Scientific base and modular concept for comprehensive assessment of streams in Switzerland

U. Bundi¹, A. Peter², A. Frutiger¹, M. Hütte¹, P. Liechti³ & U. Sieber³

¹EAWAG, Swiss Federal Institute for Environmental Science and Technology, CH-8600 Dübendorf, Switzerland

²EAWAG, Swiss Federal Institute for Environmental Science and Technology, Limnological Research Center, CH-6047 Kastanienbaum, Switzerland

³BUWAL, Swiss Agency for The Environment, Forests and Landscape, CH-3003 Bern, Switzerland

Key words: stream assessment, ecological integrity, restoration, rehabilitation

Abstract

There is a difficult polarity between reality and ecologically desirable goals of stream ecosystem management in Switzerland. Most streams are exposed to a variety of impacts. Due to a high intensity of anthropogenic activity there is a high pressure on land and water use. Essential water uses have to be guaranteed. On the other hand there is also a strong need to preserve or restore (bring back ecological integrity) or rehabilitate streams (bring back 'relative ecological integrity'). Stream assessment should, therefore, produce sound data suitable for characterizing the ecological condition of streams and for supporting their sustainable management. The methods should include a system approach as the basic unit and sound scientific principles of ecological integrity emphasizing habitat connectivities. The methods should allow: • the condition of streams to be rationally described and judged, • identification of different kind of impacts on a stream, • verification of the effects of water protection measures, • identification of suitable future actions in the context of a whole stream system. In order to cover the various requirements a modular concept for stream system-oriented analysis was developed. Altogether nine modules are elaborated. Each module deals with specific stream features (two hydrodynamic and ecomorphological modules, five biological modules, two chemical and ecotoxicological modules). Single modules, several modules, or all of them may be applied, depending on the purpose of the analysis. For each module a cost-effective survey procedure (rapid method) and a progressively more rigorous method providing more detailed information is suggested. Based on the result of the analysis, stream rehabilitation concepts can then be elaborated in cooperation with managers, river engineers and biologists.

Introduction

Situation of streams and rivers

Switzerland covers an area of 41 000 km². With an average rainfall of 1.5 m, the country is rich in water. The total length of the streams and rivers is 65 000 km. The population density (172 per km²) shows large regional variation. Most of the population as well as the economic and agricultural activity is concentrated in the non-mountainous region of the Swiss Plateau, which covers about one third of the territory. 60% of the country's electric energy consumption is covered by hydropower. The pressure on land and water use

has resulted in extensive physical degradation of rivers and streams. Figure 1 gives a synopsis of the development of river engineering works along major rivers and streams in the north-eastern part of Switzerland (Koblet, 1995).

Figure 2 shows the fractions of streams that have been lost in the Canton of Zurich, part of the Swiss Plateau, through putting them into culverts. This has been done for flood protection, to gain land for urban development and to improve farming conditions. About 35% of all streams in the Canton have been lost in this manner. First order streams are the most often involved, so that today much of the network of small streams is missing (Hütte et al., 1994). Of the

Figure 1. Development of structural modifications of Swiss rivers (north-eastern Switzerland) (Koblet, 1995).

remaining streams, a large majority has been physically altered in various ways. The situation in Canton Zurich reflects that in large parts of Switzerland. In the alpine regions there is less pressure from land use, but numerous streams suffer from the impact of hydro-power generation (total or major withdrawal of water, temporary or seasonal changes of flow regime, thermal chaos, disruptions of longitudinal connectivity).

In all, only about 10% of the Swiss streams and rivers remain in a natural or near-natural state (BUWAL, 1997). In addition to the effects of physical changes, water quality must be considered. Although water quality – measured by conventional parameters like DOC, nitrogen compounds, and phosphorous – is usually good, ecotoxicological effects due to organic chemicals, metals and drugs still create a serious threat to aquatic organisms. Recently, widespread or-

Figure 2. A broad classification of streams in Canton Zurich in terms of land-use and culverting (Hütte et al., 1994).

gan damage of fish and a decrease of fish catches was reported (Friedl & Staub, 1998). These effects are thought to have multifactorial causes, not only the presence of chemicals, but also changes in morphology, hydrology and temperature, along with fish management practices.

Political goals for stream management

Over the past 15 years some 50 km of streams have been ecologically improved every year (BUWAL, 1997), either by reopening of culverts or by rehabilitation of degraded streams. In 1992, new federal laws on Water Protection and on Water Correction Works, created the statutory basis for the protection and improvement of stream habitats. Additional regulations are found in the federal laws on the Protection of Nature and on Fisheries. The ongoing reform of the agricultural sector promotes ecologically sound farming and the creation of ecological compensation areas. The rehabilitation of removed buffer strips along streams will be possible in this context.

The Federal Water Protection Law aims at protecting water bodies against harmful effects and at the same time guaranteeing their different functions. In particular, the law serves:

- to ensure essential uses of water, like water supply and irrigation,

- to safeguard the health of humans, animals and plants,
- to preserve natural habitats for indigenous animals and plants and their communities,
- to preserve fish and fisheries,
- to preserve the water bodies as elements of the landscape,
- to maintain the natural functions of the water cycle.

The ecological goals for the surface waters are described as follows:

- The water bodies, and the surrounding area influenced by them, should maintain self-reproducing and self-regulating communities of animals, plants and microorganisms typical for a given location under near-natural conditions. The variety and frequency of species should be typical for water bodies of the same natural type which are exposed to little or no anthropogenic stress.
- The physical characteristics of water like morphology, sediment transport, flow regime and temperature regime shall have a near-natural variety and dynamics. In particular, unrestricted self-purification processes, a natural exchange of material between the water and the bottom, as well as unrestricted interactions between the water and its surroundings must be guaranteed.
- The chemical characteristics of the water must be such that
 - chemical compounds that may be harmful to aquatic life or to essential water uses do not accumulate to harmful concentrations, either in animals and plants or in suspended solids and sediments,
 - biological processes which regulate basic physiological processes of animals and plants like metabolism, reproduction and orientation by using the sense of smell, are not affected,
 - biological productivity does not exceed natural productivity.

The federal laws state that future engineering works may only be carried out if flood prevention cannot be achieved by either stream maintenance or by land use planning, or in cases where there is a major public economic interest. Unavoidable modifications should seek to retain near-natural conditions. Culverts have to be reopened when they need to be replaced. The Water Protection Law restricts water withdrawals, requiring that a certain residual flow be maintained,

but this applies solely to new and renewed water use concessions.

What do the political goals mean?

Extensive action to improve the ecological quality of streams is necessary. Though some of the new legislation is progressive, restoration of most streams is impossible. By definition, restoration means bringing an ecosystem back to its original state. Under the given conditions in Switzerland, this can never be a realistic strategy. Human needs and exploitation of ecosystems most often come into conflict with maintaining natural or near-natural habitats and biodiversity. Striking a balance between conflicting interests is the only possibility.

What is the main goal for ecological improvement under these conditions, in terms of a scientifically sound concept? Obviously it cannot be ecological integrity, because this refers to original, undisturbed conditions and basically implies a catchment that is not – or only slightly – impaired. Preference should be given to the concept of sustainable development, which means economic development that satisfies both present and future human needs for resources and employment, while minimizing its impact on biological diversity (WRI/IUCN/UNEP, 1992). In this context, the integrity of ecosystems needs a new and broadened definition.

Scientific basis for stream assessment

The concepts of restoration and rehabilitation

'Preservation' is the maintenance of undisturbed ecosystems. It is crucial in habitat protection and conservation biology, but will not be discussed here. Stream 'restoration' aims at reestablishing ecological integrity, which is the sum of physical, chemical and biological integrity (Karr & Dudley, 1981). In its original definition 'biological integrity' refers to 'the capacity to support and maintain a balanced, integrated and adaptive biological system having the full range of elements and processes expected in a natural habitat of a region' (Frey, 1977; Angermeier & Karr, 1994).

For degraded streams with strongly modified catchments, the concept of restoration aiming at ecological integrity cannot be applied. A rational aim for ecological improvement of such streams could be to develop them 'in the right direction', i.e. towards

a reference state of maximum naturalness attainable under the given conditions in a catchment. This process is 'rehabilitation' (improvement from a degraded state, Bradshaw, 1997). It implies focusing on attainable replacement of (artificial) elements and re-establishment of processes (Cooke & Jordan, 1995, cited in Angermeier, 1997). The ecosystem structure (species, habitat) is improved and ecosystem function will increase.

A rehabilitated ecosystem is different from a pristine ecosystem. It is, however, also an intact ecosystem and is characterized by complex habitat heterogeneity and the existence of longitudinal, lateral (riparian vegetation) and vertical connectivity. It possesses a certain potential for resistance (capacity to maintain natural structure and function after a natural disturbance) and for resilience (capacity to recover after a natural disturbance or following the cessation of an anthropogenic perturbation) (Kauffman et al., 1997).

Connectivity: longitudinal, lateral, vertical

Connectivity depends not only on environmental characteristics, but also on the behavior of organisms. Connectivity in a functional sense has to be distinguished from structural connection, which is the physical connection that permits exchange, including permanent or temporary connections between environmental units (Amoros et al., 1993). Connectivity is high if the physical connection is unimpaired and organisms can move in a longitudinal, lateral, or vertical direction. Fish depend on the physical connection of their habitat (spawning-feeding-wintering habitat) and fragmentation of habitat adversely affects the fish population. This is not only the case for potamodromous fish species but also for species that only carry out limited migrations (more or less resident fish species). Gravel spawning species like brown trout (*Salmo trutta fario* Linnaeus) and grayling (*Thymallus thymallus* Linnaeus) highly depend on the longitudinal, lateral and vertical dimensions of an ecosystem. They dig their redds in gravel (vertical dimension) and, after emergence, larvae depend on shelter and dead zones along the river margin (lateral dimension) (Sempeski & Gaudin, 1995). During their life cycle, individuals of both species need an intact habitat corridor and carry out migration (dispersal from the redd, feeding migration, remigration to the spawning grounds) in the longitudinal direction.

Ecologically important stream features

Hydrology/flow regime

Stream flow pattern is highly dynamic, varying not only between different sites of a stream but also over time. The catchment functions as a system which interacts with the surrounding environment. Hydrology is one of the major influences on the aquatic biocenosis.

Structure of stream bottom and instream structure

Most macroinvertebrates and many fish species live in close association with the stream bottom. Many macroinvertebrate taxa show some degree of substrate specialization and preference. Lithophilous taxa prefer stony substrate, xylophilous taxa live on woody debris and phytophilous taxa live in association with aquatic plants (Allan, 1995). In the same way, substrate preference plays an important role for spawning fish and for the time after hatching. Balon (1975) classified fish reproduction according to the site of spawning, the adaptations of the eggs and embryos and the degree of parental care.

Instream structure is mainly important for fish. It includes various kinds of overhead covers like woody debris or turbulence and submerged cover such as logs, boulders, rocks and vegetation. Instream structures transform streams into diverse, productive fish habitats.

Structure and vegetation of bank and surrounding area

Riparian zones (habitat along stream channels) are rich ecosystems in terms of biological structures and diversity. In addition they act as buffer strips, preventing fine sediment from entering the river channel. Moreover, bank vegetation provides shade, shelter and cover for organisms in the stream; it also regulates the water temperature. The transition zone between the stream and the terrestrial ecosystem consists of an ecotone which distinguishes itself by high species diversity. The well-being of continental water bodies depends largely on their terrestrial environment (Décamps & Naiman, 1990).

Disruptions of longitudinal connectivity

Longitudinal disruption may impede abiotic dynamic processes in the downstream direction (stream flow, bedload, suspended load) as well as downstream and

upstream movements of organisms (Hütte et al., 1994), especially permanently aquatic organisms like fish, mussels and Gammaridae. Because aquatic insects emerge as winged animals they are less impeded by barriers. Barriers (weirs, culverts, etc.) block upstream migration and dams and turbines seriously interfere both with upstream and downstream migration. Longitudinal disruption disconnects stream reaches and splits them into small, isolated patches. This habitat fragmentation limits the dispersal and colonization for many species (e.g. *Cottus gobio* Linnaeus, Utzinger et al., 1998).

Temperature

Temperature sets limits on where a species can live. In contrast to the maximum summer temperature, low-temperature extremes are less critical. For example, brown trout do not occur in warm-water streams (maximum summer temperature above 25 °C).

Chemistry

Under pristine conditions the chemical composition of the water in streams is regulated by hydrogeochemical and hydrological processes and by natural input of organic matter. Human activity (waste water, agriculture, sealing of land surface, atmospheric pollution, etc.) leads to the addition of different kinds of chemical compounds and suspended solids. Many different physicochemical and biochemical processes are stimulated, leading to damage of organisms, loss of species and changes in the structure of communities. Important examples are:

- increased biological self-purification following the input of degradable organic compounds;
- nitrification and production of toxic nitrite;
- acute and chronic toxic effects of metals;
- toxic effects of numerous synthetic chemicals.

Nutrients (mainly P, N) may under certain conditions enhance biological productivity in streams.

Biological features and their temporal-spatial scales

The abiotic stream conditions play a pivotal role for the biological processes in streams. The different biological features represent different temporal-spatial scales (Table 1).

Figure 3. Ecosystem structure versus ecosystem function (modified from Bradshaw, 1997). Function and structure refer exclusively to biotic parameters.

Table 1. Temporal-spatial scales of different biological stream features

Biological feature	Temporal scale	Spatial scale (upper scale)
Algae	Days–weeks	m ²
Macroinvertebrates	Month–1 year	Several 100 m ²
Macrophytes	Years	Several 100 m ²
Fish	Years	km ² (watershed)
Riparian vegetation	Decades	no scale (land–water interaction)

Approach to stream assessment in strongly modified catchments

Directing ecological improvement towards ‘relative ecological integrity’

The governing concept for the ecological improvement of most Swiss streams must be rehabilitation. Rehabilitation measures should be directed towards a reference state (Figure 3). For anthropogenically modified catchments, we define the reference state in a pragmatic way as follows:

The reference state is the near-natural state of a stream in the given anthropogenically influenced environment. Certain marginal conditions of the catchment are accepted as being immutable, or subject to only limited change, e.g. draining of large areas of wetland. The reference state is characterized by:

- absence of engineering works, i.e. planform and cross-section are the result of the (anthropogenically modified) catchment morphology,
- no flow modification by hydropower or irrigation use,
- vegetation of banks and of adjacent areas typical for the given location,
- no or only very low anthropogenic load of chemical contaminants in the water, low alteration of water temperature.

A stream corresponding to the reference state is an ecologically intact system, even if it does not qualify for ecological integrity. An appropriate term to characterize the reference state might be ‘relative ecological integrity’.

Aims of stream assessment

Methods for the assessment of streams should be in compliance with this concept. They should focus on the most important stream features and produce data suitable for characterizing the ecological condition of streams and for supporting their ecologically sound management. Since we are dealing with anthropogenically modified catchments, the methods used should always produce management-oriented data. They should include a system approach as the basic unit and be based on scientific principles of stream integrity emphasizing habitat connectivities. The methods should allow:

- the condition of a stream(system) to be rationally described and judged,

Figure 4. Factors determining the condition of a stream.

- identification at the different kinds of impact on a stream(system),
- verification of the effects of water protection measures,
- identification of suitable future actions in the context of a whole stream(system).

Parameters and processes to characterize stream condition

The condition of a stream is usually defined by quantitatively measurable values which attempt to describe the system or its constituents in detail (Wuhrmann, 1974). By considering the functions which a stream performs for people, an element of valuation or prioritization is introduced. Beside ecological functions, the functions of a stream may include different practical uses along with emotional and aesthetic values (Figure 4). Due to high intensity of human activity, streams usually have to fulfill several functions at the same time.

A comprehensive description of the condition of a stream taking into account all potentially important factors is not possible. For example, we are far from being able to understand the effects of thousands of interacting chemicals. Indeed, we are not even able to detect most of the chemicals and their metabolites, at least not with affordable expenditure. Thus, the description of stream condition must always be based on a limited set of parameters and processes.

Criteria for making a choice of parameters to measure include:

- relevance with respect to ecological pattern and functions, to the health of people and other organisms and to economic and recreational uses,
- availability of methods for measurement,
- cost of measurement.

The parameters and processes to be chosen should represent the ecologically most important stream features. The selected measures should allow a single feature to be described, e.g. the bank structure, or a set of combined features, e.g. morphology or oxygen balance, or a more comprehensive assessment to be made. Examples for such parameters and processes are:

- water flow: natural regime, direct modifications (withdrawals, returns) and indirect modifications (e.g. through land use),
- channel pattern: under pristine conditions, gradual changes through human influences,
- variability of bed width and water depth,
- natural and artificial falls,
- water temperature,
- oxygen content of water and sediment,
- concentrations and loads of oxygen-consuming compounds like DOC and ammonium,
- concentrations and loads of ecotoxicologically relevant chemicals like Cu, Pb, PCB, nonylphenol-compounds,
- occurrence of specific species, and diversity of fish, invertebrate and macrophyte communities,
- primary production of algae,
- ecotoxicological potential/effects of water samples.

Table 2. Definition of the survey levels with different degree of effort

	Level		
	I	II	III
	Regional scale survey	Catchment scale survey	Extensive reach scale survey
Spatial scale	Region	Stream system/catchment	Reach
Effort	Low	Medium	High
Aim	Overall view of stream conditions and ecological deficits, scoring of reaches	Detailed analysis of stream conditions, analysis of deficits, evaluation of measures	Specific analysis for specific questions

The parameters and processes represent different spatial scales (cm to km) and different temporal scales (days to thousands of years) of ecological processes (Ward, 1997). Different patterns of data collection (single time pairs, time series, etc.) and of statistical analysis, have to be applied for different parameters and processes, depending on their physical, chemical and biological dynamic and on the objective and the available resources for the assessment.

Other attempts at comprehensive evaluation systems and illustrations of the comprehensive approach to assessing river quality were published by Boon & Howell (1997). Boon et al. (1997) developed a system for evaluating rivers for conservation (SERCON) in the UK. SERCON is a broad-based technique for river evaluation, designed to be applied with greater consistency than other methods. Like our approach, SERCON has been developed principally for use at the scale of the catchment and subcatchment. There is a clear focus on the physical, chemical and biological features of river channels and banks, riparian zones and associated floodplains.

The Swiss modular concept for stream assessment

General principles

As an appropriate answer to the variety of the ecological processes to be assessed and the different requirements to be fulfilled by the assessment, a modular survey and evaluation concept for system-oriented

analysis has been developed (Bundi et al., 1998). Each module deals with specific stream features. The different modules are designed to be complementary to each other. Single modules, several modules, or all of them may be applied, depending on the purpose of the analysis.

For each stream feature a cost-effective survey procedure (rapid method) and a progressively more rigorous method providing more detailed information is suggested. This step-by-step approach enables a better understanding of the complexity of a stream system and the human influences on it. Based on this, rehabilitation concepts can then be elaborated in cooperation with managers, river engineers and biologists.

The different levels

The methods of the first level (regional scale survey) are rapid, cost-effective, and provide information on the conditions of all streams within a certain area (e.g. river catchment area, Canton). The second level, the catchment scale survey, comprises modules which allow a more detailed analysis of whole stream systems including tributaries. Finally, the third level of effort, the extensive reach scale, includes an extensive, costly study of a short reach of a stream (0.1–1 km) in order to investigate specific questions or problems (minimum flow, survey after stream restoration, impact of sewage plants, etc.). Only general advice is given here for this level. Table 2 provides an overview of the three levels with different monitoring efforts.

Table 3. The modular concept with level I and II

	Hydrology and ecomorphology		Biology					Chemical and ecotoxicological effects	
Level	Hydrology	Ecomorphology	Riparian vegetation	Macrophytes	Algae	Macroinvertebrates	Fish	Water chemistry	Ecotoxicology
I	General characterization of flow discharge	main morphological impairment, longitudinal connectivity, assessment of naturalness	estimation of abundance of macrophytes	estimation of abundance, studies of diatoms	simple study on a taxonomic level that is suitable for field work	random sampling to detect species range	anthropo-genetic contamination is identified by analysis of random samples	random sample, 2–3 simple test procedures, determination of NOEC levels	
II	Systematic survey	deficit analysis on a catchment scale, evaluation of measures, setting of priorities	mapping of all species	detailed studies of diatoms	comparison of taxa present with reference sites	detailed studies of species present (diagnosis of population)	study of a larger number of contamination parameters	seasonal or frequent check of important point sources	

Assessment of the survey result

Scoring in level I

For the different analyzed stream reaches a point scoring is carried out and the reaches are arranged according to their naturalness (natural stream properties) in four different classes (arbitrary scoring of each parameter with final calculation of the average).

Class 1: natural/near-natural, Class 2: little affected, Class 3: strongly affected, Class 4: artificial stream conditions. Class 1 combines the two classes 'high quality' and 'good quality' of the proposed classification by the European Community.

To present an overview, maps are drawn with different colors for the four classes. The maps are completed with additional information (e.g. natural and artificial barriers impeding upstream migration of fish, riparian conditions, etc.).

The classification of ecological status and presentation of the results are in accordance with the corresponding proposal of the European Community (Commission of the European Communities, 1998).

Deficit analysis in level II

At this level no point scoring is carried out. The actual condition of each stream reach is compared with a

reference state as already defined. The reference state (ecomorphological reference) is derived from historical references/old maps, from reference sites, or from reconstruction based on 'best-available' information. The latter implies elements of arbitrary judgment, which is often unavoidable. The deficit analysis is followed by an evaluation of potential measures to improve the ecological conditions. The measures are prioritized and ordered according to an ecological benefit-cost ratio, whereas the benefits are measured in terms of the length of stream section made accessible to migrating organisms, or the area of adjacent terrestrial ecosystem networked with the stream.

The modules

Table 3 gives a synopsis on the whole modular concept for levels 1 and 2, each comprising 9 modules.

Level III contains detailed site-specific studies and no further directions are described.

Each module will be separately developed and can be used independently or combined with any other module.

Conclusion

The Swiss modular concept attempts to provide a rational, scientifically sound tool for stream assessment and development in anthropogenically intensively used catchments. In such catchments, restoring ecological integrity is not possible. Certain anthropogenic modifications of the environment have often to be accepted as immutable and dealing with conflicting interests is unavoidable. The will to achieve ecological improvement under these premises is the driving force for the Swiss modular concept. The direction of improvement (rehabilitation) is given by 'relative ecological integrity' defined as the near-natural state in the given anthropogenically influenced environment. Following this direction will lead to 'the best-possible-ecological solution' under the given circumstances.

Standardized methods will only be useful if they are accepted by the users, for example public authorities, private consultants and interest groups. Therefore, much emphasis was put on involving various users (and scientific disciplines) in the development of methods. This process included:

1. building the scientific basis of the modular concept with the support of multidisciplinary expert groups,
2. formulating the modular concept and developing the individual assessment methods in cooperation with representatives of public agencies and private consultants,
3. submitting drafts of methods to users for practical testing and comments,
4. holding hearings with major cantonal and federal agency players on the modular concepts and individual methods.

Involving users is very time consuming. The result in terms of support, however, is worth the effort.

Though rigorous application of the assessment concept will support major ecological improvements of the running waters, it has to be recognized that the complex problem of biological impairment resulting from the very complex mixture of industrial chemicals and drugs occurring in the environment cannot be solved on a catchment level. Nationally and internationally coordinated measures are needed. Awareness of ecotoxicological effects must be developed and scientific efforts must be made to gain a better understanding of these effects. This will support the political efforts needed to control chemical uses and inputs (including drugs).

Of the modules briefly described above, that on ecomorphology has been published (Hütte et al., 1998) and some are in progress. Most modules will be available within the next 2–3 years.

Acknowledgements

We thank U. Von Blücher, W. Meier, U. Kupper, P. Niederhauser, H. P. Willi and many colleagues for valuable comments.

References

- Allan, J. D., 1995. *Stream Ecology*. Chapman & Hall, London: 388 pp.
- Amoros, C., J. Gibert & M. Greenwood, 1993. Interactions entre unités de l'hydrosystème fluvial. In Amoros, C. & G. E. Petts (eds), *Hydrosystèmes Fluviaux*. Masson, Paris: 169–199.
- Angermeier, P. L., 1997. Conceptual roles of biological integrity and diversity. In Williams, J. E., C. A. Wood & M. P. Dombek (eds), *Watershed Restoration: Principles and Practices*. American Fisheries Society, Bethesda, Maryland: 49–65.
- Angermeier, P. L. & J. R. Karr, 1994. Biological integrity versus biological diversity as policy directives. *BioScience* 44: 690–697.
- Balon, E. K., 1975. Reproductive guilds of fishes: a proposal and definition. *J. Fish. Res. Bd Can.* 32: 821–864.
- Boon, P. J. & D. L. Howell, 1997. Defining the quality of fresh waters: theme and variations. In Boon, P. J. & D. L. Howell (eds), *Freshwater Quality: Defining the Indefinable?* The Stationery Office, Edinburgh.
- Boon, P. J., N. T. H. Holmes, P. S. Maitland, T. A. Rowell & J. Davies, 1997. A system for evaluating rivers for conservation (SERCON): development, structure, function. In Boon, P. J. & D. L. Howell (eds), *Freshwater Quality: Defining the Indefinable?* The Stationery Office, Edinburgh: 299–326.
- Bradshaw, A. D., 1997. What do we mean by restoration? In Urbanska, K. M., N. R. Webb & P. J. Edwards (eds), *Restoration Ecology and Sustainable Development*. Cambridge University Press, Cambridge: 8–14.
- Bundi, U., A. Frutiger, C. Göldi, M. Hütte, U. Kupper, P. Liechti, W. Meier, P. Niederhauser, A. Peter, U. Sieber, U. Von Blücher & H.P. Willi, 1998. Methoden zur Untersuchung und Beurteilung der Fliessgewässer: Modul-Stufen-Konzept. Mitteilungen zum Gewässerschutz Nr. 26 (Vollzug Umwelt). Bundesamt für Umwelt, Wald und Landschaft (BUWAL): 43 pp.
- BUWAL, Swiss Agency for the Environment, Forests and Landscape, 1997. *Umwelt in der Schweiz*, BUWAL, Bern: 372 pp.
- Commission of the European Communities, 1998. Amended proposal for a Council Directive establishing a framework for Community action in the field of water policy. Brussels, 17.02.1998, COM (1998) 76 final.
- Cooke, G. D. & W. R. Jordan, III., 1995. Ecosystem rehabilitation. In *Using ecological restoration to meet Clean Water Act goals*. U.S. Environmental Protection Agency, Chicago, Illinois: 1–4.
- Décamps, H. & R. J. Naiman, 1990. Towards an ecotone perspective. In Naiman, R. J. & H. Décamps (eds), *The Ecology and Management of Aquatic-terrestrial Ecotones*. Man and the

- Biosphere Series, Vol. 4. UNESCO Paris and the Parthenon Publishing Group: 1–5.
- Frey, D. G., 1977. Biological integrity of water – a historical approach. In Ballentine, R. K. & L. J. Guarrida (eds), *The Integrity of Water*. U.S. Environmental Protection Agency, Washington, D.C.: 127–140.
- Friedl, C. & E. Staub, 1998. Collapse of angling catches in running waters – a new phenomenon in Switzerland and its possible causes. Poster presentation, International Conference on Assessing the Ecological Integrity of Running Waters, 9–11 November 1998, Vienna.
- Hütte, M., U. Bundi & A. Peter, 1994. Konzept für die Bewertung und Entwicklung von Bächen und Bachsystemen im Kanton Zürich, EAWAG/Kanton Zürich: 133 pp.
- Hütte, M., P. Niederhauser, U. Bundi, A. Frutiger, C. Göldi, U. Kupper, P. Liechti, W. Meier, P. Niederhauser A. Peter, U. Sieber, U. Von Blücher & H. P. Willi, 1998. Methoden zur Untersuchung und Beurteilung der Fliessgewässer in der Schweiz: Oekomorphologie – Stufe F. Mitteilungen zum Gewässerschutz Nr. 27 (Vollzug Umwelt). Bundesamt für Umwelt, Wald und Landschaft (BUWAL): 47 pp.
- Karr, J. R. & D. R. Dudley, 1981. Ecological perspective on water quality goals. *Envir. Manage.* 5: 55–68.
- Kauffman, J. B., R. L. Beschta, N. Otting & D. Lytjen, 1997. An ecological perspective of riparian and stream restoration in the Western United States. *Fisheries* 22, 5: 12–24.
- Koblet, R., 1995. Entwicklung der Korrekturen an Fliessgewässern und Seen. Kartentafel 5.5 des Hydrologischen Atlas der Schweiz. Landeshydrologie und geologie, Bern.
- Sempeski, P. & P. Gaudin, 1995. Size-related changes in diel distribution of young grayling (*Thymallus thymallus*). *Can. J. Fish. and aquat. Sci.* 52, 9: 1842–1848.
- Uttinger, J., C. Roth & A. Peter, 1998. Effects of environmental parameters on the distribution of bullhead *Cottus gobio* with particular consideration of the effects of obstructions. *J. appl. Ecol.* 35: 882–892.
- Ward, J. V., 1997. An Expansive Perspective of Riverine Landscapes: Pattern and Process Across Scales. *GAIA* 6: 52–60.
- WRI/IUCN/UNEP, 1992. Global Biodiversity Strategy: Guidelines for actions to save, study, and use earth's biotic wealth sustainably and equitably. World Resources Institute, World Conservation Union, and the United Nations Environment Programme, Washington, D.C.
- Wuhrmann, K., 1974. Some problems and perspectives in applied limnology. *Mitt. Int. Ver. Limnol.* 20: 325–40.