforms ¹⁸	Bedrock A	A/T/P/E	Riffl	e ¹⁹ A/T	/ P / E			Domin	ant		-
	Waterfall A	A/T/P/E	Po	T/A loc	/ P / E	Bars	Extensiveness	mater	rial Vegeta	ted extent	
	Cascade A	A/T/P/E	Gli	ide A/T	/ P / E	Point bars ²⁰	A/T/P/E		A / 1	Г/Р/Е	
	Step A	A/T/P/E	Sediment B	ars A/T	/ P / E	Lateral bars ²¹	A/T/P/E		A / 1	Г/Р/Е	
Bed obscured?	Yes / No	Issue	Deep flow	/ Turbidity / Veg	etation	Tributary attached bars ²²	A/T/P/E		A/1	Г/Р/Е	
Bank materials ²	LB Dominant		LB Sub-domi	nant		Mid-channel bar/ islands ²³	A/T/P/E		A/1	Г/Р/Е	
	RB Dominant		RB Sub-domi	nant		Keys: Materials - BC	/ CO / GP / SA / SI / CL	' OR / PE / NV; 1	Vegetation types - EMer	gents, GRasses,	i, SC
Key: ARtificio	il, BEdrock, BOulder, CObble, C	GravelPebble, SAnd,	Silt, CLay, OR, PE, E	Arth, NotVisible		Berms (just above low water l	ne) ³⁹	E	xtensiveness	Ve	:ge
Bank profiles*	LB Dominant		LB Sub-domi	nant			Left bank to		A/T/P/E		A
	RB Dominant	Ch4 DC TC Ch4 C14	RB Sub-domi	nant		Berms or	nigrit bank too		A/T/P/E		A
Piparian land covor	Rey: V, VO, VO, VI, SI, GI, I	CIVI, KS, TS, EIM, SM,	, PC – see Key sheet	nant		Bernsol	erm edge/ton scour ³		Δ/T/P/E		
Niparian land cover	LB Dominant		LB SUD-dOMI	nant		Benches (significant elevation	above low water)41	E	xtensiveness	Ve	aget
	Grasses TG - Tall herbe/Grass	ses SS _ Scrub_Shrub	h TR – sanling/Trees	or describe mana	red cover type	Serveres (agrineant elevation	Left han		A/T/P/E	Ve	A/
Kou SG - Short crooning hashe	IR A	/ 1 / <10 / >10	o, rn – supiing/frees	RB A/1/	<10 / >10		Right ban		A/T/P/E		A
Key: SG - Short creeping herbs/ Riparian corridor width	LD A/	1 + 1 + 10 + 10	0 m	ND A/1/	10/210	Benche	s on opposite banks ⁴		A/T/P/E		
Key: SG - Short creeping herbs, Riparian corridor width	Kev Ahsen	1							1		
Key: SG - Short creeping herbsy Riparian corridor width	Key: Absen	n, 1000, 100, 10									

	Mode of Adjustment Equation						
1	Channel responsiveness	6 Bank erosion certainty		10	Bank failure severity		
2	Bank erodibility	7	Sediment transport activity	11	Channel widening		
3	Bank suscept: morphology	8	Barform activity	12	Channel narrowing		
4	Bank suscept: vegetation	9	Planform activity	13	River bed erosion		
5	5 Channel suscept: structural				River bed aggradation		
	Sensitivity to Change		Lateral Activity		Channel Instability		
5.Stability Interpretation							

4.Convert Observations to Values to Scores

EQ 14. CERTAINTY OF BED AGGRADATION									
Rationale	Active bed aggradation is indicated from multiple lines of morphological, vegetational and structural evidence.								
INDICATOR VALUES									
Observation	Response	Indicator values	Range						
Structures buried	Presence	Y = 2, N = 0	0-2						
Backwater infilling	Presence	Y = 2, N = 0	0-2						
Bed siltation	Extensiveness	E = 3; P = 2	0-9						
Vegetation with bed siltation	Extensiveness	A = 3; T = 2, P = 2, E = 1	(Product of bed siltation × vegetation extent)						
Dominant material with bed siltation	Count, per reach	Silt = 2, sand = 1, other = 0	0-2						
Opposite bank depositional berms	Count, per reach	E = 3; P = 1	0-3						
Form of equation	prm of equation Σindicator values and vegetated bed siltation product								
Value total (0-18)	De	Indicator Score							
0-1	Little/no evidence o	0							
2-5	Limited evidence of	1							
6-9	Moderate evidence	2							
10-18	Extensive, clear evid	3							

Field Tests and Results

Pilot field tests were undertaken in the summers of 2023 and 2024, high elevation meadows of the Sierra Neveda of California, and channelised lowlands of Ireland. Banded scores from the 14 'mode of adjustment' equations are provided under each photograph ranging from red where there is negligible evidence for change to green where there is considerable evidence. The grouped scores for channel sensitivity to change, lateral activity and channel instability are shown as percentages inset on each photograph.

46 sites



- (Ode 2016) > Expectation: dynamic stability,
- (historical
- alteration?)

54 sites

> 1-module approach,





Heat Maps





The **Reach Summaries** illustrate generally expected adjustment type outcomes from the two environments The sampled rivers in California are generally sensitive to change (composed of erodible materials and with little constraining infrastructure), run a broad spectrum of lateral activity types from channels that are highly active (top left) to those with far lower apparent rates of change, and generally show low levels of channel instability (top right). Such results appear logical with their

setting as meadows at high elevation in a National Park. The sample set from Ireland are also generally quite sensitive to change largely because they are free to adjust, but as frequently oversized, straightened channels, they show few signs of lateral activity but instead are far more unstable than the California sites. Instability is generally in the form of channel recovery through fine sediment-led processes of channel narrowing and aggradation (see Heat Map).

These results are borne out more generally in the Summary Statistics illustrating the greater degree of lateral activity in the near-reference California sites and the greater instability of the heavily management Ireland

Reach summaries



sites.



Summary statistics



Sierra Nevada 2023-24

Sensitivity to Change

Lateral Activity

Channel Instability

Funding:



Pilot test results were consistent with our expectations, providing evidence that the approach has potential in judging channel adjustment processes and relative stability. The assessment technique takes only 1-2 hours per reach (5 modules), making the approach highly suitable to repeat monitoring, even when monitoring is poorly funded. Inter-surveyor bias is minimized by restricting the surveyor to field observation; interpretations are provided via expert judgments embedded into the equations. Results from earlier surveys can readily be recalculated if the equations are adjusted. The scoring system is benchmarked according to apparent intensity of dynamics (0-3) and percentage likelihood in relation to the channel's sensitivity to change, lateral activity and relative instability. percentage related to equations grouped score. The approach allows comparative assessment of channel adjustment processes which has not been possible before.

The accuracy of the outcomes and the calibration of the banded value ranges for each equation will benefit from further testing. Assessment precision will be assisted by the development of formalised training procedures, supporting documentation and using a 5-module form of the assessment. The efficiency of the approach will be aided by developing a system of tablet computer-based data collection and automated data processing.

For restoration, approach reduces the emphasis on pre-project monitoring - a nearby unrestored reach of river could probably provide a sufficient baseline for judging restoration success in sustainably restoring river processes. The approach can be combined with inventories of riverine habitat diversity and connectivity to provide overall evaluation of river restoration success.

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