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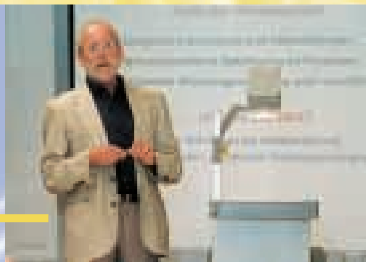
Integrated Water Assessment and Management



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Integrated Water Assessment and Management

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Editorial

Renata Behra, biologist, leader of the working group "Ecotoxicology: populations and communities".

In the field of environmental protection, experts from a wide range of professional disciplines, together with various interest groups, are increasingly joining forces to find solutions to problems. The principle of "Integrated Management" assumes a key role in this effort, as it does in efforts towards a sustainable management of water resources. During the Information Day 2000, EAWAG presented the tools and approaches used in integrated water management.
It is the goal of integrated management to find a balance between protection and use. Apart from the political, economic and social aspects, ecological functions must also be considered when assessing a stream and implementing its management. This general concept was put into a legal framework in 1991 with the Federal Laws on Water Protection and Surface Water Regulation. The implementation of this task, however, is complex and associated with considerable uncertainty. From the beginning, EAWAG has been active in developing scientifically based instruments for integrated problem analysis and remedial action planning in water management. Professional circles have also recognized the need for integrated approaches to environmental protection. A number of efforts currently under way in government, industry, and in political arenas follow this general principle; in all cases, one of the crucial decisions is the early involvement of interested parties in the development of basic strategies.
Science has a very important role to play in the development of approaches and tools that are used in integrated water management. Crucial factors for its success include collaboration across disciplinary as well as institutional boundaries and establishment of a dialogue with professional circles. Scientists must be encouraged to think and work in a larger environmental context. This also means relinquishing the usual ways of conducting scientific research, which have traditionally not involved contact with professional circles. The realization of the importance of water management problems facing us will no doubt push the science into becoming ever more transparent to the public and to those who apply scientific research in the real world.

The Perspective of Integrated Water Management

Integrated water management is a perspective for effective and efficient protection and utilization concepts for water. On the one hand, individual demands, such as water quality or flood protection, need to be coordinated and optimized; on the other, integrated water management deals with ecological-economic optimization of specific uses such as hydroelectric power generation. This article presents some basic principles and tools to implement integrated water management.

Development of Water Utilization

Aquatic ecosystems have become subjected to permanent change due to a large extent from ever changing and increasing demands for utilization. Since the 19th century, laws governing fisheries, flood protection, stream corrections, hydroelectric power generation, and water protection have been established with each law covering a specific sector of all the different aspects defining a stream. Many activities, such as farming, community development, road construction and combustion processes, have an indirect impact on streams. For a long time, these impacts were mostly ignored. Even water protection itself has become segregated into areas that have developed independently. Despite the ongoing trend for management approaches to cover wider aspects of problems (Fig. 1), stream protection still strongly reflects its historic roots.

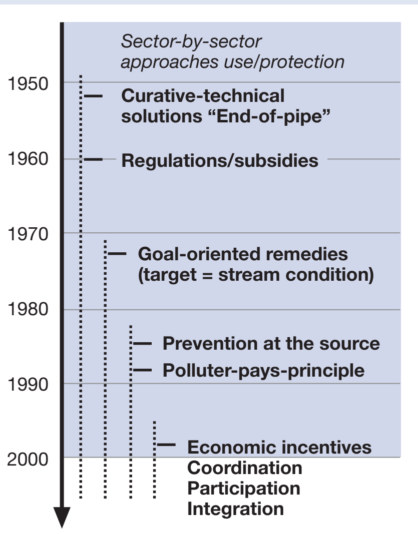

Fig. 1: Development of water protection in Switzerland: from wastewater treatment to integrated approaches. Protection and usage needs were developed in a fragmented, sectional fashion.

Preventative, cause-oriented approaches are still poorly developed when compared with "end-of-pipe" solutions. Positive examples of exceptions are the ban on phosphate in detergents (1986) and the promotion of low-pollution production processes in industry. The introduction of market economy tools in environmental politics (e.g., financial incentives, environmental tax reform) still faces resistance.

Where – in view of the new challenges – lie the problems in the historically established way we deal with streams and the corresponding legal and administrative structures?

- Problems are rarely analyzed in a larger context. Solutions are often designed for a narrow definition of the problem and deal with a very specific set of problems and uses. Cost/benefit analyses play a minor role. As a consequence, financial resources are often used poorly.
- Sectorial regulation and implementation lead to less friction within authorities and increase the burden on those who must comply with environmental regulations.
- Many problems cannot be solved without financial incentives and preventative measures.
- We often face helplessness when dealing with newly emerging problems. A recent example is the problem of hormonally active chemicals (see article of P. Holm, p. 23). What is missing are generally accepted tools for long-range risk analyses and for preventative, cause-oriented risk reduction.

We would like to contrast the current fragmented management style with an approach where the utilization and protection needs are analyzed, evaluated, and implemented while looking at the whole system. The benefits to be hoped for from this approach would be synergism between different fields, coordinated actions among all sides involved, and more efficient use of resources.

Starting Point for an Integrated Approach

Ideally, integrated water management would take into account all impacts, all forms of utilization, and all protection needs as well as predominating political, legal, institutional, economic, social and cultural aspects. Is this goal attainable in the real world?

The primary goal of integrated management is the sustainable use of water, i.e., guaranteeing that the essential forms of utilization can be maintained over long periods of time. This includes supplying drinking water, water for food production, hydroelectric power generation, flood protection, maintaining a healthy ecosystem, and also providing emotional values.

Ueli Bundi, EAWAG

Different usages influence the appearance of a stream (Calancasca, canton Grisons).

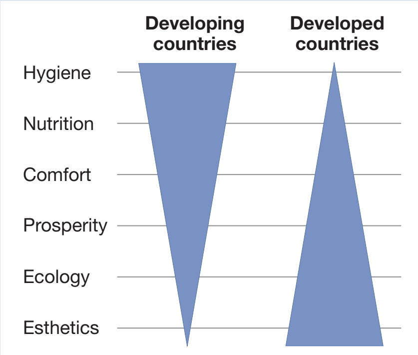

Fig. 2: Requirement profile for water management in developed and developing countries. The profiles can vary significantly even among countries within the same group.

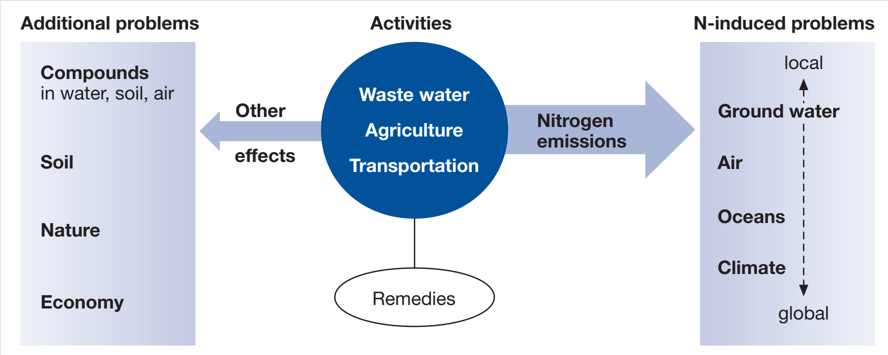

Fig. 3: Nitrogen – a complex environmental problem. Nitrogen is released by a number of activities and results in environmental problems from the local to global scale. Each activity is also responsible for a number of other environmental problems and needs to be addressed within the entire context.

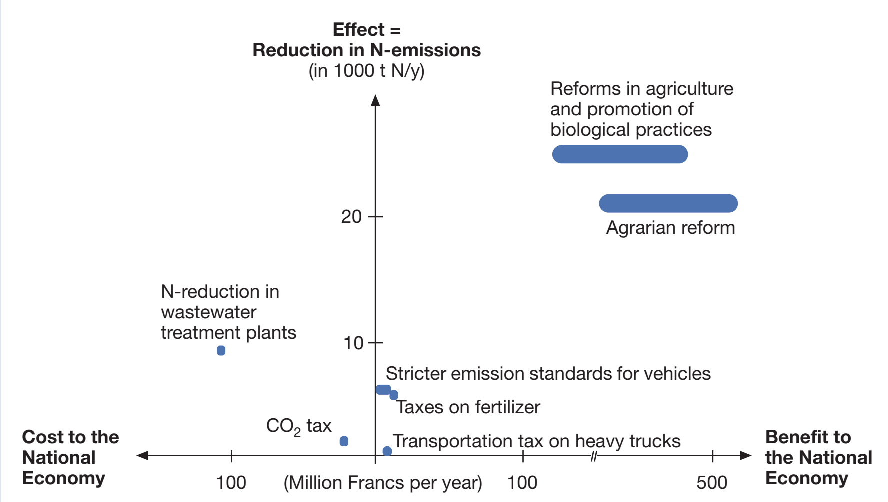

Fig. 4: Cost and effects of a reduction in nitrogen emissions in Switzerland. Political programs and options for increased consideration of ecological aspects were examined for a number of activities (BUWAL, 1996).

The priorities among all these demands may vary depending on the particular set of problems in a given situation [1]. Priorities will also depend on the culture, the dominant socio-economic factors of a country or a region, and administrative and legal structures [2]. Figure 2 illustrates the typical demands on water management for developed and third-world countries.

Problems related to water resources are by nature highly complex and specific. This leads to an apparent paradox: each of the problems is difficult enough to handle by itself, and now the interactions among the major aspects of water use need to be considered.

Connected aquatic ecosystems: Aquatic ecosystems are closely linked with one another and with their environment (see article of U. Uehlinger, p. 16). The condition of individual ecosystems is determined by interactions within this entire network and by anthropogenic influences. The processes occurring in the system are extremely complex and dynamic and may be described and predicted only to a limited degree.

Connected environmental problems: Human activities that cause water problems lead to numerous other environmental problems. Conversely, a number of human activities are often responsible for a particular problem, e.g., excessive nitrogen accumulation in the environment (Fig. 3). Each activity (such as agriculture) should therefore be optimized within an overall environmental context, and not only with regard to water [3–5].

Large spatial and temporal scales: Biological elements and ecological processes relevant in aquatic ecosystems occur on wide spatial (m^2 to km^2) and temporal (days to centuries or more) scales [6]. The same can be said of anthropogenic impacts. In minimizing environmental impacts of hydroelectric power generation, for example, the stream fauna is sensitive to the daily and weekly rhythm of residual flow volumes, while a flood plain responds to rhythms spanning decades. It is therefore very difficult to perform cause-effect analyses and to determine the effects of actions relevant for water condition [7].

Execution at different levels: Additional complexity is introduced by the fact that responsibility for different kinds of problems and decisions falls to entities that are subjected to different hierarchical and spatial levels. The entities involved comprise of governing bodies ranging from the community all the way up to international level, a suite of administrative offices, (e.g., for water use, energy, agriculture, water and environmental protection), and other groups who need to provide input, such as certain business sectors, professional associations, citizen organizations, NGOs and more.

Utilization conflicts and discrepancies in values: Even within a relatively homogenous cultural context, problems caused by water utilization can be valued very differently by various interest groups (e.g., protectors of the environment vs. protectors of jobs). This can lead to irreconcilable differences because the priorities and the remedies are determined within different value systems. The situation can be aggravated even further since the values and needs related to water use can change relatively quickly.

Synergisms between different usage modes: Opposing demands on water use usually restrict the options for action, but in some cases they may even turn out to be mutually beneficial. The certification of green electricity, for example, (see article of C. Bratrich, p. 20) can lead to conflict resolution and support integrated stream rehabilitation [8]. The opposite is done for agricultural practices which crank up the nitrogen cycle, and thus are difficult to reconcile with technological improvements in wastewater treatment [3–5].

General Directions and Principles

Our discussion so far illustrates that the goal of all-inclusive, integrated water management in the idealistic sense is not realistic.

So where are the solutions that will bring us closer to sustainable water management by using the potential of synergisms and efficiency improvements?

The new EU Water Framework Directive (WFD, see article of J. Leentvaar, p. 18) stipulates that integrated water management be implemented on the scale of entire watersheds. The directive formulates general goals and principles that must be translated into national law, and applied in specific action plans. This step-by-step application of generally accepted principles can enhance integrated approaches to water management. Another important intention of the WFD is to integrate issues related to water and environmental protection into sectors like agricultural policies and urban planning (see article of H.P. Willi, p. 26).

But even with the best intentions, the inherent complexities and uncertainties in water management cannot be overcome. Simply for practical reasons, it must be assumed that individual approaches for different aspects of water management (e.g., wastewater treatment, water supply, flood protection, restoration) and that tailor-made solutions for certain uses (e.g., hydroelectric power generation, agriculture) will continue to play an important role. What will be new, however, is that these approaches will not be worked out individually for each aspect, but will be coordinated with one another. The following principles – as they are, in part, also stated in the WFD introduced by the EU – are meant to provide general guidelines for the practically oriented definition of integrated water management in a range of different contexts.

Design water use in accordance with sustainability: The long-term regeneration of water resources is the highest principle for all actions. Irreversible impacts have to be avoided.

Choosing appropriate incentives and acting upon cost/benefit evaluations: The effectiveness of a certain measure is often crucially dependent on its acceptance by the affected parties. In finding practical solutions, we must consider how much room these parties have to maneuver, and we have to include cost effectiveness in the evaluation process. We must go beyond traditional ordinances and should increasingly resort to financial incentives, voluntary agreements, information transfer and education, and support of innovative solutions and cooperation among the various parties. The general understanding of the problems and the capacity for solving them will grow, while local initiatives will become increasingly more important.

Taking into account interactions between different spheres of interest: We should attempt to overcome the traditional antagonism between protection and usage interests and identify and promote possibilities for synergisms. Optimizing the amount of fertilizer used in agriculture, for example, can have environmental as well as economic benefits. An example of what we should not attempt to do would be pushing wastewater treatment to its absolute technically feasible optimum, since we might create new environmental problems in the process. The necessary coordination could be provided by interdepartmental committees who would examine proposed regulations as well as action plans for duplication or inconsistencies.

Participatory decision-making processes: The high level of complexity in water use and protection issues requires active participation of the various interest groups, for example in the permitting process for hydroelectric power plants. Involvement of all interested groups from the beginning can reveal synergisms early on and will place decisions on a broader basis, which will reduce opposition during the later phases of the process. Early involvement of all interest groups will also tend to reduce overall costs and shorten the planning and permitting process.

Flexible approaches which allow a learning process: Flexible management, control and correction mechanisms are needed since natural and social processes are very complex, and the effect of any particular action is difficult to predict. Actions should be conceived as experiments that will periodically be evaluated and adapted. Flexible approaches that leave some room for error are particularly important for installations with a long life time, as for example, in wastewater disposal. Technical solutions should ideally provide flexibility and options for design modifications for a long period after initial construction.

Tools for Integrated Management

In order to apply the principles described above in the real world, we need new concepts and tools. However, the scientific basis for those is often not available in a form that is directly applicable. Science needs to increase its effort to synthesize information and to present and communicate it in a generally accessible form. Furthermore, close cooperation between science and professionals on the application side will support the development of new approaches in water management.

Early identification of risks: Scientific based knowledge plays a crucial role in the early recognition of problems and in the subsequent development of remedial actions. Scientific knowledge as well as projections of risks, however, are always associated by some degree of uncertainty. It is important to openly discuss these uncertainties; ignoring uncertainties or exaggerating them can have equally fatal consequences. This type of information has to be transmitted to the public in an appropriate and understandable form, which requires the scientific community to find new ways of communicating.

Procedures for ecological assessment and evaluation of action plans: In order to develop effective responses to problems, we need to develop and apply procedures that characterize and evaluate environmental problems in appropriate ecological terms (see articles of A. Peter, p. 7, and N. Schweigert, p. 10). Such procedures need to be scientifically based and broadly accepted, and be easy to integrate in the decision-making process. Decision-support systems (e.g., analyses of cost effectiveness) will become increasingly more important (see article of W. Meier, p. 13). Figure 4 compares the costs and the affects of reducing nitrogen emissions in Switzerland [4].

Open discussion of uncertainties is important in this type of evaluation, too. We have to explicitly state how different value systems will lead to different responses to a given problem. When trying to demonstrate the need for remedial action, for example in flood protection or stream restoration, it is critical that different segments of the public provide their own risk perception. The degree of risk one is willing to accept has to be an explicit, adjustable parameter within the problem analysis framework.

Development of new technologies: At the center of our efforts are both the reduction of the amount of water used and the reduction of contaminant release into the environment. Target sectors are agriculture, industry, households, together with other areas of our society and economy where water plays an important role. We must be open to radically new socio-technical solutions and seriously evaluate their viability. Innovative technologies should not be based solely on technological considerations; the full potential of innovative technology is only realized when it is accompanied by the development of new usage patterns and institutional structures.

Promotion of efficient institutions: In some areas of water management, institutional reforms are believed to offer the largest

The Pfynwald is a floodplain of national interest. Ahead of this floodplain the water of the river Rhone is drained off and used for the production of hydropower.

potential for improvements. In the public sector, such reforms have been dominated over the past few years by various forms of liberalization and privatization. We have had to realize, however, that such reforms must be thought out very carefully in order to avoid the creation of new problems. The one indisputable principle emerging from our experiences is that the competence to make decisions should be placed with the institutions or authorities which have physically to deal with the relevant problems.

Perspective

Integrated water management, which is able to simultaneously analyze, evaluate and solve all problems in an *all-inclusive* form, is a hypothetical goal that is not attainable in the real world. It is important, however, to remain focused on the basic requirements for integrated approaches when developing new concepts for water utilization and protection. We need to be aware of the connections between different kinds of problems and to coordinate between different sectors of action. This is important when dealing with whole watersheds and also when optimizing specific water uses. One important factor in mastering this task is a consistent political framework that recognizes the links between individual sets of problems and creates incentives for initiatives to be proposed by the various players and affected parties (Fig. 5).

This article discussed some of the fundamental principles and tools towards integrated water management. We would like to emphasize once more how complex the natural and social systems are that we have to deal with. Therefore, it is important to keep the decision-making process transparent, explicitly state uncertainties, and to create an open and participatory atmosphere. Only in doing so will we make the best use of synergisms, minimize friction, and maximize efficiency and efficacy of the actions that are to be taken.

EAWAG has proposed a number of initiatives over the last few years, aimed at supporting specific areas within the framework of integrated water management. It was the goal of the Information Day 2000 to present the larger context of the various projects and to show how integrated water management might look in the future.

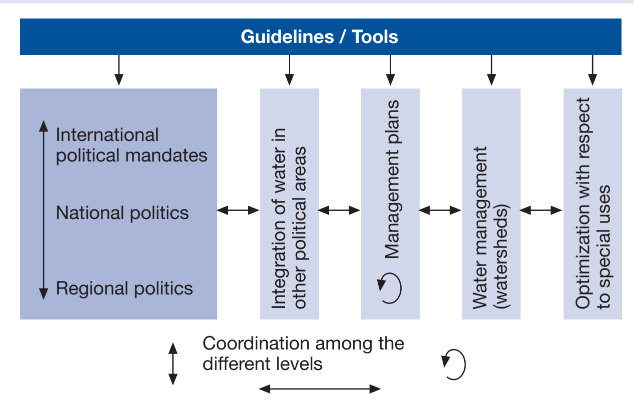

Fig. 5: Management framework for integrated water management.

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Co-author:
Bernhard Truffer is geographer and research scientist in the Department of "Human Ecology" at EAWAG since 1993. He has been leader of the EAWAG project "Green Electricity" since April 1998.

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The Swiss Modular Concept

A Basis for the Assessment of Streams

The Swiss Modular Concept creates a framework for the examination and evaluation of streams and includes hydrological, morphological, biological, chemical and ecotoxicological modules. It will become an important tool in integrated assessment and management of streams.

In Switzerland over the 20th Century, the various ways in which streams have been intensively utilized for a variety of purposes have led to extensive physical degradation of the streams. Expansion of hydroelectric installations has resulted in significantly different discharge patterns. Extensive development of towns and villages, the related expansion of roads, as well as the more intensive agricultural use of the land have continuously reduced the space left for streams. In addition, water quality has been severely impacted. With the rapid increase in chemical contamination during the 1950s, it became clear that the public sector had to get involved. The Water Protection Law of 1955 ("Gewässerschutzgesetz"; first revised in 1971) provided a legal basis for problems relating to water pollution. Due to complete coverage by wastewater treatment plants, water quality continuously improved. In addition, the Recommendations for the Examination of Switzerland's Streams ("Empfehlungen über die Untersuchung der schweizerischen Oberflächengewässer") issued in 1982 provided a set of tools for the assessment of water quality for the first time.

With the second revision of the Water Protection Law in 1991, the protection, preservation and restoration of streams as integral ecosystems became a central issue. This required improved methods for the assessment of stream health [1]. In order to gain a holistic assessment of streams, chemical parameters have to be examined along with various aspects of hydrology, ecomorphology, biology and ecotoxicology.

Armin Peter, EAWAG

A nearly natural stream: the Brenno in the flood plain near Loderio. Morphologically, this section of the stream may be classified as natural/close to natural (class I, see Table 4). It is characterized by a particularly high biodiversity. Eleven of the 12 fish species occurring in the entire Brenno system are found in this section of the stream.

Requirements for Evaluation Procedures

Depending on the specific questions asked in a particular case, the assessment of stream quality must allow for different approaches. The need ranges from fast survey methods for rapidly assessing the condition of a large catchment to methods for the detailed analysis of individual streams, even sections of streams. Streams should be evaluated from different perspectives, employing biological as well as non-biological assessment methods.

The evaluation procedure should include two steps: the analysis of the current stream condition using a range of criteria and evaluation methods and a comparison of the current condition to the desired near-natural condition. The challenge lies in combining factual and analytical information with more subjective values into one relatively objective assessment [2]. Ideally, the assessment criteria should be designed so that different evaluators come to the same conclusion. The assessment can be either in the form of a narrative or based on a point system in which the scores for individual parameters are added to obtain an overall score. In order to maximize the comparability, we need to develop methods that are applicable to any stream in Switzerland and which are consistent with methods used in other European countries.

Ecological Basis for Stream Assessment

An assessment scheme that considers all aspects of stream quality may only be realized by using a modular approach. We chose the modules hydrology/morphology, chemistry/ecotoxicology, and biology. Each of the modules incorporates the current state-of-the-art findings of the respective scientific disciplines. The biology module,

	Level I	Level II	Level III
Scale	Region/canton	Stream system	Medium to short stream section
Effort	Small	Medium	Large
Goal	Rough overview, analysis of ecological deficiencies	Detailed overview, analysis of deficiencies, development of remedial action	Detailed analysis of specific questions
Assessment	Point scores	Verbal	Verbal

Table 1: The three levels of the Swiss Modular Concept.

in particular, was shaped by the following ecological considerations (see article of U. Uehlinger, p. 16):

The **River Continuum Concept** is an attempt to identify and rationalize longitudinal changes in stream ecosystems [3]. Relationships among the catchment, the flood plains associated with the stream, and the stream system itself are demonstrated; changes in community composition between the headwaters and the mouth of the river are analyzed. In using this concept, it is clear that a particular stretch of river can never be considered an isolated entity but has to be examined in the context of the entire river system, including the surrounding land. This has a particular impact on the formulation of remedies for the ecological deficiencies.

The **Flood-Pulse Concept** suggests that the dynamic interaction between the water and the surrounding terrestrial habitats influences the inhabitants of both the stream and the flood plain [4]. Flood plains must be considered as very special habitats for plants and animals. As areas that are periodically flooded, they harbor special fauna and flora. The "flood-pulse" concept clearly demonstrates that the stream, the riparian vegetation and the surrounding flood plain should be treated as a single entity.

Hierarchical Structure of Streams: Frissel et al. [5] describe the hierarchical organization of streams (whole river systems to microhabitats), on both spatial and temporal scales. Investigations of larger portions of a river system clearly need to use approaches based on this concept and consider "scale" as an important factor both during the investigation and in the final evaluation.

The **Four-dimensional Stream Concept** describes a stream in its four dimensions; namely longitudinally, laterally, vertically and temporally [6, 7]. The strength of this concept lies in its revealing the importance of spatial exchange processes for water, material, energy and organisms along a stream corridor. The temporal dimension deserves special attention since it illustrates the dynamic behavior of a stream corridor.

The **Stream Corridor Concept** includes the stream bed, the flood plain and the transitional zone in between [8]. These three components form a dynamic entity within the landscape. Within this space, water, solid materials, energy and organisms are linked in a tight, dynamic relationship. The consideration of the stream corridor as a whole allows us to see ecological deficits and required mitigation measures in a wider context.

Restoration and Rehabilitation Concepts are supposed to assist us in bringing degraded streams back to a condition that is closer to their original state [9, 10]. The main goals are improvements to the structure of the ecosystem (e.g. habitats and species diversity) and to its ecological functioning, even though the original condition of the stream cannot usually be restored. These concepts are particularly useful once the stream assessment is complete and mitigation measures need to be developed.

Structure of the Swiss Modular Concept

The Swiss Modular Concept was developed under the guidance of the project group "Stream Assessment"[1] in collaboration with representatives from the SAEFL (Swiss Agency for the Environment, Forests and Landscape), FOWG (Swiss Federal Office for Water and Geology), EAWAG and the Canton of Zurich [11]. Each of the modules contains a three-level structure (Table 1). At the regional level (level I, regional scale survey), the goal is a rapid, cost-effective analysis. In more detailed evaluations of an entire stream system or catchment (level II, catchment scale survey), or of selected stream sections with lengths between 0.1 and 1 km (level III, extensive reach scale survey), the cost per analyzed area is significantly higher. For levels I and II, new assessment methods are currently being developed while existing ones are being continuously expanded. This is not true for level III, where specific aspects of a stream system need to be evaluated (e.g., microhabitats, structural composition, species inventory, populations). It usually is more efficient to rely on established methods.

Table 2 provides an overview of the nine modules of the Swiss Modular Concept and the specific methods used in analysis levels I and II. Each module examines a particular aspect of a stream. The modules are independent units and can be used in any combination. However, it is reasonable to combine a biological module with a non-biological module at the same time.

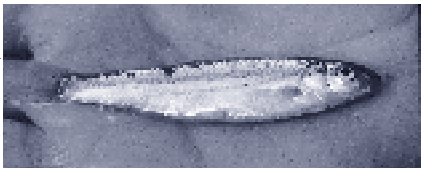
Temporal and Spatial Dimensions of the Modules

Each module has specific advantages in evaluating a stream, but at the same time also has some temporal or spatial limitations. This also holds for the biological

	Module	Level I	Level II
Hydrology and Morphology	Hydrology	General characterization of the discharge	Systematic observation
	Ecomorphology	Major ecomorphological impacts, longitudinal connectivity	Analysis of deficiencies, catalog of remedial action with indication of priority
Biology	Algae	Examination of diatoms	Not examined
	Macrophytes	Estimation of abundance	Mapping of all species
	Riparian vegetation	Simple mapping	Detailed mapping, action plan
	Macroinvertebrates	Coarse species overview	Detailed mapping
	Fish	Overview of fish species	Detailed studies, examination of populations
Chemistry and Ecotoxicology	Chemistry	Rough screening of water quality	Detailed investigations of water quality
	Ecotoxicology	Random checks, 2–3 simple analyses	Seasonal or more frequent analysis of chemical impacts

Table 2: The nine modules of the Swiss Modular Concept for assessment levels I and II.

[1] Members of the project group are: Paul Liechti, Ueli Sieber (SAEFL), Ulrich von Blücher, Hans Peter Willi (FOWG), Christian Göldi, Urs Kupper, Walo Meier, Pius Niederhauser (Canton Zurich), Ueli Bundi, Andreas Frutiger, Michael Hütte, Armin Peter (EAWAG)



Armin Peter, EAWAG

Fish are particularly well suited for the assessment of stream quality. The extremely sensitive Blageon (Leuciscus souffia) is found almost exclusively in stream sections that are very close to their original, natural state.

moduls (Table 3). Algae have very short reproductive and life cycles and can be sensitive to certain pollutants that may not cause observable effects in higher organisms. Algae, therefore, are good indicators of short-term processes that are limited to relatively small areas. Members of the macroinvertebrates on the other hand, are present in practically all streams, even if fish populations have already been eliminated. This group of organisms is, therefore, a good indicator of long-term environmental impacts on areas of several 100 m^2. Since environmental requirements of fish are well understood, the ecological interpretation of the condition of a fish population can yield a very precise assessment of a stream. Fish, thus, reflect environmental conditions of a longer period spanning several years. Because of their high level of mobility, environmental impacts to the catchment as a whole may be assessed. Prevailing conditions over time periods on the order of decades are reflected in the composition of the riparian vegetation.

Example: Module Ecomorphology Level I

The main purpose of the level I assessment within the ecomorphology module is to provide an area-wide representation of the ecomorphological condition of a stream system, together with a rough analysis of the main deficiencies [12]. Data is gathered by inspection in the field, covering the length of the stream and recording the following characteristics:

- variability of stream width (submersed area at average water level),
- width of streambed and degree of obstruction by corrective structures,
- erosion control structures along the bottom of the stream bank,
- width and condition of the area adjacent to the stream bank.

Each of these characteristics receives a separate score for each of the survey sections. The assigned score is proportional to the deviation from the ideal, natural condition. Distinct stream sections are then classified according to their overall score. A graphical representation of conditions within the entire stream system can be produced by assigning different colors to different classes of stream condition (Table 4).

Current Status of the Modules

The federation (SAEFL/FOWG/EAWAG) and representatives of the cantons have taken on the responsibility for planning and quality assurance. Over the next 2–3 years, the development of the modules should be complete. Procedures for level I of the ecomorphology module were finalized in 1998 [12]. The level I procedures for the macroinvertebrate and fish modules will be made available to users in 2001. A concentrated effort is underway to assure rapid delivery of the remaining modules.

Stream Assessment as the Basis for Sustainable Stream Management

Switzerland ratified the agreement on biodiversity in Rio de Janeiro in 1992 and has thereby made a commitment to restore damaged ecosystems. There is significant potential for revitalization along approximately 12,600 km of Switzerland's streams, which corresponds to roughly 20–25% of the total length of all stream systems in Switzerland (see article of H.P. Willi, p. 26); stream sections running in culverts are not included in these numbers.

Stream sections amenable to revitalization will be easily identified using the evaluation methods of the Swiss Modular Concept. The success of revitalization efforts can be assessed using a different set of modules. Ongoing monitoring of the revitalization results assures sustainable improvement of stream quality.

Armin Peter, fisheries and stream ecologist, project leader of the department "Applied aquatic ecology" (APEC). Current research interests: rehabilitation of streams, hydroelectric utilization of streams, population dynamics and migratory behavior of fish.

Module	Temporal scale	Spatial scale
Algae	Days – weeks	m^2
Macrophytes	Years	Several 100 m^2
Riparian vegetation	Decades	km^2
Macroinvertebrates	Month – 1 year	Several 100 m^2
Fish	Years	km^2 (whole watershed)

Table 3: Temporal and spatial scales of the modules.

Class	Condition	Color code
I	Natural/close to natural	Blue
II	Minimally impacted	Green
III	Heavily impacted	Yellow
IV	Unnatural/artificial	Red

Table 4: Classification of stream condition and color code for mapping.

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How Can the Degree of Pollutant Impact on a Stream be Documented?

The Ecotoxicology Group at EAWAG has developed a novel two-step approach to assess the toxicity of water samples. This procedure would allow for processing of a large number of water samples and evaluation of their ecotoxicological potential. For such a procedure, it is important to consider that the water samples need to be tested with respect to all relevant toxic effects and currently known mechanisms of toxicity. The approach will be included into the Swiss modular concept and opens new possibilities in the ecotoxicological assessment of water.

The Swiss modular concept employs methods for the assessment of stream quality [1, see article by A. Peter, p. 7]. The basic idea is the integrated assessment of running waters, bringing together hydrological/morphological, biological and chemical/ecotoxicological aspects. However, there still is relatively little information on the ecotoxicological evaluation of natural waters. A new ecotoxicology module was therefore developed by an interdisciplinary working group at EAWAG and in discussions with internationally recognized experts.

Substances Exhibiting Ecotoxicological Effects

Of the roughly five million chemical compounds known today, approximately 80,000 are commonly in use. Each year, some 500–1000 new compounds are added [2]. During production, use, and disposal, chemical compounds are inevitably released into the environment. They represent a significant potential threat to stream and riverine ecosystems. As fish studies have shown, even relatively low pollutant concentrations can cause damage (see article by P. Holm, p. 23). One of the problems is that these low concentrations cannot always be measured by traditional analytical methods. In addition, there are chemicals which are only harmful when they occur in combination with certain other chemicals. We need, therefore, new methods for assessing the ecotoxicological effects of chemical compounds or of mixtures of compounds which go beyond classical chemical methodologies.

Classical Test Systems

Starting in the 1950s, the toxicity of chemical compounds has been tested by using aquatic organisms. For about the last 20 years more complex environmental samples, such as wastewater and sewage sludge, have also been examined with these methods. The advantage of ecotoxicological tests over traditional chemical analyses lies in the fact that these tests address the issues of bioavailability and interactions among multiple compounds.

In classical tests, organisms such as bacteria, algae, *Daphnia* or fish are exposed to water samples for a certain amount of time. Toxicity is assessed by measuring mortality rates or growth inhibition or by observing typical behaviors. Normally these tests use short exposure times, and responses can only be observed at relatively high pollutant concentrations. These conditions may be appropriate for wastewater, but are rarely found in streams. In addition, such tests only assess direct toxicity, while the effects of other types of toxic compounds, e.g., hormone-active or carcinogenic compounds, are not detected. Such tests have only limited value for the ecotoxicological evaluation of water samples from a stream. Long-term tests, on the other hand, disclose toxic effects of chemicals at very low levels. Unfortunately, they are labor-intensive, costly, and are usually employed when some negative effects have already been observed.

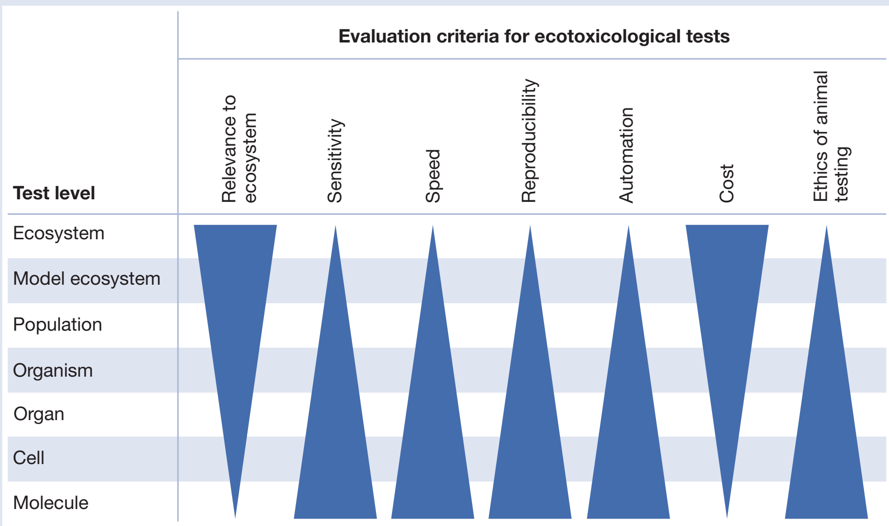
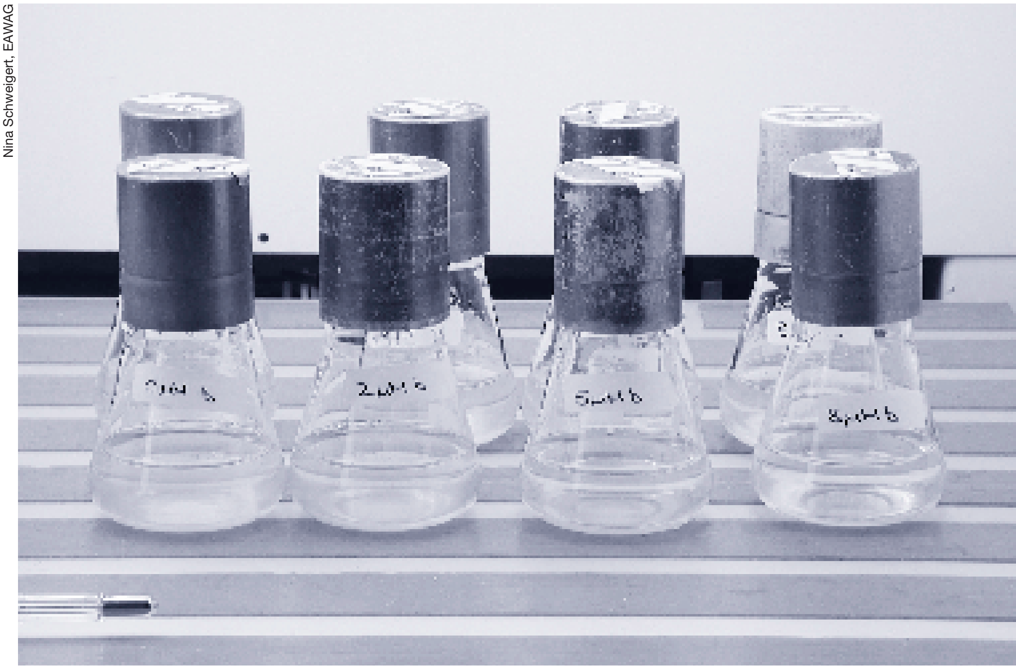


Fig. 1: Evaluation criteria for ecotoxicological tests. Criteria are more or less well defined depending on the biological level at which the test is conducted.

Nina Schweigert, EAWAG



Many single-celled organisms (ex. green algae) and cell lines are easy to cultivate.

Most classical tests have been standardized on national or even international levels, particularly by cooperation among the countries of the Organization for Economic Cooperation and Development (OECD) and the International Organization of Standardization (ISO). Standardization assures consistent sensitivity of the test organisms and reproducibility of tests between laboratories.

Alternative Testing Systems

In addition to the classical test systems, there are procedures for the evaluation of ecotoxicological characteristics of streams which approach the problem at a range of levels (Fig. 1). While the toxic effect of a chemical compound expresses itself in the organism, and ultimately in the ecosystem as a whole, the primary damage is done on the molecular level. Initial effects may include damage to proteins, DNA, or membrane lipids. If the damage is not repaired the effects carry on to higher levels and, with a certain delay, will affect the cell, the organs, and eventually the whole organism. Ultimately, the damage may manifest itself in populations, communities, or in the entire ecosystem. Typical symptoms include suppressed populations, increased frequency of certain diseases, shifts in predator-prey relationships, or changes in species composition. Unfortunately, for most of these "alternative" test systems, no standardization schemes have yet been developed.

Molecular and cellular methods: Since molecular and cellular effects manifest themselves very rapidly, the toxicity potential of water samples can be assessed in a short time span. Molecular and cellular test systems typically exhibit good reproducibility and are often more sensitive than classical tests. Costs are comparatively low, and the tests can be performed rapidly and easily. In the context of aquatic ecotoxicology, these types of tests have so far only been used in research and have been routinely used in the assessment of toxicity to mammals. These tests have the additional benefit that

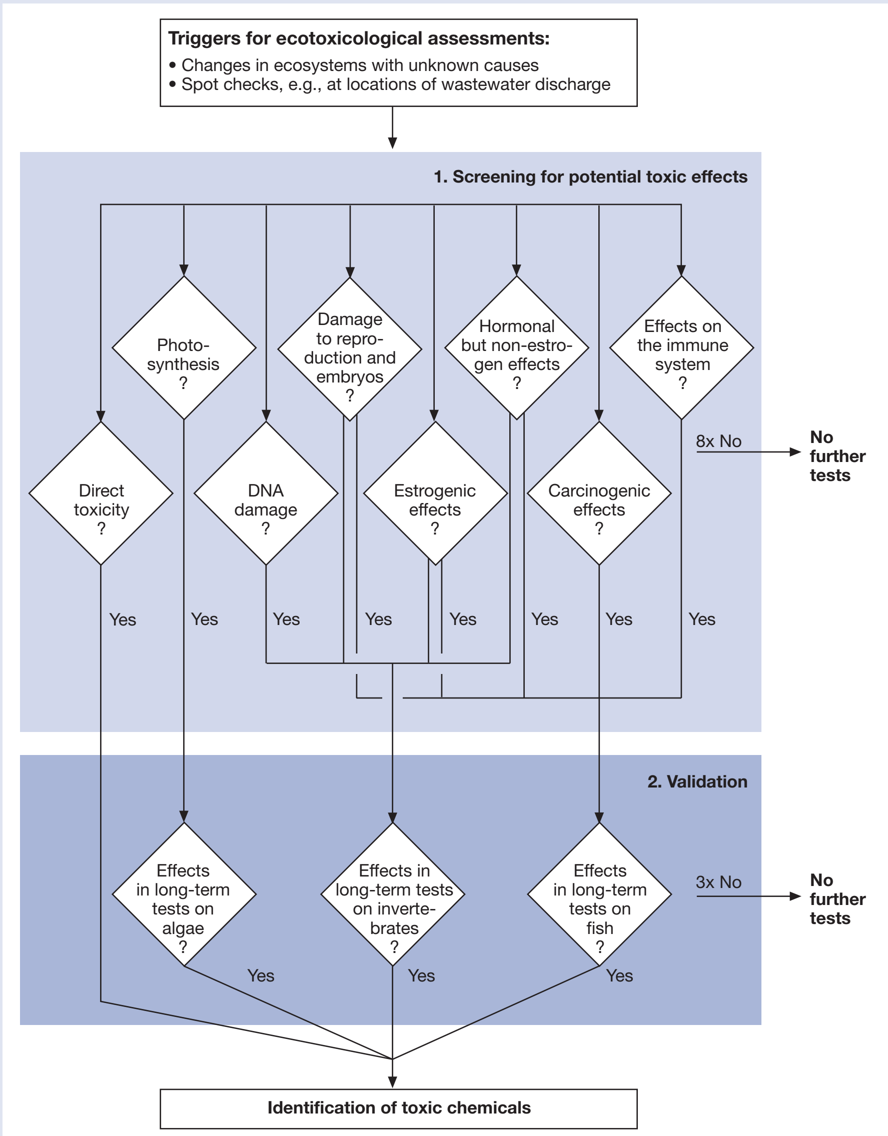
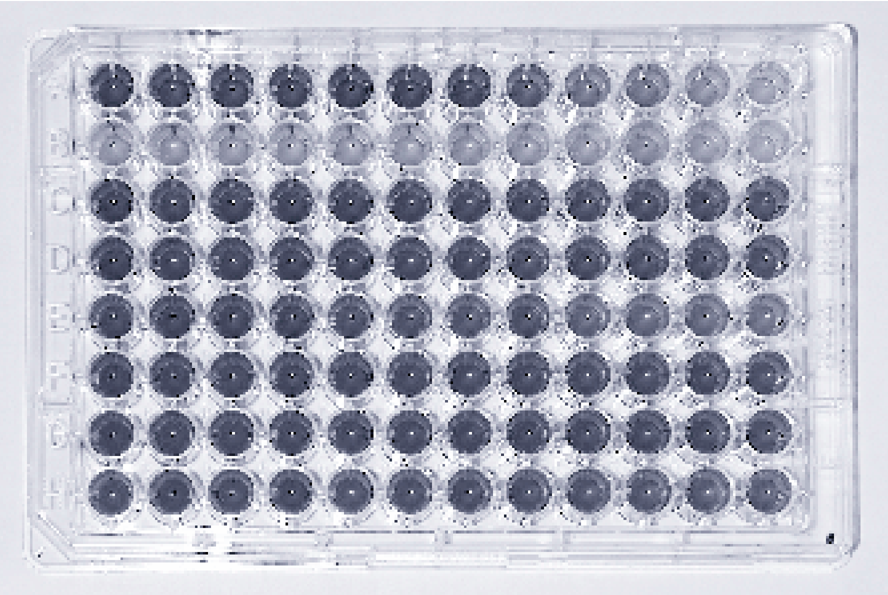


Fig. 2: A two-step approach to the ecotoxicology module for the assessment of streams.



Nina Schweigert, EAWAG

Estrogenic effect of wastewaters from different sources on recombinant yeast cells. Dark test tubes: estrogenic impact; Light test tubes: no estrogenic impact.

they not only measure direct toxicity, but also expose other relevant mechanisms by which a certain chemical may do harm.

A New Concept for Stream Assessment

Based on the rationale discussed above, we have developed the following concept (Fig. 2): Water samples are examined in a two-step approach. First, molecular and cellular techniques are used to determine potential toxic properties. In a second step, positive responses are validated; i.e., it is verified that observed toxic effects also manifest themselves on the level of the whole organism. Assessments may be triggered by indications of wastewater discharge or signs of biological disturbance. In addition, spot checks can be made to identify locations that are exposed to a higher risk.

Step 1: The toxicity potential of a water sample is assessed with cell cultures and single-celled organisms. In addition to direct toxicity, the test is also expected to uncover more subtle toxic effects. For this reason the assessment does not rely on a single test; instead, the water sample is subjected to a battery of cellular test systems. On the molecular level, recombinant cell lines of invertebrates or fish are examined for carcinogenic effects, hormone-like activity or damage to the immune system. Single-celled algae serve as representatives of plants and are evaluated for effects on the photosynthetic apparatus. Direct toxicity is assessed using bacteria. In the first step, no organisms higher than *Daphnia* or fish are used. If all tests in step 1 are negative, the water samples can be considered harmless, and no further tests are performed.

With time, the test battery will have to adapt to perceived needs and technical capabilities. Individual tests may be replaced by newer or more sensitive tests, or the number of tests may be expanded in order to include toxicity mechanisms which were previously unknown.

Step 2: Only the group of organisms which exhibits toxic effects in step 1 is subjected to further tests in step 2, thereby eliminating unnecessary testing on animals. Test organisms for a particular group should be selected such that they are typical representatives of the stream or lake from which the water sample was obtained. It should, however, be a species which is relatively sensitive and can be maintained in the laboratory. These organisms are then used in long-term tests which focus on the effects observed in step 1. A negative result at this point indicates that there is the potential for toxic effects at the cellular level, but the effect is not strong enough to manifest itself at the level of the organism. Again, the water samples can be considered harmless; however, if the toxic effects are confirmed, the specific chemical compounds responsible for the damage need to be identified in order to devise appropriate mitigation measures. If the observed toxic effects are the result of an interaction between two or more compounds, identification can become difficult or even impossible. In such cases, one must resort to a more pragmatic solution by reducing contaminant levels across the board.

Conclusions

The new concept presented is a promising approach to the ecotoxicological evaluation of streams. A large number of water samples can be examined for the complete range of relevant toxic effects. In addition, the number of tests on animals is reduced dramatically. Long-term tests need to be conducted only for water samples which indicate toxic effects in the first set of tests. The challenge now lies in developing this approach to the point where it can be applied on a routine basis. The next steps include finding answers to questions that remain open and testing the approach in case studies.

Nina Schweigert, biologist, participated in the development of this new concept for ecotoxicological assessments of streams as part of her postdoctoral research. Since April 2001, Nina Schweigert is back at EAWAG in order to develop the concept into an application.

Coauthors:
Renata Behra, biologist, leader of the working group "Ecotoxicology: populations and communities".
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Beate Escher, chemist, leader of the working group "Effect-oriented evaluation of chemicals".
Patricia Holm, biologist, leader of the project "Fish population decline network".

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The Application of Models in Stream Protection

How Models and Professional Expertise Can Contribute to the Solution of Environmental Problems

In integrated stream management, models play a central role. Models help us to understand natural systems and to predict how they will react to technical manipulations or changing environmental conditions. In recent years, traditional detailed water quality models have been joined by simplified Bayesian networks, which are used to assess the effects of environmental regulations. Optimization models evaluate the cost/benefit ratio of environmental measures and allow us to use our financial resources more efficiently.

How much does the removal of water for hydroelectric power production affect the temperature of a mountain stream? Does a reduction of wastewater discharge make a stream healthier for fish and recreational use? How can minimally industrialized countries optimize the protection of their streams in spite of limited financial resources?

Use of Models

In order to answer questions like the ones posed above, we need to be able to predict the behavior of a given environmental system as a function of external factors. This, in turn, requires an understanding of the basic processes controlling the behavior of the system; in other words, a model of the system. Depending on the specific application, we may be able to use a highly simplified model; alternatively, we may need to construct a detailed representation of the system. Models are used in three main areas [1]:

- systems analysis (e.g., increase of knowledge in scientific research),
- predicting the behavior of a system under changing external conditions (e.g., scenario comparisons in the "real world"),
- communication tools (e.g., in teaching).

When models are used in the context of assessing remedial actions in stream management, we are mainly interested in the predictive capabilities of models. We will, therefore, limit ourselves in the remainder of this article to the prognosis applications of models. One can distinguish between simple models, which merely predict the effect of certain actions, and more complex optimization models, which allow us to find optimal solutions by evaluating the costs and benefits of a range of possible actions. What is "optimal" depends on what value is assigned to a particular cost or benefit; that is, it needs to be determined and entered by the user.

Models for the Prediction of System Behavior

Predictions of the behavior of a system are the basis for decisions on corrective action. The various action plans under discussion are translated into model scenarios and then compared with one another based on the predicted effects. An evaluation of the calculated outcomes and the corresponding costs leads to the selection of a particular action plan.

In stream management, we would like to know the effect of a particular action taken on the following parameters: water yield, quality and temperature, algae, microfauna, fish, morphology of the stream bed, properties of the stream bottom, appearance of the landscape (e.g., floodplains), health aspects for recreational use, and others. Depending on the parameter targeted, different types of models may need to be used. Accurately known parameters, such as water quality or temperature, can often be described with classic predictive models. For parameters whose predictions are still rather uncertain, so called Bayesian networks may be more appropriate [2]. In these cases, the primary data that has been gathered, the model calculations, additional information from the literature, and expert input are all combined into one structure.

Application of a Classic Predictive Model: The project "Green Electricity" (see article by C. Bratrich, p. 20) is developing criteria for the certification of environmentally-friendly electricity production. One of the aspects studied is the effect of water withdrawal on the temperature of mountain streams. A case study on this issue was conducted in Val Blenio (TI) on the River Brenno and its tributaries.

In streams, the water temperature is a key parameter for organisms as well as for various chemical and physical processes. Diversion of water for electricity production has a significant impact on water temperature below the diversion point. Low residual flows translate into low water levels and high residence times, which causes the water temperature to be much higher than it would be under natural flow conditions, especially during the summer months. How can the temperature increase be quantified? This is an important question, since increased residual flows reduce energy production and are costly for the operator of a hydroelectric plant. Continuous measurements of the water temperature under all flow regimes and meteorological conditions are normally not practical. It is simpler and cheaper to use energy balance models that are able to predict water temperature as a function of flow and meteorological conditions. Since all relevant energy flows are relatively well known, the models can be very detailed. Typical parameters included in the models are solar radiation, heat radi-

ation of clouds and the water, heat produced by friction, and heat exchange with sediments [3].
Such an energy balance model was calibrated by recording detailed data on meteorological conditions, run-off volume and stream temperature for the Brenno. The water temperature was modeled as a function of the flow regime on a 20-kilometer stretch between Olivone and Biasca, which is likely to show the largest effect of changes in run-off volume. Results: at midday on a hot summer day, the withdrawal of typical water volumes would cause the Brenno to be as much as 4 °C warmer than it would be naturally (Fig. 1), while a reduction in water withdrawal by 10% would reduce the temperature increase to only 3 °C.

Application of a Bayesian Network: A Bayesian network was used to describe the effects of water quality on fish and human health in the estuary of the Neuse, North Carolina, USA [4]. The starting point for the modeling was a series of interviews with representatives of the affected interest groups, asking them to define the characteristics of the river most important to them. These characteristics, together with proposed remedies, were combined to create a qualitative Bayesian network (Fig. 2). The model was then used to quantify the probability of certain events (e.g., algal blooms, fish kills) as a function of improved water quality (e.g., reduced nitrogen or phosphorus input). However, final results for this last step are not yet available for this study. Figure 3 uses preliminary calculations to show the type of results that can be expected. In addition to calculating probable effects of remedial action, Bayesian networks are also well suited to reveal the mechanism within a system.

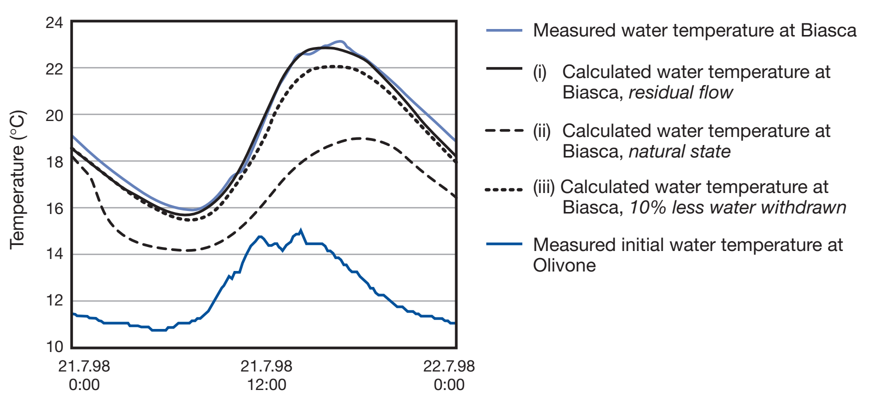

Fig. 1: Measured and calculated water temperature of the Brenno in Val Blenio on a summer day, considering three different scenarios (uncertainties are not indicated).
The three scenarios are (i) actual water withdrawal for hydroelectric power generation (corresponds to measured values), (ii) hypothetical natural state without hydroelectric power plants, and (iii) hypothetical situation with increased residual flow (current amount of water withdrawn reduced by 10%).

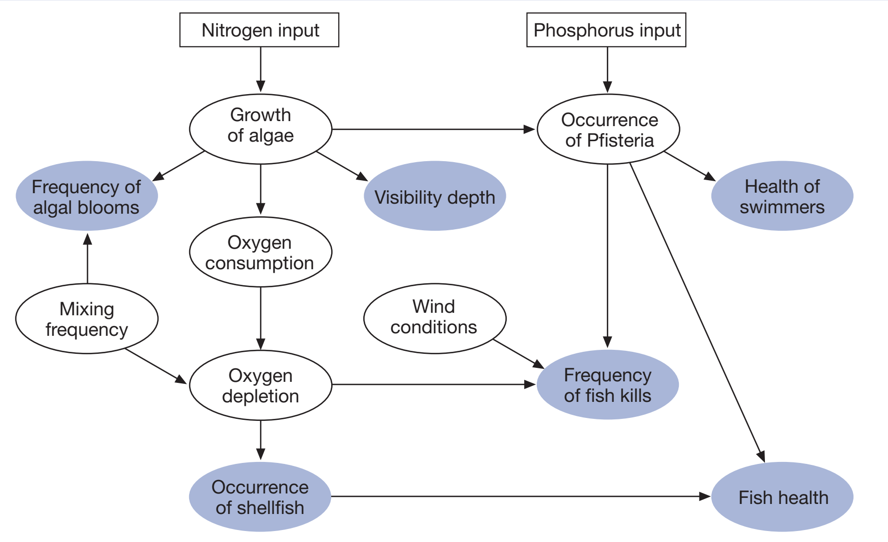

Fig. 2: Bayesian network for assessing the effect of water quality (pollution by nitrogen and phosphorus input) on fish and human health in the estuary of the Neuse River, North Carolina, USA [4].

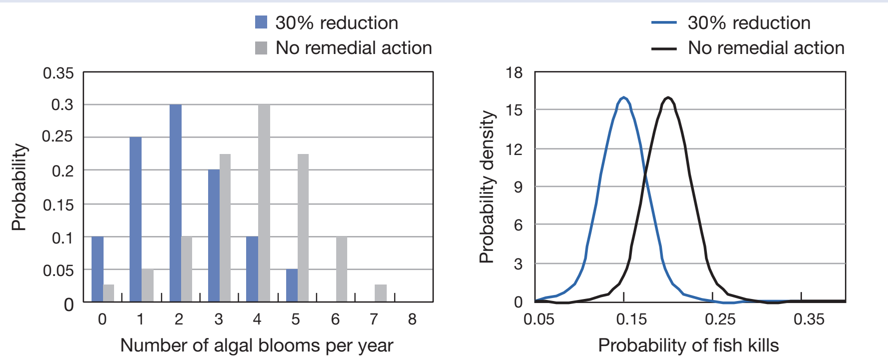

Fig. 3: Preliminary results regarding the effect of a 30% reduction of the nitrogen input on the frequency of algal blooms (left) and the probability of fish kills (right). Results were calculated using the Bayesian network shown in figure 2 [4].

Models for the Optimization of Remedial Action

The use of predictive models to calculate the effects caused by certain remedial action scenarios is often a key step in the decision-making process. Before we can base the actual decision on a model calculation, however, we need to formally define the target condition, to assign values to the various effects, and to develop a cost model for the various action scenarios. This is why optimization models usually combine a predictive, an assessment and a cost model into one unit. Such a combined model allows us to minimize costs and use financial resources in the most efficient way. Another benefit of such models is that the values assigned to certain effects are explicitly stated, which enhances the transparency of the decision-making process. Full optimiza-

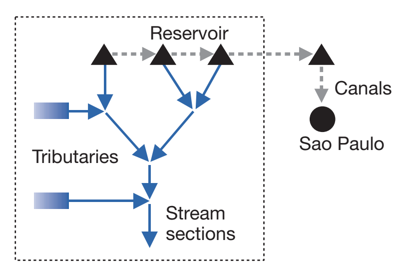

Fig. 4: Schematic representation of the Piracicaba River system (below the reservoirs) that was used in the calculation of water volume and quality [5].

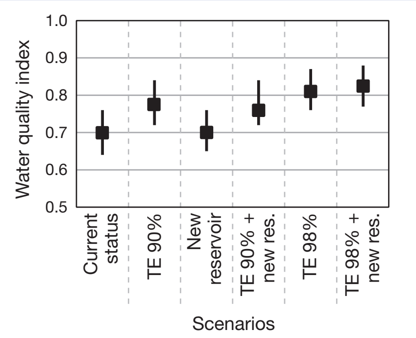

Fig. 5: Calculated water quality index (see text) for current status and for five remedial action scenarios. Associated uncertainties are also indicated. The five scenarios represent different combinations of two different options, namely improved efficiency of wastewater treatment plants (TE = treatment efficiency) and the construction of a new reservoir accompanied by optimized operation of existing reservoirs [5].

tion calculations are mainly performed on "River Basin Management Projects" involving whole river systems.

The Optimization Model in Action

An optimization model was used to evaluate remedial action for the Piracicaba River near Sao Paulo, Brazil, which is heavily impacted by wastewater [5]. Water from the river is used by several cities and in agriculture (Fig. 4). Various options for improvements are under discussion:

- wastewater treatment plants with varying levels of cleaning efficiency,
- run-off regulation by additional reservoirs,
- the combination of both options.

Water quality was evaluated by calculating dissolved oxygen, biologically degradable material, total nitrogen, total phosphorus, and total coliforms. Each of the five parameters received a score depending on the concentration value; the average of all five scores yielded the water quality index. The uncertainty of the overall assessment was calculated based on the uncertainty of the individual parameters. Figure 5 shows the water quality index for the river's current status along with five different scenarios. The scenario favored by this study involves improvements in wastewater treatment throughout the watershed, as well as the construction of a new reservoir, which would guarantee higher flow volumes in the Piracicaba, particularly during the critical summer months. This would significantly improve water quality throughout the watershed and ensure the future of the Sao Paulo water supply.

Potential Future Developments

The example described above demonstrates how a model calculation that employs a simple scoring system can produce an integrated assessment. Over the last few years, additional aspects have been built into these kinds of models [6]:

- multi-criteria analysis for different parameters (instead of simple averaging of indices as described above),
- expanded consideration of uncertainties in the formulation of models (not just in model parameters) and expression of uncertainty as a function of time in long-range predictions,
- determination of the probability for exceeding parameter limits or the maximum number of incidents when limits are exceeded,
- incorporation of more complicated management scenarios, e.g., the dependence of emissions on stream flow conditions.

The use of these models in integrated stream management will be greatly enhanced by these improvements.

Conclusions

Models are indispensable tools in assessing the effect of management methods on stream quality. For classic water quality parameters, we have detailed predictive models. Complicated systems are better described by Bayesian networks, which are capable of incorporating expert judgment into a quantifiable structure. In both cases, it is important that uncertainties associated with the model predictions are calculated and taken into account in the decision-making process. Optimization models go beyond merely predicting effects by assigning a quantifiable value to these effects and by estimating associated costs. These models contribute significantly to the efficient use of financial resources. As an added benefit, the explicit formulation and valuation of the benefits makes the decision-making process more transparent. The full power of such optimization models is most apparent when they are applied to entire stream systems.

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Peter Reichert, physicist, leader of the research area "System Analysis, Integrated Assessment and Modeling (SIAM)" at EAWAG and lecturer in "Systems Analysis" at ETH Zurich. He is working on problems relating to modeling and systems analysis.

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From Stream Reach to Catchment

The Ecological Relevance of Spatial and Temporal Heterogeneity

The understanding of natural processes in rivers is based on the conceptual foundations that have been developed in the second half of the 20th century. Natural streams are ecosystems characterized by high spatio-temporal heterogeneity, which is of crucial importance for the diversity of species and processes. Stream systems are hierarchically organized and as important landscape elements tightly linked to the adjacent terrestrial ecosystems. A successful integrated stream assessment requires consideration of the multifaceted nature of stream ecosystems at different scales.

There are presumably few ecosystems that have been more affected by human activities than streams [1]. In Europe, North America, and in many other parts of the world, streams were dramatically altered before stream ecology was established as a science that provides understanding of natural processes in rivers [2]. It has been recognized that high spatio-temporal heterogeneity and tight linkage with the terrestrial environment are the essential characteristics of natural streams. Such knowledge must be considered to bring the substantially altered streams closer to their natural state and to implement integrated stream management practices in general.

The Four Dimensions of Streams [3]

The **longitudinal dimension** is an obvious stream characteristic. A natural stream can be understood as a continuum, where all stream sections are longitudinally linked and abiotic parameters such as temperature, light, slope, flow volume, stream power and size of stream bed sediments change from headwaters to the sea. This results in a longitudinal gradient of habitat conditions and resource availability and is finally reflected by changes in the structure of aquatic communities along the river continuum [4].

The downstream transport of solid and dissolved matter stands for the longitudinal, mainly unidirectional link. Organisms like fish may also move upstream but many stream dwellers such as insect larvae are passively transported downstream. There are, however, mechanisms compensating for this continuous "flushing loss"; some species migrate upstream against the current while other compensate for drifting by flying upstream before oviposition (compensation flight). Longitudinal and lateral influences are superimposed. Compared to lakes or forest ecosystems, streams receive far more particulate and dissolved material from adjacent terrestrial ecosystems. Streams are intimately linked to the adjacent land; in forested catchments, the energy balance is dominated by leaf litter input. This material is partly processed and transported downstream. Primary production by algae plays a only minor role since very little light penetrates through the tree canopy and reaches the surface of the stream bed. As the stream widens and more light becomes available, primary production becomes more important. In large rivers, the direct input of leaf litter becomes negligible in the overall energy balance.

The **lateral dimension** of streams becomes evident in areas where a stream is not laterally constrained by topography (Fig. 1). Lateral connectivity is pronounced in natural river-floodplain systems being continuously reshaped by floods and offering a rich diversity of habitats for terrestrial, amphibian and aquatic organisms. The transition zone between terrestrial and aquatic habitats is particularly important. Trees and shrubs along the stream bank provide energy for aquatic and terrestrial organisms. Large woody debris from the riparian zone may create high spatial heterogeneity, particularly in small streams.

The **vertical dimension** of streams and rivers is less obvious. The hyporheic zone is the transition zone between surface water and groundwater and provides habitats and refugia for animals and microorganisms. Microbial biofilms play an important role in the nutrient and energy balance of streams. Hyporheic organisms, for example, nitrify or decompose organic material [5]. As in floodplains, floods may reshape the hyporheic zone. In the absence of such events, fine sediments fill small cavities and void spaces and the hyporheic zone becomes isolated from the surface water.

The **temporal dimension** becomes manifest through the permanent change of the location of gravel bars, islands and channels within a river corridor. Flow is the dominant driver of temporal variation of rivers. Floods entrain, transport and deposit sediment, thereby destroying some habitats while creating new ones. Floods are the most common natural disturbances in streams. Frequently occurring floods reduce species diversity and favor species with short life cycles and a high adaptation potential. If floods are rare or lacking, poorly competing species become extinct. Species diversity is expected to be at a maximum if flood frequency is intermediate [6]. Water diversions for irrigation or hydropower production affect the natural flow and disturbance regime. In river sections with residual flow, floods can be very rare or largely absent. In channelized streams, water transmission is accelerated and the attenuation of flood peaks reduced. This increases disturbance frequency compared to the pre-channelized situation.

The Ecological Significance of Spatial and Temporal Heterogeneity

A natural river corridor is stable over long periods of time with respect to the general pattern of landscape elements (Fig. 1). The individual elements, however, are constantly changing: stream channels are shifting back and forth, gravel bars migrate, islands disappear and new islands are formed. This dynamic spatio-temporal heterogeneity is a prerequisite for high species diversity, and thus, has a high ecological value. Preservation of high species diversity in river corridors requires a natural flow regime and sufficient lateral space, which also includes an intact riparian zone (see article of H.P. Willi, p. 26). Stream or river assessment should therefore also include (eco-)morphological and hydrological aspects (see article of A. Peter, p. 7).

The Hierarchical Structure of Streams

Describing streams as hierarchically organized systems provides a useful framework for integrated stream assessment [7]. At the top level is the *stream system,* which includes all surface waters of a catchment, and which is composed of individual *stream segments.* Segments are portions of a stream characterized by relatively uniform geology and geomorphology. Stream segments, in turn, are made up of *stream reaches;* reaches are geomorphic units delimited by changes in slope, stream bank vegetation, or width of the valley floor. *Pool/riffle* systems are sub-units within stream reaches; a pool is an area within the stream, where flow velocity is low and water depth relatively large. High flow velocities and shallow water depths characterize riffles. The lowest hierarchical level includes the extremely diverse *microhabitats* as, for example, small deposits of sand or fine gravel, individual rocks, water plants, or dead wood.

The systems evolve within the boundaries set by the higher systems within the hierarchy. Slope, sediment load and flow regime determine the structure and the temporal variability of a stream section [8]. The flow regime, and to some extent the sediment load, are determined by conditions on the next higher level of the catchment. Processes that have significant effects at low hierarchical levels have a minor impact at superior levels. The typical average lifetime of the systems ranges from weeks to several hundred thousands of years or even millions of years. A microhabitat, such as a sand deposit in a pool, is reshaped several times per year. Pool/riffle sequences may survive for months or years, flood plains are renewed every 10 to 100 years, and the life span of the entire stream system is measured at geological time scales.

The hierarchical level, at which river management tries to mitigate former anthropogenic impacts, determines how significant the effects will be and how fast the system will respond. The widening of the stream bed in a short reach of a stream may only have a local effect, while the removal of a sill at the end of a catchment may influence the fish population in the entire catchment [9].


Dave Arscott, EAWAG

Fig. 1: Stream bed of the Tagliamento (Italy).

Landscape Perspective

Streams are important elements of the landscape and intimately linked with adjacent ecosystems. The large-scale patterns of vegetation and land use within a catchment determine instream condition [10]. These parameters can override the local riparian influence. A study in Michigan demonstrated that the stream condition in different stream segments – as judged by the structure of fish populations – did not correlate with stream bank vegetation within the same stream segment. However, a significant correlation with stream bank vegetation and land use patterns in upstream sections could be shown [11]. These findings exemplify the fact that the hierarchically higher system level can override local effects and also demonstrate the limitations of ecomorphological methods.

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Integrated Water Management in River Basin Districts

Last year, the European Union agreed on a Water Framework Directive that outlines a general concept for stream protection in Europe. This directive creates the basis for unified policies on the integrated protection of streams and ground water. Each member state is required to revise its water management system.

The "Directive establishing a framework for Community action in the field of water policy" went into effect in December 2000. This "Water Framework Directive" (WFD) coordinates and unifies the numerous directives and policies on stream and ground-water protection that are currently in force in the member states of the European Union (EU). The main objective of the Directive is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and ground water. Specific goals are to:

- prevent further deterioration of aquatic ecosystems,
- promote sustainable water use,
- protect and enhance the status of aquatic ecosystems,
- mitigate the effects of floods and droughts.

According to the WFD, the member states assign all streams to a particular river basin district and determine the appropriate competent authority. For each river basin district, the competent authorities will then survey the characteristics, investigate the environmental impact of human activities, analyze economic aspects of water use, and establish a register of protected areas. The result of this effort will be a program of measures and an integrated water management plan. All remedial actions should be realized at the latest in 2015.

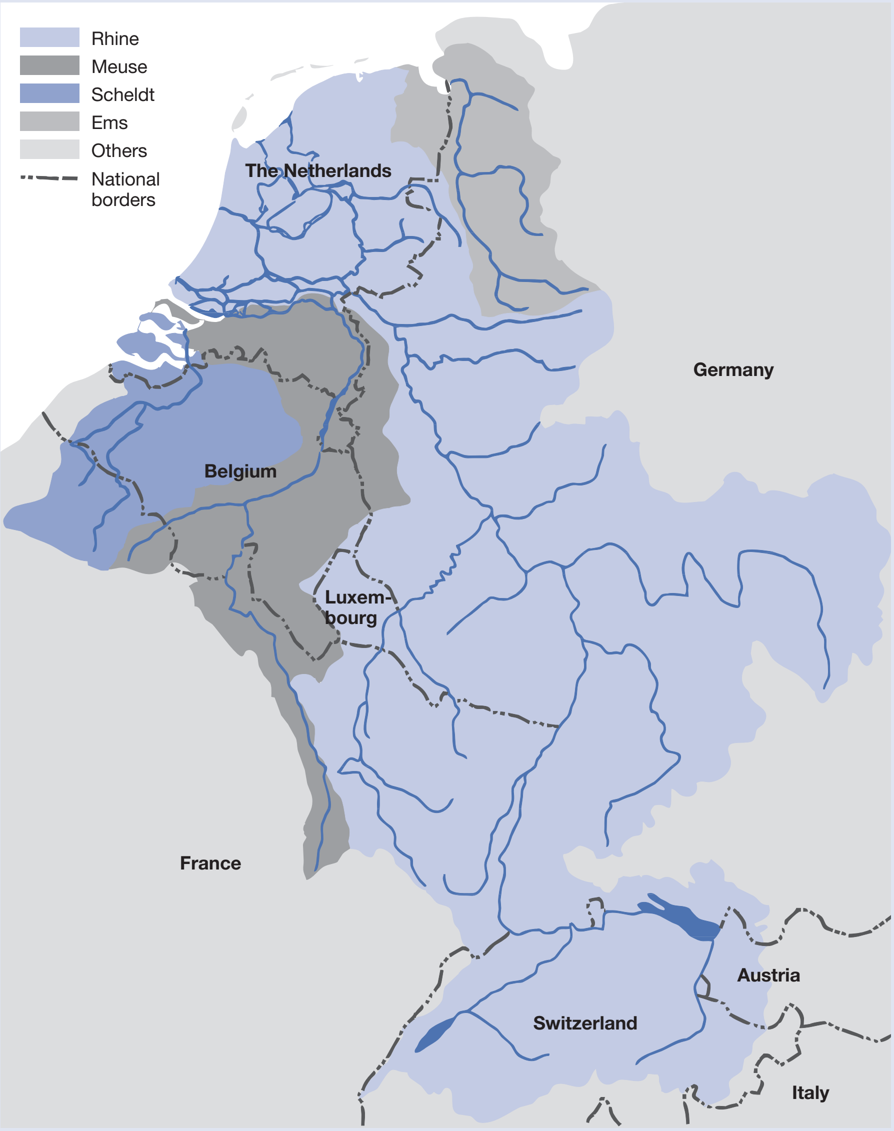

Fig. 1: Watersheds within the Netherlands.

The History of Water Management in the Netherlands

The Netherlands is situated on the river deltas of the Scheldt, Meuse, Rhine and Ems (Fig. 1). Two-thirds of the land area is a potential flood area, being threatened either by the sea or by rivers.

Water management in the Netherlands has a long-standing tradition going back to the 11th Century, when a few communities first came together to manage their water systems. The first official water boards were formed in the 13th Century. They were democratically organized interest groups consisting of elected representatives from the local farming communities. They remained independent of the national political system for a long time; i.e., they operated outside of the three-tiered (national, provincial, and municipal) constitutional Dutch government. Till the18th Century, approximately 3000 district water boards had been formed. Each district had its own water management plan and was responsible for its own flood protection. A centralized, national organization became necessary in order to coordinate all the various individual efforts and to be able to practice water management on a larger scale. The state water authority, "Rijkswaterstaat", was therefore instituted in 1798. The State Water Authority (under the Ministry of Transport, Public Works and Water Management) is still responsible for integrated water management and flood protection along larger streams and lakes, estuaries, and along the North Sea.

Water Management in the Netherlands Today

Today, some 56 relatively autonomous water boards still exist in the Netherlands. They are responsible for the regional management of water systems according to the policies of their province. They regulate, for example, management goals with respect to water quantity and quality. Overall, the current situation of water management in the Netherlands is still very complex involving at least three different ministries, 12 regions, approximately 600 towns and communities, in addition to the 56 water boards. This situation is not yet in accordance with the requirements of the WFD. France, for example, has only six water management districts, while its land area is 13 times larger than the Netherlands. Figure 2 shows a possible reorganization of the districts in the Netherlands that would satisfy WFD requirements.

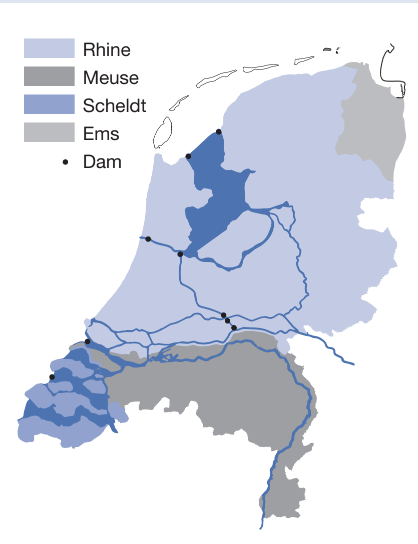

Fig. 2: Proposed boundaries for water management districts in the Netherlands.

"Integrated water management" has been at the heart of water legislation and ordinances in the Netherlands since 1989. It considers quantitative, qualitative and ecological aspects of water management. The goal is to find a balance between maintaining the ecology of a stream system while also utilizing the stream for various other purposes. Undoubtedly, the Netherlands will benefit from its past experience in integrated water management when implementing the changes required by the WFD; however, integrated water management as such is not the basis for future water management according to the goals of the WFD.

Implementation of the WFD

Each of the EU member states is responsible for the implementation of the WFD within its boundaries. In order to facilitate international coordination of the management plans, the WFD allows for the subdivision of watersheds into smaller "working areas". In the case of the River Rhine, for example, certain sections could be designated as "sub-watersheds" according to natural junctions, i.e., at the outflow of a lake or the confluence of two major tributaries. In the Netherlands, a river basin district not only encompasses streams and lakes, but also the intertidal zone; that is, the zone between river and sea where the salinity is clearly above that for fresh water but below average for the sea.

The wording of the WFD is rather vague in a number of instances, meaning that many details of implementation have yet to be worked out. A large number of working groups, in close cooperation with the EU, will have to deal with a multitude of topics: how to pay for the preparation of drinking water, how to deal with severely altered water bodies, assessing the condition of surface waters, and many more. The national governments are responsible for regular progress reports to the EU. Based on the positive experience within the International Commission for the Protection of the Rhine (ICPR), the Netherlands advocates a single, comprehensive management plan for any river system that crosses national boundaries. This will insure that ecological goals and corresponding management measures are coordinated and consistent for the whole river system. Some parts of the management plan will of course have to be dealt with on a national level.

The International Commission for the Protection of the Rhine (ICPR)

Contract partners of the ICPR are Switzerland, France, Luxembourg, Germany, the Netherlands and the European Union. The working area of the ICPR extends from the point where the Rhine leaves Lake Constance to the North Sea. During preparation of the WFD, the EU often praised the work of the ICPR as an example of international cooperation and coordination of water management practices. Since the requirements imposed by the WFD apply to the entire watershed however, Italy, Austria, Liechtenstein, and Belgium must become involved as well.

The new organization for the international coordination of water management along the Rhine was worked out in frequent meetings of the "water directors" of the individual countries. Additionally, the EU has established a preparatory committee, which reports to the water management authorities of the individual countries. Unfortunately, the "water directors" have, at least until now, not fully included the ICPR in the coordination and preparation of the water management plan for the Rhine river system.

Coordinated Action

The WFD adopted by the EU demands the rehabilitation and coordinated management of streams, lakes, ground water, estuaries and near-shore waters, but only provides very rough guidelines as to how to meet these demands. Fulfilling the requirements of the WFD represents an enormous challenge for all of the member states and will take many years of hard work and negotiation. Some of the major tasks will be to compile a list of definitions, to develop a common set of tools, and to establish coordination and management structures.

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Water Protection Using Market Tools

The EAWAG Project "Green Electricity"

The goal of the project "Green Electricity" was to define an ecological label for the identification and promotion of hydropower produced in an environmentally friendly way. Power plants receiving such a label would need to satisfy a set of basic standards with respect to stream ecology and in addition, invest part of their revenues towards the protection, improvement and/or rehabilitation of the catchments they use.

Approximately 60% of Switzerland's energy production comes from hydroelectric power plants. With a development degree of some 80%, practically all major and many smaller streams in the country are utilized for hydropower production.

Hydroelectric Power and Stream Protection – A Contradiction?

On a global scale, hydroelectric power is environmentally desirable since it is both renewable and emissions-free. Locally, however, hydroelectric power production often results in massive negative impacts on streams. In light of the liberalization of the energy market, it is questionable whether or not an ecolabel can make a positive contribution to stream protection. But, assuming that environmentally conscious customers are willing to pay a higher price for electricity, which in turn improves streams, the opening of the electricity market should actually benefit both the environment and businesses. Based on experiences in other countries, however, this will require a credible and independent certification of the producer; such a certification must guarantee that both the global and local environmental impacts are as small as possible.

Experiences with International Electricity Labels

Since the appearance of the first "green" electricity offerings on international markets in the early 1990s, the number of companies offering this type of product, as well as the number of such, have sky-rocketed. There are over 300 "green" pricing schedules worldwide, with additional product combinations also available; however, only seven independent "Green Electricity Certificates" are currently in existence [1]. All of these certificates deal primarily with renewable energy sources – sun, wind and biomass. Until recently, no generally accepted certification procedure for environmentally friendly hydroelectricity plants was available. In addition, existing certification procedures consider local environmental impacts only minimally or not at all. EAWAG was determined to close this gap with the project "Green Electricity". In the past three years, an interdisciplinary team has developed a procedure and specific criteria, which consider both impacts on stream ecology and economic aspects of hydroelectric energy generation in terms of integrated water management [2].

Ecological Credibility and Practical Realization

According to experiences made so far, a successful green electricity product must fulfill two conditions:

1. The certification criteria must be credible from a stream ecology point of view.
2. The criteria have to be effectively applicable.

In the context of hydroelectricity, this means that the procedure has to consider global environmental factors (e.g., low CO_2 emissions) as well as the ecological function of local stream systems (e.g., the connectivity of the stream, a dynamic drainage regime, the natural diversity of species). These ecological considerations have to be balanced with the managerial aspects of the power plants. The practical realization of such a procedure is only possible if the business management aspects, the social framework, and the legal, financial and political situations are taken into account in the overall management approach.

The Environment-Management-Matrix

EAWAG has developed the so-called "Environment-Management-Matrix" in order to diffuse the conflict between protection and utilization and to achieve credibility as well as pragmatic realization of proposed concepts (Fig. 1). The matrix is based on the ecological requirements of integrated stream protection and management, but

Conditions for Green Electricity Certification

According to the procedure developed by EAWAG, hydroelectric power plants can be certified as "Green Electricity Power Plants" if they demonstrate environmentally sensitive operation and installation. Two conditions have to be met voluntarily by the power plant before the certification process can be initiated:

1. The power plant meets the *"Basic Green Electricity Requirements",* an ecological standard that is measured against requirements for new operating permits in Switzerland. The standard is based on independent scientific criteria and is the same for all hydroelectric power plants.

2. Beyond that, the power plant has to contribute a fixed percentage of its revenue from the sale of green electricity for the rehabilitation, protection or amelioration of the catchments the plant is utilizing. These so-called *"green electricity contributions"* guarantee that some of the environmental improvements are made on the local level. It is intentional that this requirement is separate from the basic requirements. The explicit link between the sanitation of the local ecological system and the profit made from green electricity can be used to promote and communicate such improvements.

Certification will only be granted if both these conditions are met.

Environmental fields \ Management fields	Minimum flow	Hydro-peaking	Reservoir	Bed load	Plant structuring
Hydrologic character					
Connectivity within the river system					
Solid material and morphology					
Landscape and biotopes					
Biocoenoses					

For each field:
1. Goals
2. Criteria
3. Literature

Fig. 1: The Environment-Management-Matrix.

also takes into consideration the realities of renewing the operating permit for hydro-electric power plants. The matrix provides a scheme for the entire process and focuses on five environmental criteria as well as five management criteria (Fig. 1). The environmental criteria were selected to insure the ecological function of the stream; the management criteria are primarily related to the operational and structural aspects of hydro-electric power plants.

The procedure proposed by EAWAG [2] defines basic requirements for each of the 25 fields of the matrix in order to satisfy the designation of environmentally friendly electricity production. Beyond that, the procedure provides criteria and methods for meeting these requirements. It also contains an extensive bibliography on quality assurance, including comments from the project team.

The Two-Step Management Concept

The EAWAG concept proposes a two-step approach to the certification procedure. In the first step, the power plant must demonstrate that it fulfills the basic requirements of green electricity production, the stringency of which are consistent with the standards for Swiss relicencing rules taking into account the revised stream protection law. The power plant must achieve this first step on its own[1]. Once these basic requirements have been met, the EAWAG procedure provides for the second step; namely, the implementation of specific remediation options in the affected catchment. Part of the revenue from higher green electricity prices will be funneled into so-called “eco-investments” (currently 0.01 CHF per kWh). These funds must be used for local improvements to the stream system. Which improvements will be realized would be decided in negotiations that include local interest groups. This procedure should result in remedial action plans that are ecologically meaningful and widely accepted, without being bogged down in conflict. Before the green electricity label is actually awarded, an independent entity would have to conclude that the procedure was followed correctly and that the required improvements were implemented.

Practical Application in the Case of Minimum Flow Requirements

The goal of green electricity criteria with regard to minimum flow is to guarantee flow regimes that are appropriate for the natural character of the stream. To determine “appropriate” minimum flow volumes, the EAWAG procedure proposes to use criteria that are customized to the stream system and based on the habitat concept, such as the ones that have already become an international standard [3]. These criteria may be developed with the use of computer-based models, describing water temperature or habitat condition, as was demonstrated in the case study of the green electricity project conducted on the Brenno (Canton Ticino, Fig. 2). These models can be either developed from the ground up (see article of W. Meier, p. 13) or adapted to a specific stream [4, 5]. Using such approaches, it is possible to simulate the habitat diversity for a range of organisms, such as fish or macroinvertebrates, within a specific stream section under varying residual water conditions. The model juxtaposes these results to the annual electricity production of the power plant and the basic requirements established for “minimum flow” in the management area (Fig. 3). This will allow for optimization of ecological considerations as well as aspects of the business operation.

Armin Peter, EAWAG

Fig. 2: The Luzzone storage reservoir in Canton Ticino. Location of the EAWAG case study “ Green Electricity”.

[1] Although “green electricity” certification meets the ecological standards of new operating permits, requirement of new operating permits is de facto not necessary. However, since “green electricity” certification is a voluntary market tool, it may not replace new operating permits.

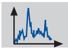
Environmental fields		Management field “Minimum flow”
Hydrologic character		■ dampened, natural flow regime ■ minimal, seasonally adjusted and inflow dependent base flow
Connectivity within the river system		■ interconnection between surface waters, ground water and adjacent land ■ no unnatural isolation of side streams ■ adequate water depth for fish migration
Solid material and morphology		■ preservation of the natural structure of the stream bed ■ coordination with bed load management
Landscape and biotopes		■ preservation of valuable habitats and landscape elements in their original function ■ separate regulations for the preservation of flood plains that are specially listed
Biocoenoses		■ preservation of the natural diversity, particularly with respect to indigenous fish species and rare and endangered communities ■ avoid critical temperature and oxygen conditions and preservation of self-cleaning capacity

Fig. 3: Criteria for the management field “Minimum flow”.

Is Green Electricity Viable in the Real World?

International experience shows that, in the long run, only a credible procedure, i.e., one that reflects the complexity of stream ecosystems, can guarantee the sale of green electricity. With the opening up of the electricity market, the conditions for a shift to green electricity production are very good in Switzerland. By the end of 1999, electricity producers, distributors, environmental organizations and consumer groups had formed an independent “Association for Environmentally Produced Electricity” (VUE, Verein für umweltgerechte Elektrizität). Its leadership is composed of representatives from all of the interest groups. In June 2000, the association announced the Swiss green electricity label “naturemade star” to the public. The certification process employed the EAWAG procedure presented in this article and so should satisfy the need for credibility for a long time to come. To ensure that the certification process is viable in the real world, pilot certifications were also initiated for six Swiss hydroelectric plants. By the Fall of 2000, all six certifications had been successfully completed; the first green electricity certificates based on EAWAG criteria have since been awarded. The city of Zürich, for example, can now sell green electricity produced at the Höngg power plant (Fig. 4), which has been certified according to the EAWAG standard. The EAWAG procedure itself is continuously being adapted and updated according to experiences made during the certification process.

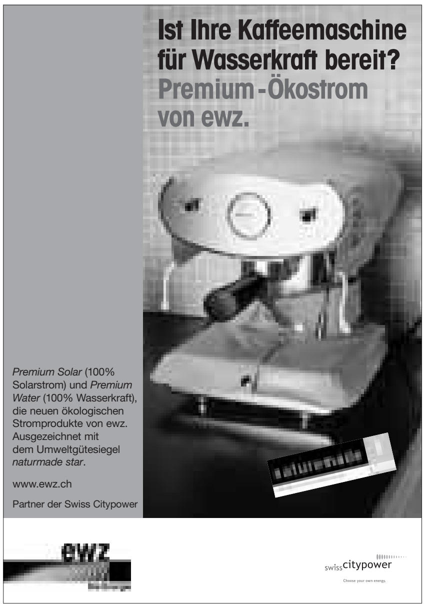


Fig. 4: Advertising campaign by the EWZ (Elektrizitätswerk Zürich) for its first green electricity products after completing the certification process using EAWAG standards.

Conclusions

From the very beginning, the research project “Green Electricity” employed concepts and methods that were geared to integrated water management. This is reflected both in the multitude of evaluation methods employed and the use of computer-based models for the evaluation of various utilization scenarios. In addition, all relevant interest groups within the catchment under consideration are explicitly involved in the certification process. Under these conditions, the market tool green electricity can indeed create a positive and innovative impulse in stream management. It is only because of recent scientific and technical advances that we are able to find ecologically *and* economically optimized solutions in water management. Different options can be compared in an objective manner, taking into account protection as well as utilization requirements. If the market tool green electricity can also be used to mobilize additional financial support, then sustainable water management has an excellent chance of becoming reality. Independent scientific groundwork is as important in achieving this goal as is the openness and willingness to compromise within the political negotiation process. We believe the project “Green Electricity” has created a solid foundation and delineated the path to realize sustainable, environmentally sensible water management.

Christine Bratrich is working at EAWAG as a research scientist since the middle of 1997. She led the working group “Assessment” in the project “Green Electricity” and played an important role in the development and realization of the certification process for hydroelectric power plants.

For additional information:
www.oekostrom.eawag.ch, www.naturemade.org

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Fish – Indicators and Winners

Over the last 10 years, fish yields in Switzerland have dropped dramatically. Investigations on the health of fish have often revealed abnormalities. The project "Network Fish Decline in Switzerland", or "Fishnet" for short, is investigating the causes of the decline and will develop proposals for remedial action over the next few years.

Switzerland's streams are intensively managed. Stream management and stream use is always preceded by an evaluation process, optimizing the management practices. Fish are important in two ways: as a tool for evaluating the health of a stream and as an economic factor.

Managing Streams

Some 6% of Switzerland's population consider themselves to be fishermen. In 1997, approximately 240,000 people between the ages of 15 and 74 picked up their fishing rods at least once. On average, a fisherman spends 3500 Francs per year on his or her hobby. Of the total of 216 Million Francs spent on fishing, 12 Million Francs find their way into the coffers of the cantons from the purchase of fishing permits [1]. Declining fish populations and compromised health of the fish, however, suggest revenue problems in the near future.

Evaluating Streams

Fish are extremely important indicators of stream quality. This is reflected, in part, in the Swiss Modular Concept (see article of A. Peters, p. 7) in which one entire module is dedicated to fish. Evaluation criteria include population sizes, fish health, and species diversity. Disturbances of habitat result in a reduction of diversity. Today, 42 of the original 54 domestic fish species are acutely endangered in Switzerland.

Assessment of population sizes is a major endeavor and requires extensive experience in fisheries. Population data are available only sporadically, although most cantons have information on the numbers of fish that are caught. Information compiled by the SAEFL shows a dramatic decline in these numbers, at least for trout, the most heavily fished species. On average, the decline in Switzerland is 42% over the past 10 years [2].

There are several very recent studies on fish health which have reported significant deviations from the norm. What has made headlines worldwide are reports that hormonally-active chemicals cause abnormal sexual development in fish [3].

The project "Network Fish Decline in Switzerland", brief "Fishnet", was initiated in December 1998 in response to these kinds of problems. The project was conceived by EAWAG and SAEFL, and currently receives additional support from the Swiss Fisheries Association, the cantons and the chemical industry. It is scheduled to operate over a period of 3–5 years. Early recognition of risk factors for fish health, population declines and related impacts on streams are some of the main goals of the project.

What is the project Fishnet trying to accomplish?

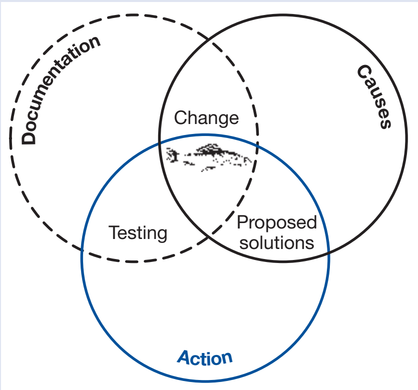

Fig. 1: Goals of the project Fishnet.

The project is targeting three levels (Fig. 1):

- Documentation: Changes in fisheries' yields and populations as well as the development of fish health in Swiss streams and lakes over the last 30 years (comparison between then and now).
- Analysis of causes: Definition of groups of causes and identification of the most important causes for the observed changes.
- Response: Development of options for remedial action and communication tools appropriate for the target audience.

A Comparison to the Debate on Forest Decline

The project Fishnet faces a number of challenges. The general character of the problems is reminiscent of the ones encountered during the debate on forest decline in the 1980s. The following three characteristics are shared by both issues:

1. Both the public and the scientific community had high expectations for the research on forest decline: the causes were expected to be identified very quickly with the formulation of practical solutions shortly thereafter. Fishnet has induced similar expectations. In the case of forest decline, the debate was often emotional and led to controversies that still reverberate today. This created divisions among scientists and between scientists and citizens. We know that public relations are very important on this type of topic, but one has to proceed with great care; all affected groups should be included in the process, and conflicts should be acknowledged and communicated to all participants as soon as possible.

2. Both problems are similar in that the systems are extremely complex and that there is spatial and temporal separation of the

causes and effects. Clearly identifying causes is, therefore, rather difficult. In the case of forest decline, the discussion focused on the effects of atmospheric pollution fairly early on. Fishnet is intentionally trying to remain open to the discussion of as many potential causes as possible. When designing such projects, one has to keep in mind the following statement: "We find cause-effect relationships where we invest money in research; we find no such relationships where we do not invest money" (P. Brang, Swiss Federal Research Institute WSL, expert discussion Fishnet, 12 April 2000). Coordination of the research effort and synthesis of the results into generally understandable conclusions are essential. Research on forest decline has taught us that the effect of pollution on trees can vary with location. We assume that this also applies to problems related to fisheries and fully expect that regional conditions are an important factor in determining fish declines.

3. Because of the high level of complexity, the prediction of trends is very difficult, both for a scenario without any change in current practices and for one with human intervention and remedial action. It is extremely difficult to convey this type of dilemma to the public; caution or restraint are often misinterpreted. Measures taken to stop forest decline turned out to be successful (e.g., the reduction of atmospheric pollutants by requiring catalysts on motor vehicles), but their scientific justification was considered questionable.

How Will Fishnet Proceed?

Fishnet sees itself not only as a network of activities, research and ideas, but also as a network of people: those causing the problems, those bearing the consequences, and those who are involved in the research. This network structure allows us to recognize gaps in our knowledge more readily and work towards our goals more methodically. Double-tracks can be avoided, while synergisms can be recognized and fostered early on. Standardized methods will be essential in assuring comparability of results. Relevant questions will be investigated in sub-projects. The sub-projects will report to the project leader who, in turn, will distribute results from the overall project to the individual sub-projects. This parallel attack on several fronts will allow us to broaden and deepen our approach without sacrificing time.

In regular meetings of the sub-project leaders, results will be discussed and methodologies updated. New or modified research directions will be considered. It will be particularly important to maintain a complete collection of documents from all of the sub-projects so that anyone within the project can efficiently access information long before it is published.

What Will Fishnet Do?

Twelve working hypotheses form the core of the project. Hypothesis 1, an "integrative" hypothesis, is based on the assumption that there are multiple effects, any or all of which can vary over time and with habitat, fish species, and sex. The various factors or effects may be additive, cancel each other out, or even enhance one another. Hypotheses 2–5 deal with effects caused by pollutants: disruption of the reproductive cycle, increased mortality of young fish, malfunc-

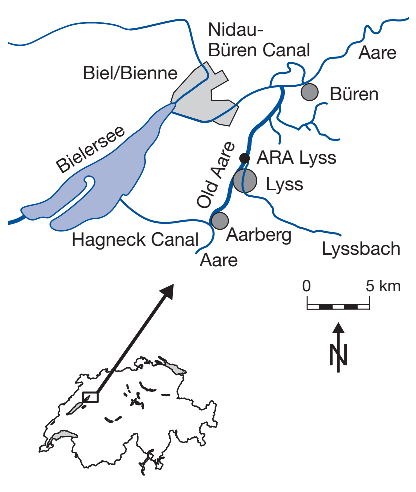

Fig. 2: The course of the Old Aare, Canton Berne [4].

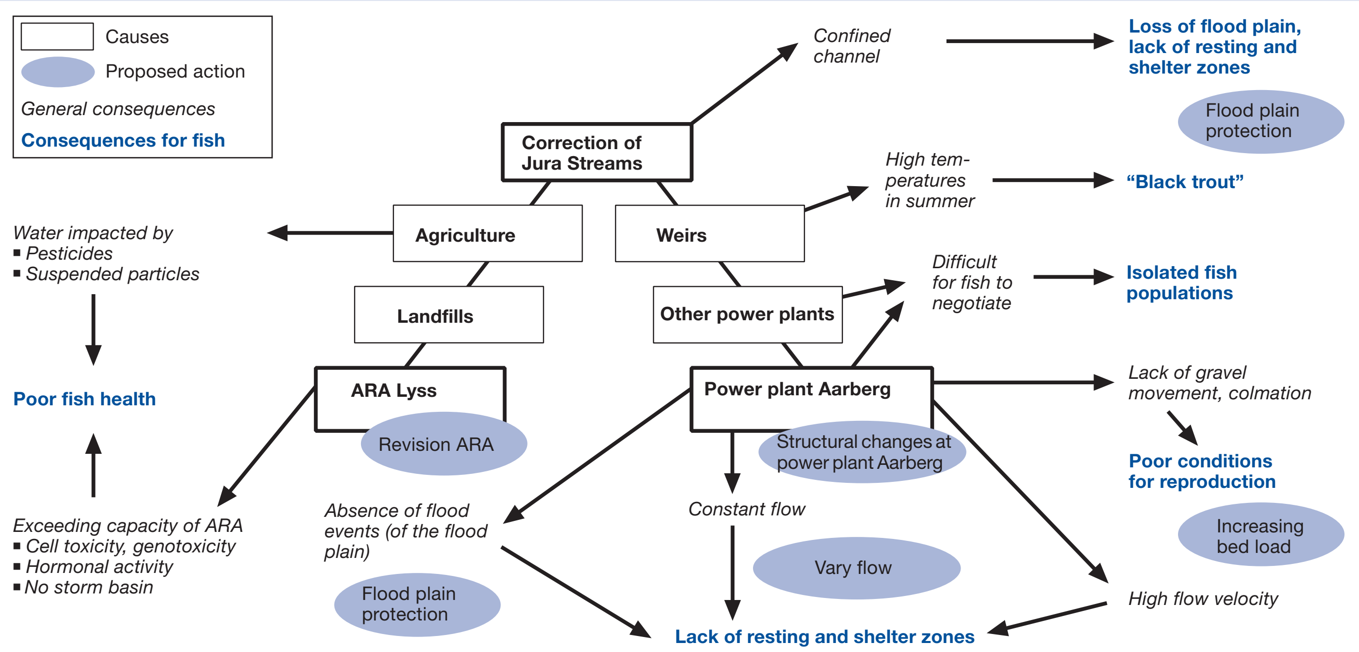

Fig. 3: Analysis of the situation in the Old Aare.

tions in organs, or impacts on the immune system after infestation with parasites or diseases. Hypotheses 6–10 focus on various other possible causes: inadequate spatial variability within a habitat, impact on reproduction by colmation (increased concentration of suspended particles in the pore volumes of the stream bed), decreased food supplies, introduction of fish species inappropriate for a particular habitat, increased utilization by fishermen, and imbalance between fishing pressure, natural predation, and population growth. Hypotheses 11 and 12 relate specifically to trout streams where climatic changes can alter the temperature and flow regimes. The hypotheses lead to primary research questions which are then assigned to sub-projects. Currently, 25 sub-projects are in progress, and there is informal contact with an additional 12 projects. Fishnet also keeps in close contact with projects and institutions abroad.

A Synthesis Project: The Old Aare in Canton Berne

Repeated fish kills and the occurrence of visible fish diseases has led to a massive fish decline in the Old Aare in Canton Berne. In response, the Council of the Canton Berne has ordered an extensive scientific investigation (Fig. 2), concentrating on fish health and population sizes, water chemistry, water pollution problems, as well as hydrological and hydrobiological factors.

Causes: Three historical events have played a key role in shaping today's appearance of the Old Aare and have led to the problems we observe today. The first "Correction of Jura Streams" (1868–1891) diverted the Aare into Bielersee via the Hagneck Canal. The formerly natural stream bed of the Aare between Aarberg and Meienried was transformed into a straight, artificial canal, which is since then called "Old Aare" (Fig. 2). The hydroelectric power plant Aarberg has been in operation since 1967. It regulates the flow in the Old Aare at a fixed volume of 3.5 m^3/s (since 1973). In 1968, the wastewater treatment plant (ARA) Lyss began operations, using the Old Aare as its receiving body.

Consequences: Consequences for the Old Aare ecosystem are all closely linked to one another (Fig. 3). Due to the constant flow volume and its canal-like structure, the Old Aare flows evenly and relatively rapidly. This results in a severe deficit of structure and habitat diversity for the stream fauna. Resting zones and areas of standing water are absent entirely, which has an impact on breeding and young fish in particular. Flow control structures and the power plant Aarberg obstruct fish migration. The presence of the power plant also disrupts the natural transport of gravel (bed load), while the combination of a high concentration of suspended particles and a constant flow rate leads to severe colmation of the river bed. Natural reproduction of species laying their eggs in gravelly river bottoms is severely impacted. The constant flow regime and significant colmatation suppress dynamic processes typical of natural flood plains (e.g., periodic flooding). The forest in the flood plain of the Old Aare has nationally been designated as "important", but is in serious danger of drying out and losing its species distribution and structure. Water quality is deteriorated even further due to the discharge of effluent from the ARA Lyss into the already impacted Old Aare. Frothing, increased turbidity, odors, oxygen depletion and the growth of fungi originating from the wastewater can often be observed. Below the ARA Lyss, the Old Aare can be considered moderately to heavily impacted. The most problematic contaminants in the effluent from the ARA Lyss are nitrogen compounds, organic substances, and bacterial counts, which can be present in precariously high concentrations. Toxicity tests indicate problems with cell- and genotoxicity as well as endocrine activity. Additionally, the Old Aare is impacted by seepage from waste disposal sites and by diffuse discharges from agriculture. A stress factor, particularly important for trout, is the high water temperature (>21 °C) observed during the summer months. These unnaturally high temperatures are caused by the numerous dammed sections of the Old Aare (Wohlensee and dams at Niederried and near Aarberg) and the discharge of cooling water from the nuclear power plant at Mühleberg. The occurrence of "black trout" (the cause of the symptoms is as yet unknown) suggests that the high temperatures may have at least an "inducing potential" for this disease.

Remedial action: Of the 12 hypotheses that have been formulated, five apply to the Old Aare: a combination of a number of small effects (in part due to input of suspended particles and chemical pollution), habitat deficiencies, including obstacles to migration, disturbance of reproductive cycles, lack of offspring and increased water temperatures. Several measures will be needed to restore health in the fish populations and to increase diversity and numbers to desired levels (Fig. 3). Improvements in the morphology of the river bed are already planned as required by regulations on the protection of flood plains. Structural changes at the hydroelectric power plant Aarberg, allowing fish migration and creating a dynamic flow regime, are in the planning stages, in part as a result of the project "Green Electricity". Water quality will be improved by revisions to the ARA Lyss, which are also currently in progress.

Outlook: The project Fishnet was designed according to the requirements for integrated stream management as described in the article of U. Bundi and B. Truffer (p. 3). The case of the Old Aare is an example of a "synthesis project". It demonstrates that it is possible to develop a remedial action plan based on input from a wide variety of experts. The next steps, namely realization and evaluation, will reveal the success of the overall approach.

Patricia Holm, biologist and lecturer for ecology at the University of Berne, leader of the project Fishnet. Her specialty is the use of fish as bio-indicators.

Further information on the project Fishnet under www.fischnetz.ch and in the publications "fischnetz-info".

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Synergism Between Flood Protection and Stream Ecology

Space as the Key Parameter

The Federal Law on Hydraulic Engineering dictates that human life and material assets be protected from damage by water. This needs to be achieved while having a minimal impact on streams and reserving sufficient space for them to fulfill their multitude of ecological functions. These general principles are to be translated into a flood protection philosophy that is in balance with the environment.

Even as recently as in the 1970s, hydraulic engineering projects were dominated by concerns for flood protection and drainage. Increasing environmental awareness and severe storms in 1987 and 1993, however, led to a fundamental change in attitude; sustainability[1] has been adopted as the guiding principle. A new general framework for flood protection was developed, and laws were changed accordingly.

The core characteristic of this new approach to stream management is integrated planning which considers ecological, political, economic and social factors. The key parameter in the planning process is the amount of space the stream will be allowed to occupy. Giving a stream sufficient space has positive effects in a number of ways: the natural habitat is preserved, the water quality is improved, recreational space is enhanced, and the risk of floods and damage to protective structures is reduced. Based on a broad-based problem analysis, the following strategic goals for flood protection have been formulated:

- areas occupied by dwellings and industrial or agricultural zones are to receive adequate protection;
- preventive measures should minimize damage in the case of flood events;
- streams are to be respected as important elements of the landscape, linking different parts of nature.

These goals will only be reached if federal policies in all of the relevant areas are coordinated, including flood protection, water protection, fisheries, environmental and landscape protection, hydroelectric power generation, forestry and agriculture. Readiness for cooperation and the ability to reach consensus will, therefore, be crucial if we want integrated planning and management to become a reality.

Sustainable Flood Protection

Based on the requirements for sustainable and integrated flood protection, the following principles have been formulated:

Principle 1: Determine stream condition and risks

Before we can evaluate the ecological condition of a stream or decide on the need for protection, detailed information is needed about its hydrological conditions, the status of current flood protection structures, its ecological condition and the primary risks or types of risks associated with it.

Principle 2: Preserve natural retention capacity

Preservation or recreation of the natural retention zones is just as desirable as the preservation of the natural course of a stream. Larger retention zones delay the flow and dampen peak flows.

Principle 3: Differentiate the aims of protection

Flood protection should differentiate between different values of the objects to be protected (e.g., communities, structures, agricultural areas). The higher the value of the object, the higher the need for protection.

Principle 4: Minimize intervention

Flood protection should be achieved with a minimum of intervention within the natural space of a stream. The stream needs to be given adequate space for fulfilling its many ecological functions. In addition to the stream itself, we need to consider the areas adjacent to the stream and their uses.

Principle 5: Maintain streams and continue to monitor problem areas

Appropriate maintenance of a stream is an ongoing task. We need to insure that protective structures remain intact, that the runoff capacity is maintained, and that no ecological functions are impaired. Protective structures need to be periodically tested for structural integrity and stability under extreme runoff conditions. Potential weak spots need to be identified and eliminated.

Principle 6: Guarantee the space required by a stream

A stream should be more than a gully; a river should not be degraded to a canal. It is the obligation of the Cantons to determine the space requirement for streams and to incorporate this information in all directives and land use plans or other activities dealing with the assignment of "space". Based on these principles, we have developed a flow chart for developing stream protection plans (Fig. 1). A sustainable flood protection project will give ecological function and flood protection equal weight. The starting point of any catalog of potential measures is always a survey of the current status; the process should identify concrete, realistic goals within each of the two areas. It can then be decided where remedial action is needed and how it should be prioritized. An overall optimization should be performed in a final review, weighing all the different demands on the stream against each other [1].

How Much Space does a Stream Need?

An interdisciplinary group has studied this question and developed two different meth-

[1] Sustainable measures in flood protection are measures that can be implemented with little effort, are socially acceptable, have the desired long-term effects, limit damage, and can easily be modified.

ods for determining the minimum space a stream has to be given [2]. Both methods will be used in the planning and design of new hydraulic engineering projects in Switzerland. If the two approaches yield different answers, the larger of the two calculated space requirements will be used. Any structures to be built have to be located outside the area assigned to the stream.

Hydraulic Approach (Flood Protection)

Based on the hydrological conditions and the specific protection goals [3], we have to determine the minimum space that has to be secured for the stream in the long-term. In settled areas, the key parameter normally is the HQ_{100}, the flood stage that is statistically reached once every hundred years. The design value corresponding to such a flood event allows us to calculate the hydraulically required minimum width of the stream bed. This is a theoretical value, and special local conditions need to be taken into account where appropriate. Allowing a slope of 1:2 for the stream bank and a buffer zone of 3 meters along both sides of the stream (guaranteeing access to the stream), we can determine the minimum space required by a stream from a flood protection perspective (Fig. 2).

Ecological Approach

The ecological approach is based on literature research and a number of case studies. Streams were treated as functional entities, including the stream as well as the stream bank, buffer zones and recreational space. We were able to define the so-called "key line", delineating the natural outline of the stream bed, which serves as the reference line for defining the minimum space to be added on either side of the stream (Fig. 3, black curve). For small streams, the minimum width should be 5 meters on each side. For larger streams (stream beds up to 15 meters wide), the requirement increases to 15 meters. This simple procedure allows us to produce a rough estimate of the

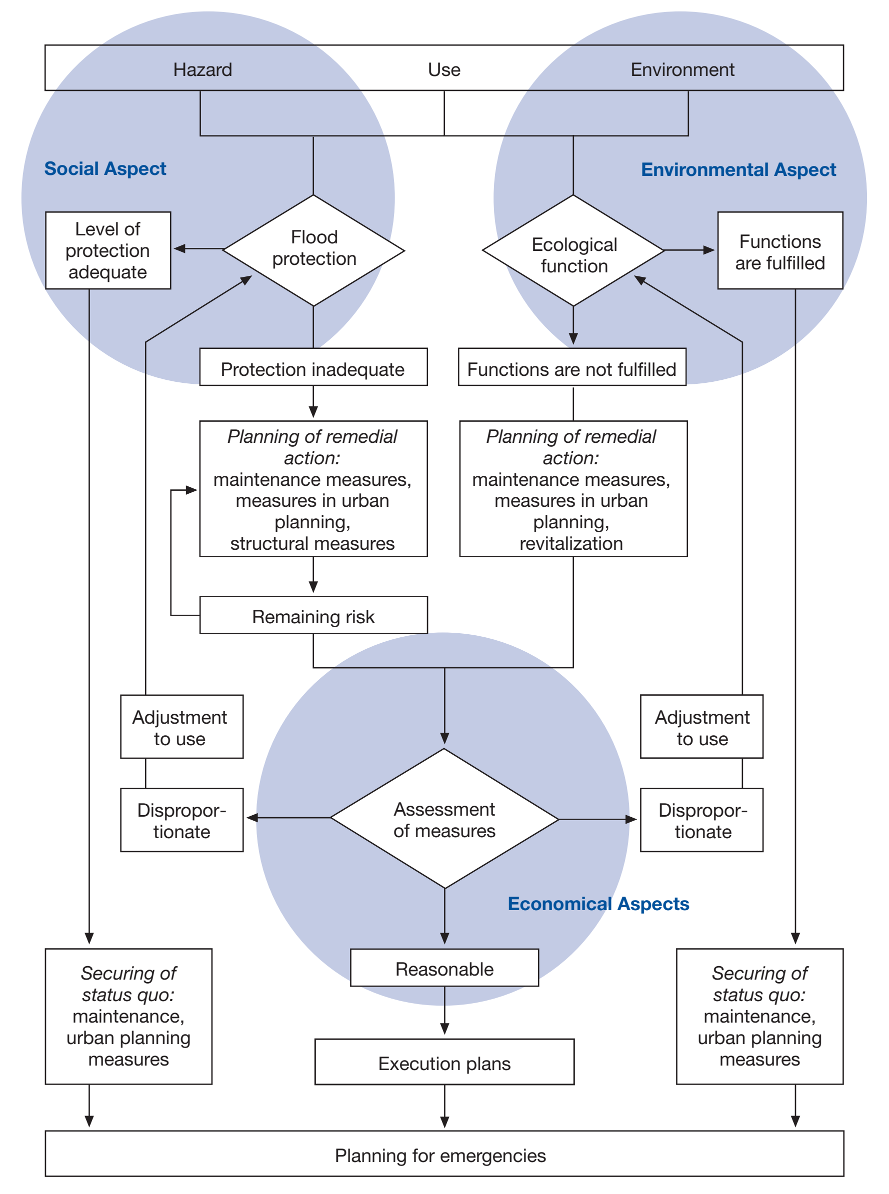

Fig. 1: Flow chart for remedial action planning.

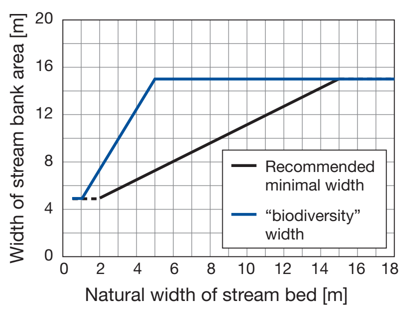

Fig. 3: Required width of stream bank area as a function of natural stream bed width.

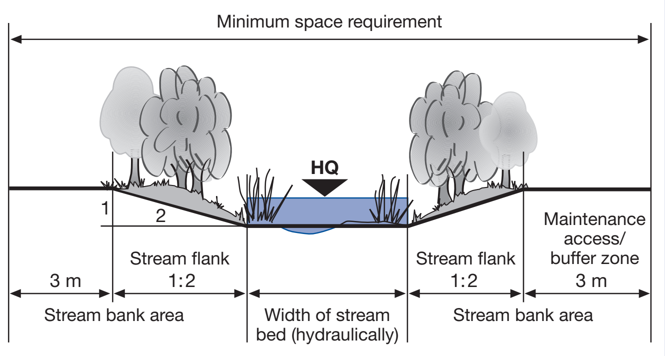

Fig. 2: Minimal spatial requirement from the flood protection perspective.

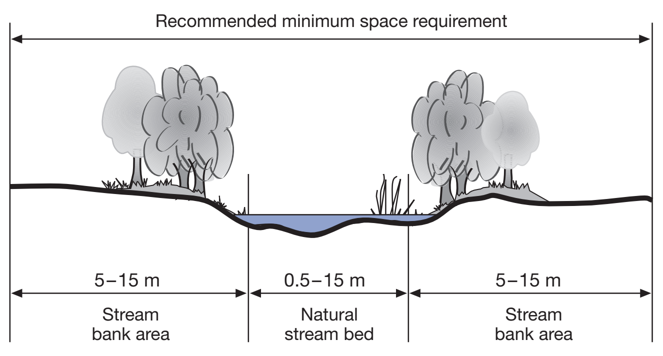

Fig. 4: Minimal spatial requirement according to ecological criteria.

Baudirektion des Kantons Uri

The flooding of the Reuss in Canton Uri in 1987. The motorway acted as a dam, effectively closing off the valley. The flood waters backed up and caused significant flooding.

minimum space requirement for a stream (Fig. 4); however, results should always be checked against the situation in the field, and additional space be reserved for recreational use.

In priority areas (e.g., nature preserves, water protection zones, fish protection zones), we must also safeguard the natural diversity of the native fauna and flora. As shown in Fig. 3, this produces a minimum space as defined by a "biodiversity line". Within areas of national priority (e.g., alluvial zones), nationally designated protected areas and in areas of extensive use, the reserved zone should be extended to 5–6 times the natural width of the stream bed in order to guarantee incorporation of the stream into the adjacent landscape (meandering of the stream, formation of side-channels).

Realization

With the obligation to determine the spatial requirements of streams and incorporate them in planning directives and stream utilization plans laid out by law, the question of how to realistically meet these requirements is raised. The basic set of tools are those of conventional urban planning (e.g., general directives, utilization plans, frontage lines, setbacks from streams, zoning, exchange/purchase of properties). For over a hundred years, streams have become more and more restricted and their space reduced to an absolute minimum. Now it has become clear that in the long term, streams must regain some of this space. A landmark decision of the Federal Court demonstrated as early as 1998 that even in urban areas, land must be set aside in order to allow environmentally responsible flood control [4]. Conflicts over land use are the most serious and the most difficult to resolve in urban areas, but even in areas dominated by agricultural uses, there is a significant potential for conflict.

Bringing in Agriculture

Naturally, farmers do not have any interest in giving up land since this reduces both their base of operations and their income. Solutions have to be found that are beneficial to agriculture, the environment, recreational and flood protection. Since agricultural policy holds a key role in this task, it is important to include farmers in the solution of the problems. One way of achieving this would be to have farmers participate in the maintenance of streams and to compensate them for their efforts.

The Contribution of Science

Remediation projects will only be accepted by the general public if they are based on solid facts and answers from the scientific community. The most pressing task is to gain an overview of the condition of streams and identify hazardous situations. Working procedures to accomplish this step have been published [5, 6]; EAWAG has been involved in the development of these procedures. They allow us to set priorities and to use available funding in the most useful ways possible. In areas where we still have open questions, we need to continue to conduct basic research while building in mechanisms for monitoring the success of any remedial action taken. Specifically, scientists need to:

- reveal interdependencies within systems,
- identify areas with potential for new developments,
- formulate goals in the area of ecology,
- devise mechanisms for monitoring success and define corresponding indicators,
- develop strategies for problem solving and conflict resolution.

The third river works of the Rhone between Brig and Martigny is a tremendous opportunity for developing these tools and strategies in a real-life situation. The enormous and highly ambitious project, which will extend over more than 20 years, offers a wide spectrum of opportunities for scientific study.

Visions of the FOWG

According to the Swiss Federal Office for Water and Geology (FOWG), the Cantons and the communities have to respect the ecologically recommended minimum stream bank widths in all future hydraulic engineering projects. Such minimum widths are to be determined beforehand using established tools of urban planning. The newly designed stream sections and the vegetation along the streams will slow down runoff (flood protection) and will at the same time be esthetically pleasing (habitat for plants and wildlife). The near-stream areas will be maintained by farmers who will be reimbursed by the federal government for their efforts.

Conclusions

Streams are important components of our environment, but are subjected to a variety of demands. We can meet all of these different needs only if the "affected parties" become "participants" and take part in the search for solutions. Streams do not stop at property or community boundaries, but must be viewed as continuous systems. Integrated and interconnected approaches are absolutely essential. We need to examine the effect that local actions have on the system as a whole. The new general directive for flood protection encourages hydraulic structures where ecological considerations and flood protection aspects are complementary to one another.

Hans Peter Willi,
Head of the section "Water risk" in the Swiss Federal Office for Water and Geology (FOWG) in Biel.

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The Dialogue Continues

Scientists and nonscientist citizens meet for the second "round table" discussion of "Science et Cité"

In July 2000, the second in a series of "round table" discussions was held in Kastanienbaum on Lake Lucerne. Twelve citizens and 12 scientists spent two days discussing the topic "Chemicals in the Water".

The goal of the foundation "Science et Cité" is to promote dialogue between science and society. One of its projects is the "round table", a platform for regular discussions between scientists and the general public. The pilot project, including citizens from the Zurich area and representatives from EAWAG, started in February 2000. The topic for the second discussion in July 2000 was "Nutrients and Pharmaceuticals in Streams and Lakes".

The Fascination with Lakes

The second "round table" was held at the idyllic location of the EAWAG's Research Center for Limnology in Kastanienbaum on Lake Lucerne. To give participants a first-hand experience in practical aspects of limnological research, the first day began with a sampling trip on the lake. An EAWAG research vessel took the participants out to the sampling location, and the questions soon started to roll. The tools of the trade were of interest, such as the water sampling devices, the temperature probe, the plankton net, but also more fundamental questions on temperature stratification of lakes and fish kills. Answers and explanations were covered in more detail back in the laboratory, where the samples were examined under magnifying glasses and under the microscope. Participants were fascinated by the variety of organisms, such as diatoms and small freshwater shrimp, became engaged in deep discussions and looked up information in the scientific literature.

Intensive Discussions

On the second day, the discussions continued, but were supplemented by scientific presentations and gradually organized into a more structured format. The main topics were the pollution of lakes, streams and ground water by phosphate and nitrogen, on the one hand, and by pharmaceuticals used in humans or animals on the other.
One of the points receiving special attention was the behavior of society as a whole towards the environment. The entire group contemplated new ways to move towards sustainable use of the environment and how to change the general way of thinking. Participants noted that environmental research often cannot provide definitive answers. This led to the conclusion that decisions on possible remedial actions should not be delegated to the scientific community and that the ordinary citizen has to take on some of the responsibility at present assumed mainly by political entities. There was broad consensus among the participants, however, that in order to fulfill this role, citizens need to receive better information. Scientific results are public information and freely accessible as such, although the language is often not understood by the nonscientist. Sometimes, even scientists have difficulties understanding terminology used in other disciplines. Scientists are faced with important challenges: how can scientific results be "packaged" such that they can be communicated to the average citizen, and what arguments and counter-arguments should be presented to the public? The goal would be to maintain scientific objectivity, while allowing the public to make informed decisions and share the responsibility for them.

Communication

Communication between science and the public was identified as one of the central problem areas during this second "round table". My own experience confirms the importance of these issues and the difficulties they often pose. I was confronted with a number of questions during our sampling event on Lake Lucerne and was met with insistent follow-up questions on points that remained unclear. Upon re-reading a scientific report that was authored by a sociologist on our team, I realized however, that my explications had not been understood by the public as I had intended.
At the conclusion of the July meeting, it was decided to dedicate the third meeting, scheduled for January 2001, to the topic of communication. In another of EAWAG's projects, means of communication have been explored previously and were practiced under the guidance of a media expert. The topic was the "NoMix Toilet", a new type of toilet separating urine and solid waste in separate waste streams, which is being studied in the group working on urban drainage systems.

(Gabriella Meier Bürgisser, EAWAG Dubendorf)

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2000 Otto Jaag Prize

On November 18, Nina Schweigert, who conducted her doctoral research at EAWAG, was awarded the 2000 *Otto Jaag Prize for Water Protection* for her dissertation entitled "Modes of Action and Toxicity of (Chloro-)Catechol/Copper Combinations".
Her work examined the correlation between the toxicity of a pollutant (assessed with the use of bacteria) and its chemical properties. In the environment, pollutants rarely occur alone but are present as mixtures. In her exemplary work, she investigated the interaction between a heavy metal (copper) and organic contaminants (catechol and its chlorinated forms).
In the presence of oxygen, catechol and copper can form dangerous reactive oxygen species, so-called ROS. These reactions also occur inside bacteria where DNA, membranes and proteins can be damaged by the ROS that is produced. However, the toxicity of the catechol-copper mixture is not due to the formation of ROS, because bacteria readily detoxify the ROS before detectable damage occurs. From the literature, it was known that the lipophilic character of catechols increases with the number of chlorines attached to the ring, and that catechols bind copper in strong complexes, which lose protons relatively easily. Nina Schweigert was able to show that the combination of these three properties is the actual source of toxicity to bacteria. Due to complex formation, the charge of the copper ion is neutralized, and the complexes accumulate in the membranes. The copper-catechol complexes are able to migrate in the membrane; they can therefore release protons on one side and take them up on the other side of the membrane, thereby destroying the membrane potential. Finally, Nina Schweigert developed a model that accurately reproduces toxicity data observed for the copper-catechol mixture.

ETH Council Approves "Socio-Economics of Water"

EAWAG maintains a high level of competence in the natural and engineering sciences and has considerable experience in collaborating with experts from the practice (government, NGOs, industry). EAWAG's group "Human Ecology" was already formed in 1992 (see EAWAG news no. 50), and now EAWAG is making a renewed effort to improve its competence in the socio-economic field. We aim at better understanding which factors determine how water is utilized and then influence decisions that foster sustainable management of the nonrenewable resource "water". Important themes include the ongoing development of water policies with the incorporation of various aspects of natural, engineering and social sciences, citizen participation in the decision-making process, and the way risks and uncertainties are handled.
In October 2000, the ETH Council approved the EAWAG project "Socio-Economy of Water", awarding it a 3 Million CHF budget. This is one of six projects within the ETH Council's framework of projects on "Autonomy Dividend – Innovation and Cooperation Projects". They will be conducted during the period 2000–2003 in collaboration with cantonal universities.

The Ecotoxicology Course "coetox"

In addition to their benefits, chemicals can have undesirable side effects on humans and the environment. Ecotoxicology is the field that identifies and prevents these effects. Since extensive regulations were not in place until the 1980s (Ordinance on Substances 1986), we still have relatively little experience in the practical application of ecotoxicology. Since 1994, scientists at ETH Lausanne (EPFL) and EAWAG, in collaboration with other partners, have held a series of courses in ecotoxicology. The main goal of these courses is to disseminate knowledge and promote dialogue between stakeholders.
In 1999, it was decided to divide the course into distinct modules, such that within a three-year period, a survey of the entire field of ecotoxicology and its practical applications can be given. Under the patronage of SAEFL (Swiss Agency for the Environment, Forests and Landscape), the course is co-organized by representatives from Cémagref Lyon, the Universities of Constance, Geneva and Zürich, and Syngenta.
In September 2000, 30 persons participated in the fundamental course, offered in French and German. Participants acquired an overview of some basic chemical and biological principles and were introduced to some of the methods and concepts currently used in ecotoxicology. The module *Evaluation of Pollutants* took place in May 2001 and between 2002 and 2003, the courses *Impact on Natural Systems* and *Risk Analysis* will be offered, each held in a three-day session.

Additional information:
http://www.eawag.ch/events/peak/coetox

coetox = "collaboration en écotoxicologie"