Michael Doering, landscape ecologist in the Aquatic Ecology department, studies the relationships between ecosystem structure and function.
Co-author: Christopher T. Robinson

Water resource management: balancing protection and use

Freshwater ecosystems provide socioeconomic services, but their function is dependent on certain ecological requirements being met. Sustainable water resource management should therefore consider the needs of both humans and the environment. What this kind of approach could involve is shown by two research projects carried out on the Spöl and in the Sandey floodplain.

Climate change and growing human demands are affecting the availability of water resources. As a result of excessive water withdrawals (around 4000 cubic kilometres per year worldwide), many large rivers now fail to reach the ocean, especially in arid regions. Globally, more than 500,000 kilometres of waterways have been altered for navigation, over 63,000 kilometres of canals have been constructed, and over 50,000 large dams are in operation. The latter store more than 6300 cubic kilometres of freshwater, and further major dam projects are planned – notably in developing countries [1]. Climate change is also associated with shifts in the timing and magnitude of precipitation, leading to increases in extreme events such as flooding and droughts.

Water – risk and resource. Taking Switzerland as an example, recent data and predictions suggest that the main precipitation period will shift to late winter and early spring. This will increase the risk of extreme spring flows, followed by low flows or droughts in the late summer. In the longer term, the situation could be exacerbated by glacier retreat. These developments will have direct consequences for flood control and also for the agriculture, energy and water supply sectors, where water is an irreplaceable resource.

As well as the changing climate, a variety of human uses will exert further pressure on freshwater ecosystems. In Switzerland, the planned phase-out of nuclear power is to be offset – in part – by an expansion of hydropower, which already accounts for around 55 per cent of the country's energy production. At the same time, efforts are underway to mitigate the adverse impacts of hydropower generation. The newly revised Water Protection Act, which came into effect in 2011, calls for remedial measures to reduce the impacts of hydropeaking operations, reactivate sediment transport and remove barriers to fish migration. In addition, over the next 80 years, about a quarter of the 15,000 kilometres of degraded river sections are to be restored [2].

Fig. 1: Sustainable management of freshwater systems seeks to integrate multiple ecological and socioeconomic interests (adapted from [3]).

While freshwater ecosystems are used as resources, providing various socioeconomic goods and services, they are also habitats which can only function if certain fundamental ecological requirements are met. In addition, they may pose risks to human life and infrastructure. These different, sometimes divergent demands and interests – accentuated by climate change – are a source of potential resource-use conflicts. Against this background, sustainable management of water resources is becoming an increasingly urgent task (Fig. 1). Sustainability involves giving due consideration to the needs of humans and of ecosystems. This means taking an integrated approach to economic, social and ecological concerns so as to achieve an appropriate trade-off of interests, acceptable to the various stakeholders. This requires interactive thinking, participative decision-making and long-term strategic planning.

Adaptive management to enhance sustainability. One tool which can promote sustainable use of water resources is so-called adaptive management. This involves a continuous development process, in which what is learned from the results of previous decisions is used to optimize future management actions, thus moving closer towards an ideal solution.

In two case studies – on the Spöl river in the Swiss National Park and in the Sandey floodplain of the Urbach valley in Canton Bern – we have investigated how, with an adaptive approach, multiple ecological and socioeconomic interests can be integrated

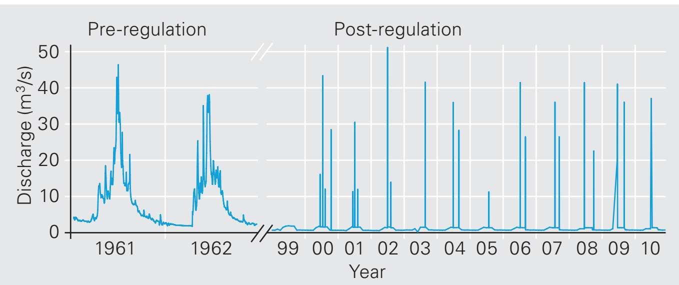
Since 2000 the constant residual flow of the Spöl is interrupted by experimental floods to test the potential for water reuse with respect to optimal ecological discharge.

into sustainable management of water resources. In the first of these two projects, the aim was to use experimental floods to improve the ecology of a regulated alpine river without adversely affecting hydropower production. In the second project, we studied the impacts of historical floodplain management and how planned restoration measures can be reconciled with flood protection and land use needs.

The Spöl originates from Lago di Livigno, a reservoir on the Swiss-Italian border. The pre-regulation discharge was 6–12 cubic metres per second (m^3/s), with peak flows up to 120 m^3/s; following regulation, the constant residual flow is 1.45 m^3/s in summer and 0.55 m^3/s in winter. Since 2000, this residual flow has been interrupted by one to three experimental floods per year, in order to re-establish a more natural flow regime (Fig. 2). The primary aim of the study was to determine whether implementation of this novel disturbance regime could produce positive effects on the Spöl ecosystem, where residual flows had remained at a relatively constant low level for over 30 years.

Optimal ecological discharge is defined in terms of the minimal base flow requirements and the timing, duration, magnitude and frequency of high flow and flood events that are most suitable for creating a sustainable habitat for resident biota – even under changing climatic conditions.

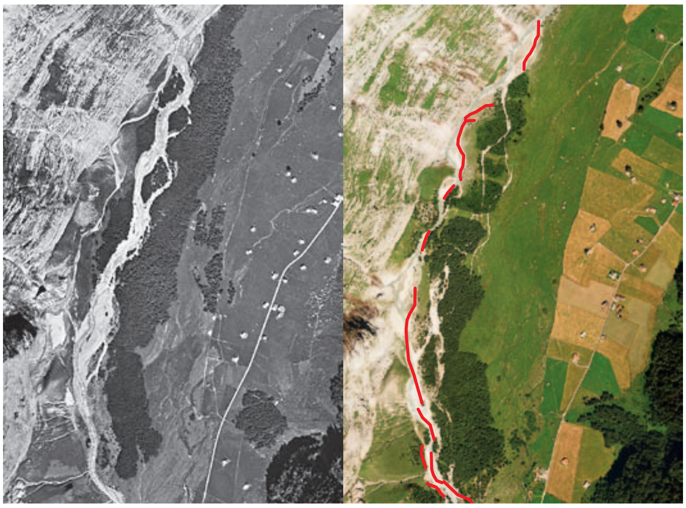
Fig. 2: Until 1970, the Spöl had a natural flow regime (left). Under regulated conditions, residual flows were continuously limited to approximately 2 m^3/s. Since 2000, regular experimental floods (up to 40 m^3/s) have been used to create a more natural flow regime.



Shift towards a more natural regime. The floods had little effect on the physicochemistry of the river, since the water source – hypolimnetic releases from the dam – was unchanged. However, they reduced the armouring of the stream bed and increased the porosity of bed sediments. The sediments were scoured and attached moss was dislodged within the first two years. The floods also reduced benthic organic matter in the river. Standing stocks of primary producers (e. g. periphyton) likewise declined. Although the Spöl is nutrient rich, the floods maintained low periphyton biomass by scouring filamentous algae from bed sediments.

The floods reduced benthic macroinvertebrate density and diversity, leading to changes in species composition, with higher proportions of smaller organisms and a lower biomass. There was a decrease in the abundance of disturbance-prone species, such as the large-bodied, sessile amphipod *Gammarus fossarum,* and an increase in the abundance of more resistant species, such as the small-bodied, highly mobile mayfly *(Baetis* spp.). Overall, after

Fig. 3: Aerial images indicate how the character of the Sandey floodplain changed between 1940 and 2007. Red lines mark the location of levees.



the ecosystem regime shift, greater variation was observed in the composition and morphology of the organisms studied.

At this point, it can be concluded that, as a result of the experimental floods, the habitat conditions and species composition in the Spöl are more similar to those of a comparable natural alpine stream. At the same time, the example of the Spöl demonstrates that it is possible to reconcile ecological and economic interests, as the water released for the floods can be diverted and used for power production in other catchments, with virtually no impact on economic costs [3, 4].

Involvement of stakeholders. The Sandey floodplain project (Fig. 3) – initiated in partnership with the hydropower company Kraftwerke Oberhasli AG and the Federal Offices for the Environment and for Spatial Development – combines field assessment, hydrological modelling and remote sensing/geospatial data to quantify and simulate the effects of historical floodplain management and of planned restoration measures such as selective opening of levees. Also to be taken into account are the maintenance of flood protection and existing land use needs. The project aims to promote sustainable management by providing a scientific basis for dialogue among stakeholders and supporting transparent decision-making for future floodplain management. The inclusion of reference studies from other river systems and the involvement of various actors at the regional, national and international level are designed to ensure that the findings are transferable to other situations.

The Sandey floodplain – around 3.5 kilometres long, with an area of 118 hectares – is characterized by a high degree of structural heterogeneity, containing habitat types which are typical of natural riverine floodplains, such as islands, alluvial forest, main channels and gravel bars. As an alluvial zone of national importance, it is a priority area for conservation. Socioeconomically, the floodplain is used for livestock grazing and for various private purposes. About 30 per cent of the average annual discharge of the Urbach river is abstracted from the system for hydropower production in a different catchment by an upstream dam built in 1950. In addition, especially in the 1990s, numerous levees were constructed to provide flood protection in the active floodplain.

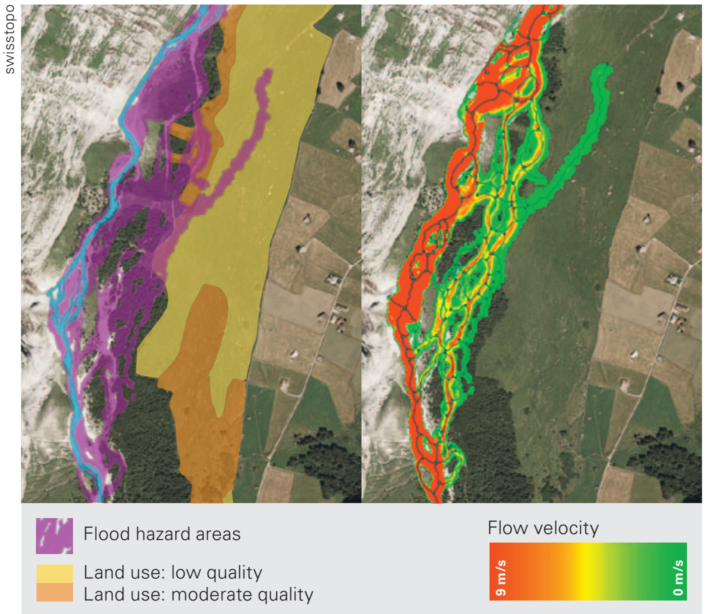
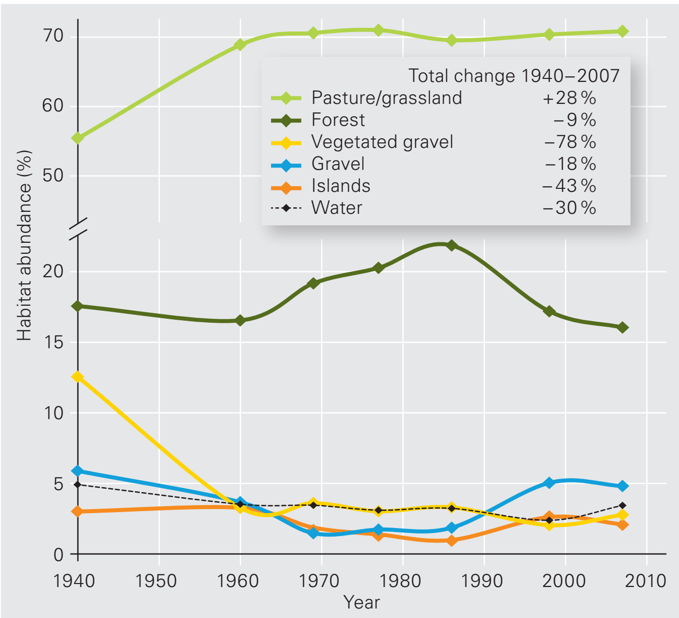


Fig. 5: Computer models can be used to simulate the socioeconomic and ecological consequences of various management scenarios for the Sandey floodplain. For example, it can be predicted how the opening of levees would affect land use, river networking and flow velocity.

Fig. 4: Changes of habitat abundance in the Sandey floodplain between 1940 and 2007. Data were derived from historical aerial images.



Historical aerial images reveal the extent to which the floodplain has changed over time. The relative abundance of habitat types, as well as channel complexity, has fluctuated greatly, which is not a typical pattern for natural riverine floodplains. Compared with the near-natural state mapped in 1940, the area is now less heterogeneous, and certain typical habitats have become less abundant (Figs. 3 and 4). This is probably due to the effects of water abstraction and, in particular, to the constraints on hydrological dynamics imposed by the installation of levees [5].

Impacts on ecosystem processes. We carried out field investigations of respiration rates – a proxy for carbon turnover – in the various habitat types. On the basis of habitat-specific respiration rates and the former extent of each habitat, we also calculated the historical carbon turnover. Comparison with current values revealed a significant shift in the total carbon budget for the floodplain over the last 70 years. These findings indicate that structural and functional floodplain properties can respond relatively rapidly to changes in the hydrological regime. The restoration of more natural hydrological dynamics could therefore enhance habitat heterogeneity and biodiversity, contributing to more natural floodplain ecosystem processes.

In a heavily used area such as the Sandey floodplain, changes to hydrological dynamics – brought about, for example, by the opening of levees – may be associated with increased flood hazards for humans and property. However, thanks to recent advances in landscape modelling, it is now possible to generate high-flow scenarios in conjunction with restored floodplain connectivity so as to simulate the rejuvenation of habitat features while minimizing risks of damage. By applying this model, we can assess which areas of the Sandey floodplain are likely to respond best, in ecological terms, to a high-flow management programme, with flood risks being kept to a minimum (Fig. 5). Initial results suggest that the opening of more side-channels could in fact reduce or mitigate the risks associated with more extreme high flows, while enhancing floodplain habitat heterogeneity and biodiversity.

The model can also be used to simulate how discharge is affected by climate change or changes in water use. The aim is to provide decision support for practitioners or policymakers in the planning of sustainable water management, ensuring a balance between ecological needs for floodplain functioning and the provision of socioeconomic services.

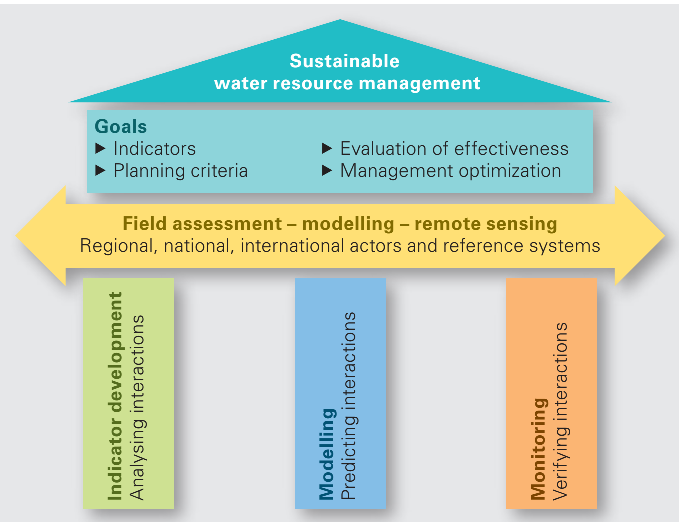
Importance of long-term monitoring. Sustainable water resource management is a complex task: as well as understanding the needs of freshwater ecosystems, the goal is to meet human demands for the goods and services provided by these systems without exceeding their overall carrying capacity. What requirements must be met if they are to remain intact and functional in the long term and thus capable of generating the services desired by humans?

The studies carried out on the Spöl and in the Sandey floodplain represent empirical and pragmatic approaches for achieving more sustainable water resource management, which recognize the complexity of the task and involve the relevant stakeholders (Fig. 6). The results obtained on the Spöl to date have been so convincing that experimental floods are now part of the regulatory framework for the river. In addition, the project has influenced similar experiments at the international level – e. g. on the Snowy River in Australia or on the Colorado River below Glen Canyon dam in the US. But the study also shows that long-term monitoring is essential for the assessment of changes and evaluation of the effects of management actions [6, 7].

The Sandey floodplain project has demonstrated how, with a combination of methods, changes can be quantified at the landscape scale and an integrative approach can be adopted to socioeconomic demands and ecological requirements. At the same time, the two studies have laid the foundations for a comprehensive monitoring programme involving remote sensing data. The aim is to evaluate the effectiveness and ensure the long-term success of restoration measures.

This broad, long-term perspective is essential for adaptive management and the restoration of freshwater ecosystems, so that it is possible to learn from unforeseen developments and, via an iterative process, move closer towards an optimal balance between ecological and socioeconomic needs. Water resource management should be considered a moral obligation vis-à-vis society and the environment, helping to assure the sustainability of ecosystem goods and services.

Fig. 6: An integrative approach to sustainable resource management: field assessment documents relevant parameters (indicators) in the study area, modelling simulates the effects of different management scenarios, and remote sensing permits long-term monitoring.



[1] Tockner K., Stanford J.A. (2002): Riverine flood plains: present state and future trends. Environmental Conservation *29 (3),* 308–330.

[2] Göggel W. (2012): Revitalisierung Fliessgewässer. Strategische Planung. Ein Modul der Vollzugshilfe Renaturierung der Gewässer. Bundesamt für Umwelt, Bern. Umwelt-Vollzug Nr. 1208.

[3] Bundesamt für Umwelt (2012): Einzugsgebietsmanagement – Anleitung für die Praxis zur integralen Bewirtschaftung des Wassers in der Schweiz. Umweltwissen *1204.*

[4] Robinson C.T. (2012): Long-term changes in community assembly, resistance and resilience following experimental floods. Ecological Applications, online.

[5] Robinson C.T., Uehlinger U. (2008): Experimental floods cause ecosystem regime shift in a regulated river. Ecological Applications *18,* 511–526.

[6] Döring M., Blaurock M., Robinson C.T. (2012): Landscape transformation of an alpine floodplain influenced by humans – Historical analysis of aerial images. Hydrological Processes, online.

[7] Robinson C.T., Döring M., Seelen L. (2011): Importance of protected areas for freshwater biomonitoring – Case studies in Switzerland. Journal on Protected Mountain Areas Research and Management *3,* 13–23.

[8] Robinson C.T., Örtli B. (2009) : Long-term biomonitoring of alpine waters in the Swiss National Park. Journal on Protected Mountain Areas Research and Management *1,* 23–34.