Integrating channel evolution into river management: towards a functional decision-support framework

Intégrer l'évolution du chenal dans la gestion des cours d'eau : vers un cadre fonctionnel d'aide à la décision

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RÉSUMÉ

De nombreuses études ont reconstitué rétrospectivement les trajectoires évolutives des chenaux dans l'Anthropocène récent à l'aide de plusieurs sources de données historiques, mais comment peut-on projeter les tendances évolutives pour renforcer les compétences prospectives dans le domaine de la gestion des rivières ? Un système de prédiction est nécessaire pour simuler les modes probables d'évolution morphologique des chenaux en fonction des changements prévus dans les conditions de forçage environnemental sur des périodes de gestion (de décennies à un siècle ou plus), et sur des distances de plusieurs kilomètres. De tels systèmes requièrent une focalisation intermédiaire au-delà de la gamme habituelle de simulation détaillée entreprise dans la modélisation hydraulique multidimensionnelle, mais avec une précision locale et temporelle supérieure à celle obtenue dans les modèles d'évolution du paysage. Il est essentiel que l'analyse soit orientée vers les besoins stratégiques d'aide à la décision du gestionnaire de la rivière en reformulant les données de sortie techniques dans un format mieux adapté à ses besoins. Nous présentons des recherches en cours simulant les changements d'état dans la morphologie des rivières sur des échelles de temps décennales, permettant aux dangers potentiels et aux atouts associés à la morphologie changeante des chenaux d'être traduits à travers un « tableau de bord » graphique d'aide à la décision qui illustre les risques basés sur des seuils liés à des problèmes communs dans la planification, l'ingénierie, la restauration et la conservation des rivières.

ABSTRACT

Numerous studies have retrospectively reconstructed channel evolutionary trajectories in the recent Anthropocene using multiple historical data sources, but how can evolutionary tendencies be projected forward to build foresight competency into the field of river management? A system of prediction is required that can simulate likely modes of channel morphological evolution to projected changes in environmental forcing conditions over management timeframes (*i.e.*, decades to a century or more), and over distances of multiple kilometres. Such systems require an intermediate focus beyond the usual range of detailed simulation undertaken in multi-dimensional hydraulic modelling, but with a locational and temporal precision greater than achieved in landscape evolution models. Critically, the analysis needs to be directed towards the strategic decision-support needs of the river manager by reformulating technical output data into a format best suited for their needs. We present in-progress research simulating state-transition changes in river morphology over decadal timescales, allowing the potential hazards and assets associated with changing channel morphology to be translated through a decision support graphical ‘dashboard’ that illustrates threshold-based risks related to common issues in river planning, engineering, and restoration and conservation.

KEYWORDS

Channel evolution, foresight competency, graphical dashboard state-transition, strategic decision support

1 INTRODUCTION

Understanding the evolutionary trajectory of river channels is critical for those involved in river corridor planning, flood risk alleviation, maintaining channel stability, and river restoration. Management strategies should, therefore, benefit greatly from improvements in the ability to simulate and communicate anticipated channel evolutionary responses to changes in the environmental forcing conditions (*e.g.*, climate, land uses, water resource management activities) over management time and space scales. Such advances would enable actions to be taken to avoid certain unlikely or undesirable possible futures (*e.g.*, severe channel instability), instead instigating strategic decision-making directed towards a preferred future condition (e.g., dynamically sustained channel diversity), which may not be the most probable future based on recent trends in the boundary conditions. Achieving strategic foresight in (river) management is a multi-phase process based on a sequence of framing, scanning, forecasting, visioning, planning and acting (Hines and Bishop, 2006). In terms of river channel evolution, the least well-developed aspects are those for *forecasting* the various possible futures via scenario-based modelling and *visioning* the modelled outcomes to maximize the chance of aligning channel evolution with a pathway towards a more favourable future state. We present a proof-of-concept decision support tool, RUBRIC (RUles-Based morphological Response In river Channels), designed to extend from a recently developed morphodynamic model for forecasting channel evolution (FRAME: Future River Analysis and Management Evaluation). RUBRIC thus addresses the largely neglected notion of visioning, facilitating decision support by translating forecast changes using a graphical 'dashboard' that illustrates threshold-based risks related to common issues in river planning, engineering, and restoration and conservation.

2 APPROACH

Graphical user interfaces (GUI) are important in Decision Support Systems (DSS) where visioning the outputs of simulations and scenario analyses are critical to facilitate the interaction of the modeller with the environmental manager. While the challenge of knowledge transfer in river restoration is recognized, examples of DSS for channel evolution are in their infancy. A practical approach for visioning channel evolution in the context of river management must resolve several requirements. Beyond the substantial task of analytically characterizing river channel evolution over multi-decadal timescales, achieved here through the FRAME tool, the channel evolutionary adjustments need translating into metrics suitable for interrogation by non-geomorphologists and, subsequently, a series of graphical indicators as part of a 'management dashboard' for decision support (Figure 1).

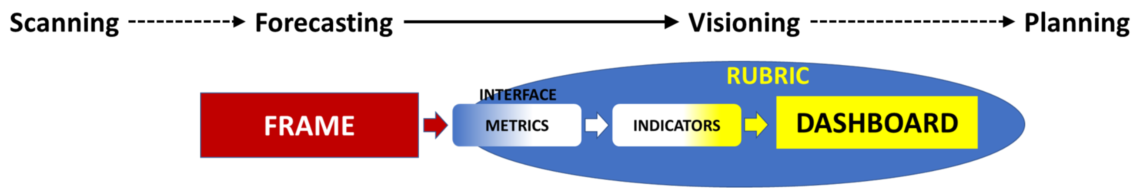

Figure 1: Contributions of FRAME and RUBRIC to achieving foresight competency in river management, as the central components of the overall six-factor foresight approach (shown above, with the initial component of 'framing' and the final component of 'acting' omitted for simplicity).

3 METRICS OF CHANNEL EVOLUTION

Seven geomorphologically-derived 'metrics of change' are proposed to provide a broad understanding of channel evolution as it applies to common concerns in river planning and management. The metrics, aimed to assist in foresight over a 50–100-year period, exploit the fundamental degrees of freedom in morphological adjustment that result from FRAME modelling (currently based on discharge, shear stress, sediment transport capacity, bed elevation, and grain size distribution changes over time). Where possible, metrics are drawn from physically-based studies to provide the strongest theoretical justification. While progressive change in boundary conditions generally implies progressive morphological evolution, the existence of extrinsic and intrinsic thresholds in geomorphic 'states' opens the prospect of abrupt morphological response across thresholds and into a new state. Ideally, foresight needs to be capable of describing within-state and between-state transitions, implying the use of a 'state-transition model' basis for characterizing evolution. Metrics were thus also chosen to provide risk-based indications based on proximity to and crossing of thresholds in state transitions where such transitions are known. Metrics for land use planning include those for channel planform adjustment, channel cross-sectional adjustment, and the erodible river corridor. Metrics for hazard reduction and asset increases include those for floodplain hydrological connectivity and riverbank erosion rate. To support conservation management there are metrics for bedform habitat type and ecohydraulic diversity. Functional realization of metrics related to riverbank erosion and meander migration await developments in FRAME modelling abilities.

4 RISK INDICATORS AND MANAGEMENT DASHBOARD

Graphical indicators are intended to convey information in a visually intuitive manner, generally relative to proximity to a relevant state-transition threshold in the metric. Prototype dashboards were designed to display (i) the spatial variation of indicators for a user-chosen year in the forecast timeframe and (ii) variation through time of indicators at a user-chosen cross-section. RUBRIC currently runs within an Excel spreadsheet: output data are exported from FRAME (also Excel-based) and the channel metrics calculated automatically, which are then translated into the indicators for dashboard display and interrogation. This 'semi-automated' system allows checks on data quality and calculations.

Proof-of-concept case studies were developed for two sand-bedded rivers, including a 300-km reach of the Lower Mississippi River, MS, and a 100-km reach of the Kankakee River, IN/IL. Both are sand-bed channels. Case studies for gravel bed rivers will follow. Four scenarios were run including 60-year scenarios based on recent hydroclimatic conditions and under conditions of higher flows resulting from climate change. The third scenario involved a hypothetical management intervention under current hydroclimatic conditions, and the fourth combined the management intervention with climate change. An example display is provided in Figure 2: projected changes are limited as the initial test scenarios are in low-gradient sand-bedded rivers.

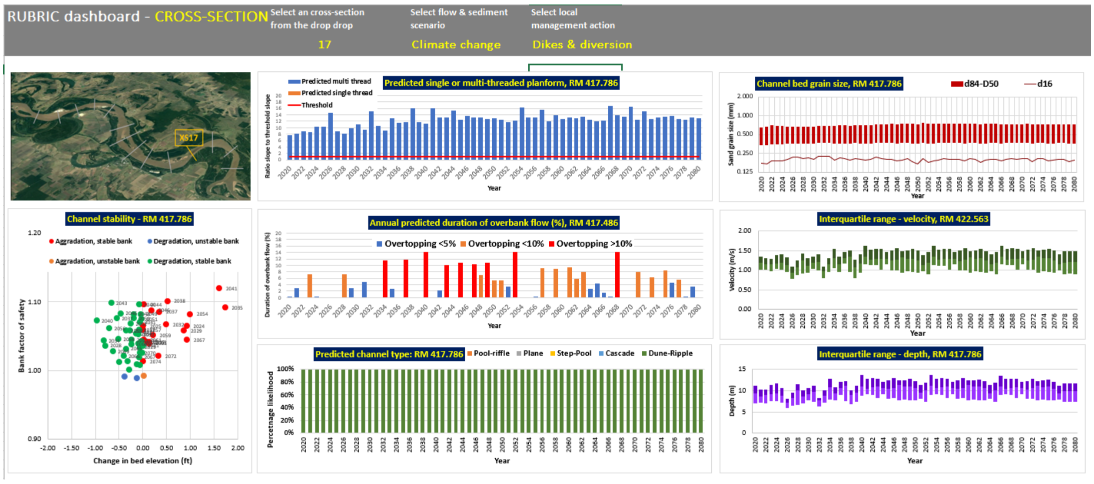

Figure 2: Proof-of-concept dashboard design illustrating changes in indicators at an individual cross-section following changes in the hydroclimate (after 2040) and the hypothetical installation of dikes and a flow diversion.

5 PROSPECT

Development of a proof-of-concept approach for integrating multi-decadal channel evolution into river management has resulted in a functional, semi-automated decision-support tool. Next step developments are to develop the FRAME model further, particularly with the addition of a gravel sediment transport function. As many of the metrics were initially proven in gravel-bed river settings, such capability will likely provide a truer indication of the sensitivity of the metrics to different management futures. Near-term development of width and sinuosity adjustments within FRAME will enable the final metrics and indicators for each to be compiled and the dashboard design to evolve further. Subsequently, many of the currently semi-automated 'RUBRIC' functions will be integrated within the FRAME model. Tests are planned to receive user feedback, and for the development of a fully interactive dashboard operation that will allow users to simulate alternative management futures. Once completed, RUBRIC will provide a novel system of decision support for strategic river planning and management, addressing the outstanding requirement for *visioning* capabilities in the foresight competency of applied fluvial geomorphology.

LIST OF REFERENCES

Hines, A. and Bishop, P. (2006). Thinking about the Future: Guidelines for Strategic Foresight, 2nd edition 2015, Hinesight, TX.