Prediction of channel morphology in a large braided river

Prévision de la morphologie des chenaux d'un large fleuve anastomosé

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RÉSUMÉ

La possibilité de prévoir l'évolution des chenaux d'un cours d'eau présente diverses implications pratiques, car elle pourrait offrir un outil essentiel pour mener des stratégies de gestion. L'objectif de cette étude est de découvrir les dynamiques futures d'une section anastomosée du fleuve Tagliamento, situé au nord-est de l'Italie. Cette étude associe deux approches de modélisation afin de prévoir la morphologie des chenaux : (i) un modèle conceptuel fondé sur une analyse historique des changements subis par les chenaux ainsi que sur des facteurs de contrôle et (ii) une modélisation numérique utilisant un modèle à complexité réduite (CAESAR). Selon le modèle conceptuel, un élargissement des chenaux va se produire, mais la trajectoire évolutive dépendra de l'ampleur et de la fréquence des crues morphogènes. Le modèle numérique, qui utilise des conditions stables pour le régime du fleuve et différentes conditions (c.-à-d. des scénarios) pour l'apport de sédiments, a révélé que les chenaux allaient continuer de s'élargir dans les prochaines décennies, et ce quelles que soient les stratégies de gestion des sédiments mises en œuvres. Comme on pouvait s'y attendre, le phénomène d'élargissement s'avère plus intense dans le scénario qui implique le retrait des protections des berges que dans celui qui prévoit une diminution de l'apport de sédiments en amont. Les résultats des modèles conceptuel et numérique se révèlent être très cohérents, améliorant ainsi la fiabilité des prévisions. Ces résultats offrent des informations essentielles pour la gestion des cours d'eau, car ils présentent les trajectoires évolutives et l'impact des différentes stratégies de gestion des sédiments sur la morphologie des chenaux et notamment leur largeur.

ABSTRACT

Prediction of future channel evolution has several practical implications because it may represent a key tool to guide management strategies. The aim of this work is to explore future dynamics of a braided reach of the Tagliamento River (north-eastern Italy). Two modelling approaches were combined to predict channel morphology: (i) a conceptual model based on a historical analysis of channel changes and controlling factors and (ii) numerical modelling, using a reduced complexity model (CAESAR). According to the conceptual model channel widening will take place in the future, though the evolutionary trajectory will depend on magnitude and frequency of formative discharges. The numerical modelling, using constant conditions for flow regime and different conditions (i.e. scenarios) for sediment supply, showed that channel widening will continue in the next decades, independently from sediment management strategies. As expected, widening turned out to be more intense in the scenario where bank protections were removed compared to the scenario where upstream sediment input was reduced. Results of the conceptual and numerical model turned to be very coherent, thus increasing reliability of the predictions. Such results are instructive for river management since they show future evolutionary trajectories and the effects of different sediment management strategies on channel morphology, in particular on channel width.

KEYWORDS

Cellular model, channel adjustments, evolutionary trajectory, river management, Tagliamento River.

1 INTRODUCTION

Prediction of future channel evolution has several practical implications because it may represent a key tool to guide management strategies. Prediction requires use of models (e.g. conceptual, physical, analytical or numerical models) (Wilcock and Iverson, 2003). Uncertainty associated with any kind of model and complexity of fluvial systems, specifically of braided rivers, are major issues to be taken into account. This means that we should be aware that prediction of channel morphology has inherent limitations since results of any model are affected by a degree of uncertainty and braided rivers are very complex systems that exhibit self-organized critical behaviour.

In this work a long braided reach (33 km in length) of the Tagliamento River (north-eastern Italy) is analysed. This large gravel-bed river (average channel width was 760 m in 2009) underwent notable channel adjustments due to human interventions (i.e. sediment mining and channelization) in the past. Our aim is to explore future channel evolution taking into account different scenarios of flow regime and sediment supply at catchment and reach scale. Two different modelling approaches were combined to predict channel morphology: (i) a conceptual model based on a historical analysis of channel changes and controlling factors and (ii) numerical modelling, using a reduced complexity model (CAESAR; Coulthard et al., 2007).

2 METHODS

Channel changes over the last 200 years were analysed using historical maps, aerial photos, cross-sections and by geomorphological surveys. Changes in channel width, braiding intensity, and bed-level were reconstructed. As for controlling factors we analysed human interventions at reach (i.e. bank protection structures and mining activity) and basin scale (i.e. land use changes and torrent control works) and flow regime over the period 1886-2010.

A cellular model (CAESAR) was used to predict channel morphology over the period 2001-2081. After sensitivity analysis, calibration, and validation the model was applied using constant conditions for flow regime and different conditions (i.e. scenarios) for sediment supply (Ziliani, 2011). Flow regime in the period 2000-2010 was replicated several times, thus assuming no changes in flow regime in the next years. As for sediments, we explored different possible scenarios of management: in two scenarios bed load supply was increased (for instance assuming removal of bank protection structures), in one scenario upstream bed load input was reduced, in the fourth scenario no change in sediment supply was assumed, referring to present condition.

3 RESULTS AND DISCUSSION

River channel underwent different phases of adjustment over the last 200 years (Fig. 1). From the end of the 19th century to early 1990s, the channel was characterized by narrowing (channel width decreased from 1560 m to 700 m) and incision (about 1.0 m); from early 1990s to nowadays, by widening (from 700 m to 760 m) and slight aggradation (about 0.3 m). Combining evolutionary trajectories of channel morphology and analysis of controlling factors we concluded that the phases of narrowing and incision were driven only by human intervention at reach scale (i.e. sediment mining and channelization). Changes in sediment supply in the catchment area had no effects in this reach. The most recent changes (i.e. widening and slight aggradation) are explained as a response to past disturbances which have produced a remarkable increase of unit stream power. Magnitude and frequency of formative discharges are a key driving factor of the type and intensity of recent changes (1993-2009).

According to this interpretation of channel adjustments, channel widening should continue in the future, though the evolutionary trajectory will depend on flow regime (i.e. formative events). For instance assuming that flow regime in the next years will be similar to that in the period 1993-2009, channel width will increase up to 1020 m in 2080 (in this case an average widening rate of 3.7 m/yr is assumed) (Fig. 1). From this conceptual model different future trajectories could be derived, for instance more intense channel widening is predicted if an increase in magnitude and frequency of formative discharges is assumed.

The numerical modelling showed that channel widening will continue in the future (up to 2080), independently from sediment management strategies (Fig. 1). As expected, channel width (w) was larger in the scenario (SC) where bank protections were removed (w = 1230 m in SC2) and smaller in the scenario where upstream sediment input was reduced (w = 1130 m in SC4). It is worth noting that SC1 (scenario with no interventions) and SC3 (scenario with an increase of upstream sediment input) produced very similar results in terms of channel width (Fig. 1), confirming a low influence of upstream sediment input on channel dynamics in the study reach. Bed-level changes were of small magnitude in all the four scenarios.

There are clearly some differences in the results of the two models, but overall the results can be considered satisfactory. Both models predict that channel widening will continue in the future and magnitude of widening in the five scenarios is comparable. Besides inherent errors associated to both models (e.g. it is possible that the cellular model underestimated the effect of vegetation growth on channel dynamics), some differences are also due to input data. Specifically, the flow regime of the periods 1993-2009 and 2000-2010 were used as input data for the conceptual and the numerical model respectively.

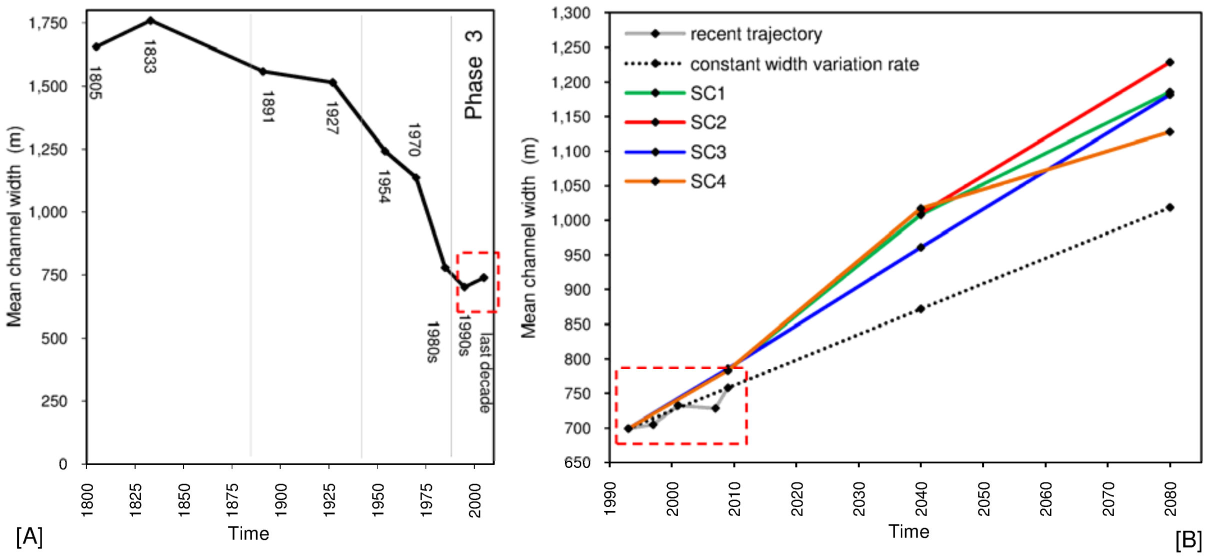

Fig. 1. (A) Changes in channel width over the period 1805-2009; (B) Prediction of channel width for the period 2009-2080; recent trajectory: channel width measured from aerial photos; constant width variation rate: derived from the conceptual model; SC1, SC2, SC3, SC4: simulations of different scenarios of sediment management using a numerical model (CAESAR), assuming no intervention (SC1), removal of bank protections (SC2), increase of upstream sediment input (SC3), and decrease of upstream sediment input (SC4).

4 CONCLUSIONS

This work should be taken as an attempt to predict channel morphology over long spatial and temporal scales (i.e. tens of km and tens of years) that are rarely considered in river modelling. Such scales are very relevant for river management. Because uncertainty can be very high in modelling long river reaches over several decades, it is worth using different models to reduce uncertainty. The results of the two models used in this study turned to be very coherent, thus increasing reliability of the predictions. Results of the different scenarios are instructive for river management since they show future evolutionary trajectories and the effects of different sediment management strategies on channel morphology, in particular on channel width. The next step of this work will be to include changes in flow regime in future scenarios.

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