Benchmarking fluvial geomorphic processes for river restoration and monitoring

Analyse comparative des processus géomorphologiques fluviaux pour la restauration et la surveillance des rivières

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RÉSUMÉ

La « restauration » des rivières implique généralement des efforts pour rétablir l'intégrité et la résilience des formes, des processus et de la connectivité des rivières dans l'espoir d'une augmentation significative et durable de la biodiversité. Bien qu'il existe diverses façons de caractériser les changements dans les formes et la connectivité des rivières, il existe peu de méthodes pour évaluer le caractère actuel et les changements dans les processus géomorphologiques fluviaux au fur et à mesure de l'évolution d'un chenal. Nous présentons un protocole d'évaluation rapide développé pour quantifier le mode et l'intensité des processus d'ajustement du canal et pour évaluer si le canal est fonctionnellement stable. Il convient de noter que nous séparons les observations sur le terrain de leur conversion interprétative en « indices d'ajustement » afin de réduire le biais entre les enquêteurs et de permettre une amélioration de l'interprétation après l'enquête. L'approche a été testée dans des chenaux de prairie de haute altitude relativement peu perturbés en Californie et dans des chenaux de plaine fortement modifiés d'Irlande. La méthode estime 14 indices représentant les modes d'ajustement du canal, classés en 4 niveaux d'intensité apparente, et avec des résultats intégratifs résumant la sensibilité du canal au changement, l'activité latérale et de l'instabilité relative. En tant qu'évaluation rapide, l'approche est bien adaptée à la surveillance avant et après le projet pour juger de la trajectoire évolutive des processus d'ajustement des chenaux et de la stabilité relative dans le cadre de l'étalonnage des processus géomorphologiques fluviaux pour la gestion et la restauration des rivières.

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.

KEYWORDS

Benchmarking, channel adjustment, channel instability, geomorphic processes, restoration monitoring

Benchmarking, ajustement de canal, instabilité de canal, processus géomorphologiques, suivi de restauration

1 INTRODUCTION

River restoration usually aims to restore the ecological (i.e., physical and biological) integrity of river systems by creating a diverse suite of river forms and processes and ensuring that the river is functionally connected both laterally and longitudinally. Evaluating the success of restoration activities ideally requires monitoring the evolution of forms, processes and connectivity and over a sufficient period of time (Downs and Kondolf, 2002) to determine that the restoration actions have indeed created a resilient and self-sustaining river environment. In most restoration projects, there is insufficient effort expended on establishing pre-project baseline conditions as a benchmark against which the restored environment can be compared. As such, there has been the gradual development of methods that are internally self-referencing (i.e., from 'poor' to 'good'), whereby the good score implies conditions that are near-natural or fully-functional. For physical habitat, this includes the MoRPh survey (Gurnell *et al*., 2020) and, for river connectivity, the free-flowing river assessment (van de Bund *et al*., 2024).

An inherent issue in assessing the adjustment processes in rivers is that are multiple modes of river adjustment, operating at different intensities, preventing a singular score from low-to-high. Further there is a challenge, perhaps unique to fluvial geomorphology, of distinguishing the 'dynamic stability' of rivers in an equilibrium state from channels that are functionally unstable. 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. We prefer a rapid assessment protocol approach using systematised field observations over remote assessments or use of adjustment metrics: the former is more rapid, is highly site specific and does not require multiple years of survey before interpretations can be drawn. Field observations have long been used as evidence of channel adjustment processes (starting with Pfankuch, 1975), with schemes frequently used to judge channel adjustments in proximity to critical infrastructure such as bridges and highways (*e.g*., Simon and Downs, 1995; Johnson, 2006), but under this use both natural adjustment processes and genuine channel instability are amalgamated. Prior surveys have also typically required interpretative understanding by an experienced field surveyor and thus risks significant inter-surveyor bias. Separating field observations from their interpretation both helps to reduces this risk and also allows observations to be retrospectively re-scored if required.

Below, we document a new approach for assessing channel adjustment processes and illustrate the technique using results from two pilot tests undertaken in highly contrasting environments. Results demonstrate the conversion of field observations into 14 modes of channel adjustment, 4 levels of apparent adjustment intensity, and summary judgments about the each channel's relative stability. Prospects for the approach are discussed.

2 APPROACH

The approach taken here is summarized in Figure 1. Diagnosing channel adjustment processes from field survey relies on 'reading' multiple adjustment indicators from attributes of the channel morphology, in- and near-channel vegetation and relationship to nearby infrastructure. Here, indicators were derived from prior approaches for rapid assessment of channel instability supplemented by indicators drawn from inventories of channel naturalness and other rapid inventories of geomorphic parameters. Approximately 40 indicators were assembled into a systematized checklist that regulates field surveys and allows efficient data collection. Field surveys are undertaken over a reach length that balances the need to adequately characterize the channel's adjustment processes yet supports a feasible field effort. Scaling survey distances by channel width allows assessment to be undertaken over a distance equivalent to a recognized unit of fluvial geomorphology, such as a meander wavelength. Many of the features were recorded using the 'ATPE' non-linear scaling system (Gurnell *et al*. 2020, a variation of the DAFOR system used by ecologists) with the categories denoting the Absence (0% occurrence), Trace (1-5%), Presence (5-33%) or Extensiveness (33-100%) of each indicator.

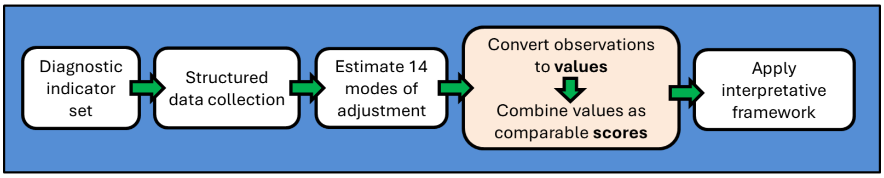

Figure 1: Approach to field data collection and processing to diagnose channel adjustment processes

Acknowledging that rarely does one observation provide conclusive evidence for an adjustment process, individual observations (i.e., indicators of change) are assembled into suites of observations indicative of one particular *mode* of channel adjustment. Fourteen suites of observations were identified (see Table 1) and quantified as a series of equations that might combine ten or more field indicators. In each equation, the field indicators of change were converted into values that address the apparent non-linear certainly and/or severity of adjustment. For example ATPE observations were frequently valued as A=0, T=1, P=3, E=7, but considerable care was required to ensure that values in each equation are comparable and did not create an inherent weighting towards certain indicators. Because each adjustment equation subsequently had a different value range, each was converted to a banded category (0-3) that indicates whether there is negligible (0), some (1), moderate (2) or considerable (3) evidence for change. This allows for equations to be compared and provides an interpretation of the apparent *intensity* of the adjustment process. Boundary values between the banded categories can be revisited as the sample data set grows to ensure broadly equal variance in the equations. Finally, equations were grouped (see Table 1) 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.

Table 1: Fourteen modes of channel adjustment diagnosed from assembled field indicators, and their relation to three summary judgments regarding channel stability (see text). Suscept. = susceptibility.

Eq	Sensitivity to Change	Eq	Lateral Activity	Eq	Channel Instability
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	Channel suscept: structural			14	River bed aggradation

3 FIELD TESTS

Pilot field tests were undertaken in the summers of 2023 and 2024. In high elevation meadows of the Sierra Neveda of California, surveys were undertaken to re-occupy a series of biological reference sites whereas in channelised lowlands of Ireland the surveys were used as part of validating a recently developed river restoration planning tool. The California sites (n=54) were expected to indicate mostly equilibrium conditions, dynamic stability and possibly the effects of occupation by early Euro-American settlers to the region. The lowland sites in Ireland (n=46) were expected to indicate channels adjusting by fine sediment-led recovery processes, or a forced stasis imposed through regular channel maintenance (e.g., dredging). The California surveys characterized each reach via one survey extent of approximately one meander wavelength in length: in Ireland the same survey length was achieved but by breaking the reach into 5 modules. Several test results are provided inset on an indicative photograph in Figure 2. The 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.

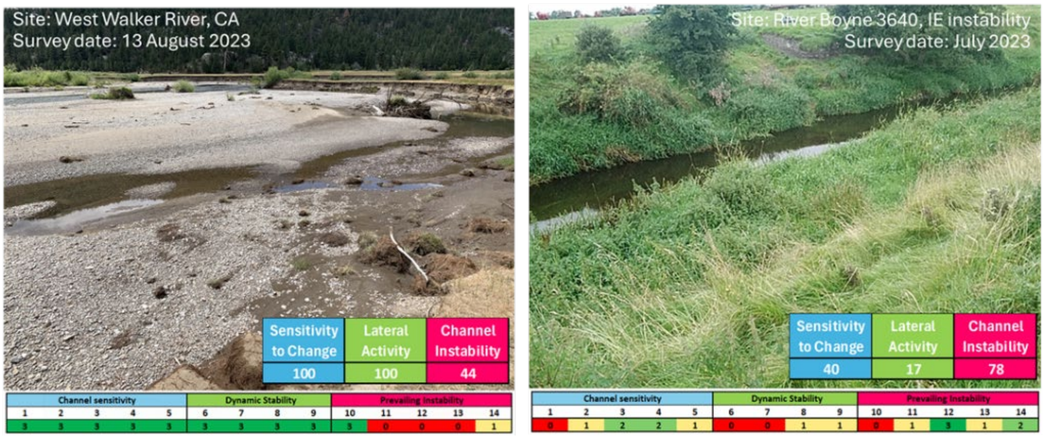

Figure 2: Example field results from pilot testing of the channel adjustment assessment (equation numbers as Table 1).

On the left in Figure 2, a highly active channel in California shows maximum scores for potential sensitivity to change and signs of lateral activity, but limited score for channel instability. We interpret this channel as dynamically stable and likely in an equilibrium state. The channel in Ireland scores moderately for potential sensitivity to change, possesses few indicators of lateral activity but significant evidence for channel instability –

in this case as the channel narrows (large berm in the foreground of the photograph) and aggrades.

The examples illustrated in Figure 2 reflect our expectations of adjustment types from the two environments. Such expectations are borne out more generally across the sample set (Figure 3). 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 (Figure 2, left) to those with far lower apparent rates of change, and generally show low levels of channel instability. 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 (relative to the California samples). Mirroring our example in Figure 2 (right), instability is generally in the form of channel recovery through fine sediment-led processes of channel narrowing and aggradation.

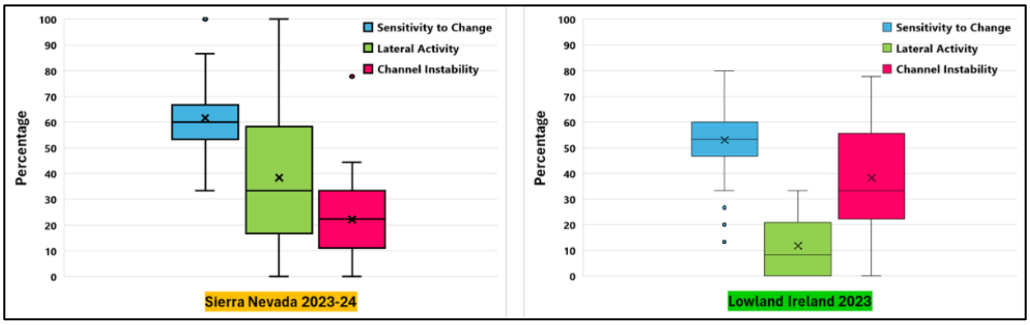

Figure 3: Box-and-whisker plots illustrating summary results for the California and Ireland pilot test sites. The coloured boxes span the interquartile range (25–75th percentiles, median indicated by the central line); crosses indicate mean values.

4 CONCLUSION

Pilot test results are consistent with our expectations, providing evidence that the approach has potential in judging channel adjustment processes and relative stability. Further the assessment technique takes only an hour or two for each reach, making the approach highly suitable to repeat monitoring when evaluating river restoration and management schemes, even when monitoring is poorly funded. The scheme minimizes inter-surveyor bias by restricting the surveyor to field observation; interpretations are instead provided via expert judgment embedded into the equations for the mode and intensity of adjustments. As such, results from earlier surveys can readily be recalculated if the equations are adjusted. Clearly, 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, we believe, by using the 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.

Finally, because our scoring systems are bounded we can benchmark observed modes of adjustment according to their apparent intensity (0-3) and percentage score (0-100) in relation to the channel's sensitivity to change, lateral activity and relative instability. This has considerable value both because it allows comparative assessment of channel adjustment processes which has not been possible before, but also because in evaluating river restoration projects, it reduces the emphasis on pre-project monitoring which is rarely funded or undertaken to any rigorous extent. Indeed, assessing a nearby unrestored reach of river as a control would probably provide a sufficient baseline for judging the success in sustainably restoring river processes, and could be combined with inventories of riverine habitat diversity and connectivity to provide overall evaluation of river restoration success.

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