Process-oriented river restoration scenarios for a large river-floodplain system: the Upper Rhine River (France, Germany)

Scénarios de restauration fonctionnelle d'un grand fleuve et sa plaine inondable : le Rhin supérieur (France, Allemagne)

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RÉSUMÉ

Pour les grands fleuves fortement aménagés depuis plusieurs siècles, le retour à un état de pré-perturbation apparaît irréaliste. Les objectifs potentiels d'une restauration durable doivent alors chercher à équilibrer la réhabilitation partielle de la dynamique fluviale avec les limites imposées par les usages de l'hydrosystème. Le Rhin supérieur à écoulement libre en aval du barrage d'Iffezheim (frontière France-Allemagne) est un bon exemple de ce type de situation avec des plaines inondables présentant une biodiversité élevée, mais où les processus naturels de rajeunissement des communautés biologiques sont quasi-inexistants, avec un vieillissement dominant. Des scénarios de restauration basés sur les processus ont été élaborés sur la zone d'étude, sur la base des mesures telles que le déroctage et l'élargissement des chenaux latéraux, dans le but d'améliorer la connectivité hydrologique latérale et de retrouver une dynamique de régression (i.e. rajeunissement des successions végétales). Les résultats des simulations hydrauliques bidimensionnelles permettent d'identifier des zones-clés d'augmentation des hauteurs d'eau, des vitesses et des contraintes de cisaillement où des processus bio-géomorphologiques (érosion/sédimentation, renouvellement de la végétation) peuvent survenir. Le développement et l'analyse de tels scénarios de restauration des grands fleuves peuvent aider les décideurs à définir les cibles de restauration les plus efficaces possibles. De tels outils peuvent aussi contribuer à sensibiliser le grand public et à impliquer ce dernier dans la prise de décision.

ABSTRACT

For most large rivers, converted throughout the past centuries into straightened and impounded channels, the returning to a pre-disturbance state appears unrealistic and potential sustainable restoration targets must balance partial rehabilitation of riverine dynamics with the limitations posed by current human uses. The free-flowing Upper Rhine River downstream from Iffezheim dam (border France-Germany) is a good example of the situation of many large rivers, whose floodplains still keep a proportion of high natural biodiversity but where natural rejuvenating processes are almost non-existent and succession dominates. Process-based restoration scenarios have been created for the studied segment, including measures such as rip-rap removal and side channel widening, with the aim of improving hydrological connectivity and regaining regression dynamics, while maintaining navigability. Results from 2-D hydraulic simulations indicate changes in water depth, velocity and shear stress in crucial areas where self-forming biogeomorphic processes (erosion/sedimentation, vegetation renewal) would initiate. The development and analysis of restoration scenarios can help in depicting potential results and involving public and decision makers alike in selecting the most effective restoration target.

KEYWORDS

Fluvial processes, 2-D hydrodynamic modelling, restoration target, scenarios, Upper Rhine River

1 INTRODUCTION

Alluvial zones along large rivers are potentially highly diversified environments but, at the same time, they are greatly endangered due to the alterations they have endured throughout history. Included among these are incised channels, sedimented floodplains and modified hydrology (Buijse *et al.*, 2005). On the border between France and Germany, the Upper Rhine River downstream from Iffezheim is a distinct example of floodplain disconnection where rejuvenation processes, which involve the re-setting of floodplain habitats (e.g. channel shift, erosion and vegetation rejuvenation), are almost non-existent (Díaz-Redondo *et al.*, 2016).

It is by all means a great challenge to try to recover, at least partially, some of those natural processes in a large river-floodplain system. Essential for the success is a good selection of restoration targets that balance societal needs and natural processes. In particular, process-oriented river restoration measures can be directed towards a self-dynamic development, i.e. measures merely initiate self-forming biogeomorphic processes (Beechie *et al.* 2005). However, results from activated interactions between morphodynamics and vegetation can easily extend to the mid- and long-term and their quantification may infer high complexity. Nevertheless, available tools, such as scenario simulation, allow for some degree of analysis of success in initiating processes of proposed measures.

The main objectives of the study are twofold: (1) the proposal of a sustainable process-based restoration target for the study area, taking into account the limitations posed by current uses and legislation, and (2) the evaluation of process initiation in different restoration scenarios in terms of water connectivity (eupotamon area) and erosion/sedimentation tendency (shear stress values).

2 METHODS

2.1 Study site

The Upper Rhine segment downstream from Iffezheim is a free-flowing river section, with still valuable hydrological dynamics, thus offering a good potential for process-based river restoration (Díaz-Redondo *et al.*, 2016). Besides, its floodplain preserves a high level of biodiversity, and most of its area is part of nature reserves, both in the German (Rastatter Rheinauen) and French (Delta de la Sauer) sides.

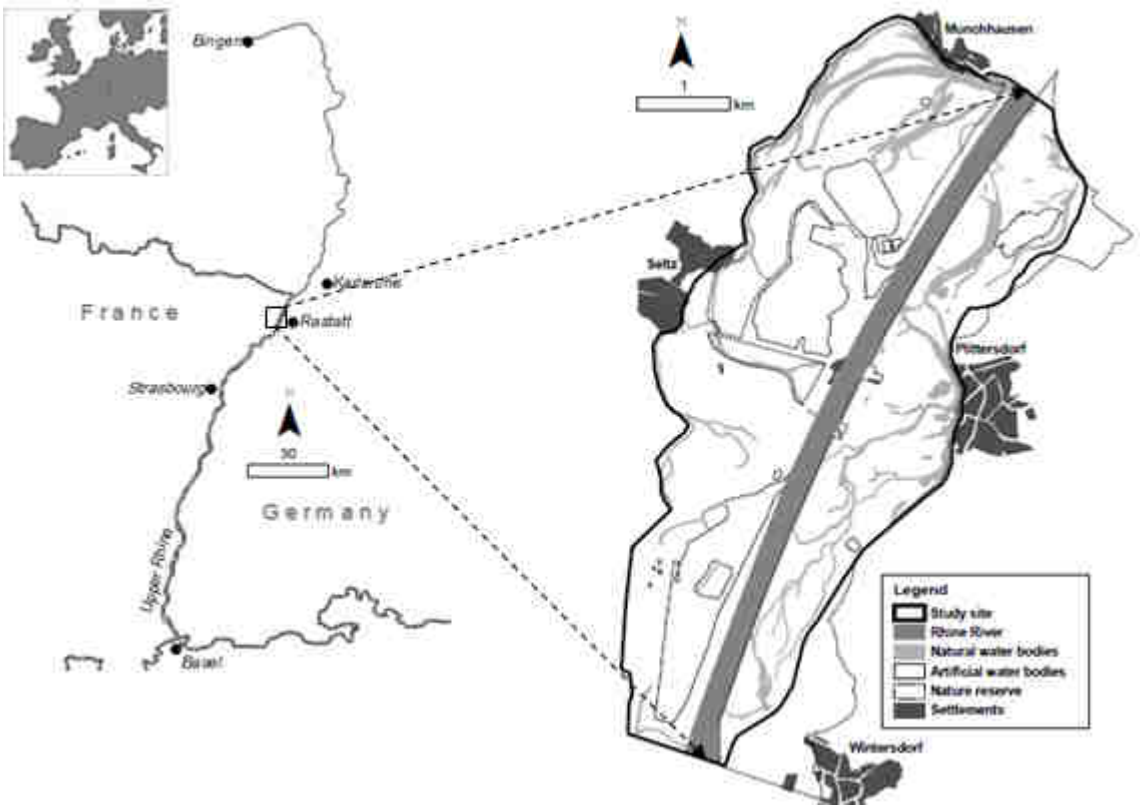

Figure 1. Location of the studied Upper Rhine River segment (Rhine-km 335.7-344)

2.2 Restoration target and scenarios

Given the existing boundary conditions, the selected restoration target for the studied Upper Rhine River segment revolves around partially regaining lateral hydrological connectivity, and enhancing regression dynamics (natural erosion/sedimentation processes and vegetation rejuvenation).

Three scenarios were generated with Global Mapper GIS software: (1) the base scenario represents the situation of the study site in July 2016, (2) Scenario 1 includes rip-rap removal in the main channel to reconnect floodplain side arms, and (3) Scenario 2 comprises the measures of Scenario 1 plus side channel widenings.

Hydraulic simulations were run with IBER 2-D software (developed by the Universities of A Coruña and Catalonia, Spain). Results include parameters such as water depths, velocities and shear stress which are used for a sensitivity analysis, comparing the current situation with the proposed scenarios.

Water connectivity is assessed through the analysis of areas of different types of water bodies, and the study of shear stress is used as a surrogate for the initiation of channel erosion.

3 RESULTS AND CONCLUSIONS

Results from simulations show that eupotamon area (side channel area connected at both ends to the main channel) increases in both scenarios, when compared with current situation (Figure 2). It is necessary to mention that the main differences occur for low discharges (starting at mean discharge).

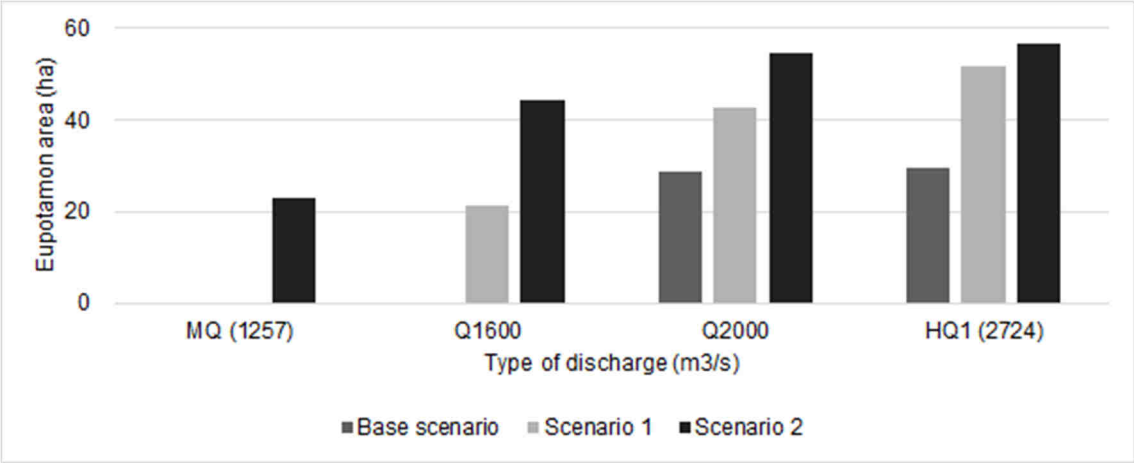

Figure 2. Eupotamon area (ha) for the base scenario (current situation) and the restoration scenarios. MQ: mean discharge; HQ1: discharge for a return period of 1 year

Thus we can conclude that measures of Scenario 1 and 2 succeed in re-establishing lateral hydrological connectivity between the main channel and the floodplain side arms. Furthermore, we have identified increases in shear stress values, especially in Scenario 2, at critical zones, such as channels bends. These results are an indication that those areas may be potentially eroded, and they will be used in an ongoing effort to assess and implement the respective measures in the study area.

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