

**Eawag**

# INews



## **Flood Protection and Rehabilitation – New Directions for Our Rivers**

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Bruno Schädler, atmospheric physicist and hydrologist, scientific advisor in the Hydrology Division, Federal Office for the Environment, FOEN

## Rhone-Thur Project: Moving Towards Integrated River Management

In the autumn of 2000, large parts of the Southern Alps and the UK were hit by devastating floods. Against this background, James Dooge – the doyen of the hydrological sciences, now 84 years old – called on the delegates at an international symposium on flood management to translate the vision of integrated and sustainable water resource management rapidly into action. As an emeritus professor and former politician (Irish Foreign Minister), Jim Dooge combines all the skills and experience needed to promote the realization of this vision. As he has argued, it is not only important to bring together experts from the fields of hydraulic engineering, biology and ecology; what would also be required are additional contributions from the social sciences, communication studies, economics and law.

Since the first United Nations Conference on Water, held in Mar del Plata (Argentina) in 1977, demands for integrated water resource management (IWRM) have met with ever-wider acceptance in scientific and international political circles. But despite some laudable exceptions, implementation has remained difficult at the local and regional policy level and in actual practice. Within Europe, this was the environment in which the time became ripe for the adoption of the EU Water Framework Directive and the development of an EU directive on the assessment and management of floods. The aim is not only to preserve or restore the good ecological status of surface waters, but also to protect people and property against floods. In Switzerland, the new Federal Constitution of 1999 incorporates requirements for sustainable development (Articles 2 and 73) and specifically for water management (Article 76). However, there are no explicit provisions concerning integrated water resource management.

Major water management projects are currently on the agenda: river alterations carried out over a hundred years ago in accordance with the best practice of that period now need to be renewed and

adapted to the requirements of the future – the Rhone in Canton Valais, the Linth Canal, the Alpenrhein (Rhine River above Lake Constance) and the Thur, to mention just a few examples. How should the political guidelines now be implemented in these large-scale river engineering projects? This question has been taken up by a number of forward-looking researchers at Swiss higher-education institutions, whose enthusiasm has also motivated colleagues in other institutes, private-sector consultancies, and cantonal and federal agencies. Together they have launched a major transdisciplinary project on “integrated river management,” better known by the working title “Rhone-Thur research project”.

These efforts have already borne fruit, as witnessed by the present edition of Eawag News, the website [www.rivermanagement.ch](http://www.rivermanagement.ch) and numerous published articles on specific topics, as well as a host of dissertations and doctoral theses. As an additional measure, training courses are being offered for practitioners.

The four key success factors for transdisciplinary cooperation were memorably spelled out by Jim Dooge at a recent public gathering: conducting frank and open discussions, finding a common language while respecting dialects and technical terminology, and showing an effort to understand other views. This underlines the importance of the fourth element: Listen carefully!

Bruno Schädler

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**Publisher, Distribution:** Eawag, P.O. Box 611, 8600 Dübendorf, Switzerland, Phone +41 (0)44 823 55 11, Fax +41 (0)44 823 53 75, [www.eawag.ch](http://www.eawag.ch)

**Editor:** Martina Bauchrowitz, Eawag

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**Translations:** Jeff Acheson, Bottmingen; Alan Hawkins, Erlinsbach; James Morris, Blackawton (UK)

**Linguistic Revisions:** Helen Brügger-Clarke, Zurich

**Publication:** 2–3 times per year in English, German and French. Chinese edition in cooperation with INFOTERRA China National Focal Point.

**Figures:** Peter Nadler, Küssnacht

**Design:** TBS Identity, Zürich

**Layout:** Peter Nadler, Küssnacht

**Printed:** On original recycled paper

**Subscriptions and changes of address:** New subscribers are welcome!  
[eawag.news@eawag.ch](mailto:eawag.news@eawag.ch)

ISSN 1440-5289

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## Rehabilitation – to What Extent, and Why?

All over the world, watercourses are heavily engineered. But since intact rivers and streams provide substantial benefits for society, there is a wish to restore them to a more natural condition. Scientific foundations and tools for sustainable watercourse management have been developed by the Rhone-Thur research project.

Switzerland's watercourses have been severely degraded by flood control measures and other engineering operations. This is also true of the Rhone and Thur rivers, which have largely lost their ecological diversity and characteristic landscape features. For this reason, increasing efforts are now being made to rehabilitate watercourses, and new flood control projects almost always involve rehabilitation measures. A case in point is the "Third Rhone Correction", which was approved by the Great Council of Canton Valais in 2000. The aim of this project is to remedy deficiencies in the existing flood control system and, at the same time, to enhance the Rhone ecologically. In addition, the five cantons lying in the catchment of the Thur are committed to the natural or semi-natural development of this river and its tributaries. Several stages of the "Second Thur Correction" – initiated in 1993 – have already been implemented, and rehabilitation work is to be continued in the coming years.

From 2002 to 2005, these two cantonal projects received scientific support in the form of the transdisciplinary Rhone-Thur research project (see Box). This involved the development of both scientific foundations as well as practical instruments and methods that can be applied in future river engineering projects (also for habitat enhancement purposes).

### **Main Problems Today: Unnatural Hydro-morphology and Altered Flow Regimes.**

According to published estimates [1, 2], 75–95% of watercourses worldwide are degraded. The impairments are of various kinds (see Tab. 1, p. 8). Many rivers and streams have a monotonous morphology or heavily modified flow regime, or are

chemically polluted. Multiple pressures tend to be the rule rather than the exception. In the US, only 2% of watercourses are now classified as natural, and more than a third are considered highly degraded or polluted [1].

In Switzerland, efforts over the past 50 years were focused on improving chemical water quality. Today, unnatural watercourse

### **The Rhone-Thur Research Project**

The aim of the transdisciplinary research project was to establish scientific foundations for sustainable watercourse management, largely focusing on the Rhone and Thur rivers.

#### *Three main areas were studied*

- ▶ biology/ecology (Eawag and the Swiss Federal Institute for Forest, Snow and Landscape Research/WSL),
- ▶ society/landscape (WSL and Eawag),
- ▶ river engineering (Laboratory of Hydraulics, Hydrology and Glaciology/VAW of the Swiss Federal Institute of Technology/ETH Zurich and the Laboratory of Hydraulic Constructions/LCH of the Swiss Federal Institute of Technology Lausanne/EPFL).

#### *Products of the Rhone-Thur project presented in this edition of Eawag News:*

- ▶ a handbook for participation and decision-making in river-engineering projects [3],
- ▶ an integrative model for the prediction of outcomes of rehabilitation measures [4],
- ▶ a riparian forest succession model [5],
- ▶ a report on synergies and river engineering measures (to be published at the end of 2006),
- ▶ a summary report on channel widenings [6],
- ▶ a summary report on hydropeaking (Rhone only) [7],
- ▶ a handbook for assessing the outcome of river restoration projects [8].

A detailed list of publications is to be found on p. 36 and is also available online at: [www.rivermanagement.ch](http://www.rivermanagement.ch) and [www.rhone-thur.eawag.ch](http://www.rhone-thur.eawag.ch)

Other partners involved in the Rhone-Thur research project were the federal authorities (Federal Office for the Environment/FOEN), the cantons of Thurgau and Valais, the Universities of Zurich and Neuchâtel, the Alluvial Zone Advice Centre at Yverdon, and various environmental and engineering consultancies (in particular Limnex AG).

morphology and, in particular, habitat fragmentation and lack of connectivity are counted among the main problems. Figure 1 provides an overview of the ecomorphological state of the country's rivers and streams: action is required for more than a third of the total watercourse network.

Also problematic are altered flow regimes, generally associated with hydropower generation. More than 1600 hydropower plants operate in Switzerland. In many cases, water is diverted from watercourses into reservoirs. As a result, flow rates in downstream stretches are reduced. In addition, there may be substantial fluctuations in streamflows, with surges occurring when water is returned from reservoirs (hydropeaking). About 25% of the country's medium-sized and large watercourses are affected by these flow regimes.

**Ecological Functioning Compromised by Abiotic Factors.** The deficiencies in the abiotic environment described above have adverse effects on biotic communities and ecological processes, impairing the functional capacity of watercourses and reducing biodiversity. Accordingly, the species extinction rate in lakes, rivers and streams is five times as high as in terrestrial ecosystems [9]. This has been attributed largely to fragmentation resulting from barriers such as dams and streambed stabilization structures [10], which impede the dispersal and migration of organisms. In non-fragmented watercourse systems, biodiversity is less sensitive to climatic variation, for example, since organisms can relocate to more suitable sites.

**Exploiting Synergies Between Flood Control and Conservation.** The intensive use of watercourses gives rise to a need for integrated concepts for sustainable management and protection. Society is dependent on the various services provided by these ecosystems – supplies of water for drinking and irrigation, self-purification capacity, climate regulation, biodiversity, fisheries, recreational activities, spiritual/aesthetic values, etc. In the long run, however, we can only benefit from these services if the key functions of watercourses are secured. For this reason, rehabilitation programmes are urgently required.

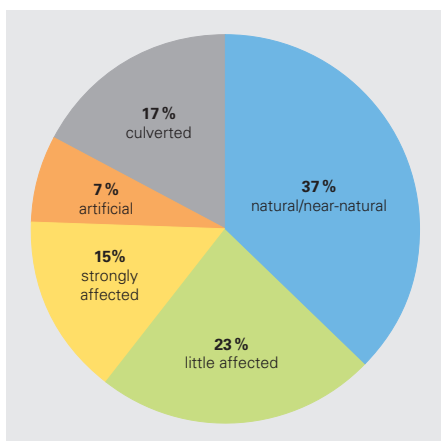
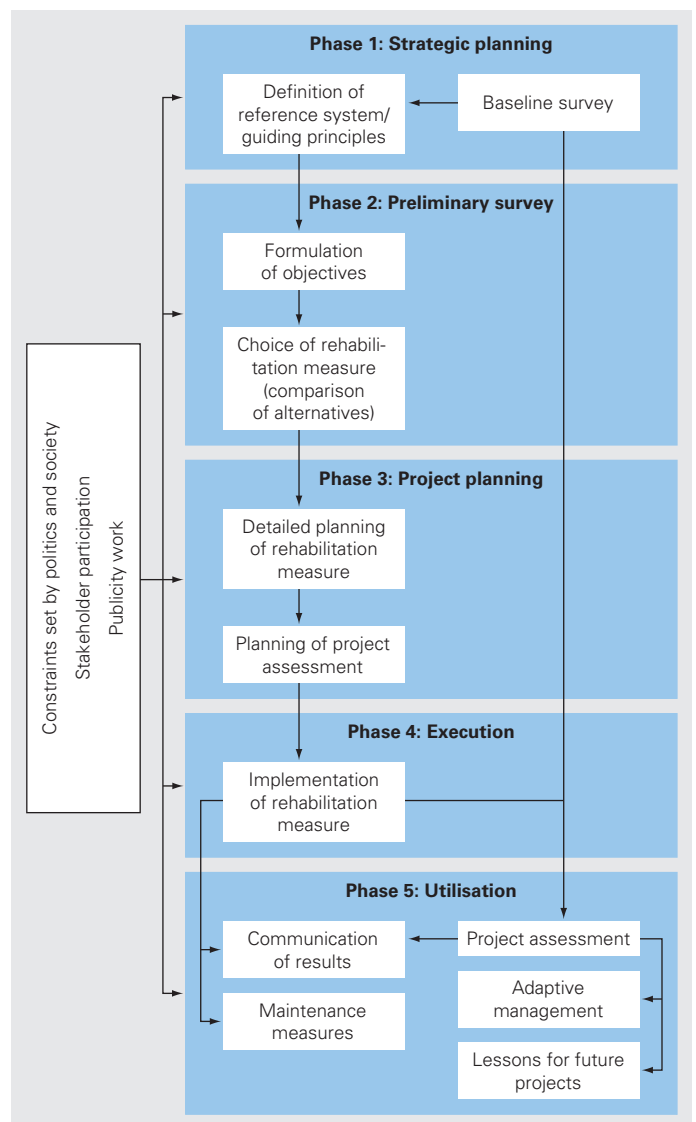


Fig. 1: Ecomorphological classification of Swiss watercourses based on the Modular Stepwise Procedure (data from October 2005, FOWG) [8].

At the same time, settlements, transport and industrial infrastructure, and agricultural land have to be protected against flooding. In many cases, existing flood control measures are no longer adequate, as was underlined by the flooding that occurred in August 2005 (see article by H.P. Willi, p. 9). There is a growing awareness that, in the interests of effective flood control, the space made available for watercourses needs to be increased. Important synergies thus arise between river engineering and ecology (see article by A. Schleiss, p. 18).

**Careful Planning – Successful Rehabilitation.** Rehabilitation projects are a complex undertaking, with flood control, fluvial dynamics and ecology all being central elements. Careful project management is essential to the success of rehabilitation efforts. The ideal sequence of events – from planning to outcome evaluation – is charted in figure 2. In the first two stages (“strategic planning” and

Fig. 2: Flow-chart for a rehabilitation project [8].



“preliminary studies”), rehabilitation objectives and measures are defined. Instruments designed to facilitate this decision-making process in the future have been developed by the Rhone-Thur research project.

One key step in the planning process is the initial discussion of fundamental rehabilitation issues:

- ▶ What synergies can be achieved between flood control and habitat enhancement measures?
- ▶ Which ecosystem services are to be improved or restored?
- ▶ To what extent can habitat enhancement and connectivity measures be implemented?
- ▶ Which severely diminished or vanished species are to be re-established?
- ▶ What measures would facilitate cost-effective restoration of ecologically valuable habitat?

In this process, the political and social framework needs to be taken into account, with the involvement of all stakeholders: guidance on promoting a constructive dialogue is to be found in the handbook entitled “Wasserbauprojekte gemeinsam planen” (Joint planning of river engineering projects; see article by M. Zaugg, p. 12).

The decision-making process can also be facilitated by the application of mathematical models that predict the outcome of possible measures. The riparian forest succession model specifically addresses landscape and vegetation development (see article by C. Glenz, p. 24). In contrast, the integrative model adopts a broader approach, seeking to predict both the economic and the ecological consequences of measures (see article by P. Reichert,

The Thur at Altikon-Niederneunforn before (June 2001, left) and 2 years after widening (September 2005, right). Involving a 1.5-km stretch of the river, this was Switzerland’s most extensive local widening project to date, and it was closely studied by the Rhone-Thur research project. Particularly striking is the marked increase in shoreline length resulting from the development of gravel banks. The new habitat types that emerged were rapidly colonized by plants and wildlife.





Photos: C. Herrmann, BHAteam, Frauenfeld

p. 21). At present, the ecological module considers elements such as hydraulic and morphological changes, and their effects on fish, vegetation, the shoreline fauna and the benthic organisms. A simplified version of the riparian forest model is also to be incorporated into the integrative model.

**Passing on Experience to Future Projects.** Once rehabilitation measures have been defined and implemented, it is essential to evaluate whether the project objectives have been achieved. Assessing the outcome of river restoration is an important step in the overall sequence (Fig. 2), as it allows lessons to be learned for future projects. Step-by-step guidance on how to proceed is provided by an outcome evaluation handbook for watercourse rehabilitation projects (see article by C. Weber, p. 32).

As far as possible, the indicators used in assessing the project outcomes should be readily measurable parameters. Those described in the handbook are predominantly ecological indicators, such as shoreline length or species occurrence and abundance (see article by K. Tockner, p. 15). Further indicators relate to project objectives in the areas of finance, river engineering, drinking water supplies, amenity value, political acceptance and stakeholder participation.

The results of the Thur widening project carried out at Gütighausen were assessed on the basis of specific indicators describing both landscape structure and vegetation development (see article by S. Rohde, p. 26).

**Problem of Hydropeaking.** In certain cases, river engineering and habitat enhancement tasks are complicated by additional difficulties – specifically, in the case of the Rhone, the problems associated with hydropeaking. The fluctuations in water flows downstream of a reservoir hydropower plant have impacts on physical and chemical water quality (e.g. temperature and turbidity) and on river-dwelling organisms. The fundamentals of hydropeaking are dis-

Anthropogenic interests	Background – impacts – examples
Flood control: straightening and channelization	<ul style="list-style-type: none"> <li>▶ lack of lateral/longitudinal/vertical connectivity</li> <li>▶ fragmentation by streambed stabilization structures following channelization: 11 artificial barriers per kilometre of watercourse in Canton Zurich, 5 in Canton Aargau, 2 in Canton Bern</li> <li>▶ more than 33 000 km affected in Sweden [11], 80 % of Austria's major rivers [12]</li> </ul>
Flood control and structural improvements: culverting = watercourses in enclosed channels	<ul style="list-style-type: none"> <li>▶ on agricultural land, at road crossings and in urban areas</li> <li>▶ 17 % of Swiss watercourses culverted</li> </ul>
Land reclamation	<ul style="list-style-type: none"> <li>▶ for settlements, agriculture, transport and industry</li> <li>▶ more than 95 % of lowland waters in south-east England and in Denmark [13]</li> <li>▶ development in riparian areas and often total loss of alluvial zones</li> </ul>
Irrigation and hydroelectric power	<ul style="list-style-type: none"> <li>▶ reservoirs: ~800 000, worldwide, including ~45 000 large-scale dams; 156 large reservoirs in Switzerland</li> <li>▶ flow regulation: European rivers most severely affected, 70 % of Swedish rivers regulated [10]; dammed and residual flow sections; hydropeaking in 25 % of medium/large Swiss watercourses [7]</li> </ul>
Pollution	<ul style="list-style-type: none"> <li>▶ from agricultural, municipal and industrial sources</li> </ul>
Navigation	<ul style="list-style-type: none"> <li>▶ heavy-goods transport</li> <li>▶ major rivers: Rhine, Danube, Elbe, etc.</li> </ul>
Forestry/timber floating	<ul style="list-style-type: none"> <li>▶ radical deforestation (clear-cutting) with soil erosion, especially in North America and in rainforests</li> <li>▶ timber floating in 20<sup>th</sup> century especially in Scandinavia</li> </ul>
Gravel extraction	<ul style="list-style-type: none"> <li>▶ streambed lowering due to lack of gravel</li> </ul>

Tab. 1: Key anthropogenic interests leading to impairment of the ecological integrity of watercourses.

cussed in detail in a summary report (see article by T. Meile, p. 28), which also suggests possible measures for reducing or eliminating surges. The effects of hydropeaking operations on the streambed and shoreline areas – and thus on surface/groundwater exchanges – were investigated in a study conducted on the Rhone plain between Sion and Martigny (see article by M. Fette, p. 30).

**Watercourse Rehabilitation – a Growth Industry.** Watercourse rehabilitation works have only been carried out on a large scale over the past 15 years or so. The last 10 years have seen a dramatic increase in the number of projects worldwide, and this trend is likely to continue. In Europe, rehabilitation schemes will also become more widespread as a result of the Water Framework Directive adopted by the European Union in 2001. This legislation calls for the achievement of “good ecological status” for all surface waters by 2015. Priority action is required in cases where flood protection is no longer adequate and where major ecological deficits

are identified by conservationists. What both of these interests have in common is the demand for more space for waterbodies. As a result, measures serving both flood control and conservation purposes are no longer a contradiction in terms! ○ ○ ○

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Hans Peter Willi, civil engineer, head of the Hazard Prevention Division, Federal Office for the Environment, FOEN

## Meeting the Challenge of Flood Protection

Since the 1987 flooding disaster, Switzerland has been committed to sustainable flood protection – an approach that has already borne fruit. However, flood protection is becoming increasingly complex in view of possible changes in the climate as well as in land use. Forward thinking is essential.

The flooding that struck Switzerland in August 2005 was catastrophic – financially, it was the costliest loss event experienced in this country over the last 100 years. According to an official overview that has been maintained since 1972, losses have quadrupled in the second half of this period. Investment statistics indicate that the resources committed since the events of 1987 have had to be doubled. But although substantially more has been invested, losses have not declined, but actually increased. What are the implications for the current protection strategy? Can it be said to have failed?

**Flood Protection Measures: Opportunities for Ecological Enhancement.** The past 15 years have seen a decisive change in the approach to the management of natural hazards. The National Platform for Natural Hazards (PLANAT), with its broadly based strategy, has shown that purely technical measures are not sufficient to deal with hazards of this kind [1]. What is required is a comprehensive risk culture and integrated risk management. Nonetheless, in the future, flood control structures will still have to be installed in and around watercourses in order to ensure an adequate level of protection. At the same time, however, such intervention, or alteration, also represents an opportunity to improve ecological conditions. This is the intention of Article 4 of the River Engineering Act, which requires ecological deficiencies to be remedied as far as possible whenever alterations are implemented. This new flood protection philosophy has been espoused by the federal authorities since the new River Engineering Act came into effect in 1993.

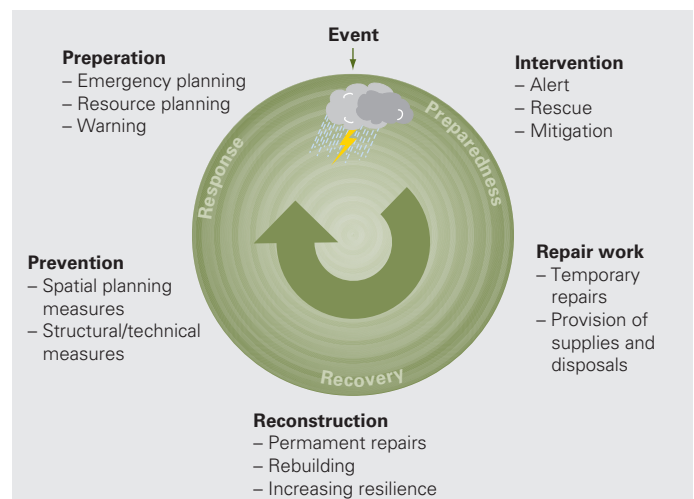
**Absolute Safety is Unattainable.** Knowledge of possible hazards is a key requirement for flood protection projects. Following an analysis of the causes of the flooding in 1987, various aids and recommendations were published: a leaflet on flood protection requirements (1995), recommendations on “Considering Flood Hazards in Regard to Activities with an Impact on Land Use” (1997) [2], guidelines on “Flood Control at Rivers and Streams” (2001) [3], and the “Guiding Principles for Swiss Watercourses” (2003) [4]; together, these documents provide a comprehensive account of the federal authorities’ current strategy. However, the current

status of hazard map preparation demonstrates that recommendations are only a preliminary to action. While 80 % of all communes in Switzerland are exposed to flood risks, hazard levels are only known in 50 % and have only been incorporated in land use plans in 15 %.

In addition, as shown by the disaster cycle of the Federal Office for Civil Protection (Fig. 1), loss events will always occur and absolute safety cannot be assured. Accordingly, it is necessary and advisable to prepare for such events, with preventive, proactive measures being particularly important.

In 1995, the new differentiated, integrated approach to flood protection was presented to experts through the practical example of the Engelberg Aa river, and further projects based on the new principles have been carried out in the last 10 years. Practice-oriented research conducted as part of the Rhone-Thur project was designed to promote the development of sustainable flood protection and integrated solutions, as well as permitting an evaluation of the results of completed projects. On the basis of these studies and an analysis of other events, the appropriateness of the current flood protection strategy can now be assessed.

Fig. 1: Integrated risk management (based on [1]).





Swiss Air Force

Fig. 2: The Engelberg Aa river on the plain between Ennetbürgen and Buochs during the flooding in 2005. The arrows indicate two of the three points at which the floodwaters are allowed to inundate the plain in a controlled manner. A secondary dam currently under construction is marked by an orange line.

**Success Factors.** How do structural flood control measures have to be designed if they are to provide effective protection in the event of an emergency? It is important to consider a number of factors at the planning stage:

- ▶ selection of the responsible planner: an interdisciplinary planning team is a key decision for the developer;
- ▶ integrated planning for the resolution of complex problems: a systems-level approach is indispensable to ensure appropriate action at the local level;
- ▶ room for safety and ecological concerns: discharge capacity and structural diversity;
- ▶ consideration of overload conditions: protective structures should be robust, overloadable and adaptable;
- ▶ secondary measures outside watercourses: remaining risks can be limited e.g. by terrain modifications, designation of flood corridors;
- ▶ participatory planning process to obtain broad support for the project;
- ▶ prioritization of measures: maximizing the effects achieved with limited resources;
- ▶ adequate time for careful planning.

Today, planning of protective structures is an iterative process, in which the effects of various approaches are estimated. The option considered optimal from a global perspective is then implemented. The watchword here is sustainability: the aim is not simply to max-

imize safety, but to develop a proportionate solution that can be adapted to future changes and performs robustly in the event of an emergency or overload. In choosing the appropriate option, the service life and need for renewal of protective structures also need to be taken into account.

**Managing Uncertainties – the Case of the Engelberg Aa.** The idea of differentiated flood protection was embraced by the canton of Nidwalden in its flood control project for the Engelberg Aa river. Here, flooding is not to be prevented at any cost. Instead, the degree of protection is adapted to the value and significance of the assets to be preserved. Accordingly, priority is given to the provision of flood protection measures for the area extending from Dallenwil to the plain of Stans, with the villages of Stans, Stansstad, Ennetbürgen and Buochs. At the same time, the flooding of farmland is considered to be tolerable. The key element of the protection scheme implemented on the Engelberg Aa river is the controlled flooding of selected areas. At three points, floodwaters are allowed to overflow the dam and are diverted across open country towards Lake Lucerne, without causing any damage to buildings or settlements (Fig. 2).

The remaining risks are kept to a minimum through spatial planning measures: development will in future be prohibited on a flood corridor demarcated by terrain modifications. Property owners are given advice on the adoption of on-site measures to protect against



H.P. Willi, FOEN

Fig. 3: When the Engelberg Aa river is swollen by rainfall, additional local protection measures are put in place at the Dallenwil power station.

residual risks (Fig. 3). In addition to the regulation of flood discharges, dams have been renovated in line with modern geotechnical requirements. Channel-widening measures have substantially improved not only the discharge capacity but also the structural diversity of the Engelberg Aa river, although this work necessitated modifications to seven bridges. Finally, longitudinal connectivity is gradually being restored, so that the lake trout will once again be able to reach its spawning grounds.

The effectiveness of this flood protection scheme was fully confirmed by the flooding that occurred in 2005. Thanks to investments of CHF 26 million, well over CHF 100 million worth of damage was avoided. It also became clear that safety can be further enhanced through simple additional measures, particularly secondary defences away from the watercourse.

**Forward Thinking and Dynamic Action.** In the business sphere, companies seek to secure their survival by adapting to changes in the marketplace through a strategy of “dynamic capabilities”. Certain analogies arise with the sphere of natural hazards, where relatively rapid shifts in environmental conditions may also occur. In economic terms, favourable solutions are those that achieve the maximum reduction in damage with the minimum expenditure of resources and exhibit the greatest possible flexibility in adapting to changes, with the lowest possible resultant costs. At a time of growing uncertainties, arising for example from climate change, the significance of dynamic capabilities is clearly increased. In addition, not only hydrological conditions but also land use interests should be regarded as dynamic variables. For this reason, the course and location of developments need to be managed in a forward-looking manner. In high-risk areas, which can only be secured at great expense, if at all, no further assets should be established. As far as possible, these zones should not be used. Instead, well-secured areas should be further developed. Together with the scientific community, we need to reflect, without any preconceptions, on a whole series of questions: How is our living space changing? How

is global warming affecting our environment? How is the risk situation developing? How could we make our landscape safer through deliberate remodelling? There is a need for innovative scenarios and options for action.

**Guiding Principles for Future Flood Protection.** How can we meet the increasingly complex challenges of flood protection? A number of guiding principles may be offered:

- ▶ Integrated risk management: only by exploiting all available options can we increase the security of our living space and keep damage to a minimum. It is essential that institutions which are still operating along sectoral lines should act in a coordinated fashion.
- ▶ Moving from a reactive to an active and proactive approach: it has been forecast that, as a result of climate change, not all the areas currently subject to intensive use will henceforth remain usable without any restrictions. In addition to the status quo, therefore, future risk management must also consider potential changes in fundamental conditions (e.g. in land use). The unthinkable has to be thought, and multi-tiered measures need to be elaborated.
- ▶ Provision of flood corridors and detention areas: this will lead to significant improvements in safety during extreme events and help to avoid an uncontrolled increase in damage potential.
- ▶ Support for effective measures: since the “reform of financial equalization and task allocation (NFA)”, an even greater emphasis has been placed on effective measures. To promote sustainable projects, a system of incentives is currently being developed at the federal level.
- ▶ Strengthening of education and training: expertise depends on efficient knowledge transfer. Everyone involved in the planning of flood protection measures needs to be familiar with possible natural hazards.
- ▶ Interdisciplinary, practice-oriented research: the effectiveness of control measures will be central to future support for flood protection projects. Further development of the indicators used to assess project outcomes is therefore required. ○ ○ ○

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# From Decisions by Experts to a Risk Dialogue

The implementation of sustainable flood protection projects is an exceedingly complex process, requiring a detailed analysis of the broader context and the involvement of all stakeholders. An aid to decision-making is provided by a handbook on joint planning of river engineering projects (*Wasserbauprojekte gemeinsam planen*) that was produced as part of the Rhone-Thur research project.

Until as recently as the 1980s, flood protection for watercourses involved a technical approach based on river alterations and land reclamation – a consequence of the requirements and threats that had arisen for the rapidly industrializing society of the nineteenth century. Since the 1950s, however, adverse ecological impacts have become increasingly evident: 98% of the country's smallest waterbodies disappeared, and the area covered by alluvial zones, formerly 3% of the total area of Switzerland, declined to a quarter of a per cent. As a result of man-made structures and the channelization of watercourses, nature underwent a transformation from "threatening" to "threatened" – a process that aroused concerns, highlighted by various political protest movements [1–3].

**From Technical to Sustainable Flood Protection.** But the adverse effects of technical flood protection measures went beyond impairment of the ecological integrity of watercourses: increased streamflows, a loss of retention areas, and the development of settlements or infrastructure in flood-risk zones led to continuous

growth in the exposure to risk and the potential for damage. In addition, the same level of flood protection was provided for developed and agricultural areas, irrespective of the potential scale of losses. This gave rise to enormous costs for the Swiss state, which is generally responsible for the construction and maintenance of river engineering works. The 1970s, therefore – against a background of ecological debate – saw the beginnings of a paradigm shift in the Swiss approach of river engineering. This sector, hitherto primarily technology-oriented, evolved into an expert system committed to the idea of sustainability (Fig. 1). Sustainable flood protection seeks to strike a balance between flood control on the one hand and the conservation of watercourses and adjoining areas, such as alluvial landscapes, on the other. Instead of relying on "hard" engineering measures, rivers and streams are once again to be allowed more space. Other key elements of sustainable flood protection include coordination of policy with related sectors such as nature protection, agriculture and spatial planning, and involvement of the public in specific projects. One essential process in

Fig. 1: The shift from technical to sustainable flood protection [3].

Year	1960	1970	1980	1990	2000
Influential factors		Ecological discourse	Flooding in the 1970s, 1980s and 1990s Debates on costs of flood protection Debates on efficient use of public funds Sustainability debate		
	<b>"technical" flood protection</b>			<b>"sustainable" flood protection</b>	
Objectives	comprehensive flood protection, expansion of agricultural production and disease control			sustainable flood protection, conservation and promotion of near-natural state of waterbodies	
Characteristics	cost-intensive, same level of protection for all assets			cost-effective, adapted to differentiated protection goals	
Landscape	channelized watercourses			watercourses with adequate space	
Design	rigid, uniform and generally artificial structures			variable, if possible near-natural structures	
Decision-making	"technocratic"; primarily based on expert knowledge, non-transparent involvement of other interests			based on expert knowledge, with transparent involvement of divergent social interests	



Dialogue in practice – definitions of problems, objectives and measures are elaborated in a participatory manner.

today's flood protection projects is the definition of differentiated protection objectives. Increasingly, the aim is to protect complex transport and communication infrastructure, while the protection provided for agricultural areas is decreasing as Swiss food production becomes less relevant. In the 1990s, the principle of sustainable flood protection – implementation of which is based on balancing social, economic and environmental concerns in specific situations – was enshrined in federal river engineering legislation and in the corresponding policies.

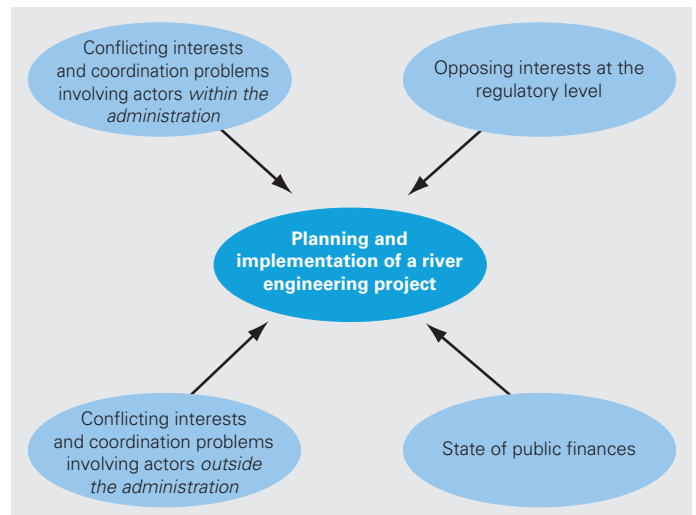
**Challenges Facing Sustainable Flood Protection.** Translating the goals and principles of sustainable flood protection into practice is a complex undertaking, with problems arising from at least four different areas (Fig. 2) [4]:

- ▶ **Oposing interests:** In several cantons, the regulations, approaches or objectives adopted in the various related policy areas – e.g. conservation, groundwater protection, drinking water provision – embody opposing interests. This necessitates delicate balancing of the various agencies' interests.
- ▶ **Internal cooperation:** in certain cases, agencies from various policy sectors are not (yet) accustomed to, or prepared to engage in interest-balancing processes.
- ▶ **External cooperation:** actors outside the administration are most frequently opposed to river engineering measures that place constraints on agriculture and the development of settlements. In

such cases, the actors may be supported or even instrumentalized by political representatives.

- ▶ **Limited financial resources:** river engineering is currently restricted by the state of public finances. River engineering interests run counter to current fiscal policy objectives. In view of the com-

Fig. 2: Four problematic areas for river engineering projects [4].



munes' budgetary problems, it is difficult to achieve the priority goal of ensuring flood protection through maintenance of river engineering structures – even though sustainable maintenance and expansion reduces costs in the medium to long term.

Enforcement difficulties are particularly evident in relation to the aim of implementing “spatial requirements” for watercourses. In settled areas, efforts to secure the required space collide with the demarcation of construction zones. Communes perceive their scope for development as being restricted. Outside developed areas, farmers (sometimes supported by farmers' associations or cantonal agricultural offices) resist transfers of land or restrictions on use based on river engineering or ecological considerations. The implementation of sustainable river engineering is thus widely impeded by the scarcity of available land within and outside settlement zones.

#### **Recommendations for Decision-making in a Complex Environment.**

The new approach to flood protection has cast river engineering experts in the role of “moderators” in a complex process of negotiation. Participating in this process are various governmental and civil-society actors, with their respective resources – e.g. legal regulations, expertise or political influence [5]. Successful moderation of such processes depends crucially on systematic, in-depth analysis of a project's context and the appropriate use of decision support tools:

- ▶ Contextual analysis: Careful consideration of the technical and scientific foundations for decision-making needs to be supplemented by analysis, evaluation and documentation of the political, social and historical context of the project. This includes efforts to identify all the key environmental conditions, such as legal regulations or the interests and stakeholders concerned.
- ▶ Involvement of stakeholders: The contextual analysis will enable project managers to plan their cooperation with the various stakeholders. Here, the communication channels selected should be appropriate to the heterogeneous nature of the interested parties. It is advisable to conduct face-to-face discussions with those directly concerned at an early stage. These actors should be involved through working groups in the planning and implementation process. The public at large must also receive timely and regular information, and should be consulted via interviews or questionnaires. Conflicting objectives or interests among different policies and agencies can be detected within the administration at an early stage with the aid of internal coordination instruments [4].
- ▶ Use of decision support tools: Formal tools can be used to support the processes of reaching conclusions and decisions. These tools make it possible, for example, to compare various options in consultation with the stakeholders involved. In this process, conflicts between differing interests can be pinpointed and consensual solutions developed [6]. In addition, decision support tools can indicate the effects of various river engineering options on important target areas such as “ecology” and “local economy”.

The fundamentals of decision-making and the associated methods are presented in detail in the handbook on joint planning of river engineering projects (*Wasserbauprojekte gemeinsam planen*), produced as part of the Rhone-Thur research project [7].

**Equitable and Transparent Procedures.** Today, river engineering objectives and measures form part of an integrated spatial planning policy, which also encompasses agriculture, water protection and recreational amenities. The new demands placed on the development and execution of river engineering projects require the application of novel methods and instruments in the areas of knowledge and interface management, as well as decision support. In accordance with the principles of sustainable development, these tools facilitate the balancing of interests in equitable and transparent procedures. Using these new methods, river engineering experts can appropriately moderate the processes while retaining their capacity for action and decision. ○ ○ ○

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# Using Ecological Indicators to Evaluate Rehabilitation Projects



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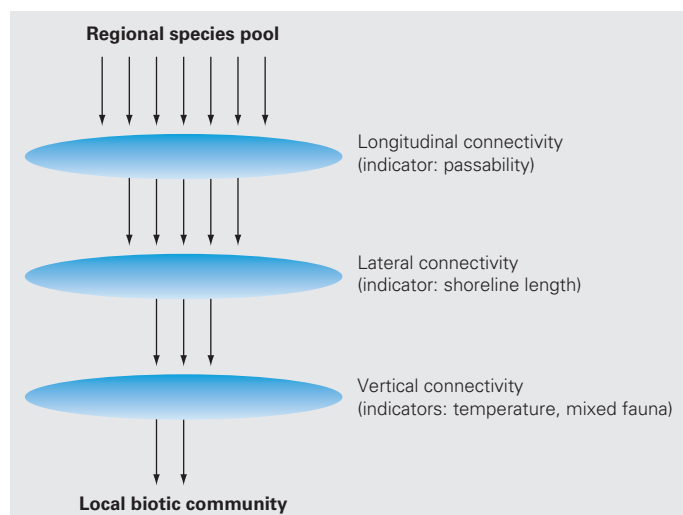
Stream and river rehabilitation projects are currently enjoying a worldwide boom. But do these efforts in fact significantly enhance the ecological condition of watercourses? Evaluations are facilitated by the use of ecological indicators.

Clearly defined ecological standards are essential to the success of rehabilitation activities, and every project should meet at least the following criteria [1, 2]:

- ▶ A “guiding image” has been defined, involving dynamic ecological endpoints.
- ▶ Ecological conditions are measurably improved.
- ▶ The ecosystem shows greater resilience, with ecological integrity being enhanced.
- ▶ An ecological assessment is carried out.

The essential goal of rehabilitation measures is a sustained improvement in ecological integrity, i.e. the ecosystem’s ability to maintain its structural and functional capacity in the face of natural disturbances such as floods and droughts. Since it is almost impossible to determine the degree of integrity of a river or a riparian ecosystem directly, there is a great need for ecological indicators. These are applied whenever complex ecosystem conditions and processes cannot be readily measured.

Fig. 1: The environmental filter model.



**Assessing Outcomes with Ecological Indicators.** The recent publication of an evaluation handbook for river rehabilitation projects – a product of the Rhone-Thur research project – means that a user-friendly guide to the assessment of project outcomes is now available for the first time [3]. This handbook contains 45 ecological indicators that can be used to assess the structural and functional characteristics of a watercourse. However, if these indicators are to be refined and correctly interpreted, sound ecological knowledge is indispensable.

The biological diversity of a river section may be used as an example. Fish, invertebrates, and algae are frequently considered for assessment purposes. But what determines local species diversity? It can be considered as a function of:

- ▶ the regional species pool within the entire catchment,
- ▶ the hierarchical arrangement of environmental filters, i.e. specific environmental conditions such as climate, type of waterbody and degree of connectivity, and
- ▶ the traits of individual species enabling them to “pass through” these filters (i.e. to tolerate the environmental conditions, e.g. mobility, feeding habits, life cycle).

This model is exemplified in figure 1, where the degrees of longitudinal, lateral and vertical connectivity are acting as environmental filters. Also shown are potential indicators permitting an evaluation of the various filters. Due to the hierarchical position of the individual filters, there would be no increase in local species richness if only the vertical connectivity is increased through rehabilitation measures, while tributaries and riparian areas remain neglected. The filter model can be illustrated by two further examples: in a river affected by hydropeaking, bank-widening measures will contribute little to the promotion of aquatic invertebrates, since any positive effects arising from the morphological enhancement will be offset by the impact of artificial diel flow fluctuations – a higher-level factor. Similarly, if a weir in the lower reach of a watercourse acts as a barrier to upstream fish migration, the diversity of fish species in the upper reaches cannot be enhanced even under optimal habitat conditions. More fish species will only become established once the higher-level environmental filter (the weir) has



A helicopter-mounted infrared camera was used.

been eliminated, i.e. longitudinal connectivity has been secured. Here, a widespread myth is reflected in rehabilitation practice: "All you have to do is create a natural watercourse, and then organisms will colonize it automatically."

**Watercourses as Elastic Systems: Example of Refugia.** Extinction rates for freshwater fauna are five times greater than in terrestrial ecosystems [4]. Long-term preservation of the biological diversity of waterbodies thus represents an important motive for rehabilitation. A high level of biodiversity depends in particular on the availability of refugia – habitats from which species can recolonize areas after a disturbance (flooding, drying, anthropogenic stresses). It is now known that the distribution and use of refugia varies with the type and extent of disturbances along the length of a river. In mountain streams, insect larvae – but also fish species such as the bullhead (*Cottus gobio*) – seek refuge in deeper bed-sediment layers influenced by groundwater. Near-natural tributaries also play a key role in re-establishment following debris flows or catastrophic flooding. However, in larger rivers, aquatic invertebrates disperse towards riparian areas during a flood event. Therefore, for the long-term maintenance of the ecological integrity of a watercourse, a network of unregulated tributaries and strong linkages with the associated groundwater and riparian zones are required. Accordingly,

Photos: U. Uehlinger, Eawag



Fig. 2: Widened section of the Thur River at Schäfäuli, viewed from a helicopter. The delineated area corresponds roughly to the infrared image in figure 3.



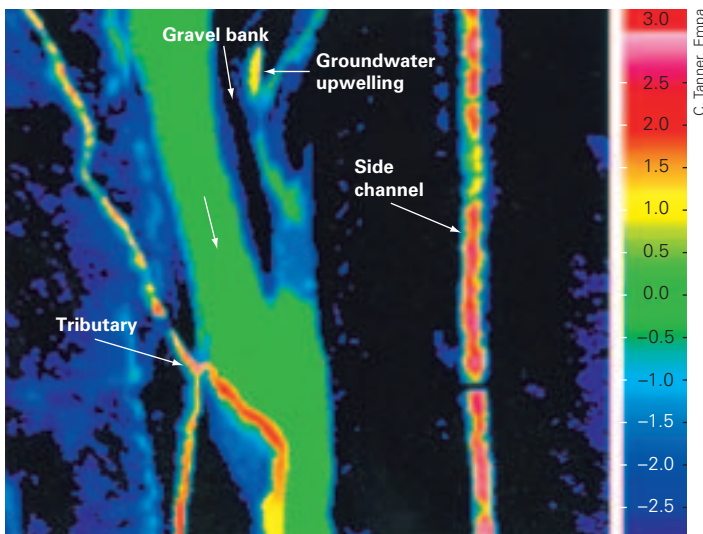


Fig. 3: Temperature variation in the widened section of the Thur River at Schafftäuli, recorded in January 2005. The infrared image (resolution 1 m<sup>2</sup>, accuracy 0.1 °C) corresponds roughly to the delineated area in figure 2.

the number of near-natural tributaries, temperature heterogeneity as a measure of surface/groundwater interactions (see Box and Figs. 2 + 3), and shoreline length serve as indirect indicators of the availability of refugia and thus of the ecological integrity of a river.

#### Riverine Landscapes as Interconnected Habitats: Example of Shorelines.

Watercourses are “open” ecosystems, which interact intensively with the adjacent terrestrial and aquatic habitats. Of particular importance is the riparian zone, which represents a dynamic boundary between the waterbody and the surrounding terrestrial area. This zone harbours a diverse fauna and flora, including both aquatic and terrestrial species.

An indicator of the degree of lateral connectivity is the length of the shoreline. The longer the shoreline, the greater the functional interaction between water and land. In natural watercourses, shoreline length may be as high as 25 km per river-kilometre, and the availability of aquatic habitats remains relatively constant in time despite major water level fluctuations. In channelized sections, however, shoreline length is reduced to a minimum of 2 km per river-kilometre. Used as an indicator, shoreline length also offers the advantages that it can be investigated in both small and large rivers, and that it is highly sensitive to changes in both hydrology and morphology.

In addition, shoreline length has been shown to be positively correlated with the diversity of juvenile fish species, or with the number of breeding pairs of limnicole birds – waders such as the little ringed plover (*Charadrius dubius*). For example, along the Tagliamento River, one of the last free-flowing rivers in the Alps, the density of this species increases with shoreline length up to 22 breeding pairs per river-kilometre.

**Testing Newly Developed Indicators.** The preparation of a handbook to evaluate river rehabilitation projects made the elaboration

of a series of ecological indicators necessary. These novel indicators include the species richness and density of the terrestrial riparian fauna, the composition of floating organic matter and its colonization by organisms, and the availability of refugia as a measure of the recolonization potential for benthic organisms. These indicators need to be tested, calibrated, and adapted in practice – a task which we would invite practitioners from environmental authorities and engineering consultancies to perform. ○ ○ ○

#### Temperature as an Indicator

The use of an infrared camera allows the mapping of thermal conditions of a watercourse with a high spatial resolution. As shown in figure 3, braided rivers – in this case, the widened section of the Thur at Schafftäuli – often exhibit marked variations in temperature between main and side channels. This provides evidence of the availability of refugia. Sensitive fish species such as the grayling and the brown trout are dependent on cold-water refugia in the summer and on warm-water refugia in the winter (yellow to red patches in Fig. 3). In contrast, the temperature in the main body of the Thur is highly uniform.

In addition to a warmer tributary, an area of upwelling groundwater can be seen on the infrared image. This suggests that surface/groundwater interactions were partly restored as a result of the widening project. As the image was recorded in January, the habitats influenced by groundwater are warmer than the surrounding areas. Groundwater upwellings and tributaries prevent freezing in winter and create cooler habitats in summer.

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# River Dynamics and Flood Protection: a Contradiction in Terms?



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Near-natural watercourses should provide dynamic – constantly changing – habitats. This requirement can be met by adopting innovative approaches and taking advantage of possible synergies, even in cases where only limited space is available and local construction of river training works are unavoidable.

*“Nature is not to be trifled with, she is always true, always earnest, always severe; she is always right, and the faults and errors are always those of man.”* Hydraulic engineers responsible for planning flood control measures on rivers would do well to bear this quotation from Goethe in mind. Reliable protection against floods can only be assured by structures that preserve the natural character of a watercourse. Accordingly, modern river engineering must take a river’s natural forces and behaviour into account. For example, attempts to straighten a meander that has developed naturally may be dangerous: in extreme flood conditions, if not earlier, the apparently tamed river will recall and reoccupy the space to which it is entitled.

**River Dynamics and Channel Modifications.** *“The world is like a river, running along in its bed, this way and that, forming sandbanks by chance and then being forced by these to take a different course. Whereas this all proceeds smoothly and easily and gradually, the river engineers have great difficulties when they seek to counteract this natural behaviour.”* Goethe (once again) recognized that the dynamics of a river can only be controlled to a limited extent by channel modifications and rigid river training works. The term “dynamics” refers to variations in hydromorphology over space and time due to flood discharges and sediment transport. These processes regularly lead to the destruction of habitats, especially in riparian areas, and the creation of space for new habitats. Dy-

Fig. 1: Course of the Reuss with three meanders in Gurtellen-Wiler before the floods of 1987.



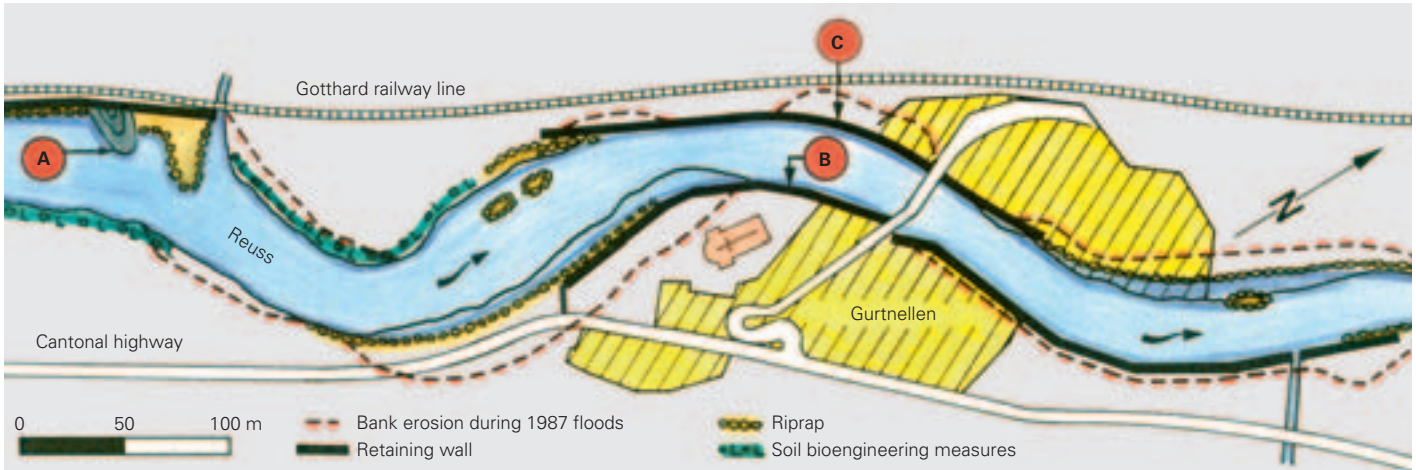


Fig. 2: Bank erosions that occurred during the floods of 1987 in Gurtellen-Wiler and the flood protection measures subsequently implemented (A, B, C; see text for details).

dynamic watercourses require a great deal of space. For example, naturally meandering rivers migrate laterally within a meander belt roughly 5–6 times the width of the channel bed [1]. This belt may be further enlarged by natural side channels shifting the main channel towards the opposite side of the valley. For this reason, the watercourses in the valleys of the Alps and Pre-Alps originally required the entire valley floor.

As well as providing flood protection, watercourse alterations carried out over the last two centuries were designed to reclaim land for development and agriculture. Efforts were thus made to impede the dynamics: rivers and streams were channelized, and channel bed widths were optimized with regard to sediment transport. This resulted in monotonous watercourses, with almost no variation in hydraulic or morphological characteristics.

**Structural Flood Protection and Rehabilitation.** *“Water is a friendly element for whoever is familiar with it and knows how to manage it.”* This quotation from Goethe reminds us that structural

Fig. 3: Built-up bluff designed to stabilize meanders in Gurtellen-Wiler.



Photos: A. Schleiss, EPFL

flood protection measures need to be based on a detailed knowledge of the processes associated with flooding and of hydro-ecological conditions. In this way, interventions can be kept to a minimum. Even so, river dynamics will inevitably be reduced by flood control structures.

The aim of rehabilitation measures is to restore watercourse dynamics as far as possible, thereby increasing structural diversity. This aim is only attainable if the river engineering measures such as river training works permit diversity of streamflows [2], which in turn will have favourable effects on the species diversity of the watercourse. Even unavoidable riprap on an almost straight stretch of water should be undulated in such a way as to increase flow diversity [3]. Structural richness always depends on a minimum level of river dynamics, leading, for example, to regular rearrangement of sediments in the channel and local bank erosions.

**Gurtellen-Wiler Case Study: Synergies between Near-natural River Engineering and Flood Protection.**

The commune of Gurtellen-Wiler was particularly hard hit by the Reuss Valley floods of 1987. In Gurtellen, the Reuss River follows a meandering course, with three bends (Fig. 1). In severe flood conditions, the meander bends are enlarged and displaced as a result of bed and bank erosion. This was the cause of the catastrophic damage (Fig. 2). Here, in what was one of the first applications of the new approach to flood protection in Switzerland, a near-natural river engineering option was chosen – despite the immense destructive force of the Reuss – with the original channel alignment being maintained [4]. With the aid of three main protective elements (Fig. 2: A, B, C), it proved possible to stabilize the meanders – even under extreme flow conditions [5]:

- ▶ A raised rocky groyne combined with an artificial “peninsula” (A): This serves to stabilize the upper meander of the Reuss and optimally channel water into the lower meanders. The new large groyne was provided with a rocky or near-natural surface, enabling several protected plant species to become established within a very short period (Fig. 3).

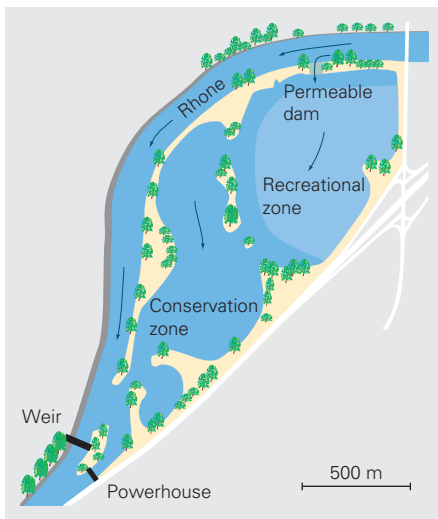


Fig. 4: General layout and elements of a multi-purpose water management facility on the Rhone.

► A buried protective wall upstream of the church (B): On the opposite bank, the current diverted by the man-made bluff meets a covered supporting wall, which protects the church area of the village and guides the Reuss into the next bend.

► A curved retaining wall upstream of the village bridge (C): The retaining wall running alongside the Gotthard railway line stabilizes the most downstream meander. Using a hydraulic model, the curvature of the wall was optimized so as to preserve the historic arched bridge.

With these measures, it was possible to preserve the natural mountain-river character of the Reuss and to enhance the appearance of the village of Gurtellen-Wiler.

**Synergies in Multi-purpose Projects.** Today it is almost impossible for water-management projects concerned with flood protection, hydropower generation or river rehabilitation to be implemented as single-purpose undertakings, given the existence of often irreconcilably conflicting interests and funding difficulties. Such projects should therefore be placed on an integrated and sustainable basis, incorporating as many interests as possible. This can be achieved through innovative multi-purpose projects, satisfying a variety of interests and goals (Fig. 4).

Over the last century, the Rhone – like most other Alpine rivers – was modified and channelized. Today, it is subject to the tensions existing between flood protection and a wide variety of interests relating to agricultural and industrial use, hydropower generation, conservation and recreation.

This is the context in which the “Third Rhone Correction” is to be seen – an enterprise that will extend over several generations. In this connection, integrated and sustainable multi-purpose projects are of great interest [6]. As part of the SYNERGIE research project, an interdisciplinary team, comprising hydraulic and environmental engineers and architects, is analysing the interplay of all the relevant technical, ecological and socioeconomic factors involved in a multi-purpose project on the Rhone. This could give rise to synergies between the following objectives (Fig. 4):

- Flood protection: reducing peak flows through retention and controlled management of washlands.
- Ecological flow regulation: elimination of harmful hydropeaking phenomena.
- Creation of new biotopes: shallows, bird sanctuaries, periodically flooded areas of vegetation.
- Recreation: water sports, hiking and bridle paths, angling, additional river crossing.
- Hydropower: baseload energy production with ecological flow regulation, renewable CO<sub>2</sub> emission free power.

**Sustainable River Engineering Measures.** “*The water rushed, the water rose, a fisherman sat by ...*” These lines from Goethe’s well-known poem *Der Fischer* illustrate the fact that a dynamic river can be both a valuable habitat and an attractive recreational amenity. Nonetheless, in densely settled areas, unrestrained river or stream dynamics can no longer be restored. However, today’s monotonously modified watercourses exhibit not only ecological but also flood protection deficiencies, not least because the structural protection measures often show insufficient regard for the original character of the watercourse. In flood management and rehabilitation projects, there is therefore a need for innovative approaches designed to restore river dynamics and thus structural diversity within the constraints imposed by the available space. Consideration should also be given to other interests such as recreation, agriculture, infrastructure and the use of rivers for the purposes of renewable energy production and water supplies. This means that river training works and flood protection measures are now to be designed and implemented not only with a view to flood protection but also for the benefit of the environment, society and the economy. ○ ○ ○

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# Predicting the Consequences of Rehabilitation Measures



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What effect will the proposed measures have? Decision makers are confronted with this question when evaluating alternatives. Mathematical models can summarise the current level of knowledge on important cause-effect relationships in a transparent way. They can therefore make a substantial contribution to support of decision-making.

Making good decisions is difficult. This particularly applies to river rehabilitation when the best combination of measures has to be chosen from various alternatives in the planning phase. Causes of difficulty include:

- ▶ conflicts between contradictory objectives: e.g. concerning space requirements for rivers and agriculture;
- ▶ different interests of different groups of stakeholders: e.g. farmers and environmentalists;
- ▶ complex decision-making procedures: e.g. democratic and participative processes at municipal, cantonal and federal levels;
- ▶ uncertainty about the consequences of suggested measures arising from our incomplete knowledge of complex natural systems.

Therefore, procedures have to be developed that support the decision making process (see Box) [1]. An important step of such

procedures is to predict the consequences of alternative rehabilitation measures. For this purpose, we have developed a mathematical model of the consequences of river rehabilitation measures. This was done in the context of the Rhone-Thur project.

**Methodology of Prediction – an Integrative Model.** A mathematical model is a strongly simplified representation of the structure and processes in the investigated system using mathematical expressions. The system attributes that are to be predicted are the indicators used for quantifying the objectives (see article by K. Tockner on p. 15). The model describes the effect of important influence factors on these attributes. Because rehabilitation measures have morphological, hydraulic, ecological and economical consequences, knowledge from different disciplines must be integrated. Sources of this knowledge include data from literature, more detailed models, results of research projects in the Rhone-Thur project and expert elicitations.

Figure 1 shows the most important pathways in which rehabilitation measures take effect. According to the identified subsystems, we decided to split the integrative model into several sub-models. For each of these submodels, a similar diagram showing cause-and-effect relationships can be drawn whereby, appropriate to the larger level of detail, measurable system attributes can be introduced (Fig. 2). On the basis of these diagrams, mathematical

## Decision-support for River Rehabilitation

Structuring the decision-making process using the following steps can add to the objectivity of discussions and to the development of solutions that have a higher degree of consensus among stakeholder groups (simplified from [1]).

1. Analyse the problems to be solved and identify the stakeholders involved in or affected by the decision.
2. Describe and quantify the objectives of decision makers and stakeholders.
3. List alternative measures to reach the objectives.
4. Predict the consequences of the suggested measures.
5. Provide an analysis of the degree of fulfilment of objectives by the alternative measures and of reasons for conflict between stakeholder groups.

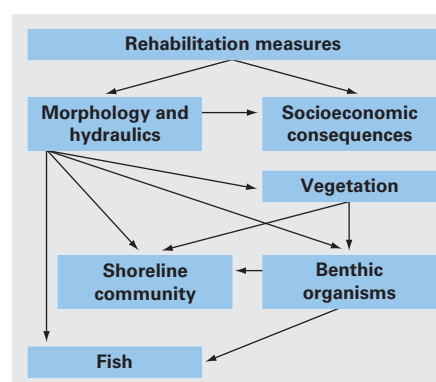


Fig. 1: Schematic diagram of the integrative river rehabilitation model. Important pathways of propagation of the effects of river rehabilitation measures [1].

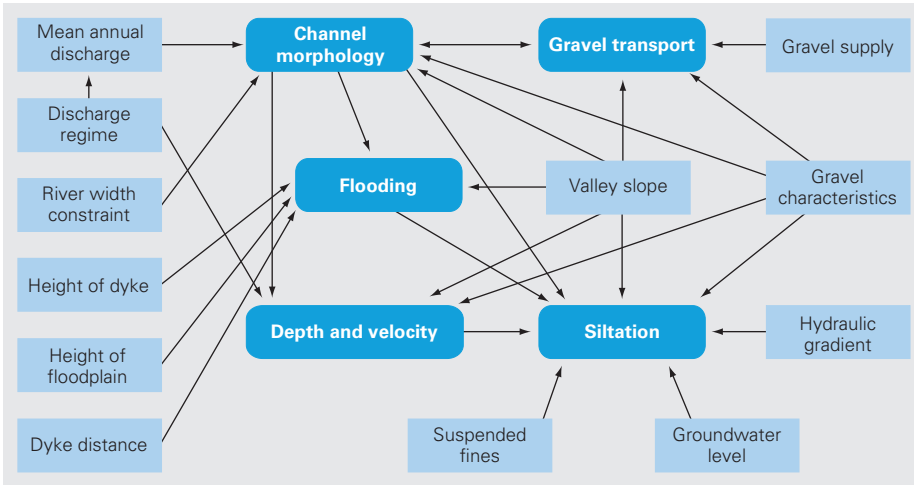


Fig. 2: Simplified dependencies between system attributes in the "Morphology and hydraulics" submodel [2].

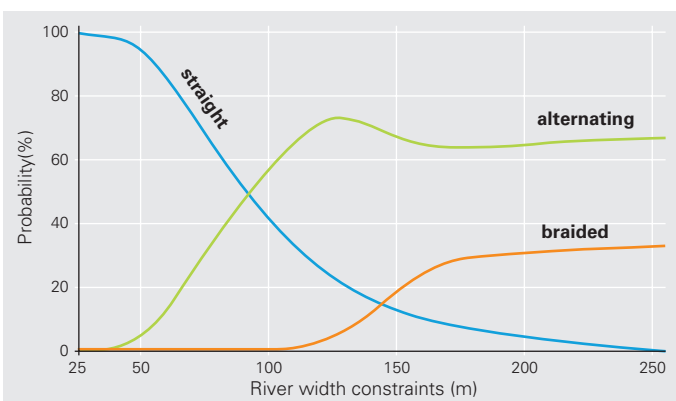
relationships can be formulated for all the dependencies represented by the model. The alternative rehabilitation measures are characterised by different input values of the model. As the model takes scientific uncertainty into account, model results are obtained in the form of probability distributions of system attributes for all rehabilitation measure.

**The Submodels.** The integrative model [described in detail in 1] consists of six submodels:

*Morphology and hydraulics:* Illustration 2 shows the structure of this submodel [2]. Input values, such as, for instance, constraints of the river's width or the distance between the dykes, are shown in light blue boxes, model output, such as the channel morphology or clogging of the riverbed by fine particles, are shown as dark blue boxes.

*Flood-plain vegetation:* This submodel is not available at the moment. It is to be developed as a simplification of the detailed

Fig. 3: Modelled probabilities for various river morphologies as a function of riverbed width for the Thur between Bürglen and Weinfelden. The morphologies considered are: straight river course, course alternating between gravel bars and braided river system [2].



flood-plain vegetation model described in the article by C. Glenz on p. 24 [3].

*Riverbed organisms:* This submodel describes the abundance of organisms belonging to specific functional groups (algae, grazers, shredders, collectors, predators) as a function of external influence factors (hydraulic conditions, frequency of floods, stability of the riverbed, nutrients, temperature, irradiation, etc.). A prototype version of this submodel is already available.

*Shoreline fauna:* Only little research on shoreline fauna has been done up to now. For this reason, this submodel still supplies very uncertain predictions. The current prototype is based on data from Paetzold et al. [4] and describes the abundance of ground beetles (carabidae) and spiders, dependent on the river morphology, drainage regime and on aquatic insects that serve as food for the predatory carabidae.

*Fish:* A specific submodel was developed for brown trout. It simulates the population of brown trout as a function of several influence factors such as water quality, existence of the fish kidney disease PKD, water temperature, maximum fish density, frequency of floods, stocking and fishing activity [5]. A somewhat simpler model for white fish (cyprinides) is being developed.

*Economy:* This submodel formulates the effects of expenditure for planning and building activities on the local economy. It considers the integration of the various economy sectors and calculates the effects as number of workplaces per sector [6]. It also estimates change in recreational tourism affects the local economy.

**First Model Forecasts Using the "Morphology and Hydraulics" Module.**

The "morphology and hydraulics" submodel has been used for the first time on the section of the river Thur between Bürglen and Weinfelden [2]. We calculated how the river would develop if it were widened (Fig. 3). In its current state, the width of the Thur has been reduced to around 30 m as a result of dyke-building and incising and its course is straight. If the river is widened to about 100 m, the probability that a alternating course with gravel bars will develop increases. If the river is given even more space,

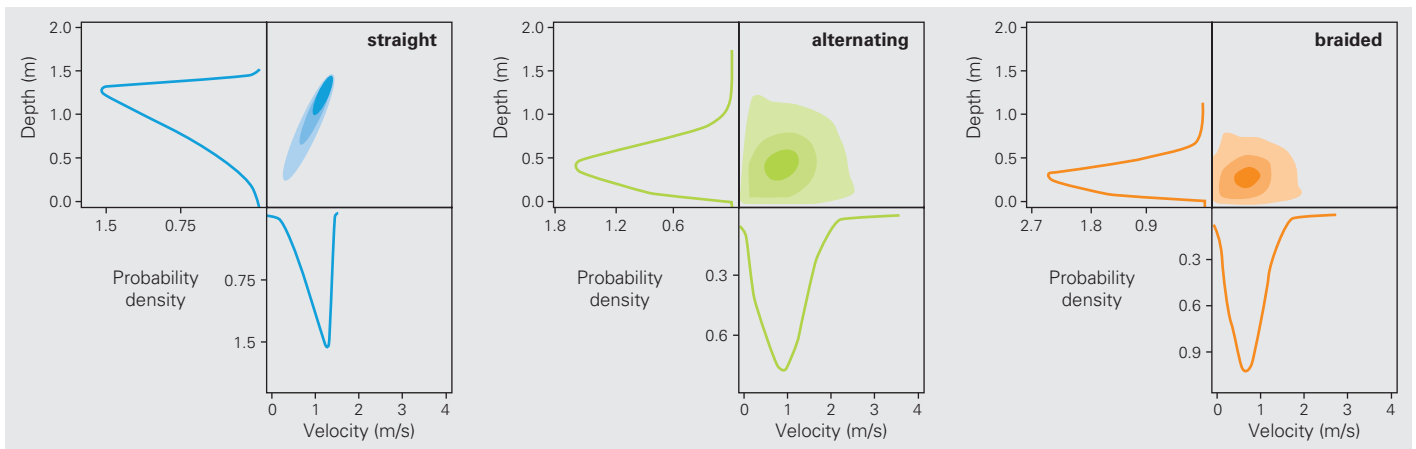


Fig. 4: Predicted joint frequency distribution of water depth and flow velocity for the Thur between Bürglen and Weinfelden.

Left: current state with a 30 m-wide riverbed. Centre: 200 m-wide riverbed, if alternating gravel bars develop.

Right: 200 m-wide riverbed, if river branches develop. The coloured areas in the main diagrams contain 25% (dark coloured), 50% (medium and dark coloured) and 95% (whole coloured area) of the paired values. The diagrams at the side show the marginal frequency distributions for flow velocity and water depth [2].

the probability rises to around 30% that a braided river system will form and to around 70% that a river course with alternating gravel bars will develop.

Figure 4 shows the joint distributions of water depth and flow velocity that are to be expected. For today's straight river course, small flow velocities always occur together with low water depth (near the banks) and large velocities coincide with deeper water (in the middle of the river). If the riverbed is widened to 200 m, more variations in depth will develop for both the alternating and the braided course. Both high and low flow velocities can occur for large or small water depths, whereby the values for depth and flow velocity for the braided morphology are generally lower. This greater variety of habitats favours a higher diversity of riverbed organisms and fish and therefore also indirectly supports the development of shoreline fauna. These effects are described in the appropriate submodels.

**First Model Forecasts Using the "Economy" Module.** The economical submodel shows that a total of around 8 work places will result for each million Swiss Francs invested per year. Of these, around six will be created in the construction sector and one in the service sector; a further workplace is distributed over other sectors. For an investment volume of around 30 million Francs over 5 years, approximately 50 workplaces would result during this time period. In comparison, the longer-term effects on tourism and leisure activities are rather small: For the rehabilitation of this relatively short section of the river Thur, they are expected, according to a rough estimate, to be in the range of 5–6 workplaces at the most [6].

**Further Development of the Model.** The first complete version of the integrative model should be finished by the end of 2006. To make sure that the model really makes its way into practice, Eawag

will be exchanging ideas with potential users. Feedback from both science and practice are important in order to continuously improve the model in the future. The model could then support the scientific accompaniment of rehabilitation projects. ○ ○ ○

- [1] Reichert P., Borsuk M., Hostmann M., Schweizer S., Spörri C., Tockner K., Truffer B. (2006): Concepts of decision support for river rehabilitation. Environmental Modelling and Software (in press).
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# Landscape Development of Rehabilitated Riparian Areas



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Riparian areas are complex, dynamic habitats, and it is difficult to predict how they will develop in the long term following rehabilitation measures. This may impede the acceptance and practical implementation of restoration projects. Process-based riparian forest succession modelling is a first possible method of resolution.

River corridor widening is currently a favoured river engineering option, as it combines ecological and flood protection interests. But how will the landscape develop following widening measures? Is the establishment of a riparian forest with natural succession processes to be expected or not? These are questions to which no generally valid answers can be given in advance. Today, these issues are usually dealt with in debates on the "optimum" design of widened corridors by consulting experts – leaving considerable scope for interpretation. The associated uncertainty frequently hampers decision-making, planning and implementation processes in rehabilitation projects.

**What Makes it so Difficult to Predict Riparian Landscape Development?** The difficulty stems from the extremely complex nature and interactions of the geomorphological, hydraulic and ecological processes (driving processes) operating in riparian areas, and from the fact that the habitat conditions for vegetation are subject to constant change.

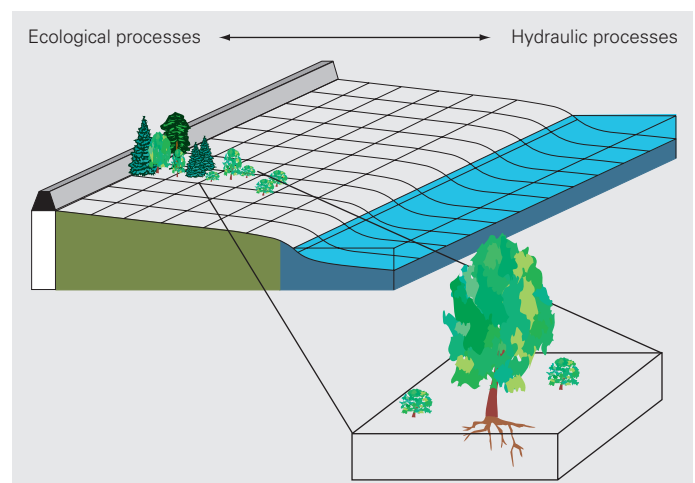
To address this situation, prediction of riparian landscape development requires dynamic, process-based computer models that take the driving processes into account. Such models should also incorporate the abiotic and biotic processes responsible for plant growth. This makes it possible to simulate the effects of constantly changing environmental influences on vegetation. This type of approach has already been pursued in the development of two wetland forest succession models [1, 2]. However, these were not designed for Central European conditions: they do not adequately integrate the specific environmental factors found in Alpine and Pre-Alpine floodplains, and they fail to consider the above-mentioned interactions.

**RIFOD: a Process-based Succession Model.** As part of the Rhone-Thur research project, a model known as RIFOD ("Riparian Forest Dynamics") was developed, which couples a forest succession model (ecological model) with a quasi-2D hydraulic model [3]. RIFOD simulates short- or long-term riparian forest dynamics for

65 Central European tree and shrub species on a 10-metre-square grid (Fig. 1). The model considers specific interactions of ecological and hydraulic processes depending on the position of the simulated grid cells in the study area. In particular, this permits modelling of the interplay of vegetation roughness (i.e. density, shape and elasticity of vegetation) and water flows. This is an important aspect, since the development of vegetation is directly and indirectly dependent on flow patterns (e.g. flow velocity and flooding duration/depth). At the same time, however, vegetation also influences water flows; for example, flow velocity decreases as vegetation becomes more dense, leading to an increase in flooding depth.

The riparian forest succession model has a modular structure. The population dynamics module is concerned with the germination/regeneration, growth and mortality of trees and shrubs. Other modules simulate both habitat conditions and species- and development-specific stresses – e.g. drought stress, nitrogen scarcity

Fig. 1: Application of the RIFOD model.





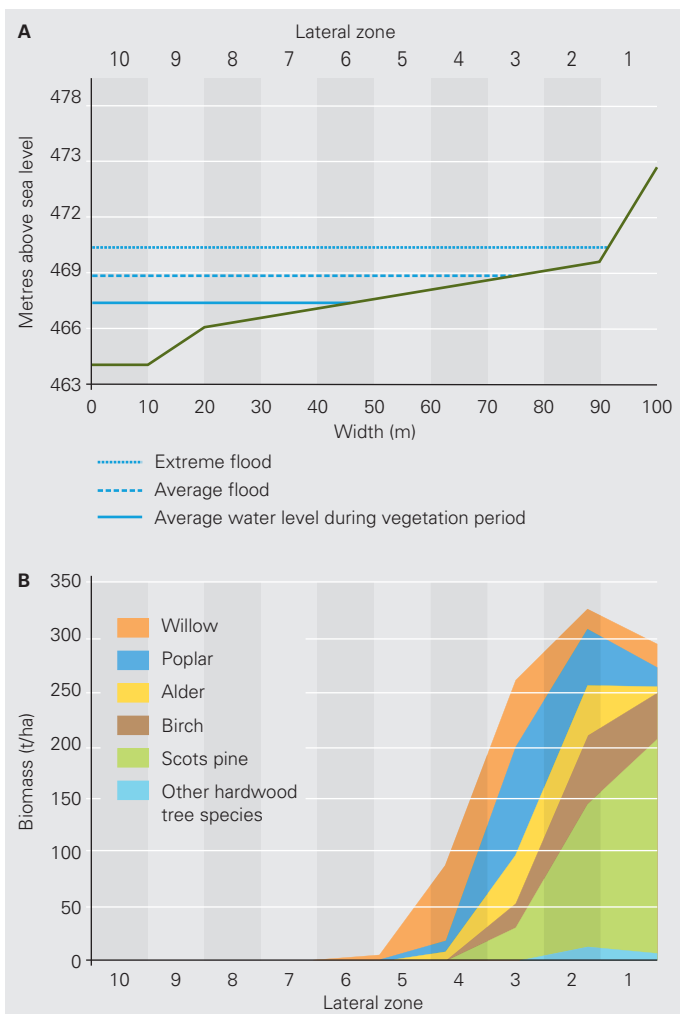


Fig. 2: Riparian profile showing water levels for a widening of the Rhone below Sitten (A) and modelled lateral riparian stand composition 100 years after widening (B).

and mechanical and physiological flooding stress. As geomorphological processes have yet to be integrated, the model is initially only applicable for riparian areas with a low level of geomorphological activity (e.g. lowland rivers) or – in the case of river corridor widening – for areas with a relatively stable profile (e.g. lowered foreshore).

**First Model Predictions.** The RIFOD model was first used to predict riparian development following the widening of the Rhone below Sitten (Fig. 2A). Inputs to the model consisted of flow and climate data from the past 20 years collected by various monitoring stations in the Sitten region (including the floods of 1987, 1993 and 2000) and data on soil structure. Figure 2B shows which tree species are likely to be found in the riparian forest 100 years after the widening. According to our predictions, zones 7–10 will remain free of trees and shrubs. Stands on the margins of the river corridor are dominated by Scots pine, while conditions in the zones closer to the river only permit the development of certain willows

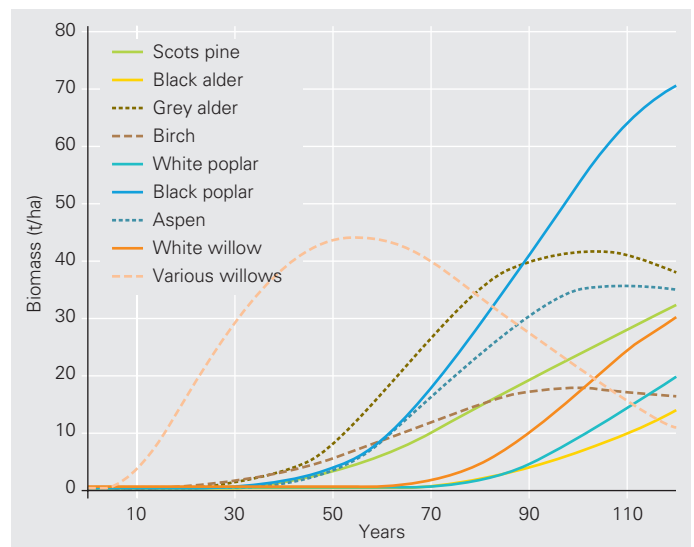


Fig. 3: Stand development in lateral zone 3.

at a low density. In between, the main species appearing are those of a softwood forest, dominated initially by willows and subsequently by alders and poplars. In contrast to the grey alder, the black alder only develops at a later stage, as nutrient levels are insufficient at the beginning of the succession (Fig. 3). In lateral zone 3, no substantial losses of biomass are apparent within the 100-year prediction period. This means that, with a stabilized main channel, the trees in this zone will not be uprooted even in the event of extreme flooding.

**Refinement of RIFOD.** The model developed in this project simulates trends in riparian forest development and the associated characteristics (e.g. vertical structure, productivity) for various river corridor profiles or changes in flow regimes (e.g. reduced flows due to a run-of-the-river hydropower plant). To increase the reliability of the model predictions, greater inputs of quantitative data will be required (e.g. long-term tree-ring measurement series as a function of environmental factors in riparian areas) for the formulation of the processes, and for calibration and validation of the model. This will further reduce the parameter- and process-related uncertainties of the model. Although geomorphological processes are not currently accommodated, the RIFOD model can already be used to support decision-making in river rehabilitation projects. ○ ○ ○

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# Widening as a Rehabilitation Measure



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The “ecological” success of river-widening measures – a preferred method of rehabilitation – depends crucially on the choice of design and location. The results of an outcome evaluation provide valuable lessons for the planning and implementation of future widening projects.

Local channel-widening measures serve as a good example of how the objectives of river engineering can be combined with those of nature and landscape protection. Widening measures can help to reduce the extent of bed erosion and the risk of flooding. At the same time, they may restore the capacity for the development of a characteristic equilibrium in accordance with the river's natural dynamics. As a result, riparian species and biotic communities can become reestablished. But how is the ecological success of river-widening projects to be assessed?

As part of the Rhone-Thur research project, five river stretches were studied in detail before and after widening [1–3]: the Emme at Aefligen, the Thur at Gütighausen, the Rhone at Chippis, and the Moesa at Grono and Lostalio. The indicators chosen for this pur-

pose (cf. the articles by K. Tockner and C. Weber on pp. 15 and 32) were parameters that describe landscape structure, e.g. habitat type, diversity, size and shape, distance between two areas of a given habitat type, and habitat boundary length. In addition, on the basis of literature and expert knowledge, a list of typical riparian plant species was compiled. This list, which was used exclusively to characterize the development of vegetation on the widened stretches, is available online [4].

**Patchy Habitat Mosaic on Widened Stretches.** By way of example, figure 1 shows the various habitat types occurring on the rehabilitated stretches of the Rhone and Thur before and after widening. The most striking findings are that (a) the formerly channelized bodies of gravel-bearing, (pre-)alpine rivers divide into several channels (winding/braided course), (b) islands and gravel/sand bars are formed, with varying stages of development (succession), and (c) eroding banks develop. In the case of naturally meandering rivers, by contrast, undercut and slip-off slopes tend to develop. In the channel itself, widening of the profile gives rise to a variety of bed forms with different water depths and flow patterns.

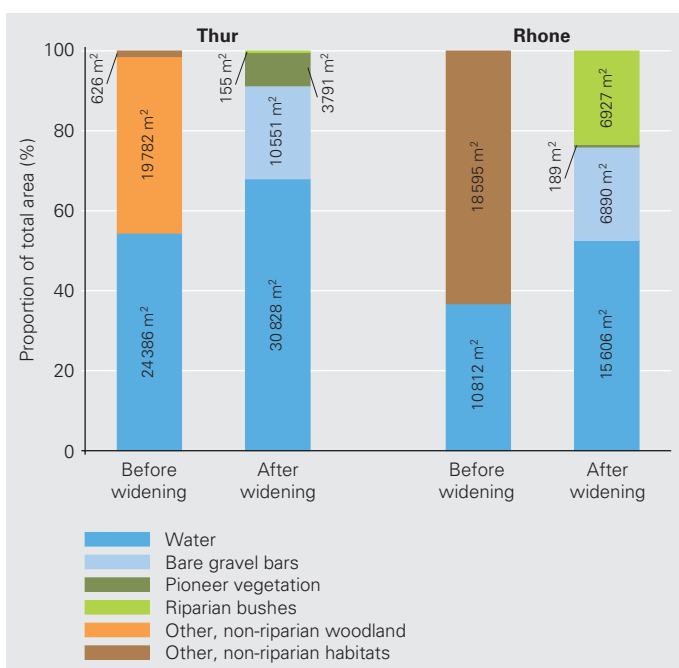
However, on account of the limited extent of the widenings, both longitudinally and laterally, it was only possible for part of the natural spectrum of riparian habitats to be restored. The main types developing were habitats colonized by pioneer plants. Riparian shrubs occur only in patches, and riparian forests are wholly absent. Overall, compared with near-natural alluvial sites, the habitat mosaic of the widened stretches is patchier and more complex.

**Rapid Colonization by Riparian Pioneer Vegetation.** The vegetation studies suggest that river-widening measures can make an important contribution to the promotion and conservation of riparian species. Altogether, 28 riparian plant species were recorded on the widened stretches investigated.

This group consists of species that are essentially dependent on alluvial sites for their survival or mainly occur in this type of habitat, e.g. Alpine willowherb.

Most of the 28 species are (pioneer) plants of gravel bars and banks. They are able not only to survive dry periods but also to tolerate intermittent flooding, after which they are rapidly regener-

Fig. 1: Habitat types and extents before and after the widening of stretches of the Thur at Gütighausen and the Rhone at Chippis.



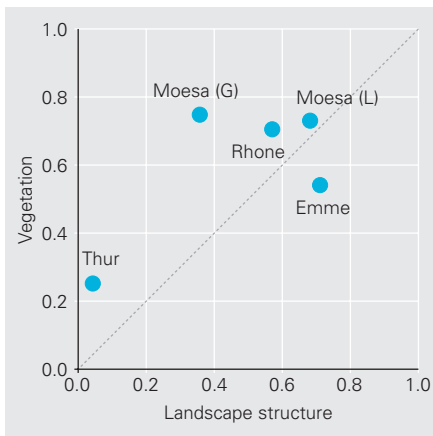
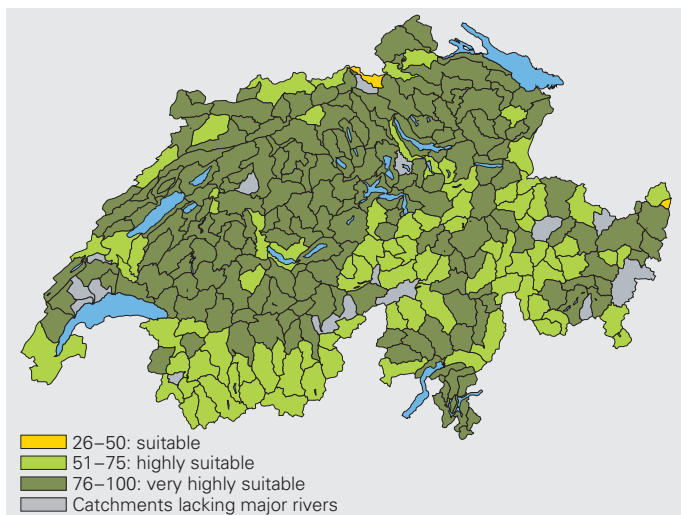


Fig. 2: Degree of naturalness of stretches studied after the implementation of widening measures. A unitless index is used for the assessment (for details see [3]). 0 = channelized state, 1 = near-natural state.

ated – with the various willow species being the classic example. Meanwhile, species that are not adapted to the changeable and sometimes completely unpredictable conditions of gravel bars and banks fail to thrive and are thus rarely found. These include, in particular, riparian hardwood forest species.

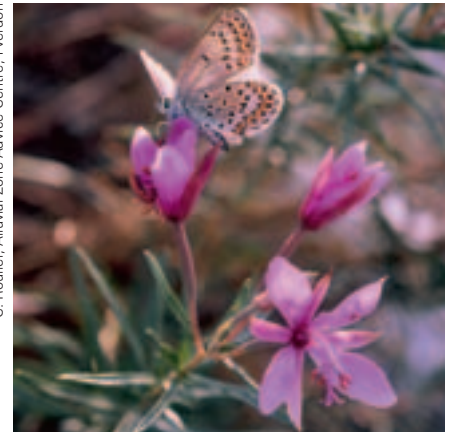
**Degree of Naturalness Attained.** To assess the degree of naturalness attained by the watercourses after widening, the values determined for the indicators were transferred to a unitless index, with a scale from 0 to 1. The value “0” represents the initial channelized state, and “1” the desired near-natural target state. By and large, the widened stretches achieved a relatively high degree of naturalness (Fig. 2). The remaining deficiencies in comparison with near-natural reference sites are due to the lower habitat diversity and patchy structure arising from the limited spatial extent of the widenings. Only the widening of the Thur stretch was found to be less successful. Here, the values achieved lay at the lower end of the scale: –0.23 for vegetation and 0.03 for landscape structures.

Fig. 3: Suitability of rivers for channel widening, as indicated by the mean values of the ecological restoration suitability index per catchment [5].



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- [4] [www.rivermanagement.ch/download.php](http://www.rivermanagement.ch/download.php)
- [5] [www.rivermanagement.ch/aufweitungen/aufw\\_p7.php](http://www.rivermanagement.ch/aufweitungen/aufw_p7.php)

C. Roulier, Alluvial Zone Advice Centre, Yverdon



Alpine willowherb (*Epilobium dodonaei*).

This is partly due to the fact that the gravel bars at this site are less substantial and thus more frequently flooded.

**Widening – a Worthwhile Measure!** The success of a rehabilitation project depends not only on the measures implemented but also on the (ecological) conditions prevailing at the site. Widening of relatively unimpaired rivers is frequently more effective, while the benefits of such measures may not be fully realized in the case of heavily degraded watercourses. It is therefore important to identify those (stretches of) rivers that are particularly suitable for channel-widening on account of favourable ecological conditions and thus appear to offer good prospects of success. For this reason, an ecological restoration suitability index was also elaborated for Switzerland’s catchments as part of the Rhone-Thur research project [3]. Overall, the fundamental conditions for future rehabilitation projects were shown to be favourable or highly favourable (Fig. 3). Detailed information on the search strategy developed and calculation of the suitability index is available online [5].

# Hydropeaking on Watercourses



Tobias Meile, civil engineer, Hydraulic Constructions Laboratory LCH at EPF Lausanne

The operation of storage hydropower plants leads to rapid and frequent changes in flow regimes. This may have adverse impacts on the ecological integrity of watercourses. To mitigate hydropeaking effects, both structural and operational measures can be envisaged.

At storage hydropower plants, water from elevated reservoirs is passed through turbines into lower-lying watercourses. This mainly occurs at times of peak electricity demand, leading to frequent, regular alternation between rising and falling flow rates (surges and declines, or "hydropeaking"), which differs fundamentally from natural flood events (Fig. 1).

In the period from the end of January to the beginning of March 2005, rapid surge-type fluctuations in water level with a magnitude of at least 10 cm were recorded on at least 6 days at 44 stations within the federal authorities' hydrological monitoring network (Fig. 2). The watercourses mainly affected by hydropeaking are medium to large rivers in the valleys of the Alps and Pre-Alps. Frequently, these rivers are also subject to other anthropogenic stresses, such as straightening, channelization, discharges of treated wastewater and runoffs from intensively managed agricultural land.

Only a small number of plants with hydropeaking operations are to be found on the Swiss Central Plateau. Downstream of run-of-the-river plants, at which dams generally do not permit significant storage and/or have to maintain a relatively constant water level,

hydropeaking is only observed following the emergency shut-down of turbines – a very rare occurrence. Accordingly, hydropeaking phenomena are rarely seen on the rivers of the Central Plateau below the large Alpine border lakes, which serve as natural retention basins. Pumped-storage plants likewise do not give rise to hydropeaking, as the water passes through turbines between two reservoirs or ponds.

**Impacts on Watercourses.** Hydropeaking affects a variety of abiotic parameters in watercourses:

- ▶ hydraulics: rapid and significant changes in discharge, flow velocity and bed shear stress;
- ▶ chemical and physical water quality: effects on the diurnal cycle of turbidity and temperature, conductivity, and concentrations of nutrients and contaminants;
- ▶ morphology: movement of an overlying fine gravel layer, re-suspension or deposition of fine sediments.

In turn, these changes in abiotic factors influence biotic communities. Baumann and Klaus [1] reviewed numerous studies con-

Fig. 1: Discharge and rates of increase/decrease in flows on the Rhone at Porte du Scex. Comparison of an October week from 1907 (autumn flood) and from 2003 (characteristic turbine operation cycles) [figure taken from 2].

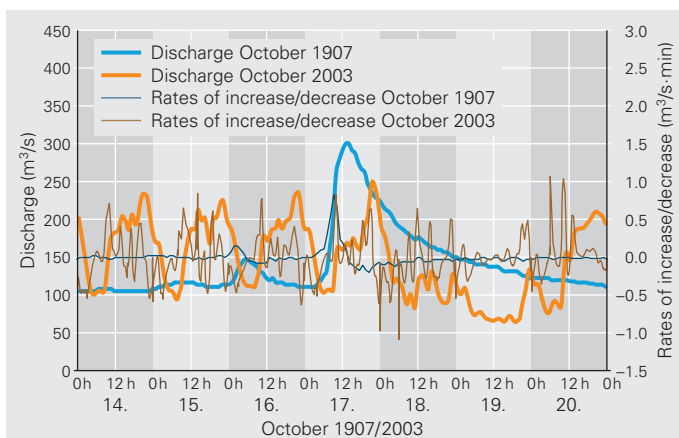
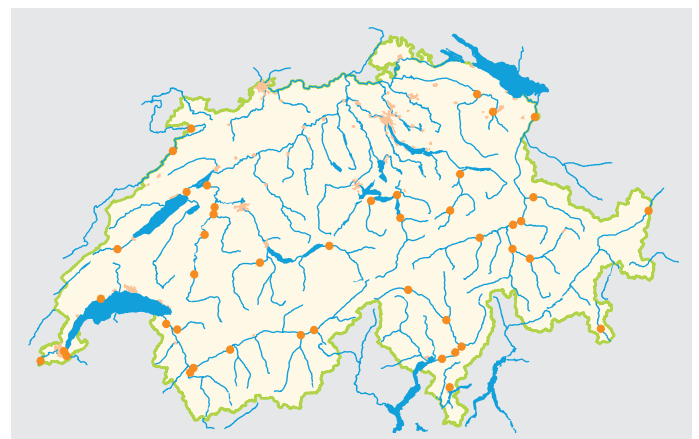


Fig. 2: Network of major watercourses in Switzerland, showing the 44 federally operated discharge-monitoring stations that produced hydrographs indicating unequivocal hydropeaking events in the period from 29 January 2005 to 6 March 2005 [figure taken from 3].



	Structural measures	Operational measures
Tailwater not to be discharged into river	Direct discharge into a lake Separate watercourse for tailwater	
Tailwater discharges into river to be moderated	Construction of retention basin Discharges into the forebay of a run-of-the-river plant (possibly a multi-purpose facility; cf. article by A. Schleiss, p. 18)	Restriction of output (maximum discharge) Increase in minimum discharge from reservoir/minimum-flow turbine Slow, stepped up- and down-ramping of turbines Countercyclical turbine operations at various plants
Affected watercourse zones to be minimized	Morphological optimization of watercourse, watercourse remodelling	

Tab. 1: Mitigation measures.

cerned with the biological effects of hydropeaking in the Alpine region. In the great majority of cases, structural state variables were determined for the aquatic biocoenosis. Thus, it was observed that the composition of biotic communities generally changed, and that the abundance or biomass of various groups of organisms (fish, benthic macroinvertebrates, benthic algae) declined. Only a few studies investigated the colonization of the riparian zone, which is inundated by surges and dries out under low-flow conditions (see article by M. Fette, p. 30).

Functional biological parameters have also been assessed. For example, several studies have shown marked increases in the drift density of benthic macroinvertebrates and algae under surge conditions, and stranding of organisms was observed in association with rapidly declining flow rates and water levels in riparian shallows and in hollows connected to the main channel (e.g. on the Saane in Canton Bern and the Lech in Bavaria). While stranding and drift are clearly attributable to hydropeaking, it is difficult post hoc, merely on the basis of the current biological situation, to differentiate between the effects of morphological, physicochemical and hydrological changes in a river.

**Mitigation Measures and Surge Indicators.** In theory, a variety of river engineering and operational measures can be used to mitigate hydropeaking (Tab. 1). However, the disadvantage of operational measures is that, if storage plants can no longer operate their turbines without any restrictions during peak load periods, the economic viability of hydropower generation may be jeopardized. According to a study for the Alpine Rhine, the loss of revenue arising from operational restrictions was 3.5 times greater than the costs of constructing equalizing basins [4].

To determine the effectiveness of mitigation measures, there is a need for so-called surge indicators, i. e. characteristic/guideline values used to describe and assess hydropeaking. For a number of surge indicators, proposals have been made regarding guideline values based on hydroecology. For example, a value of 12 cm per hour is recommended as the maximum rate of decline in water levels to ensure that the stranding of juvenile fish is largely prevented. For the ratio of maximum surge to minimum low water, values ranging from 5:1 to 2:1 are taken to be acceptable. It would, however, be more advisable to determine these ecological guideline values in a watercourse-specific manner. Customized criteria of this

kind have been defined for the Alpine Rhine and used to develop various possible scenarios for the regulation of hydropeaking [5].

**Hydropeaking: a Limiting Factor in River Rehabilitation Projects.** Approximately one in four medium to large watercourses in Switzerland's Alpine and Pre-Alpine region is affected by hydropeaking. Consideration should therefore be given to frequent and rapid variations in flow regime as a limiting factor in morphological river rehabilitation projects. In addition, any surge mitigation measures should be specifically adapted to the watercourse in question. Existing gaps in research relate to interactions between morphology and hydropeaking, and the effectiveness of mitigation measures. To address this question, it will be necessary to evaluate the outcome of implemented and future restoration projects. ○ ○ ○

Note: This article summarizes the most important findings of the Rhone-Thur research project report on hydropeaking [2].

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# Effects of Hydropeaking on Groundwater

As part of the “Third Rhone Correction” project, the river bed is to be widened at various points. Engineering works of this kind may stimulate the frequently limited exchanges between surface and groundwater – but possibly with adverse consequences for groundwater use.

Over the last 150 years, hydrological conditions in the Rhone valley have been profoundly altered by two major correction projects, with a formerly dynamic Alpine river being transformed into a monotonous, heavily engineered channel. Changes in groundwater conditions, though invisible, have been no less dramatic: today, previously extensive surface/groundwater interactions are severely restricted. This trend is intensified by constant fluctuations in water levels due to hydropeaking operations (cf. article by T. Meile, p. 28). If water exchanges are promoted once again by rehabilitation measures, groundwater use may be adversely affected. For this reason, particular consideration should be given to hydraulic aspects in cases where a rehabilitation project involves a watercourse stretch that is also influenced by hydropeaking.

**Reduced Exchanges Due to Water Table Lowering and Riverbed Clogging.** In addition to flood protection objectives, the Rhone corrections were designed to reclaim former alluvial land for purposes of agriculture or development. The projects therefore involved not only channelization of the river but also systematic

Various degrees of clogging: non-clogged (Töss) and heavily clogged bank area (Rhone).



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drainage of the valley floor, leading to a lowering of the water table. A hydraulic gradient developed between surface and groundwater, i.e. a permanent flow of water in the direction of the groundwater [1]. This gradient is responsible for the fact that fine particles from the upper sediment layers are flushed into the pores of the sediment, where they are deposited, producing clogging (colmatation) of the river bed. At the same time, the remaining larger particles form a compact, immobile surface layer. In unaffected rivers, the hydraulic gradient is reversed under low-flow conditions, so that the bed is flushed clear (de-clogging). Heavy floods can also bring about de-clogging.

It may well be assumed that on river stretches subject to hydropeaking, the river bed is also de-clogged as a result of the “daily floods.” However, this is not the case. Indeed, clogging of the river bed is actually increased: small-scale upward and downward movements, caused by frequent changes in the current, lead to an even more effective incorporation of fine particles, filling the pore system [2].

**Clogging Influenced by Hydropeaking on the Rhone.** With the aid of studies based on temperature time series (Box), we showed that hydropeaking influences clogging processes in the Rhone. Firstly, clogging is intensified on stretches subject to hydropeaking, where permeability was found to be lower ( $K = 1 \times 10^{-5}$  m/s) than upstream of the hydropower plant ( $K = 5 \times 10^{-5}$  m/s). Secondly, the development of vertical zones of varying permeability was detected in the bank area. In the lower zone – the permanently wetted river bank – the values are around  $K = 11 \times 10^{-6}$  m/s. In the higher-lying zone, which is only wetted under surge conditions, hydraulic conductivity is up to two orders of magnitude greater ( $K = 1.4 \times 10^{-4}$  m/s), suggesting that clogging is less marked.

**Bringing Together River Ecologists and Groundwater Protection Experts.** Surface waters make a substantial contribution to the recharging of aquifers, thereby ensuring that about 80% of Switzerland’s drinking water supplies can be sourced from groundwater. Some of this, the bank filtrate, is abstracted with the aid of pumping stations installed in the immediate vicinity of a river. In general, bank filtrate can be supplied to households without the need for any



Hydropeaking on the Rhone: daily fluctuations in water level are indicated by the snowline.

further treatment. This is made possible by the fact that the water is naturally purified as it passes through the ground between the river and the pumping station. However, if rehabilitation measures lead to breaking-up of the clogged layer, the subsurface will become more permeable, and water will reach the pumping station

more rapidly and less well purified. The enhancement of the watercourse thus poses a potential threat to groundwater use. It is therefore important even at the planning stage of a rehabilitation project to bring together all the parties concerned for discussions, and to determine in detail the specific characteristics of the watercourse: What is the hydraulic situation? Is the river affected by hydropeaking operations? To what extent are the river bed and bank area clogged? Are there any drinking water wells nearby? The rehabilitation efforts will only be successful if river ecologists and groundwater protection specialists work hand in hand. ○ ○ ○

### Determination of Clogging

As part of the Rhone-Thur research project, we developed a simple method for the estimation of clogging, based on river and groundwater temperature measurements [3]. By comparing time series for surface and groundwater temperature, it is possible to estimate the advective infiltration rate and hence the hydraulic conductivity  $K$  as an indirect measure of clogging. The value  $K$  describes the permeability of materials – generally soils or rocks – to water. Under natural conditions, it usually ranges in orders of magnitude between  $\sim 10^{-2}$  m/s (gravel) and  $\sim 10^{-9}$  m/s (clay).

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# All's Well that Ends Well? A Tool for Outcome Evaluation



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Co-authors: Sharon Woolsey and Armin Peter, Eawag

The excavators have gone, the plovers have returned and the local community is enthusiastic. Does this mean that the rehabilitation work has been successful? The outcome evaluation handbook for watercourse rehabilitation projects is designed to help answer this question.

Unfortunately, the completion of a rehabilitation project does not necessarily spell its success. For example, a US study showed that numerous habitat enhancements have been ineffective and short-lived [1]. Nonetheless, in many cases, the outcome of a rehabilitation project has never been evaluated. It remains unclear whether the objectives have been achieved, or whether cost-effective use has been made of the resources committed to the project. The result is a loss of valuable inputs for future projects, since favourable assessments provide motivation and trigger further efforts, while experiences from less successful projects are also instructive. In addition, an opportunity to make specific adjustments to the management concept following rehabilitation (adaptive management) is missed, thereby remedying any remaining deficiencies. An outcome evaluation may not be performed for various reasons:

- ▶ inadequate funding,
- ▶ poorly defined project objectives,
- ▶ fear of failure,
- ▶ a lack of appropriate guidelines.

It was therefore decided, as part of the Rhone-Thur research project, to prepare a handbook offering step-by-step guidance on the conduct of an outcome evaluation [2, 3].

**Outcome Evaluation Based on Project Objectives.** Rehabilitation projects may pursue a wide variety of objectives. However, they all specify an optimum state that is to be attained through habitat enhancement measures. For example, the aim may be to promote the plant communities typical of the locality, to secure supplies of drinking water and to create an attractive recreational area for the local population. The objectives of a sustainable project will not be one-sided; rather, they will accord equal consideration to all three domains of sustainability (Fig. 1).

An outcome evaluation will check whether the individual objectives have indeed been achieved. Given the multiplicity of possible project goals, it was necessary for outcome evaluation in the handbook to be restricted to 14 objectives (12 objectives shown in italics in Fig. 1), with the emphasis being placed on the “environ-

ment and ecology” area. Another topic covered by the handbook is that of project implementation, based on the objectives of “political acceptance” and “stakeholder participation”.

**Assessing Objectives on the Basis of Indicators.** One important condition for the definition of project objectives is that they should be evaluable. This requires the use of specific, practical parameters – or indicators – which should be easy to measure and interpret, cost-effective and non-destructive [4].

In addition, reference values should be available for every indicator. These are to be derived from reference systems, describing

Fig. 1: Possible objectives of a watercourse rehabilitation project, classified under the three headings of sustainability [5]. The items in italics are discussed in detail in the handbook.

Society: protection and resource use	Environment and ecology	Economy
Sustainable flood protection	Near-natural flow regime	<i>Budget compliance</i>
<i>Sustainable drinking water supply</i>	<i>Morphological and hydraulic variability</i>	Creation of new jobs
<i>High recreational value</i>	<i>Near-natural sediment regime</i>	Increase in value of property
	<i>Near-natural temperature regime</i>	
	<i>Longitudinal connectivity</i>	
	<i>Lateral connectivity</i>	
	<i>Vertical connectivity</i>	
	Near-natural water quality	
	<i>Near-natural diversity and abundance of flora</i>	
	<i>Near-natural diversity and abundance of fauna</i>	
	<i>Functioning organic cycles</i>	



the optimum state that is to be attained through rehabilitation. Ideal reference systems are natural or scarcely affected sections of watercourses from the same geographical region. Unfortunately, such reaches are few and far between, especially in the intensively managed areas of the Swiss Central Plateau. For this reason, recourse is made – if possible – to historical references, e.g. old maps showing the original path taken by a river, or records of former species distribution. Alternatively, a theoretically reconstructed reference system may be used, based on hydroecological concepts and general scientific knowledge – although this method introduces considerable scope for interpretation.

The outcome evaluation handbook describes a total of 50 indicators, with reference values. Also included is important procedural information, e.g. the survey method and the expected time required. Many of the indicators, such as shoreline length (see Box), were specially developed for the handbook. Others are based on established international methods. Each indicator characterizes one or more project objectives: for example, the indicator “fish – species numbers and frequency” provides a direct measurement for the project objective “near-natural diversity and abundance of fauna”; at the same time, the fish species detected permit indirect conclusions as to the longitudinal connectivity of the watercourse (presence or absence of migratory species). If possible, each project objective is assessed against various indicators (Fig. 2).

**Standardization of Indicators and Evaluation Procedure.** The various indicators have specific units, such as the number of individuals per square metre or Swiss franc. To make the different quantities amenable to a joint evaluation, they have to be converted into standardized, dimensionless values. These lie on a scale from 0 to 1, reflecting the degree of naturalness or satisfactoriness for the indicator in question. For most indicators, naturalness is determined with the aid of mathematical standardization functions (Box). In cases where this is not possible, the degree of naturalness is

Project objectives							Indicator
High recreational value	Morphological and hydraulic variability	Near-natural sediment regime	Longitudinal connectivity	Near-natural diversity and abundance of flora	Near-natural diversity and abundance of fauna	Functioning organic cycles	
			●				Fish passability
	●	●	●		●		Age structure of fish populations
	●	●	●		●		Species numbers and frequency
	●	●	●		●		Ecological guilds of fish
			●	●			Typical alluvial plant species
			●	●	●	●	Composition of floating organic matter and colonization by organisms
	●	●		●	●		Variability of flow velocity
	●	●		●	●		Variability of maximum discharge depth
	●	●	●	●			Sediment regime
●							Visitor numbers
							Project acceptance among stakeholders
							Stakeholder satisfaction with participation in decision-making process
						●	Project costs

Fig. 2: Recommended set of indicators for assessing the outcome of measures intended to improve longitudinal connectivity.

### Example: the “Shoreline Length” Indicator

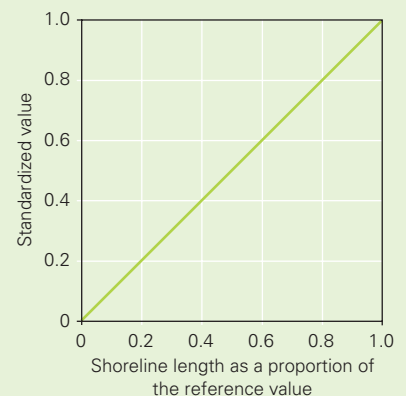
The length of the land/water interface (shoreline) is used as an indicator of lateral connectivity. The longer the shoreline, the more near-natural the state of the watercourse. But what exactly is the procedure for using this indicator in outcome assessment? By way of example, data from the widening of the Thur at Schäf-fäuli is given.

► Data gathering: three values are determined. The reference value describes the length of the shoreline per kilometre of river prior to engineering works, ascertained from historical maps. For the Thur, this value is 4.47 km/km (Zurich cantonal game map, 1862). Pre- and post-rehabilitation shoreline lengths are measured in the field. The pre-project value is 2.00 km/km and the post-project value 2.90 km/km.

► Standardization: The pre- and post-project values are each divided by the reference value, and the results are converted

into dimensionless pre- and post-project indicator values, using the function shown. The indicator value calculated for the pre-project state is 0; after the widening, the value is 0.4.

► Evaluation: The indicator values are compared in the evaluation matrix (Fig. 3), which enables the success or failure of a measure to be read off. In terms of shoreline length, the Schäf-fäuli widening project can be rated as a minor success.



assessed semi-quantitatively or qualitatively, using several different criteria and classes.

In order to detect a change after rehabilitation, at least two comparison points are required, describing the degree of naturalness prior to implementation (pre-project state) and after the completion of rehabilitation (post-project state). This before/after comparison of the standardized indicator values is the essential task of the outcome evaluation. It is performed with the aid of an assessment matrix (Fig. 3). Depending on the change in the value, the outcome may be assigned to one of five "success categories." The procedure takes into account not only the magnitude and direction of the change but also the starting point. Depending on the initial state, an increase of 0.3 will be considered a minor success (e.g. initial value rising from 0.1 to 0.4) or a moderate success (e.g. from 0.5 to 0.8) (Fig. 4).

The assessment matrix can be applied either for individual indicators or for all the indicators relevant to a project objective. For this purpose, the results of the before/after comparisons are averaged for all the indicators relating to the same objective. In the "environment and ecology" area, a large number of objectives exist, and these cannot be readily combined into a whole. Accordingly, further aggregation may be performed, based on qualitative criteria.

To simplify the various steps involved in the outcome evaluation process, the handbook includes an Excel tool.

**Consistent and Simplified Outcome Evaluations.** The handbook is conceived as an aid and an initial step towards the standardi-

zation of outcome evaluation practice in Switzerland. After a 2- to 3-year period of application, the interim results are to be reviewed and, if necessary, the handbook is to be revised. ○ ○ ○

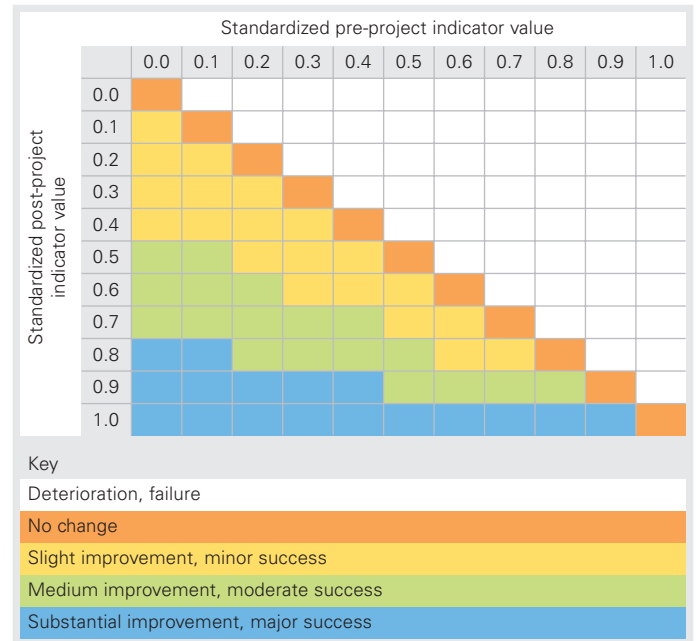
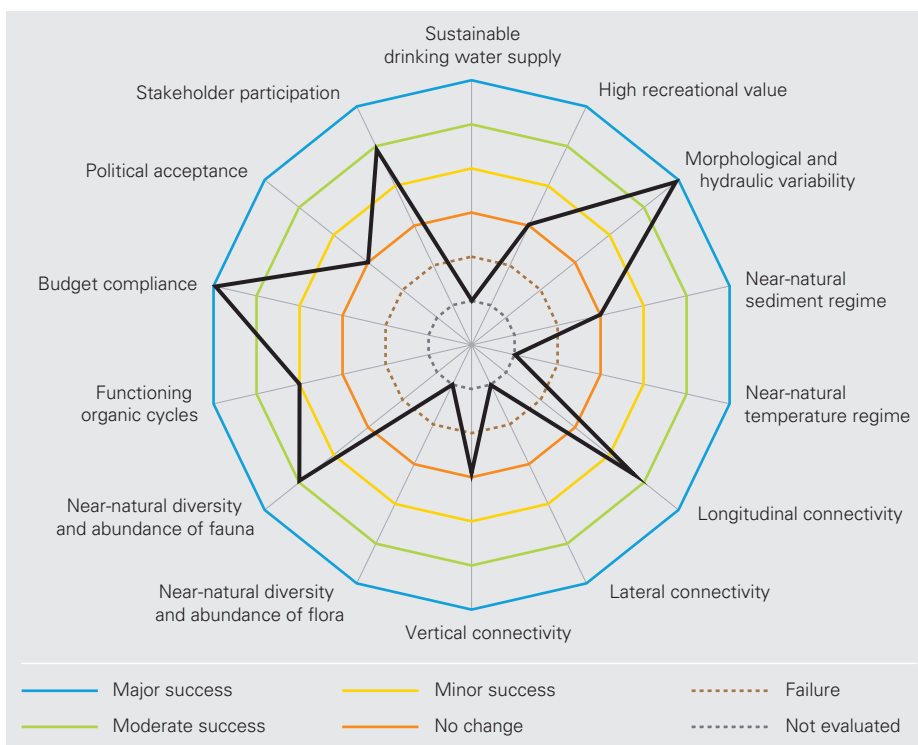


Fig. 3: Matrix for assessing the outcome of a watercourse rehabilitation project.

Fig. 4: Radar diagram showing the results of an imaginary outcome assessment.



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# Conclusions

## Rhone-Thur Project – A Thurgau Viewpoint

I found the collaboration between the scientific and research communities, the various higher-education institutions and practitioners to be stimulating, interesting and instructive. What was special about this project was the fact that methods and instruments were developed using the actual object of study. As they have yet to be tested on other watercourses and in practice, the project has not, in this sense, been completed. My request to cantonal river engineering agencies and to hydrological engineers would be that they should use the handbooks and instruments in their next projects and provide feedback, so that they can be further developed.

Many scientific, engineering and social-science disciplines were brought together in the Rhone-Thur project. This has led to the establishment of new networks and platforms for successful interdisciplinary cooperation. Meeting, working and learning together – the hallmark of the Rhone-Thur project was its broad, cross-cutting, networked approach.

Of particular importance for me were the following two aspects:

► The findings of the social scientific studies: What happens “alongside” the actual planning process, and what factors influence a river engineering project? Every project has its own historical, political and geographical context. Recognition of this by the project manager will not make planning easier, but it will facilitate negotiations with the parties concerned.

► The possibility for direct input of ideas from practice into research. A good example is the “beaver” question. A suggestion from practitioners gave rise to a dissertation, and the results were subsequently presented in a Cantonal Council debate.

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Mario Baumann, head of the division «Water management», Environment Agency, Canton Thurgau

## A Need for Simple Instruments

The Swiss Foundation for Practical Environmental Protection (Pusch) promotes the implementation of measures designed to benefit the environment. It seeks support from representatives of local authorities and organizations. One of the main questions with which we are constantly confronted is: how can we motivate local actors to do something for the environment, for example to enhance or “daylight” a watercourse? And what arguments can we use to persuade them?

A distinction that needs to be made here is whether the watercourse and the adjoining land are in public or private ownership. Public actors may be expected to concern themselves with the promotion of nature, landscape and habitats – if for no other reason than that they have a legal obligation to do so.

Private landowners or farmers, however, may not in general have any great interest. For them, practical and financial questions are of paramount importance. Will they still be able to manage their land effectively afterwards? Will they suffer any loss of production or revenues? If so, how can this be offset?

To complement the findings presented in this publication, I would therefore mention two additional requirements: we need planning and evaluation instruments which satisfy scientific demands but at the same time are sufficiently simple that they can also be applied in the case of small-scale projects without causing undue expense. Another useful tool would be a set of arguments and case studies that would make it possible to gain the support of landowners and farmers for rehabilitation projects, even if they are not instinctively sympathetic to environmental concerns. Any disadvantages should, however, also be openly addressed.

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Ion Karagounis, CEO Praktischer Umweltschutz Schweiz PUSCH (Environmental Protection in Practice)

## Watercourse Development Workshop

People manage surface waters as they see fit. In Switzerland, resource use and flood protection interests were predominant until around 1980, while little attention was paid to ecological and aesthetic concerns. The necessary instruments were made available by river engineers, and the views of experts were decisive when it came to structural alterations of watercourses. The past 20 years have seen a substantial shift in perspectives.

The question now raised increasingly often is what variety of functions a watercourse should serve in the future – conservation, recreation, tourism, water supplies, agriculture, hydropower, or some combination thereof? This is no longer to be decided primarily by experts, but by all the parties concerned. There is, therefore, a need for new approaches to the assessment of options for the development of watercourses.

In the Rhone-Thur research project, scientific foundations were elaborated for this purpose, and methods were developed and tested. Particular emphasis was placed on instruments for predicting and evaluating the effects of measures, and on the involvement of key actors and affected parties in decision-making processes.

The new approaches call for cooperation between a wide range of disciplines and stakeholders. This “transdisciplinarity” represents a major challenge for the scientific community. Eawag intends to serve as a “workshop” promoting integrated watercourse management. But the workshop cannot be operated in isolation. As already in the case of the Rhone-Thur project, we are dependent on viable partnerships. This is what we will be pursuing in the years ahead – in the scientific arena and beyond.

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Ueli Bundi, acting director, Eawag

# Publications of the Rhone-Thur Project

Incomplete literature list. Further publications appear until mid 2007.

Most of these publications are available as pdf files: [www.rhone-thur.eawag.ch/publikationen.html](http://www.rhone-thur.eawag.ch/publikationen.html) and [www.rivermanagement.ch](http://www.rivermanagement.ch)

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# In Brief

## Forum Chriesbach inaugurated

On 1 September, Eawag celebrated the opening of its new headquarters, Forum Chriesbach. The building represents a unique combination of functionality, aesthetics and sustainability, thus offering a practical response to the need for greater sustainability highlighted by the institute's own research. For example, thanks to the optimal use of all energy sources – includ-



Photos: Eawag

ing the occupants' body heat – the building operates without conventional heating or air-conditioning systems. All the materials employed were assessed for sustainability. Rainwater is collected and used to flush the toilets – which are all NoMix systems, where urine is collected separately. The new building accommodates 150 office workplaces, together with training facilities and meeting rooms, the joint Empa-Eawag library and the staff canteen "aQa". The facade, consisting of 1232 adjustable blue glass fins on all five storeys, makes it an eye-catching structure. The atrium of the reinforced concrete skeleton construction also gives the interior a striking appearance, with clearly defined and spacious forms. Almost 2,500 people took the opportunity to attend the inauguration, view

the Forum Chriesbach, and gain an insight into the fascinating world of aquatic research. ○ ○ ○



## Independent Review of Large-scale Hydropower Projects

To date, insufficient consideration has been given to the environmental impacts of the Merowe Dam, currently under construction in Sudan. This structure, which will create a reservoir at the fourth cataract of the Nile, is designed to produce peak-load power for the country's cities.

According to a report published by Eawag researchers in March, projects on this scale should be subjected to independ-

ent evaluation, taking account of the latest scientific findings. The authors of the report estimate that 130 million tonnes of sediment will accumulate each year in the 200-kilometre-long reservoir. A plan for the management of this load has yet to be developed. Unless countermeasures are taken, problems could also arise in connection with reservoir water quality and greenhouse gas emissions. ○ ○ ○

## High Accolade for René Schwarzenbach

René P. Schwarzenbach, who has served at Eawag since 1977 (a Member of the Direc-



EPF Zurich

torate from 2000 to 2005) and is currently head of the Department of Environmental Sciences (UWIS) at the Federal Institute of Technology (ETH) Zurich has received the American Chemical Society's Award for Creative Advances in Environmental Science & Technology. Schwarzenbach is known as one of the authors (with co-authors Philip M. Gschwend and Dieter M. Imboden) of the classic textbook Environmental Organic Chemistry. He is the first non-US recipient of the award, granted in recognition of his innovative contributions to the field. ○ ○ ○

## Red Cross Prize for SODIS

In June, Eawag's SODIS (solar water disinfection) project, led by Martin Wegelin, was awarded the inaugural Red Cross Prize by the Swiss Red Cross (SRC). The CHF 25,000 award – established to mark the SRC's 140th anniversary – is designed to recognize special humanitarian efforts. The jury was impressed by the personal commitment of the project's initiator Martin Wegelin, who "seeks to put his research and development work into practice himself, and personally endeavours, through partnerships and fund-raising, to help improve living conditions for the disadvantaged." SODIS was judged to be a "striking" way of helping to reduce (diarrhoeal) diseases and hence mortality in developing countries. ○ ○ ○



SRC