Introduction

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Hydrological and hydraulic processes, such as sediment transport, affect aquatic, amphibian and terrestrial organisms and their habitats, far beyond the main channel of a river. This area, the so-called 'riverscape', includes a high diversity of riparian habitats, which can vary in space and time depending on the water discharge and sediment dynamics. The animals and plants adapted to life in riverscapes benefit from the changing environment. Specifically, sediment dynamics can provide nutrients, promote reproduction, and both create and temporarily alter habitats.

In near-natural riverscapes, the large area connecting land and water provides sufficient space to mitigate flood hazards. In altered riverscapes, however, human infrastructures and agricultural land are affected by events that exceed the design discharge, and protection measures and residual risk management are therefore necessary. To link flood protection and ecological functions in riverscapes, an understanding of the degree of connectivity is of utmost importance. Near-natural rivers are connected to their surroundings in multiple dimensions: longitudinally from the source to the mouth, laterally from the water to (and including) the shores, and vertically from the surface water to the groundwater. Sediment dynamics affect connectivity in all of these dimensions, and the processes involved range from the catchment to the patch scale.

In ecologically connected riverscapes, species can find refuge in areas where the impact of extreme events (e.g. floods and droughts) is reduced. Functional connectivity also promotes biodiversity, even in small areas, as it interlinks habitats and makes it possible for organisms to disperse or colonize new areas. The recolonization of riverscape habitats is a key process, as the dispersal of riparian species is possible over large distances along functional waterways. Strategic planning for restoration and conservation at the catchment scale benefits from a holistic perspective. Models can help to project the potential for species to reach habitats within riverscapes after years or decades, also under changing climatic and morphological conditions (see Chapter 1; Fink and Scheidegger 2023). Furthermore, aquatic and terrestrial species in riverscapes depend on specific habitats to establish, grow and reproduce. The formation of these habitats in particular locations is shaped by climatic and hydrological factors at the catchment scale and by hydrodynamic factors at the local scale (see Chapter 2; van Rooijen *et al.* 2023).

In near-natural riverscapes, the water and land are well connected, including food webs where insects emerging from the water serve as nutritious food for terrestrial predators (e.g. spiders and birds; see Chapter 3; Kowarik and Robinson 2023). Functional lateral connectivity between aquatic and terrestrial habitats may also be important for the prevention of natural hazards, e.g. flood water diversion. Riverscapes with sufficient space for water retention are able to reduce high water peaks and thus mitigate flood impacts downstream. In the case of a major flood event, lateral diversion structures divert flood water but also affect the sediment transport in the main channel (see Chapter 4; Frei *et al.* 2023). Because regular flooding is important for floodplain vegetation, the construction of lateral diversion structures may also be an effective ecological measure.

During small and large flood events, riverscape species seek shelter in refugia, which are aquatic or terrestrial habitats where the impact of high discharge and sediment mobilization is reduced (see Chapter 5; Rachelly *et al.* 2023). The mosaic of habitats within near-natural riverscapes creates an abundance of refugia, with sediment supply being a prerequisite for refuge provision and function. Additionally, the deposition of fine sediment on floodplains during floods is important for the formation of terrestrial riparian habitats such as species-rich floodplain forests. This process is highly dependent on the structure within the habitat, for example, shrubs and grass-like vegetation promote sediment deposition. Further, knowledge about the deposition characteristics of fine sediment in compound channels is crucial for flood protection in regulated rivers (see Chapter 6; Conde *et al.* 2023).

Suspended sediment may also be deposited in the river substrate, with fine particles being retained in the pore space, leading to clogging (also referred to as colmation) and hence reducing porosity and water exchange (see Chapter 7; Dubuis *et al.* 2023). With increasing discharge, declogging occurs as a result of increasing bedload mobilization and a resuspension of fine sediment. It is important to understand the factors responsible for clogging, as this process hinders nutrient fluxes and prevents free circulation of well-oxygenated water. The latter is of major importance for the development of the eggs of substrate-spawning fish, such as brown trout. Further, the type and size of sediment in the river substrate have an impact on the spatial distribution of brown trout, depending on the age and sex of the individual fish (see Chapter 8; Takatsu *et al.* 2023).

The establishment of near-natural sediment dynamics is key to enhancing the ecological function of river substrate. Impaired sediment continuity can be mitigated by sediment augmentation. The optimal approach to bedload restoration measures varies depending on the desired goal, e.g. improving fish spawning habitat, promoting riverbed structures, or enhancing channel dynamics (see Chapter 9; Mörtl *et al.* 2023). For all measures, the ideal timing, quality and quantity of the added substrate are highly dependent on the flood protection objectives and on the ecological characteristics of the aquatic and terrestrial species or habitat affected by the augmentation (e.g. fish and vegetation in the river reach).

This publication is the result of an interactive process involving the researchers working on the project and the advisory board consisting of practitioners from private consultancies, NGOs, and cantonal and federal administrations. It summarizes the main findings of the project phase 2017–2021 (see Box 1) and includes perspectives from researchers or practitioners who were not directly involved in the project (see the 'In practice' box in each chapter). More information about the programme 'Hydraulic engineering and ecology' and the projects can be found on the website *www.rivermanagement.ch*, which also includes links to previous reports and scientific publications.

Box 1: Research programme 'Hydraulic engineering and ecology'

The Federal Waters Protection Act (WPA, 1991) and the Waters Protection Ordinance (WPO, 1998) ask for functional rivers in near-natural riverscapes while maintaining flood protection. Since 2011, a national restoration strategy has been implemented to fulfill this mission. With foresight, the Federal Office for the Environment (FOEN) launched the interdisciplinary research programme 'Hydraulic engineering and ecology' 20 years ago, together with the research institutes VAW (ETH Zurich), PL-LCH (EPFL), Eawag and WSL. The aim of this programme is to develop scientific principles and practice-oriented solutions for dealing with watercourses and to process them in a way that is suitable for implementation. Researchers from various disciplines and experts from practice participate in the programme. The results are intended to contribute to the implementation of the Federal Waters Protection Act and the Hydraulic Engineering Act (1991) and are available to practitioners in the form of scientific and technical articles, manuals, reports and fact sheets.

'Riverscape – sediment dynamics and connectivity' was the fourth multi-year research project in the 'Hydraulic engineering and ecology' programme, following 'Rhone-Thur', 'Integral river management' and 'Sediment and habitat dynamics'. It comprised two main research topics, both focusing on flood protection and ecology in medium-sized rivers: (i) sediment dynamics and (ii) longitudinal, lateral and vertical connectivity. A detailed description of the research project with its specific foci, subprojects and research questions can be found in Vetsch *et al.* (2018) and Fink *et al.* (2018).

Important practice-related products of the research programme that have been generated so far include:

- Handbook for evaluating rehabilitation projects in rivers and streams (Woolsey *et al.* 2005)
- Integrales Gewässermanagement – Erkenntnisse aus dem Rhone-Thur-Projekt (Rohde 2005) [in German]
- Synthesebericht Schwall/Sunk (Meile *et al.* 2005) [in German]
- Wasserbauprojekte gemeinsam planen. Handbuch für die Partizipation und Entscheidungsfindung bei Wasserbauprojekten (Hostmann *et al.* 2005) [in German and French]
- Merkblatt-Sammlung Wasserbau und Ökologie. Erkenntnisse aus dem Projekt Integrales Flussgebietsmanagement (FOEN 2012) [in German, French and Italian]
- Merkblatt-Sammlung Wasserbau und Ökologie. Geschiebe- und Habitatsdynamik (FOEN 2017a) [in German, French and Italian]