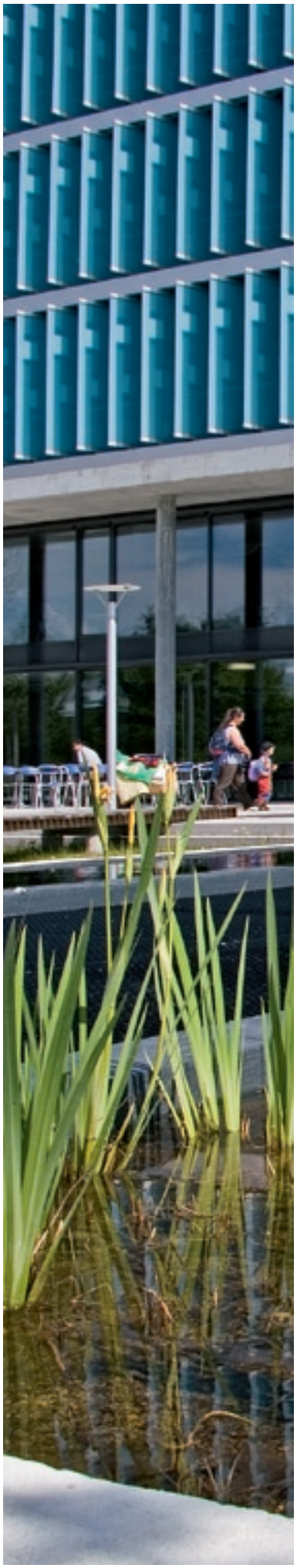
eawag
aquatic research

Annual Report 2006

Eawag: Swiss Federal Institute of Aquatic Science and Technology



Eawag is one of the four independent research institutes of the ETH Domain. Nationally rooted and internationally linked, it is committed to concepts and technologies for the sustainable management of water resources and aquatic ecosystems. In cooperation with universities, other research centres, public authorities, the private sector, and NGOs, Eawag strives to harmonise ecological, economic and social interests in water, providing a link between science and practical applications.
About 400 staff are employed in research, teaching and consulting at the Dübendorf (Zurich) and Kastanienbaum (Lucerne) sites. From 1936, the German acronym "EAWAG" stood for the Swiss Federal Institute of Water Supply, Sewage Treatment and Water Pollution Control. As this cumbersome designation does not adequately express the complexity of today's water-related issues, "Eawag" has been used since 2005 as a proper name for the Swiss Federal Institute of Aquatic Science and Technology.

Cover photo
"In-house" research: the NoMix toilets in the new building Forum Chriesbach are flushed with roof run-off stored in an outdoor reservoir. We are analysing the water for substances washed out by rainwater, e. g. from the flat roof sealing sheets.
Photo: Andri Bryner. Articles: pp. 9, 49 and 62.

Content

Creating and applying water-related knowledge

Water management is one of the major challenges of the twenty-first century. In many parts of the world, supplies of freshwater are extremely limited and water quality is frequently seriously degraded. At Eawag, we generate knowledge relating to water and the – often apparently incompatible – demands placed on this key resource. At our own headquarters, the new "Forum Chriesbach" building, we apply this knowledge ourselves. Ueli Bundi

Water is essential for the natural world, food production, industry, and human health and well-being. Water resources are subject to a variety of competing claims, often involving acute conflicts of interest. In Switzerland, too, the management of waterbodies and water is a crucial factor in our development. We need to optimize a creation of values in managing water resources for the benefit of society and the environment over the long term. This is a complex undertaking, as it calls for an integrated view of widely varying interests and spheres of activity.

For Eawag, dealing with the topic of water is a privilege. We develop knowledge in important water-related fields and apply this knowledge in efforts to resolve water-related problems. Our mission is in line with the goals pursued by the other research institutes of the ETH Domain. They all seek to elaborate scientifically sound, long-term solutions promoting the sustainable management of vital resources, thereby making significant contributions to sustainable development.

Careful use of resources in-house

Eawag's operations are governed by a strict environmental programme. Striking evidence of this is furnished by our new building, Forum Chriesbach. It demonstrates that we not only research and propagate sustainability but put it into practice ourselves. Sustainability, here, is to be understood in its broadest sense. This cutting-edge building – together with the newly established daycare centre – addresses important ecological, economic, social and communicative concerns. At the same time, it impressively combines functionality with architectural aesthetics.

In the planning of Forum Chriesbach, invaluable expert support was provided by Empa. As well as creating a joint library in the new building, the two organizations work closely together both scientifically and operationally. For this collaboration and the friendly relations we enjoy. I would like to express my sincere thanks to our neighbouring institute.

The celebrations and the open day marking the inauguration of Forum Chriesbach at the beginning of September aroused great interest among our scientific and other partners and among the general public. The new building and the presentations on Eawag's activities were widely appreciated. Once again, the numerous visitors were struck by the manifest commitment and enthusiasm of our staff (see also the article on p. 62).

Manifest commitment

This remarkable enthusiasm is an expression of the "Corporate Identity" that characterizes Eawag. A spirit of this kind could scarcely be imposed, and we count ourselves lucky that it runs so deeply here – thanks to meaningful activities, a broadly based mission and highly motivated and responsible staff. They deserve our appreciation and thanks for their substantial contributions in research, teaching and consulting and in the supporting functions. Highlights of 2006 worthy of special mention are the major, successfully completed "Rhône-Thur" and "Lake Brienz" projects.

New developments

At the beginning of 2006, we established Cirus – a social science department for innovation research in utility sectors. The department of Applied Aquatic Ecology (APEC) was closed down, with its functions being reallocated to other departments – Surface Waters (SURF), Fish Ecology + Evolution (FISHEC) and Cirus, APEC, originally established in 2000, was a key player in the development of inter- and transdisciplinary water research at the national and international level and thus helped to shape Eawag.

I would like to thank all those who offered kind support and valuable advice to Eawag in 2006. In particular, I would mention the ETH Board and its staff, and Eawag's Advisory Board. I am delighted that the latter body now has a distinguished new member – State Councillor Erika Forster (Canton St. Gallen). I am grateful to the staff representatives (PV) for their dedicated contributions to important projects. Since the beginning of 2006, our staff canteen has been operated by the caterer DSR. We greatly appreciate the outstanding services of the DSR team, who contribute a good deal to our well-being.

We need to optimize value creation over the long term in managing water resources for the benefit of society and the environment. This is a complex undertaking.

On 31 December 2006, my 3-year term as interim Director came to an end. I am deeply indebted to my colleagues at Eawag for all the goodwill I experienced during my tenure. Thanks to its staff, Eawag is well positioned to make further advances along the aquatic research path. Moreover, new horizons will open up for Eawag under its new Director, Janet Hering. I wish her every success in her work with Eawag, as well as great satisfaction and enjoyment.

A sneak preview: 2007 and beyond

It is a great honour and privilege to have been selected as Eawag's Director. My first five months have been extremely busy, but I feel that the time has been well spent in getting to know Eawag and the ETH Domain. In the coming months, I look forward to working with Eawag's talented research and support staff to provide an environment that embraces innovation and stimulates our researchers. Janet Hering

Returning to Eawag nearly twenty years after I began my postdoctoral work with Professor Werner Stumm, I am struck by both similarities and differences. There are still a few familiar faces from that era, which has helped to ease the transition into my new role. Eawag continues to be recognized world-wide as a leading institute for research, education, and consulting in aquatic science and technology, but it has also expanded its scope to include new scientific areas, such as biodiversity and evolution, as well as the social sciences and a growing emphasis on developing and emerging countries.

Eawag on four columns

As Eawag moves forward to face new challenges and exploit new opportunities, it is important to recognize that its success rests on a strong, four-fold foundation:

- a clear and well-defined focus on water and the water environment.
- outstanding human infrastructure of professional, technical, and support staff.
- cutting-edge facilities and analytical instrumentation.
- a strong base of direct financial support that enables Eawag to conduct innovative and transdisciplinary research.

With this foundation, Eawag is able to take an integrated view of the water environment, a view that encompasses the continuum from relatively unperturbed aquatic ecosystems to fully engineered water and wastewater management systems. Eawag focuses on high impact research, that is, on scientific research that will lead to fundamental advances in the aquatic sciences and on engineering research which addresses important societal needs. Eawag also plays a unique role in working with practitioners to maintain the bridge between theory and practice that is needed to implement novel concepts within society.

The coming years offer a wealth of opportunities for Eawag researchers to address important scientific questions and technological challenges both in Switzerland and throughout the world. The ETH Domain has recently expanded its international focus through bilateral agreements between Switzerland and China and India, and through a joint initiative with the National Research Foundation of Singapore. Eawag will benefit from these opportunities as well as its own long-standing tradition of international collaborations.

New Centre for Ecotoxicology

Eawag will also play a key role in the new Centre for Applied Ecotoxicology, which will be established in 2008. This centre will provide practice-oriented continuous education, contract research, and ecotoxicological evaluation of chemical compounds and will meet critical needs of industry and governmental organizations.

I am deeply indebted to Ueli Bundi and his predecessors for their leadership, which has positioned Eawag at the forefront of aquatic science and technology. I am confident that, through the efforts of its talented and highly skilled research staff, Eawag will maintain its standing and make major contributions in generating new scientific knowledge and engineering solutions in the field of aquatic science and technology. ○○○

Janet Hering

In January 2007, Janet Hering (born in 1958) joined Eawag as its new Director and ETH Zürich as a Professor of Environmental Biogeochemistry. At ETH Zürich, she is a member of the faculty in the Department of Environmental Sciences and also an associated faculty member in the Department of Civil, Environmental, and Geomatics Engineering. Hering most recently served as Professor of Environmental Science and Engineering at the California Institute of Technology (Caltech). Her research focuses on the biogeochemical processes controlling the fate and transport of trace metals in the environment and their removal in treatment systems for drinking water. She is no newcomer to Eawag, having carried out postdoctoral research at the institute from 1988 to 1991. She studied chemistry and received her Bachelor's degree from Cornell University in 1979 and her Master's degree from Harvard University in 1981. She earned a Ph.D. from the Massachusetts Institute of Technology-Woods Hole Oceanographic Institution joint program in oceanography in 1988. After completing her postdoctoral work at Eawag in 1991, she joined the faculty at the University of California, Los Angeles as an Assistant Professor of Civil & Environmental Engineering and was promoted to Associate Professor in 1995. She moved to the California Institute of Technology as an Associate Professor of Environmental Science & Engineering in 1996. She was promoted to Full Professor in 2002 and served as the Executive Officer of the Keck Laboratories from 2003–2006. She is also an Associate Editor of the journal "Environmental Science and Technology" (see page 60).

Eawag's participation in the Competence Centres of the ETH Domain

Spurring innovation in business and society

The ETH Domain's five Competence Centres commenced operations in 2006, with more than 70 research projects advertised and launched. Eawag's knowledge and expertise in interdisciplinary cooperation are being deployed in particular in the area of environment and sustainability. Bernhard Wehrli

By pooling the scientific strengths of its research institutes in five Competence Centres, the ETH Domain is seeking to promote sustainable solutions in business and society (see Box). Eawag has made significant contributions to the establishment of the Competence Centre Environment and Sustainability (CCES), and approved projects have now been initiated by a number of Eawag researchers.

In each of the two thematic areas "Climate & Environmental Change" and "Natural Resources", research efforts are focused on two projects:

▶ "BioChange" is exploring genetic diversity, contemporary evolution and the maintenance of biodiversity in alpine ecosystems, which are already seriously affected by climate change. The research, led by Jukka Jokela, brings together seven groups from Eawag, ETH Zurich and WSL. They are developing scientific foundations and biodiversity management strategies for these dramatically changing habitats.

▶ "BigLink" is investigating soil formation in a newly exposed foreland of the Damma Glacier in Canton Uri. Weathering and soil formation following glacier retreat are dependent on rapid colonization by plants, bacteria and other microorganisms.

▶ "RECORD" is concerned with the modelling of hydrological and ecological dynamics on a restored section of the River Thur – including interactions between river and groundwater. The project, led by Olaf Cirpka, involves collaboration between groups from Eawag, ETH Zurich, EPF Lausanne and WSL. This research can build on the foundations provided by Eawag's successful cross-cutting "Rhône-Thur" project.

▶ "ADAPT", led by Bernhard Wehrli and Alfred Wüest, is developing integrated approaches to the management of large dams and riparian wetlands in the Zambezi Basin (Southern Africa). Local research capacity is also to be built up in Zambia and Mozambique. The study will draw on findings from the "Rhône-Thur" project and also on the results of the transdisciplinary Green Electricity project and analyses conducted in connection with the Grimsel dams.

Projects on trace gases, climate change and water supplies, and climate policy, in which Eawag is to participate, are currently under review. A project proposal on new environmental monitoring technologies is to be further developed: the aim of the "Swiss Experiment" is to exploit and refine networks of intelligent sensors for environmental research in the Alpine region and on watercourses.

Eawag is also participating in projects currently being run by the Competence Centre for Energy and Mobility (CCEM) – involving. for example, sediment management in pumped storage power plants or the efficient use of biomass in power generation.

The ETH Board's initiative establishing the Competence Centres has been criticized in certain quarters. The funding of around CHF 30 million a year has been withdrawn from the individual institutes and now has to be "regained" through complex projects. This ties up key personnel resources. However, an initial assessment indicates that cooperation among the institutes of the ETH Domain – and interdisciplinary research – has been strengthened. Thanks to its experience with cross-cutting projects, Eawag is contributing significantly to these developments. ○○○

The Competence Centres of the ETH Domain

The five Competence Centres of the ETH Domain bring together research and knowledge from the ETH Zurich, EPF Lausanne, PSI (Paul Scherrer Institute), WSL (Swiss Federal Institute for Forest, Snow and Landscape Research), Empa (materials science and technology research) and Eawag. The focus is on projects with the potential to yield economically innovative and socially relevant results. In 2006, the ETH Board provided CHF 19 million in funding for the Competence Centres and earmarked another CHF 30 million for 2007. Eawag plays a particularly active role in the Competence Centre Environment and Sustainability (CCES). This supports research projects in five thematic areas – "Climate & Environmental Change", "Natural Hazards & Risks", "Natural Resources", "Food, Environment & Health" and "Sustainable Land Use". Under the administrative direction of the ETH Zurich, the CCES leverages the potential of the entire ETH Domain in the environmental sciences. The aim is to integrate the principles of sustainability into technological developments and political processes, and to develop environmental knowledge for specific target groups. In addition, the CCES promotes the establishment of technology platforms that can be jointly used by a number of different partners while undergoing further scientific development. In the four other Competence Centres, research groups from the ETH institutes focus on Energy and Mobility (CCEM), Materials Science and Technology (CCMX), Systems Biology (SystemsX) and Biomedical Imaging (NCCBI).

Urban water management

Problematic substances, the huge investments required to renew infrastructure established over many decades and the need to manage resources as sustainably as possible – all these factors are compelling the urban water management sector to consider new approaches. Accordingly, Eawag's research in this area is focused on identifying alternative wastewater disposal options and assessing these alongside existing systems.

With 759 centralized wastewater treatment plants and 47 000 kilometres of public sewers, Switzerland's wastewater management infrastructure is well developed and contributes a great deal to the quality of the country's surface waters. But these facilities represent a major investment: the replacement value of the urban drainage and water supply systems combined amounts to almost CHF 200 billion. Can we actually afford to preserve the value of and renew existing systems over the long term? How does the urban water management sector respond to new technologies and the growing uncertainties associated with, for example, emerging pollutants or rapid changes in demand? The integration of social science innovation research – as conducted by the new Cirus department – ensures that organizational forms, questions concerning the transition from old to new systems and economic aspects are given due consideration as well as scientific and technical problems.

Studying new approaches

Eawag's research does not relate exclusively to Switzerland. Approaches to wastewater management that have scarcely been questioned to date (flush toilets, water-borne sewage disposal and treatment at centralized plants) cannot necessarily be exported – e. g. to arid regions or to rapidly expanding cities in emerging countries, where the construction of sewer networks cannot possibly keep pace with population growth. In addition, new approaches can facilitate flexible responses to the most pressing problems. In the transdisciplinary Novaquatis project, for example, Eawag and its partners – researchers and practitioners – showed that urine source separation could be a highly effective measure for combating excessive nutrient levels in coastal waters. In settings

er in areas

where flushing water is scarce, the reuse of flushing and greywater becomes increasingly important. With small-scale treatment plants, such as that operated at over 3000 m above sea level in Zermatt, or a project designed to improve greywater management in developing countries, Eawag has identified promising methods. This research involves consideration not only of technical aspects but also of questions concerning the acceptability of new systems to users, dialogue between the private sector and public authorities, and decision-making processes in particular.

Drinking water: psychological factors

Drinking water quality requirements are increasingly stringent. Quite apart from the detection of new trace substances in water resources, a number of constituents have yet to be adequately studied, such as taste and odour compounds, viruses and nanoparticles. In the integrated Wave21 project (Drinking water in the 21st century), Eawag is studying these parameters across various treatment steps (membrane filtration, oxidation, activated carbon filtration) so as to provide a basis for the maintenance of very high levels of water quality and for the renovation of water treatment plants in the coming decades. Among the factors influencing drinking water consumption are media reports on hazards to this vital resource; the mechanisms involved are being investigated in an internal project within the urban water management area. The decisive role played, not by chemistry, but by psychology was demonstrated by a blind test carried out at the opening of Eawag's new headquarters: although visitors were well able to distinguish between water from different sources, they failed when asked to identify samples as commercially bottled or tap water.

Urine source separation: a promising wastewater management option

Although urine makes up only 1% of the total volume of wastewater, it accounts for 50–80% of the nutrient content. To prevent eutrophication of surface waters, nutrients have to be removed by resource-intensive processes at wastewater treatment plants. Many problematic substances like hormones and pharmaceuticals also enter wastewater via urine and may subsequently be released into the environment. As the transdisciplinary Novaquatis project shows, separate collection and treatment of urine could make significant contributions to water pollution control and nutrient recycling worldwide. Judit Lienert, Tove A. Larsen

In a report issued in 2004, the United Nations Environment Programme (UNEP) warned that, in future, nutrient overload could pose a greater threat to fish stocks than overfishing. Excessive inputs of nutrients, particularly nitrogen and phosphorus, lead to the proliferation of algae. As large amounts of oxygen are consumed when the short-lived algae are decomposed by microorganisms, oxygen-depleted "dead zones" can develop, especially in coastal waters. Where these zones are too extensive for fish to flee, as a result they die.

Rapidly growing problem

The question of whether algal growth is controlled by phosphorus or nitrogen availability has been debated for many years. Numerous experts now argue that emissions of both nutrients should be limited. The UNEP recommends that nitrogen emissions should be dramatically reduced to rescue fish stocks; worldwide, the number of marine dead zones has increased by a third since 2004. We are thus confronted with a rapidly growing problem, and rapid action is required.

In 1990, 21 million tonnes of nitrogen was excreted by humans worldwide, with only 6% being removed at wastewater treatment plants. Compared with the 48 million tonnes of nitrogen per year flowing into coastal waters from the world's continents, this is a substantial amount. Since 1990, the world's population has already grown by 25%, and migration to cities continues to increase, especially in coastal areas. The construction of conventional sewer networks and treatment facilities cannot keep up with the escalating problem of nutrient overload. One possible solution is provided by the so-called NoMix technology, since 80–90% of the nitrogen excreted by humans is contained in urine. If urine were separately

Separate treatment of urine could alleviate problems arising from excessive nutrient levels in coastal waters.
Top: Urine storage tanks in Eawag's new headquarter building (Ruedi Keller). Bottom: Algal blooms caused by excessive nutrients; beach on the Baltic Sea, Sweden (Keystone).

Modern NoMix toilet. One bowl, two separate paths. The drain for urine in front, the one for faeces in the back. A valve prevents the dilution with flushing water.

collected and the nitrogen eliminated – or possibly recovered and used in agriculture – this system would surpass the efficiency of most of the world's nutrient eliminating wastewater treatment plants.

NoMix in Switzerland

Urine source separation makes the wastewater management system as a whole more flexible and efficient – in particular, more energy-efficient. At treatment facilities, the emphasis can be placed on eliminating problematic substances other than nutrients. The construction of new plants is less costly if large tanks are no longer required for nutrient removal. This frees up resources for measures taken at the household level, such as investments in the NoMix technology.

In Switzerland and other countries with a well-developed sewerage and wastewater treatment infrastructure, it remains to be seen how far the introduction of the NoMix technology is a viable option. In this country, the nutrient issue has been addressed by generations of water pollution control experts – provided with the necessary financial resources from the public purse. But in Switzerland, too, certain problems have yet to be resolved. In the case of Lake Greifen with its very dense settlement, for example, it is not possible to meet the reduction targets specified for phosphorus despite the modern technology available. In future, the urban wastewater management sector will face new challenges that could lead to major increases in costs – assuming that these challenges can even be dealt with by the system in its present form. Among the emerging issues are micropollutants and climate change, Central Europe is very likely to experience drier summers. As a result, wastewater will be less diluted in rivers, and ammonia and nitrite toxicity could once again become an issue in this country. If the frequency of brief but intense downpours increases – as already recorded in Denmark, for example – overflows from combined sewers will also increase, with wastewater being discharged untreated into rivers and streams. This is especially serious if the water flow is already reduced by a dry summer. The NoMix technology could help to tackle all three problems – nutrient inputs, micropollutants and climate change.

NoMix in China

In countries with limited wastewater treatment facilities, the NoMix technology already offers a sustainable alternative and supplement to the establishment and expansion of wastewater treatment plants. This applies in particular to cities in coastal areas, which are growing rapidly worldwide.

As part of the Novaquatis project, the wastewater situation in Zurich's sister city Kunming (China) was studied: here, almost 2000 tonnes of phosphorus per year enter Lake Dianchi, including 1600 tonnes from wastewater. This lake used to be the source of the city's drinking water but is now heavily polluted, with excessive nutrient levels. The lake only has the natural capacity to absorb 60 tonnes of phosphorus per year. The required reduction in inputs could not be achieved by pursuing the end-of-pipe strategy – even with a massive expansion of the sewer system and modern wastewater treatment plants. Source control measures – such as urine source separation and agricultural measures – are thus indispensable. We therefore discussed the desirability of various options with experts from Kunming and the surrounding area. It transpired that they were very receptive to the idea of urine source separation and prepared to adopt new approaches. Given the rapid expansion of cities such as Kunming – by 2020 the population is expected to grow from 2.4 to 4.5 million – measures could also be implemented much more quickly than in this country. This in turn could open up an attractive market for the NoMix technology produced on an industrial scale. Separate urine collection can also – not least – save water, as it

avoids the need to use more than 20 litres of (drinking) water to dilute a litre of urine. Water-free urinals require no and certain NoMix toilets very little flushing water for urine drainage.

Urine-based rather than artificial fertilizers

One of the priorities of the Novaquatis project was the development of methods for processing urine. These can be used to achieve a variety of objectives, including the elimination of nutrients: the methods suitable for this purpose (e.g. biological treatment) are similar to those used at sewage plants. However, in contrast to heavily diluted wastewater, the nutrients in urine are present in a highly concentrated form. As a result, process engineering becomes more flexible and the facilities required are much smaller.

Another objective may be to recover nutrients from urine for recycling as agricultural fertilizers. If nutrient recycling is envisaged, micropollutants (i.e. medicines and hormones) will need to be removed from the urine. To this end, a number of different methods were tested in the Novaquatis project. For example, 98% of the phosphorus in urine can be recovered by precipitation with magnesium. The product – struvite ($MgNH_4PO_4$) – is an attractive fertilizer in powder form, free of pharmaceuticals and hormones. Other methods of separating nutrients from possible pollutants are nanofiltration and electrodialysis. The combination of electrodialysis and ozonation is used by the utilities agency (AIB) of Canton Baselland to process urine collected at the Cantonal Library in Liestal. In 2006, the fertilizer produced in this pilot project (overseen by Eawag) was successfully tested by the Research Institute of Organic Agriculture (FiBL): its effectiveness on fodder maize was similar to that of artificial mineral fertilizer and significantly better than that of slurry or commercial organic fertilizers. In Switzerland, nutrients from human urine could serve as substitutes for at least 37% of the nitrogen and 20% of the phosphorus demand that is currently met by imported artificial fertilizers.

The NoMix technology thus opens up novel process engineering options for wastewater management, which can be flexibly applied depending on the desired goal. In most cases, however, the methods have yet to be implemented in practice – in larger-scale pilot plants or in subsequent development by companies seeking to market the technology. At Eawag, a project is in preparation with the aim of developing methods for treating small volumes of urine, which are applicable as far as possible in decentralized systems (also see last chapter).

The Eawag pilot plant at the BL Cantonal Library, where urine is processed to produce a liquid fertilizer.

M. Koller. FIBL

Maize successfully grown with a urine-based fertilizer.

Medicines: halving the environmental risks

In the Novaquatis project, ecotoxicological and chemical analytical methods were developed in order to evaluate the quality of the urine-based fertilizer product. With the aid of a newly developed ecotoxicological test battery, the overall impact of a sample can be determined before and after processing. It was shown that the treatment methods tested remove different pharmaceutical substances to different extents. For example, the efficiency of a bioreactor (degradation of organic compounds and nitrification with the help of bacteria) was not very ef-

Pipes can be blocked by a build-up of precipitates (urine scale).

ficient in this respect. However, struvite precipitation was shown to be highly efficient: the micropollutants studied were almost completely separated from the nutrients. Membrane filtration and ozonation also showed varying results. With respect to the toxic potential, nanofiltraion (membrane pores in the range of nanometers) can separate 50–90% of the toxicity of micropollutants from the nutrients. Ozonation removes – depending on the ozone dose – 55–99%.

Medicines and hormones enter wastewater via human urine to widely varying extents. For 212 active substances ingested (corresponding to 1409 pharmaceutical products), the average rate of urinary excretion is 60–70%. The remaining fraction reaches the wastewater via faeces.

The algal assay shows the toxic effects of pharmaceutical substances on cells.

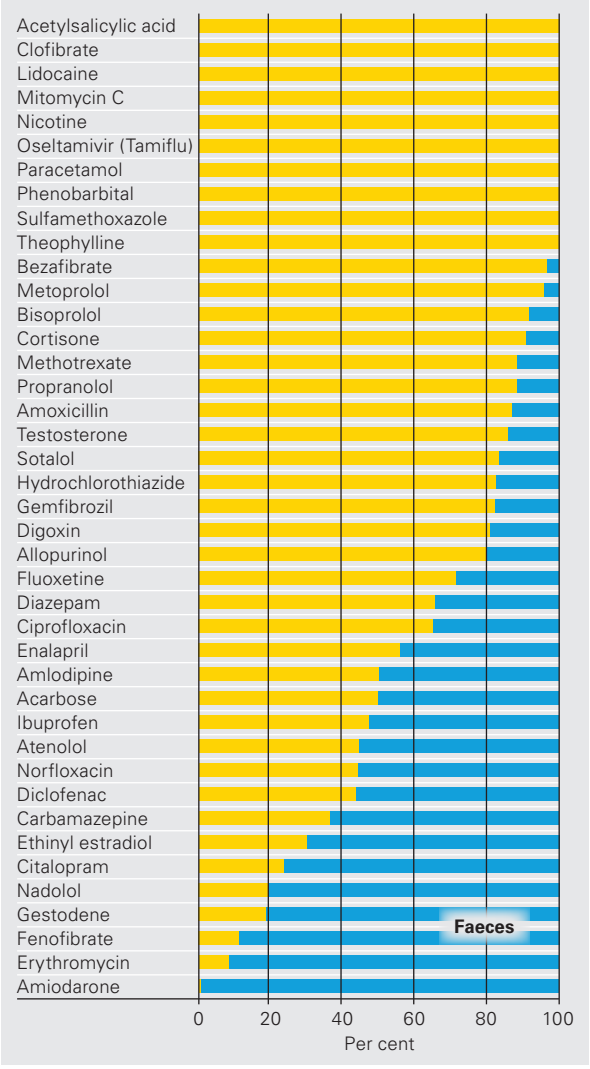
In the Novaquatis project, a screening method was developed which makes it possible to assess the environmental risks associated with excreted pharmaceuticals. The hazards posed to the aquatic environment were investigated for 41 commonly used medicines: urine accounts for the entire ecotoxicological hazard in the case of 25% of all active substances, and for at least half in the case of another 40%. This means that, as well as relieving the nutrient burden on wastewater treatment plants, urine source separation can reduce the environmental risks associated with pharmaceuticals and hormones of human origin in wastewater by an estimated 50%.

High levels of acceptance

The NoMix technology is well received by the Swiss public, as indicated by surveys carried out in pilot projects in public buildings. These involved a total of 1750 people who used the NoMix toilets at their workplace (Eawag), at a vocational college, or at the BL Cantonal Library in Liestal. Altogether, 70–80% of respondents thought that urine source separation was a good idea, and around 80% rated NoMix systems as equivalent or superior to conventional toilets with regard to design, hygiene and odour. More than 80% would be prepared to move into an apartment fitted with a NoMix toilet. Many users of NoMix toilets are willing to adapt their behaviour; for example, the urine source separation system requires all users – including men – to sit down to urinate, and 72% of respondents actually did so. Urine-based fertilizers also meet with approval: three quarters of the 501 people surveyed at the BL Cantonal Library would buy vegetables grown with a fertilizer of this kind. In a survey of farmers, 57% approved of the idea of urine-based fertilizers.

In public and office buildings, sanitary facilities are cleaned and maintained by service personnel. In all three pilot projects, the efforts required were shown to be greater for NoMix toilets and waterless urinals than for conventional models. In certain waterless urinals, for example, a cartridge has to be periodically replaced. In NoMix toilets, blockages caused by urine scale need to be prevented, e.g. by flushing the urine drain regularly with a weak citric acid solution. This makes the installation of NoMix toilets in a household setting more problematic. Not everyone is prepared to accept the additional cleaning efforts required. Other drawbacks of NoMix toilets may also cause greater inconvenience in a private bathroom: children in particular find it difficult to adopt the required sitting posi-

tion. In Switzerland, our small pilot project only involved four households, but the objections raised are confirmed by experience abroad – e.g. a project in which 88 apartments in Linz (Austria) were fitted with NoMix toilets.
Further development of NoMix toilets is thus essential before they can be installed on a large scale. Although this is a task for sanitary technology companies, major investments are only likely to be made by this sector if a sizeable market exists. However, if the potential of the NoMix system to resolve water pollution problems in fast-growing coastal cities is recognized, a global market could rapidly emerge.



Distribution of the toxicity for 41 pharmaceutical substances after metabolism in the human body to the urinary (yellow) and faecal (blue) fractions. The values are scaled up to 100%. It is not possible for the various substances to be compared in absolute terms. For example, the entire toxicity of acetylsalicylic acid resides in the urine, whereas in the case of diclofenac only 44% of the toxicity is found in the urine. Nonetheless, it is possible that the residues of diclofenac excreted via this route pose a greater risk to aquatic organisms than those of acetylsalicylic acid. To investigate this, further modelling is required.

Challenges: precipitation and urine transport

The NoMix toilet operates according to a simple principle: wastes collected at the back of the bowl are flushed into the sewers with water in the normal manner. In the front compartment, urine is collected and drained with a small amount of flushing water – or undiluted – into a local storage tank. However, two difficulties arise for the NoMix technology: What can be done about the precipitation of salts that can block narrow pipes and siphons after only a few thousand usages? And how is urine to be transported to the treatment facility? Novaquatis suggests solutions to both of these problems.
Decentralized measures appear to be particularly promising. The problem of blockages could be dealt with by developing NoMix appliances in which the unavoidable build-up of precipitates is deliberately promoted in a replaceable unit integrated into the toilet – comparable to what is already done in a number of water-free urinals. The need for transport can be avoided if urine is treated as close to the source as possible – in a user-friendly unit located in the basement or in the toilet itself. If the system is to be implemented in practice, however, further research and development will be required, essentially involving cooperation with wastewater professionals and the sanitary technology industry.
For Eawag researchers, plenty of work thus remains to be done. Novaquatis has clearly shown that the NoMix technology merits further development. However, if it is to become widely established, considerable efforts will be required, both in research and in practical implementation. Engineers will need to develop processing methods that allow urine to be treated in compact, decentralized units as near to the source as possible. A "urine machine" of this kind will have to be a stable, low-maintenance device – much like a modern coffee machine. As well as technological development, cooperation will be required with social scientists and local experts in developing and emerging countries, who will need to show how NoMix can be introduced as a mass-use technology as smoothly as possible. ○○○

Publications on the cross-cutting Novaquatis project include a Final Report (English, German) and an issue of Eawag News (63d, e, f, chin.). Further information and links to all the relevant publications are available at: www.novaquatis.eawag.ch

Railways as another source of substance emissions

While air, soil and water pollution along roads is well documented, this is not the case for railways. For the first time, Eawag has assessed the substance emissions arising from the operations of Swiss Federal Railways (SBB): every year, abrasion alone accounts for releases of around 2500 tonnes of metals from overhead wires, wheels, rails and brakes. Other emissions include 1300 tonnes of hydrocarbons from lubricants and wooden sleepers. Michael Burkhardt, Luca Rossi, Markus Boller

An assessment of substance emissions and their impacts on the environment is indispensable, both for sustainable water and soil management and for the implementation of appropriate measures along railway lines (Figure). In the "Water protection along railway tracks" project, therefore, the emissions generated by the operations of the SBB – around 140 million train-kilometres across a network of 7200 km – were assessed for the first time for the reference year 2003. Studies of comparable scope have yet to be performed in other countries [1, 2].

The balance of materials allows the identification of emission hot spots.

Brake abrasion: main source of emissions

In railway network operation and maintenance, emissions depend on a wide variety of factors, such as freight or passenger traffic, train frequency, track on rising gradient and braking zone. The bulk of emissions are associated with abrasion processes or diffuse leaching (Table).

▶ *Braking processes* lead to the release of approx. 1912 t of abrasion particles per year and are thus the main source of emissions. Freight traffic accounts for about 80 % of this total. The emissions are dominated by iron (>95 %), followed by copper and chromium. The emissions from composite brakes increase continuously but their composition is nearly unknown.

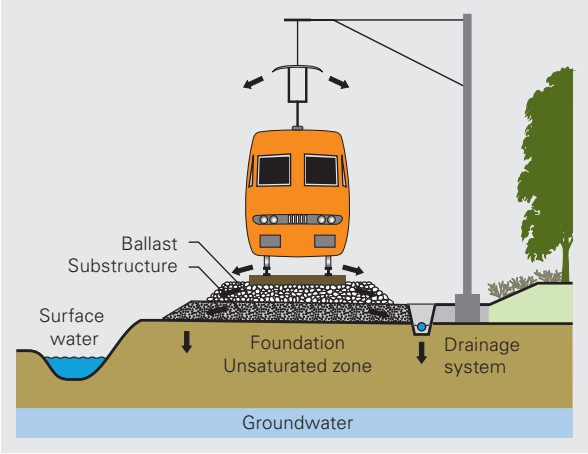
▶ Abrasion losses also occur with *contact lines,* leading to total emissions of approx. 38 t of copper. This type of abrasion is the main source of railway-related copper releases, which are of the same order of magnitude as copper emissions from road traffic.

▶ *Wheels and rails* are also responsible for particulate emissions into the environment. These are estimated at 124 t (from wheels) and 400–550 t (rails). Emissions from rails consist mainly of iron (>96 %), followed by manganese and chromium, with wheels also contributing copper, nickel, molybdenum and vanadium. Rails constitute the SBB's main source of chromium emissions.

▶ The SBB network includes 144 000 *hot-dipped galvanized catenary support.* The annual losses by dissolution are estimated at 20 t of zinc, or 140 g per pole.

▶ For the *lubrication* 390 t were used by SBB. For engines, buffers, bearings, etc., about 197 t of oil and 69 t of grease are applied. While only a proportion of the lubricating oils is expected to be released, the greases are emitted in their entirety. These releases occur diffusely across the network, but preferentially at stations and in marshalling yards. On lines with numerous curves or steep slopes, 39 t of oil was applied directly to wheels and rails. The total lubricant consumption of 6000 lubricated track switches was about 68 t or, per switch, 11 kg. This makes switches significant point sources for emissions of hydrocarbons, with the potential for releases being increased by regular steam cleaning. About 17 t lubricants are applied in different closed systems.

▶ The SBB track network includes around 5.1 million *wooden sleepers,* which are impregnated with creosote. This preservative is a mixture consisting of 80–85 % polycyclic aromatic hydrocarbons (PAH), 5–15 % monocyclic aromatic hydrocarbons, 1–12 % phenols and 5 % heterocyclic compounds. Over a life cycle of 25 years, an average of 5 kg per sleeper is released [3]. On that basis, annual releases of creosote from all wooden sleepers were estimated at 990 t. It enters the track bed via leaching, exudation and abrasion. Although the use of wooden sleepers has increased again in recent years,



Emissions of substances along railway lines and possible pathways for environmental transport via drainage water systems.

SBB – almost no diesel soot

Eawag's assessment of substance emissions shows that railways can also contribute to air, soil and water pollution. Compared with road traffic, however, emission levels are considerably lower: according to the FOEN, road traffic emits about 4500 tonnes of fine particles (PM10) per year, including 1800 tonnes of carcinogenic diesel soot. In contrast, rail traffic is responsible for emissions of 800–1200 tonnes of fine particles per year – with an almost negligible proportion of diesel soot, thanks to widespread electrification.

concrete sleepers offer a good alternative.

▶ For *vegetation control* on railway lines, 3.9 t of glyphosate was used, with the herbicide being applied to about 50% of the network. Various studies have shown that glyphosate is mobile and that losses may occur via track drainage water (see also the article on p. 50).

Substantial local variation

Emissions of environmentally relevant substances along railway lines are associated with dynamic processes (braking/contact lines abrasion, etc.) and fixed installations (poles, switches, etc.). When and where particular substances are released into the environment is influenced by additional factors such as axle load, rail traffic density, kilometric performance and speed. Thus, emissions in braking or acceleration zones are higher than average, and lubricant consumption and contact lines, wheel and track abrasion are expected to increase as traffic density rises. As a result of the variation in local conditions, emission patterns are heterogeneous, giving rise to specific contamination patterns for soil close to railway lines, track drainage water and nearby surface waters.

In most cases, however, the mobility of the substances emitted requires elucidation. Also inadequate is our knowledge of the environmental behaviour of particulate emissions – as an adsorbent for immobilization of solutes, as a vehicle for particle-bound transport, or as a toxic fraction (PM10).

Is track drainage water contaminated?

Although railway lines are closely interconnected with the environment (Figure), hardly any studies are available on the pollution of nearby soil, track drainage water and surface waters, or on the effectiveness of existing track drainage measures [4]. What has been demonstrated to date for track materials – through extensive studies of old ballast – is contamination with heavy metals and hydrocarbons, including PAH. The contamination at track-switches is currently the highest.

According to the Swiss Water Protection Guideline (GSchV), drainage water of tracks is not generally considered to be polluted unless pesticides are applied. However, on the basis of our assessment and the assumptions in the FOEN Guidelines on water protection by drainage systems of transport infrastructure, track drainage water must be regarded as potentially contaminated on numerous sections of track. Treatment measures are likely to be required – locally at least.

Our assessment will now allow the identification of local areas with significant emissions and contamination. Individual contamination hotspots, such as marshalling yards, should be further assessed and also experimentally studied so that the rough estimates can be confirmed by quantitative measurements. ○ ○ ○

Hydrocarbons from wooden sleepers, grease from switches, abrasion from contact lines, breaks, wheels and rails – railway operation emits a substantial amount of substances into the environment.

Substance	Emissions (t/year)	(g/track km/year)	Source
Iron	2176	302 000	Brakes >>> rails > wheels
Copper	46.6	6480	Overhead wires >> brakes
Zinc	19.8	2750	Galvanization
Manganese	15.5	2170	Grey iron brakes > rails > wheels
Chromium	6.9	960	Rails > grey iron brakes
Nickel	0.4	50	Wheels
Vanadium	0.06	8.5	Wheels
Lead	0.003	0.5	Sinter brakes
Antimony	0.003	0.5	Sinter brakes
Cadmium	0.002	0.3	Galvanization
Binder	21	2900	Composite brakes
Hydrocarbons (73% PAH)*	1357	176 800	Wooden sleepers >>> loss lubrication >> switch lubrication > flange lubrication
Glyphosate	3.9	540	Vegetation control

* Wooden sleepers account for approx. 70% of the hydrocarbons emitted (estimated values).

Levels and sources of the main emissions associated with normal operations of the SBB railway network; minimum values for the reference year 2003.

This study was supported by the Federal Office for the Environment (FOEN), the Federal Office of Transport (FOT) and Swiss Federal Railways (SBB).

[1] Burkhardt M., Rossi L., Boller M. (2005): Stoffemissionen durch Bahnanlagen und Bahnbetrieb. Der Eisenbahningenieur 12, 18–22.
[2] Burkhardt M., Rossi L., Boller M. (2006): Diffuse Release of Environmental Hazards by Railways. Proceeding of 10th International Specialised Conference on Diffuse Pollution and Sustainable Basin Management, Istanbul.
[3] Kohler, M. (2000): Gehalte und Emissionen von polyzyklischen aromatischen Kohlenwasserstoffen in und aus teerölbehandelten Holzschwellen des schweizerischen Eisenbahnnetzes, EMPA, Dübendorf, im Auftrag des Buwal.
[4] Verband des öffentlichen Verkehrs (2005): R RTE 21110 – Unterbau und Schotter. Regelwerk Technik Eisenbahn RTE, Schweizerische Bundesbahnen SBB, Bern.

Europe's highest sewage treatment plant

Even in a country as rich in water as Switzerland, there are certain locations where this resource is scarce and wastewater disposal is difficult. In the sensitive mountain environment of Zermatt – at an altitude of over 3000 m above sea level – we have demonstrated for the first time that it is possible to operate a biological sewage treatment plant with a virtually closed system. Marc Boehler, Adriano Joss, Simone Buetzer, Martin Holzapfel, Hansruedi Siegrist

At peak times, up to 5000 people per day use the Hohtaelli cableway station (3286 m a.s.l.), which is one of the main starting points for winter sports activities in Zermatt. The dry toilet facilities that were used here until 2004 proved increasingly unacceptable in view of the standards of comfort expected by visitors, unpleasant odours and the high personnel costs associated with cleaning and waste disposal (transport of bags down to the valley). But where were water supplies to be obtained for a flush toilet system? The solution proposed was the installation of a small-scale treatment plant with a membrane bioreactor (MBR), so that purified wastewater could immediately be reused for flushing the toilets.

Support from Technology Promotion programme

During the first season, this goal could not be achieved. The build-up of substances from urine and faeces in the recycled water was too high, and the plant's operation was not sufficiently adapted to the specific requirements. In cooperation with Zermatt Bergbahnen and the Zurich-based company terraLink, Eawag therefore optimized the technology and processes to permit continuous operation of the MBR system. This development project was supported by the Swiss Federal Office for the Environment's Technology Promotion programme. Thanks to the commitment of an ETH intern and undergraduate, the system was closely monitored throughout the 2005/06 winter season. It was possible to provide answers to a wide variety of questions concerning accumulation of salts, decolouration of purified wastewater, the problem of marked seasonal variation in nutrient loads, nitrogen removal at a low ratio of organic compounds, sludge disposal and year-round maintenance of decentralized MBR systems of this kind.

High nutrient elimination rates

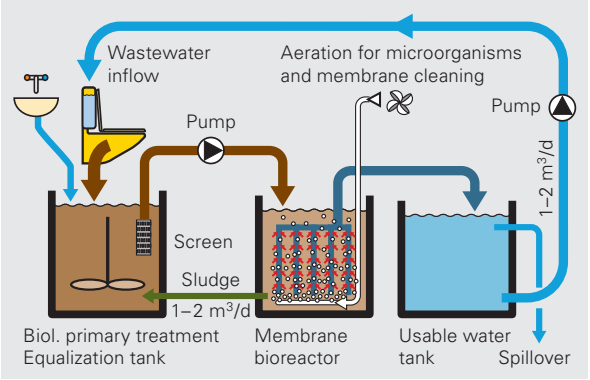
By the inclusion of activated sludge recycling into the first compartment – initially designed as a biologically inactive sedimentation tank – and adopting an intermittent aeration strategy in the MBR, surprisingly high rates of nutrient elimination were achieved for nitrogen (100%) and phosphorus (85%) without any organic substrate addition. The key processes underlying the high purification performance are efficient hydrolysis of suspended solids and enhanced biological phosphorus removal.

It has been shown that with an adequate adaptation period for the MBR biocoenosis, the high performance of the system can be sustained despite substantial accumulation of salts – conductivity in the MBR at the end of the skiing season is equivalent to about half that of pure urine. The problem of the treated wastewater taking on a yellow colouration has been addressed by adding appropriate doses of powder activated carbon directly into the MBR.

The optimized processes mean that fully biological treatment can now be applied on a compact scale at a decentralized plant. The project demonstrates that efficient and cost-effective purification of a highly specific type of wastewater is possible within a virtually closed system.

The significance of this enterprise thus goes beyond the regional level since the problem at issue is frequently encountered in mountainous areas; in addition, reuse of wastewater is likely to become an increasingly important concern in arid regions worldwide. In recognition of their innovative work, Eawag and TerraLink received the 2006 Muelheim Water Award. ○○○

Assembly in tight quarters. Before the installation of the sewage plant, this room was filled with plastic bags, used to transport faeces from the mountain.



The system requires no more than 200 – rather than up to 2000 – litres of fresh water per day.

www.eawag.ch/projekt-zermatt

Buetzer S., Joss A., Siegrist H. (2006): Diploma thesis «Modelling of a decentralized toilet wastewater treatment plant with closed water circulation», Eawag.

Böhler M., Joss A., Buetzer S., Holzapfel M., Mooser H., Siegrist H. (2007): Treatment of Toilet wastewater for Re-use in an MBR, Wat. Sci. Tech., accepted

Efficient treatment of motorway runoff

A new treatment scheme of road runoff offers a good example of cooperation between practitioners, researchers and authorities. This treatment scheme, implemented at three facilities on the St. Gotthard motorway, is now being closely monitored. The initial results are encouraging. Michele Steiner*, Markus Boller

Motorway runoff contains high levels of contaminants, such as heavy metals and polycyclic aromatic hydrocarbons (PAH). Vegetated filters currently used to treat runoff are not always suitable, as they require a relatively large area. For this reason, there is a need to develop and test barrier systems that can be subjected to significantly greater hydraulic performance and still retain pollutants effectively.

New method

A new treatment scheme for road runoff on the St. Gotthard motorway (A2) was proposed by the engineering consultants André Rotzetter & Partners in Baar. In addition to a lamella separator for coarse particle removal, it comprises two retention filters, each filled with a layer of sand on top of a layer of adsorber material. The upper layer retains fine particles and the adsorber layer removes dissolved heavy metals, so that the water discharged into the "Stille Reuss" river is as unpolluted as possible. In maximizing retention while keeping costs to a minimum, the choice of adsorber material is of crucial importance.

Eight materials tested

For some years, Eawag has studied the retention of heavy metals from roof and road runoff and, in particular, heavy metal adsorption. As well as scientific foundations, a method was developed for determining the performance of adsorbents. This makes it possible to test adsorbents for various applications without the need for costly long-term studies.

The necessary tests were carried out at Eawag for eight possible adsorber materials, with funding provided by the Civil Engineering Department of Canton Uri. Three criteria were considered in the evaluation – sorption capacity, sorption kinetics and desorption of heavy metals as a result of the use of deicing salts during winter.

Influence of deicing salts

The most expensive material, granulated ferric hydroxide (GFH), exhibits the best performance, followed by the two ferric hydroxides Ferrosorp and Everzit, which are cheaper. An inexpensive material with relatively good performance was zeolite C, although the disadvantage here is that adsorbed heavy metals undergo desorption when deicing salt is used in the winter. On the basis of these results, Ferrosorp was chosen as the absorbent for one of the two retention basins and zeolite C for the other – with the proviso that the latter should not be operated during the winter. We assume that, with normal operation, the adsorber layer will need to be replaced after 8–10 years. However, the ferric hydroxides can be reused as raw materials and the zeolites can be regenerated.

The choice of materials affects not only costs and performance, but also how the facility is operated.

Close monitoring

The everyday operation of this innovative treatment system is currently being closely monitored. The initial measurements indicate excellent performance. The system now requires fine-tuning. As this task goes beyond the scope of a research project, it is being performed by a private company (wst21) – a spin-off of Eawag, which focuses on the treatment of road runoff and strategies for the management of surface runoff.

One of the two retention basins on the A2 motorway in dry weather.

* Michele Steiner conducted research at Eawag and is now the director of wst21.

Hermann E., Schwengeler R., Steiner M., Boller M.: Behandlung von hochbelastetem Strassenabwasser. GWA 12/2005.

Steiner M., Langbein S., Boller M. (2006): Development and full scale implementation of a new treatment scheme for road runoff. Proceedings of 8th International Symposium on the Highway and Urban Environment. 6-2006, Nicosia, Cyprus.

How does the Swiss wastewater sector deal with radical innovations?

Great demands are placed on the wastewater management sector, and investments typically involve considerable sums. These investments are made under conditions of growing uncertainty. So to what extent is the Swiss wastewater sector capable of managing innovation? A case study of membrane technology highlighted the issues that need to be addressed if opportunities are to be better exploited. Cornelius Wegelin, Bernhard Truffer

For wastewater management professionals, dealing with technological and organizational innovations is becoming an increasingly challenging task. Investments made in this sector have always been of a long-term nature, and social and economic developments are multiplying the uncertainties affecting investment decisions. Against this background, the Swiss wastewater sector's capacity for innovation was analysed in a Bern University diploma thesis, which was supervised by Eawag.

1 Aeration process
2 Notter-Roboscan
3 Composting toilet
4 Terra-N process
5 Ecolith sand filter
6 Automated pipe-laying technologies
7 Vacuum toilet and pressure drainage
8 Constructed wetlands
9 Solar sewage sludge drying
10 Electrooxidation process
11 Privatization
12 Ultrasonic sludge treatment
13 Liner method of pipe renewal
14 Water-saving fittings
15 Decentralized rainwater utilization
16 Heating/cooling with wastewater
17 Ozonation
18 UV treatment
19 Mini-flush toilet
20 Contracting
21 Waterless urinals
22 Energy-optimized WWTP systems
23 Separation systems
24 Greywater recycling
25 Fluidized bed process
26 WWTP sequencing batch reactor
27 Decentralized small-scale treatment plants
28 WWTP membrane technology

Classification of wastewater sector innovations by complexity and radicalness (degree of change required in the sector for successful implementation).

Difficulty of assessing innovations

As a first step, we considered the demands placed on the wastewater sector by innovations currently under discussion. For this purpose, 28 innovations were evaluated on scales of complexity and radicalness (see Figure). Certain new developments are uncomplicated and can be readily integrated into existing structures. Others are complex, involving substantial uncertainties and requiring adaptation of various elements of the wastewater system. In such cases, innovations are only adopted if they can be shown to be highly beneficial. The assessment and implementation of complex and radical innovations thus pose major challenges.

Secondly, we identified current barriers to the implementation of radical innovations in the wastewater sector. Lastly, we sought to define the capacity existing in this sector for dealing with radical innovations. As an example, the use of membrane technology in municipal wastewater treatment was studied.

Functional deficiencies

With the aid of innovation system analysis – a method developed at Eawag – the current state of development of membrane technology in Switzerland was investigated, and possible development paths were outlined. A survey of 14 experts from industry, wastewater organizations, authorities, planning and research revealed the existence of significant functional deficiencies in the "membrane technology innovation system", which impede the further spread of the technology:

- inadequate communication among the various actors,
- gaps in expertise,
- a lack of supporting institutions and inappropriate regulatory frameworks,
- unclear allocation of authority and responsibilities among the various actors,
- unfavourable cost structures – low-volume production leads to high unit costs of systems.

The conclusions drawn from the example of membrane technology can be applied to the wastewater sector in general: in order to improve innovation dynamics, there is a need for a strategic view of current challenges facing the sector as a whole, combined with a professional approach to innovation management at the level of individual wastewater organizations. Only then can the sector take advantage of the additional scope for dealing with the growing uncertainties in the operating environment, technology and organizational structures. ○ ○ ○

A strategic view and professional innovation management are essential if the wastewater sector is to take advantage of new opportunities.

Wegelin C. (2006): Innovationsdynamik im Schweizerischen Abwassersektor – Eine Untersuchung des Innovationsfeldes Membrantechnologie in der kommunalen Abwasserbehandlung. Diploma thesis, Institute of Geography, University of Bern.

What does wastewater disposal really cost?

Infrastructure is considered to be a key element of Switzerland's public sector provision. For communities, wastewater disposal is one of the most capital-intensive services, involving major long-term capital commitments. The value, costs and condition of the wastewater infrastructure across Switzerland have now been documented for the first time in a study carried out jointly by Eawag and the Federal Office for the Environment. Anja Herlyn, Bernhard Truffer, Max Maurer

▶ **WWTPs:** Switzerland's wastewater is treated at 759 centralized plants (serving more than 500 inhabitants and population equivalents from trade and industry). The replacement value[] of these facilities is CHF 10.1 billion. The annual costs of wastewater treatment at these plants are CHF 819 million – with operating costs accounting for 54%, depreciation 37% and interest 9% of the total.

▶ **Sewerage system:** Sewage and stormwater are conveyed along 47400 km of public sewers. According to our calculations, the replacement value of these facilities is CHF 55.2 billion, or around CHF 7600 per inhabitant. It is interesting to note that this sum is almost independent of population density, as the greater length of networks in rural areas is offset by the greater complexity of urban engineering works. The annual operating and capital costs are CHF 875 million – with 1/3 for operations and almost 2/3 for depreciation. The interest costs arising are negligible since most sewers were built with the aid of interest-free community funding. Two thirds of the network was constructed over the past 50 years, although the infrastructure is significantly older in urban than in rural communities.

Enough to encircle the globe twice

In addition to the 759 treatment plants and the 47400 km of public sewers, more than 3400 small-sized plants and 1.7 million house service connections with about 42000 km of largely private drainage systems ensure effective sanitation and water protection. Laid end to end, all the pipes would easily encircle the globe twice.

We estimate the total replacement value of Switzerland's wastewater disposal infrastructure, including all privately owned installations, at just under CHF 100 billion. This is about three times the value of the telecommunications network or 1/3 of the total value of the road and rail network. Assuming an interest rate of 3%, this results in costs to the economy as a whole of around CHF 4.3 billion per year. Despite this immense sum, wastewater charges in Switzerland are low. In many areas, customers benefit from the use of tax revenues, from others paid connection fees, subsidies and not least the long service life of the robust infrastructure. However, based on the data concerning the age and condition of the facilities, the need for renovation can be expected to rise sharply, with costs increasing as a result. Significant damage is evident in about 23% of the sewers investigated.

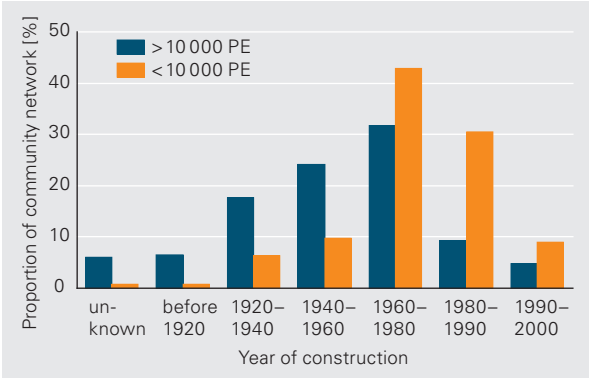
Maintenance and new approaches

Wastewater disposal in Switzerland is moving from a phase of construction into one of optimization. The aim now should be to ensure that existing infrastructure is professionally maintained, to reduce costs and to develop more modern, improved technologies and approaches. These challenging tasks call for sound expertise, professional management and a sense of responsibility on the part of the authorities. Naturally, water pollution control systems are also dependent not least on a steady flow of innovations from research, as generated by Eawag's activities. ○ ○ ○

[1] The replacement value is the amount that would need to be invested if the existing facilities were to be rebuilt.

Wastewater treatment plants	
No. of plants (>500 PE)	759
No. of inhabitants connected	7.3 million
Total capacity	16.7 million PE
Mean capacity utilization	10.4 million PE
Annual operating costs	CHF 440 million
Annual capital costs	CHF 379 million
(Depreciation costs	CHF 306 million)
(Interest costs	CHF 73 million)
Total annual costs of WWTPs	CHF 819 million = CHF 112 per inhabitant
Sewerage system	
Community-owned networks	43500 km
Regional association networks	3600 km
Other main sewage collection channels	300 km
Total length of public networks	47400 km = 6.5 m per inhabitant
Annual operating costs	CHF 287 million
Annual capital costs	CHF 588 million
(Depreciation costs	CHF 569 million)
(Interest costs	CHF 19 million)
Total annual costs of public sewerage system	CHF 875 million = CHF 120 per inhabitant

Key data on wastewater treatment plants and the public sewerage system in Switzerland. Operating and capital costs were calculated on the basis of a cantonal survey. PE = total number of inhabitants and population equivalents from trade and industry.



Average age of the sewerage system in 376 smaller and 21 larger Swiss communities. Particularly in the small communities, more than 80% of the network was constructed between 1960 and 1990. The study covers 7067 km of community-owned sewers, with 44% in urban areas.

Herlyn A., Maurer M. (2007): Status quo der Schweizer Abwasserentsorgung – Ein nationaler Überblick über die Kosten, den Zustand und den Investitionsbedarf. Gas, Wasser, Abwasser (GWA), 2007(3), S. 171–176.

Elimination of medicines in wastewater treatment plants

Excreted pharmaceuticals enter wastewater streams and – if they are not completely eliminated at sewage treatment plants – also surface waters. For four widely used antihypertensive drugs, toxicity and elimination processes and rates were experimentally determined, and the results were checked against real-life measurements.

Alfredo C. Alder, Max Maurer, Beate Escher, Philipp Richle, Manuela Richter, Christian Schaffner

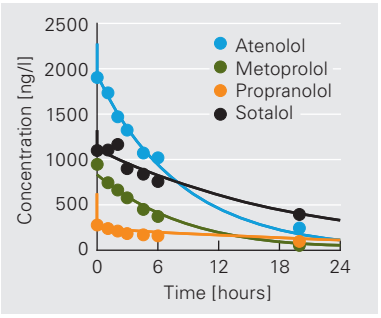
As part of the development of a membrane bioreactor (MBR) for municipal wastewater treatment, the behaviour of previously unexamined micropollutants was studied by ecotoxicological and chemical analysis. We focused on the beta-blockers most widely consumed in Switzerland – atenolol, metoprolol, sotalol and propranolol. These medicines are used in the treatment of high blood pressure and to prevent recurrences in post-myocardial infarction patients.

Biological and chemical analysis are mutually complementary.

Minimal removal with sludge

The main elimination processes occurring during wastewater treatment are sorption to sludge and biological transformation. Substances can thus be removed from the wastewater stream with excess sludge or undergo biodegradation. In experimental reactors, we determined the sorption coefficient (K_d) and degradation rate of the four selected beta-blockers.

K_d describes the ratio of the concentration of sorbed substance (ng/g activated sludge) to the concentration of dissolved substance in wastewater (ng/l). A low value indicates that the substance is scarcely sorbed to sludge and that, accordingly, the difference between the concentrations in treatment plant influent and effluent is attributable to biodegradation. For atenolol, sotalol and metoprolol, sorption to sludge is minimal (K_d <0.04 l/g). Although the sorption coefficient of propranolol is higher (K_d = 0.29 l/g), the rate of elimination via excess sludge is less than 5%, i.e. the quantities involved are not significant.



Results of a degradation experiment. Points: measured concentrations. Curves: simulation results.

The processes running under controlled conditions in this experimental set-up are the same as those in the large ponds at a WWTP. The reactors make it possible to determine the degradation rates and sorption coefficients for medicines in wastewater treatment.

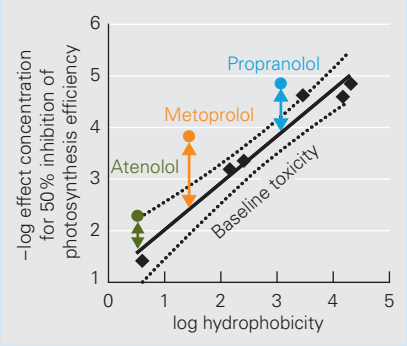
Half-life between 8 and 19 hours

The biological degradation rates (expressed as $l\ d^{-1}\ g^{-1}$) estimated for the beta-blockers were 0.63 for atenolol, 0.53 for metoprolol, 0.36 for propranolol and 0.26 for sotalol. These values indicate that in MBR systems – given the higher sludge concentrations – around half of the two substances metoprolol and atenolol can be degraded, while less than a quarter is degraded in the case of sotalol and propranolol. For treatment plants with typical sludge concentrations of 2.7 g/l, this implies a half-life of 8–19 hours (see Figure).

The concentrations measured in 24-hour mix samples of WWTP influent and effluent varied from one beta blocker to another: the influent concentrations were between 1900 and 2500 ng/l for atenolol and between 50 and 340 ng/l for the other beta-blockers; the effluent concentrations

Disruption of photosynthesis

Following on from the question of whether beta-blockers are eliminated in treatment plants is the question of what effects they may have in natural waters. In our mode of action-based test battery, the toxicity of medicines varied with hydrophobicity but was generally minimal. An exception was the case of algae, where specific toxicity is observed – i. e., damage does not only occur with very high concentrations. In an assay involving the inhibition of photosynthesis, all the beta-blockers studied exceeded their predicted baseline toxicity by a factor of about 10 (Figure). The algal assay was therefore selected for studies of the fate of this substance class in wastewater treatment plants. While endocrine disruptors can be quantified in wastewater using bioassays, this was not possible for beta-blockers since the algal assay also shows a response to many other substances in wastewater and the modes of action sought are non-specific. Efforts to obtain clearer results with selective enrichment of beta-blockers were also unsuccessful. Bioassays are thus a suitable tool for the monitoring of ecotoxicological sum parameters, but less so for the detection of specific substances or substance classes. Rather than being mutually substitutable, biological and chemical analysis are mutually complementary.



For baseline (non-specific) toxicants, toxicity (expressed as the negative log of the effect concentration) increases with increasing hydrophobicity. All the beta-blockers are about ten times more toxic than predicted by the baseline toxicity model, suggesting that for the "photosynthesis inhibition" endpoint, they exhibit a specific mode of action.

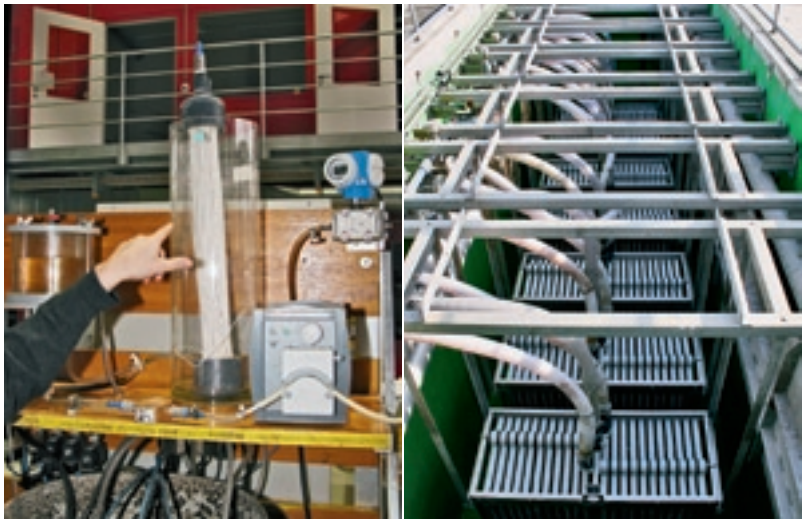
were 400–700 ng/l for atenolol and 30–250 ng/l for the others.

Agreement between laboratory and real-life values

The elimination rates observed at the treatment plants accord well with the estimates from the laboratory experiments. Only in the case of metoprolol was the elimination rate significantly overestimated (see Table). The degradation rates experimentally determined with sludge from an MBR can thus be readily transferred to other situations. Taking into account the consumption data for the medicines in question, the volume of wastewater arising and the estimated sorption coefficients and biological degradation rates, a good prediction can be made of the concentrations in the influent and effluent of a WWTP. ○○○

		WWTP Kloten-Opfikon		WWTP Dübendorf	
	[%]	measured	estimated	measured	estimated
Sotalol		26 ±7	27 ±14	27 ±2	41 ±11
Atenolol		79 ±17	53 ±9	73 ±9	71 ±6
Metoprolol		31 ±11	47 ±10	29 ±5	64 ±7
Propranolol		28 ±2	39 ±15	35 ±3	54 ±12

Elimination of beta-blockers (percentage, with standard deviation) measured over a 3-day period, compared with estimated values. According to Maurer et al.; Wat. Res. 2007/41.



A lab-scale ultrafiltration module at Eawag and the same membrane (pore size approx. 40 nm) right before operation in a sewage plant in Monheim Bavaria. Wastewater is sucked through the hollow fibres of the membrane and thereby cleaned. Solid matter remains on the membrane.

Escher B.I., Bramaz N., Richter M., Lienert J. (2006): Comparative ecotoxicological hazard assessment of beta-blockers and their human metabolites using a mode-of-action based test battery and a QSAR approach, Environ. Sci. Technol. 40, 7402–7408.

Maurer M., Escher B., Richle P., Schaffner C., Alder A.C. Elimination of β-blockers in sewage treatment plants; Wat. Res. 41, 1614–1622.

Bacteria slipping through the micro-net

To date, filtration of freshwater using membranes with microsized pores has been considered a reliable method for the removal of bacteria. New tests now demonstrate that larger numbers of microorganisms survive filtration and that a process of selection occurs. favouring strains whose morphology enables them to slip through the pores.

Yingying Wang, Frederik Hammes, Nico Boon1, Thomas Egli

Microfiltration – with membrane pore sizes ranging from 0.1 to 0.45 µm – is used worldwide to sterilize solutions and also to remove microbial cells in the treatment of drinking water for bottling. The findings concerning bacteria that can pass through membrane filters have been largely based on the heterotrophic plate count (HPC, enumerating colony-forming cells after plating on solid culture media). However, as this method has severe shortcomings for the detection of natural bacteria, the hygienic quality of drinking water and other filtered aqueous solutions may be overestimated. With the aid of flow cytometry (FCM), cells can be rapidly and accurately enumerated irrespective of their culturability. We used FCM coupled with fluorescence-staining and a natural regrowth assay to quantify, cultivate and enrich filterable bacteria from freshwater.

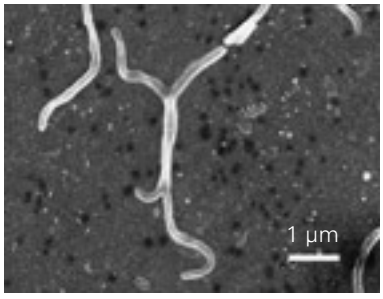
If filtered bacteria are allowed to regrow, a greater proportion can pass through the membrane on subsequent filtration.

Filterable bacteria prevalent in natural freshwater

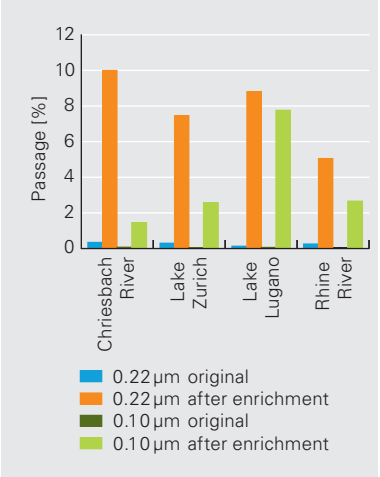
Filtration of ten samples representing a broad range of water types revealed that a high proportion (49–87%) of the natural aquatic microbial community passes through 0.45 µm pore size filters. Up to 3% can even pass through pore sizes of 0.22 µm, and up to 0.2% through 0.1 µm pore size filters. With initial concentrations of 2–3 million cells per millilitre, this implies that on average about 10000 cells per millilitre remain in a 0.22 µm filtrate and about 1000 cells per millilitre in a 0.1 µm filtrate. In addition, the filtered bacteria are not dead, as formerly supposed: they were subsequently able to grow on natural assimilable organic carbon (AOC) with a doubling time of an hour.

Slender bacteria favoured

If filtered cells are allowed to regrow, the percentage of bacteria passing through the membrane is significantly increased on subsequent filtration. After a single filtration-regrowth cycle, the proportion rose from 1% to 10% with 0.22 µm pore size filters and from 0.06% to 4% with 0.1 µm filters. In all cases, the dominant populations comprised slender, spirillum-shaped bacterial cells, including numerous *Hylemonella gracilis* strains, which appear to pass through membrane filters preferentially. This is also likely to be true of other bacteria with *Hylemonella*-like morphology, e.g. pathogenic *Leptospira* and *Treponema*.



Scanning electron micrograph of the bacterium *Hylemonella gracilis* on a membrane filter.



The proportion of filterable bacteria in enrichment cultures is substantially increased through successive filtration-regrowth cycles. A comparison of the passage of four freshwater samples through 0.22 µm and 0.1 µm pore size filters

AOC preferable to laboratory nutrient media

The standard bacterium used for filter testing is the rod-shaped *Brevundimonas diminuta*, which is generally pre-cultured in a growth medium with high nutrient concentrations. The cells formed as a result are relatively large and thick. However, such growth conditions are rarely encountered in natural aquatic environments, where biodegradable carbon concentrations are typically in the range of only 50–400 µg per litre (compared with 1 million µg per litre in nutrient media). For this reason, spirillum-shaped bacterial cells cultivated with natural AOC are more suitable candidates for testing filtration efficacy.

Our results rule out the possibility of "leaky filters" as an explanation for the occurrence of bacteria in the samples. They indicate a need to revise filter testing and grading methods and the overall procedure of using filtration for sterilizing liquids.

[1] Ghent University. Faculty of Bioscience Engineering. Laboratory of Microbial Ecology and Technology (LabMET). Coupure Links 653. B-9000 Gent. Belgium

Sustainable greywater management

The treatment and reuse of greywater have yet to achieve mainstream status. But especially in developing and emerging countries, where clean water is a scarce resource, improved greywater management could not only reduce household water bills but also decrease damage to the environment and human health. Stefan Diener, Antoine Morel

Every household produces greywater – from the kitchen, bathroom and laundry. Greywater comprises domestic wastewater from all sources except toilets. While in the industrialized world greywater and toilet wastewater (blackwater) are discharged into sewers for centralized treatment, the situation in developing and emerging countries is quite different. In cities, greywater is released untreated into drains or waterbodies, and in periurban and rural areas untreated greywater is used to irrigate agricultural land. This leads to degradation of the environment, with increased risks to public health. For although greywater is less contaminated than blackwater or industrial wastewater, it may contain high concentrations of pathogenic microorganisms or problematic substances such as fats, oils and detergents.

The quantity and characteristics of greywater produced by a given household are influenced not only by the climate and available infrastructure but also, to a considerable extent, by the household's standard of living, cultural habits and demographics. All these factors need to be taken into consideration if a greywater management system is to meet the needs of "users" as well as technical requirements.

Keep in view the whole system

A study recently published by Eawag was designed to document international experience in the area of decentralized greywater management and to describe the key elements of successful greywater treatment at the household and neighbourhood level. The approach adopted was holistic: although the advantages and disadvantages of specific treatment technologies were reviewed, the emphasis was placed on optimization of the system as a whole. Thus, the recommendations covered (household) source control measures, the rational combination of technical measures, and safe and efficient reuse or disposal of treated greywater.

Compare alternatives

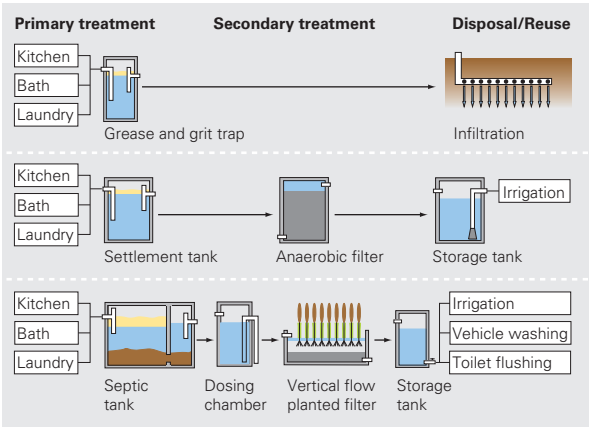
The technical installations reviewed differ in terms of complexity, performance and costs. Simple systems such as infiltration trenches or garden irrigation are used by individual households. Systems employed at neighbourhood level tend to be of greater complexity (e.g. series of horizontal- and vertical-flow planted soil filters). However, as their complexity increases, so does the need for maintenance. Case studies carried out, for example, in Mali, Jordan and Nepal show that the failure of a greywater treatment system is usually due to a lack of maintenance. It is therefore advisable to ensure that systems are kept as simple as possible – in line with the required level of performance.

Instruction required for users

A greywater treatment system can only provide environmental and health benefits and reduce water bills if it remains functional. It is therefore crucial for users to understand how the system works and to perform essential maintenance. In a project carried out in Mali, for example, bathroom greywater was drained via a grease and grit trap and a vertical-flow filter into a vegetable garden. When the first barrier to solids – a wire-mesh screen – began to rust, it was summarily removed, which increased the load on the treatment units and led to clogging of the gravel filter. The users subsequently also removed this filter so that the garden could at least be watered. However, the untreated greywater soon clogged the perforated irrigation pipes in the garden, leading to complete failure of the treatment system.

Alderliveste MC (left), Langeveld JG (right)

A street in Djenné, Mali, before and after the introduction of simple greywater infiltration systems.



Greywater treatment systems of varying degrees of complexity. Top: Djemé. Mali; middle: Ein Al Beida. Jordan; bottom: Kathmandu. Nepal.

Morel A., Diener S. (2006): Greywater Management in Low and Middle-Income Countries, Review of different treatment systems for housholds or neighbourhoods. Eawag: Swiss Federal Institute of Aquatic Science and Technology. Dübendorf. pdf-download: www.sandec.ch/greywater

Quantification of freshwater resources in West Africa

How much water is available to a country? A new modelling tool provides answers to this question which are more precise than existing estimates. It delivers output with a higher spatial and temporal resolution and takes account of uncertainties, facilitating risk assessments. The results can be applied for water resource management purposes. In addition, the model can simulate the consequences of various scenarios, e. g. concerning climate change. Jürgen Schuol, Karim C. Abbaspour, Hong Yang

Without information on freshwater availability, the provision of secure supplies cannot be planned

Information on spatial and temporal variations in freshwater availability at the national and regional level is of crucial importance for strategic water planning and management, especially with regard to water and food security.

Taking soil water into account

The assessments of national freshwater resources published by major international bodies such as the Food and Agriculture Organization (FAO) and the United Nations Educational, Scientific, and Cultural Organization (UNESCO) contain merely rough estimates of the average availability of so-called blue water (river discharge and groundwater recharge) on an annual basis. In addition, no estimates have been made, at this scale, of so-called green water (soil moisture or evapotranspiration), although these resources play an essential role in sustaining the ecosystem and rain-fed agriculture.

At Eawag, we use the semi-physically based, distributed hydrological model SWAT (Soil and Water Assessment Tool). With the aid of this program, we quantified the freshwater resources available over a 4 million km^2 area encompassing 18 countries in West Africa (Fig. 1). To calibrate the model and to estimate the prediction uncertainty arising from uncertainties in the input data, model structure and model parameters, SUFI-2 (Sequential Uncertainty Fitting Algorithm) was used.

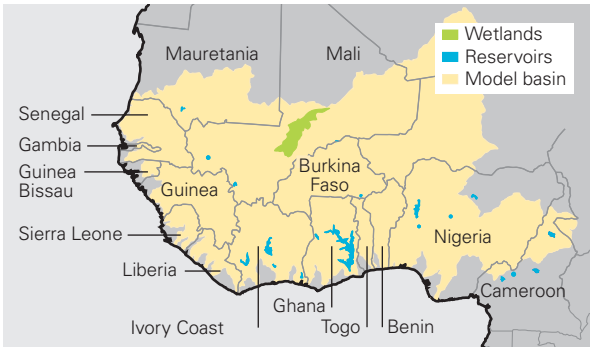
The main advantages of our approach are as follows:

- ▶ All the components of the hydrological cycle are estimated on the basis of daily weather data, generated from monthly climate grids.
- ▶ All the components of freshwater resources (blue and green water) can be quantified on a monthly basis.
- ▶ The calculations are based on individual spatial units consisting of soil-land use overlays, taking major wetlands and large reservoirs into consideration. This makes it possible to calculate a country's freshwater resources at a sub-basin or regional level.
- ▶ Modelling includes in-depth calibration and validation, together with uncertainty estimation. This makes it a reliable tool for decision support.
- ▶ The model can be readily expanded as soon as additional input data become available.

Extension to the whole continent

The aggregated results for 11 countries – relating to the "blue" component of internally renewable freshwater resources – were compared with estimates from two previous studies (the FAO's Aquastat system and Kassel University's WaterGAP model) (Fig. 2). Although, in most cases, the estimates from these studies fall within the prediction uncertainty interval of our model, they do not permit conclusions at a finer level of spatial or temporal detail.

Our study is part of a larger project designed to quantify global freshwater resources. As a next step, in the light of our positive experience to date, we intend to develop a model for the entire continent of Africa. ○○○



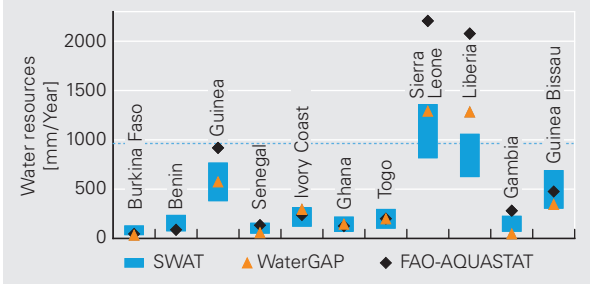


Fig. 1 (top): The area of West Africa covered by the model
Fig. 2 (bottom): SWAT estimates (including uncertainty intervals) of internally renewable freshwater resources (blue water) compared with the Aquastat and WaterGAP estimates; for comparison, the horizontal dashed line shows the mean value for Switzerland (968 mm/year).

Schuol J., Abbaspour K.C. (2006): Using monthly weather statistics to generate daily data in a SWAT model application to West Africa. Ecological Modelling, in press.

Schuol J., Abbaspour K.C., Yang H., Srinivasan R. (2006): Estimation of freshwater availability in the West African sub-continent using the SWAT hydrologic model. Journal of Hydrology, submitted.

Closing nutrient cycles

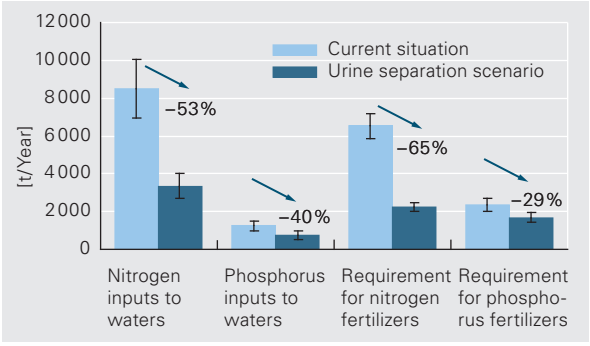
In the rapidly growing cities of developing and emerging countries, new approaches to urban wastewater and solid waste management are urgently required. As well as improving public health, there is a need to use resources sustainably and to protect the environment. In cooperation with local partners in Vietnam, Eawag has developed a model that can predict how new systems would affect water and nutrient consumption, nutrient inputs to the environment and nutrient recycling. Agnès Montangero, Le Ngoc Cau, Nguyen Viet Anh, Vu Dinh Tuan, Pham Thuy Nga, Hasan Belevi, Roland Schertenleib

Over the past few decades, Hanoi, the capital of Vietnam, has experienced dramatic population growth and economic expansion, with rapid industrialization. Increases in environmental pollution and resource consumption have been equally dramatic. Growing volumes of wastewater are discharged into surface waters. Rivers and lakes exhibit high concentrations of organic matter, nutrients and pathogenic organisms, together with low concentrations of oxygen. The use of artificial fertilizers in periurban agriculture has shot up. Groundwater is also being overexploited, and land is subsiding in various parts of the city.

Model to support local actors

How can the region's natural resources be conserved for future generations? Working together with partner organizations in Vietnam, we have developed a mathematical model to predict – even with limited data – how various scenarios affect water and nutrient flows. This model is generally applicable to urban regions in developing countries, using data from the areas of water supply, wastewater and solid waste management, and agriculture. Where data is not available, we show how gaps can be filled by eliciting expert judgements [1]. Probability distributions are used to describe uncertainties [2, 3].

The model supports local actors in the development of appropriate strategies and measures. For example, it can help them to select those systems of excreta and wastewater management that are most conducive to closing nutrient cycles. In Hanoi, toilet wastewater is usually treated in septic tanks before being released into open roadside drainage channels and ultimately entering the nearest receiving waters. However, only a small proportion of the nutrients is retained as sludge in the septic tank (5–14% of the nitrogen and 11–27% of the phosphorus load) [1]. The tanks are thus not an efficient option for reducing nutrient inputs to surface waters. We found that the double-pit urine diversion latrines formerly widespread in North Vietnam offer crucial advantages over septic tanks. Apart from a small amount of nitrogen released as ammonia during urine storage, this latrine system retains all the nutrients contained in human excreta. These nutrients could be used as an alternative to artificial fertilizers, and at the same time nitrogen and phosphorus inputs to surface waters would be substantially reduced (see Figure).



Urine source separation could substantially reduce nutrient inputs to surface waters and the amounts of artificial fertilizers required in Hanoi Province.

Part of an integrated planning approach

Our model now needs to be incorporated into an integrated planning approach and undergo further testing. Before a city can adopt a given wastewater management strategy, a number of other questions have to be taken into consideration – for example, the impacts on public health, the acceptability of new sanitary facilities, the readiness to shoulder additional costs, or the issue of whether, over the longer term, a market actually exists for "products" such as urine and hygienized faecal matter. ○○○

Urine source separation in Vietnam: a double-pit latrine, with openings in the latrine floor to the two chambers for faeces, a urine diversion channel and a urine pot (right).

[1] Montangero A., Belevi B. (2007): Assessing nutrient flows in septic tanks by eliciting expert judgement: A promising method in the context of developing countries. Water Research 41, 1052–1064.
[2] Montangero A., Belevi B.: An approach to optimise nutrient management in environmental sanitation systems with limited data availability. Submitted to Journal of Environmental Management.
[3] Montangero A., Cau L.N., Viet Anh N., Tuan V.D., Nga P.T., Belevi H. (2007): Optimising water and phosphorus management in the environmental sanitation system of Hanoi, Vietnam. Science of The Total Environment (accepted).

Aquatic ecosystems

This area of Eawag's research is concerned with the sustainable management of aquatic ecosystems, focusing on the restoration of near-natural habitats and biodiversity – not least in connection with climate change. Understanding how and why species develop and disappear is essential if we are to find ways of stemming irretrievable losses of genetic resources.

There is a growing awareness worldwide that intact waterbodies are not only important for the preservation of biological diversity but also beneficial for humans. The valuable "services" provided by aquatic ecosystems include the safeguarding of water resources and uses over the long term and integrated flood protection. In the EU, the Water Framework Directive calls for the achievement of "good ecological status" for all surface waters in the coming years. In most cases, rehabilitation will be required. Similar goals are defined by the World Conservation Union (IUCN) in its 5-year action plan for "healthy rivers and heathy communities". This initiative is also in line with the aims of the UN Water for Life Decade (2005–2015).

Sustainable water management

Eawag is developing scientific foundations for sustainable water resource management. This research takes into account not only human influences on the quantity, quality and ecology of water resources but also the impacts of climate change. Several Eawag projects from this field have been directly incorporated into the education and research units of the newly established Competence Centres of the ETH Domain for Environment and Sustainability (CCES) and for Energy and Mobility (CCEM) (see page 5). One example of how criteria elaborated by water researchers can be successfully applied in practice is the greenhydro standard. This tool, developed by Eawag in a transdisciplinary project in 2001, is now being successively adopted internationally for the certification of green hydropower (page 37). The criteria specified include, for example, functional bypass channels or modern fish ladders. These can help to restore the connectivity of rivers disrupted by hydropower plants, as demonstrated by studies on the upstream migration of lake trout in the Alpine and Anterior Rhine (page 35).

as a tat

Another key area of Eawag's research involves the impacts of large dams, particularly in developing and emerging countries. What levels of greenhouse gases are emitted by new reservoirs in tropical regions? What organisms are damaged? How are sediment and nutrient balances altered, and how is the regional hydrological cycle affected? In the case of the Zambezi Basin, for example, questions also arise as to the allocation of scarce water resources to satisfy competing needs – irrigation, hydropower or nature reserves.

Switzerland: an ideal open-air laboratory

In the coming years, one of the major research projects in the aquatic ecosystems field will be concerned with the rapid, but scarcely documented, decline of biodiversity in Central Europe. Switzerland is particularly well suited for this research since, especially in Alpine and pre-Alpine waters, a broad spectrum of species developed within a short time during the postglacial period. In addition, these habitats not only encompass, within a small area, the four main Central European river systems (Rhine, Rhône, Po and Danube) but also exhibit widely varying climatic conditions, from Arctic to Mediterranean. Only by explaining, quantifying and modelling species loss trends and patterns, can we develop solutions for sustainable management of biodiversity – in the face of pressures from global environmental change and regional socioeconomic conditions.

Emergence and loss of species

The potential impact of human interventions on biodiversity is illustrated by the article on cichlids of Lake Victoria (page 36). Here, the introduction of a rapidly spreading alien species and the increased turbidity of the water due to deforestation have led to the disappearance of around 200 cichlid species over the past 25 years. The Aquatic Ecology (formerly Limnology) and Fish Ecology + Evolution departments have expanded their research in the area of population genetics: just as changing environmental conditions can lead to the extinction of individual species, evolution brings forth new species through specific adaptations to local conditions

Under the ice: more life than expected

Up till now it has been assumed that lake ecosystems do not begin to function fully until spring, when temperatures have risen, the snow has melted and the lake ice cover has thawed. However, we were able to show that life does not come to a standstill under the ice cover, and that conditions there are not as adverse for all species as had previously been supposed. Michael Sturm, David M. Livingstone

Temperatures well below zero, icy winds, a thick layer of ice and several metres of snow – such are the inhospitable winter conditions prevailing on numerous Alpine lakes, which even today are still regularly frozen over for many months of the year. Certain organisms, however, are resistant to or actually thrive under these conditions, although they would appear to be hostile to life.

Life within the ice itself

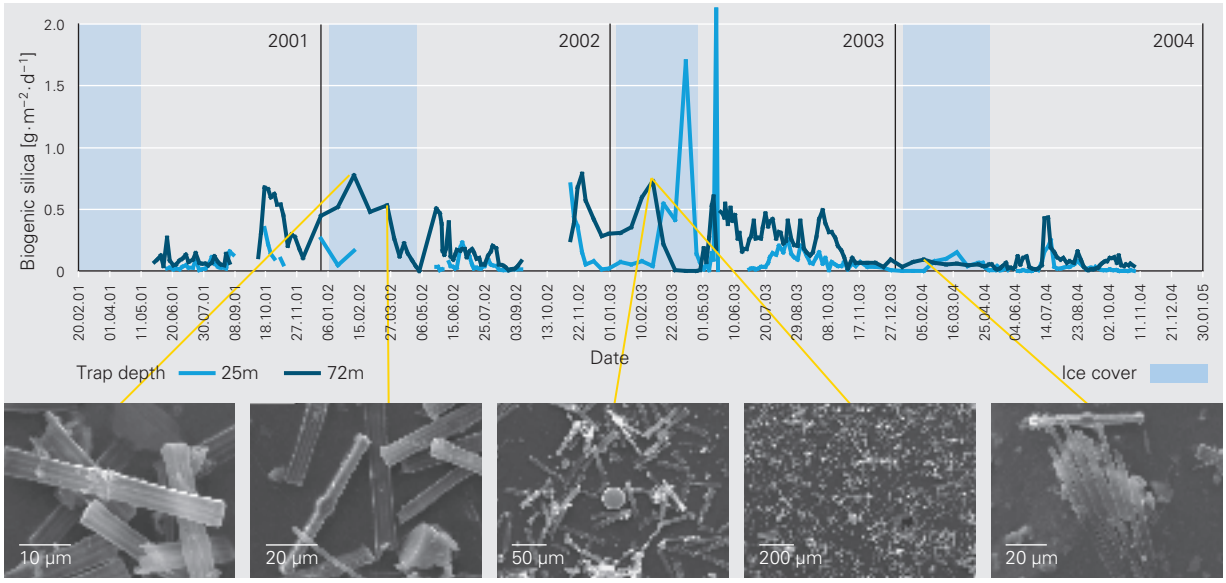
In recent years, a number of research teams, prompted by research on global warming, have begun to investigate cryophiles or psychrophiles, i. e. groups of organisms that are dependent on cold environmental conditions for their survival. On Lake Baikal in Siberia, for example, Russian researchers observed a variety of single-celled organisms (particularly ciliates) that can live and survive within and directly below the ice.

Sediment traps at the lake bottom

From 2001 to 2006, we deployed sediment traps in Lej da Silvaplauna ("Lake Silvaplana") in the Upper Engadine region of Switzerland. With these automatic sampling devices, suspended particles sinking through the water column can be measured at intervals of only 1–2 days even when the lake is covered with ice. As expected, the results of the laboratory studies showed seasonal differences, with markedly higher sedimentation rates occurring during ice-free periods, owing to summer meltwater run-off and internal biological production. In the exceptionally hot summer of 2003, peak sediment concentrations – 71 g/m^2 per day – were three to five times greater than those recorded in "normal" summers (Figure). This was due to the increased melting of glaciers in the catchment area.

More surprising, however, than the findings from the hot summer of 2003 was the fact that increased levels of biogenic silica (BSi) were observed in sediment samples

Top: Divers retrieve the sediment traps from the frozen Lake Silvaplana, after the ropes got entangled. Bottom: Lake Walen, like all other European lakes, is warming up.

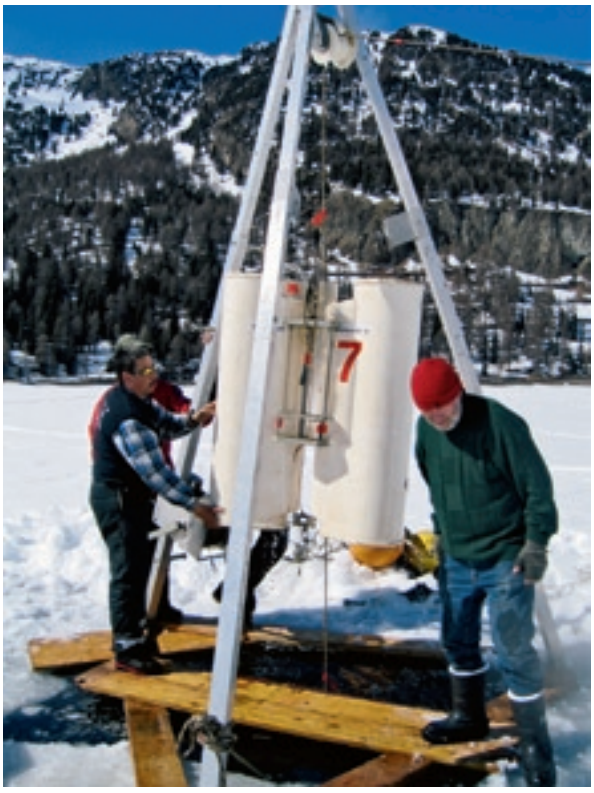


Seasonal distribution of biogenic silica (BSi) in sediment trap material from Lake Silvaplana in the Swiss Alps. Electron micrographs of samples with increased BSi concentrations show that the peaks are attributable to the proliferation of the shells of diatoms (rod-shaped) and, in isolated cases, also of golden algae (round).

not only during summer but also during the months of ice cover. Since BSi is derived exclusively from autochthonous algae (diatoms, golden algae/Chrysophyceae), this implies that in Lake Silvaplana – which is ice-covered during 146 days per year on average – the nutrient, temperature and light conditions necessary for photosynthesis must prevail at times even under the ice. Conclusive evidence of biological production – "life under ice" – is provided by the simultaneously elevated concentrations of organic carbon (C_{org}), the excellent correlation of C_{org} with BSi ($r^2 = 0.99$, $p < 0.001$), and the low carbon-to-nitrogen ratio, which is indicative of algal growth (C/N values ≤10). Finally, it was confirmed by scanning electron microscopy (SEM) studies that the samples consisted mainly of the debris of diatoms and golden algae. As the sinking speed of the shells of the dead algae is known, we were able

Climate research in the Engadine

The interdisciplinary research project ENLARGE (ENvironmental changes in mountain regions recorded in high-resolution archives of LAkes of the UppeR EnGadinE), launched in 2001 and funded by the Swiss National Science Foundation (SNF), investigated climatic and environmental conditions in the Upper Engadine – including the topic of life under the ice. ENLARGE was carried out in close cooperation with the SNF National Centre of Competence in Research (NCCR) Climate. Since 2001, this network has brought together more than 150 scientists from 12 universities and research institutes. The aim of this collaboration is to improve our understanding of the climate system and of the consequences of climate change for ecosystems. A booklet (in German) on climate research in the Engadine has just been published by the NCCR Climate and the Graubünden Museum of Nature. It can be obtained free of charge by contacting info@bnm.gr.ch or Tel. +41 (0)81 257 28 41.



Recovery of the sediment traps from Lake Silvaplana (1791 m a.s.l.).

Sediment core and water samples were collected for the first time from Lake Lunghin (2484 m a.s.l.). A helicopter was required to transport the material.

to exclude the possibility that the debris originated from organisms formed before the onset of ice cover.

Similar findings in Sweden and Siberia

We also looked for – and found – life under the ice in Nylandsjøn, a small lake in northern Sweden close to the Arctic Circle, and in Lake Baikal. In both lakes, which are ice-covered for more than 150 days a year, sediment traps were deployed for automatic sample collection. Here, too, it was shown that diatom production begins under the ice in April/May, leading to increased concentrations of BSi and C_{org} in the suspended particles. As in the case of Lake Silvaplana, SEM analysis of samples from these two lakes confirmed that these increased concentrations were the result of the presence of the siliceous shells of cryophilic diatoms.

Life under the ice thus represents an important element of the ecological cycle that has been largely neglected to date. Among the effects of global warming already evident today is a marked shortening of the duration of ice cover on lakes and seas (see right). The effects of this on cryophilic organisms, and hence its potential for inducing changes in aquatic ecosystems, therefore needs to be studied more closely. This will require an improved knowledge of the interactions between ice and life. ○ ○ ○

Europe's lakes are warming

Eawag participated in the EU CLIME project (Climate and Lake Impacts in Europe), contributing data from the Lake of Zurich, Greifensee and the Lake of Walenstadt. The findings from Switzerland were confirmed across Europe: temperatures are rising steadily in the continent's lakes, even well below the surface. In the Lake of Zurich, for example, water temperatures have increased by over 1 °C at the surface and by around 0.5 °C at 20 metres depth. In addition, measurements indicate that the summer period in the Lake of Zurich now lasts on average two weeks longer than 30 years ago. However, the high temperatures at the surface are not the only problem confronting fish. Because the period of stable thermal stratification in summer – during which lake water cannot circulate between lower and upper layers – is now longer, less oxygen is transported into the deep waters. Higher temperatures also promote the growth of algae, and the decomposition of dead organic matter increases oxygen depletion. Thus, life-threatening low-oxygen zones expand within the lake. Further impacts are to be expected, including, potentially, adverse effects on water quality, e. g. due to increased growth of potentially toxic blue-green algae.

Measurement platform on Lake Tscheppa (2616 m a.s.l.) in the Engadine.

Later freezing, earlier thawing

The effect of rising air temperatures on lakes can be traced back even further by analysing historical ice phenology records – i. e., records of observations of the timing of freezing and thawing of lakes and rivers. Continuous ice phenology data extending back to 1832, for instance, is available from Lej da San Murezzan ("Lake St. Moritz") in the Upper Engadine. We compared these data with records of ice cover from Northern Hemisphere lakes and rivers stretching from Lake Baikal in Siberia to Lake Mendota in Wisconsin. Since the mid-nineteenth century, all the lakes studied have tended to freeze later and thaw earlier, with mean trends of 5.7 days per 100 years for freezing and 6.3 days per 100 years for thawing. The resulting decreasing trend of 12 days per 100 years in the duration of ice cover corresponds to an increase of 1.2 °C per 100 years in air temperature. The consequences of shorter periods of ice cover have yet to be established, but it is already clear that the resulting earlier onset of spring mixing is leading to earlier phytoplankton blooms. However, the shorter days lead to a reduction in the available light intensity, which may affect the phytoplankton species composition.

Blass A., Grosjean M., Troxler A., Sturm M. (2007): How stable are 20th century calibration models? A high-resolution summer temperature reconstruction for the eastern Swiss Alps back to A.D. 1580 derived from proglacial varved sediments.The Holocene 17/1, 51–63.

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Weyhenmeyer G.A., Meili M., Livingstone D.M. (2004): Nonlinear temperature response of lake ice breakup; Geophys. Res. Lett., 2004, 31 (7).

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Livingstone, D.M. (2003): Impact of secular climate change on the thermal structure of a large temperate central European lake. Clim. Change, 57(1), 205–225.

Environmental change and increased risk of disease in freshwater ecosystems

Environmental changes such as rising temperatures can be stress factors for certain species. We demonstrated that stress increases the susceptibility of freshwater clams to disease or parasite infection. This has an impact on biodiversity in aquatic ecosystems. Jukka Jokela

The situation is only too familiar; it is winter. We work long hours at the office, sleep badly because of a project deadline, eat on the go and finally come down with flu the night before an important meeting. How stress renders humans prone to disease is fairly well documented. Another scenario is less well known: It is summer. Trout are living in a polluted river; the water is warmer than usual, food is sparse, and parasites are present. We are studying how environmental stress factors associated with changes in the freshwater ecosystem – such as anoxia, temperature increase or starvation – promote diseases in aquatic organisms.

Warm rivers preferred by parasites

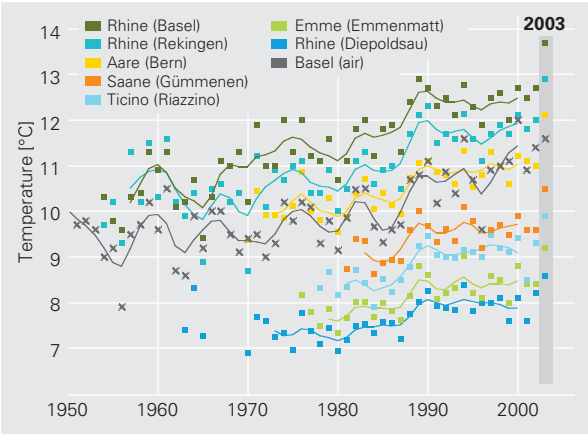
Over the past 50 years, the temperature in Switzerland's rivers has steadily increased. Extended periods of extreme temperatures (such as the hot summer of 2003) and higher extremes expose organisms to severe stress. Increased stress is assumed to weaken their defences, promoting the invasion of opportunistic parasites and pathogens and leading to a higher incidence of disease and mortality. A case in point in Switzerland is the increased incidence of proliferative kidney disease (PKD) observed in recent decades. This is partly responsible for severe reductions in populations of wild fish – trout in particular – in rivers and lakes. The disease is more likely to spread as temperatures rise [1, 2]. In a current study, we are analysing the life cycle and transmission dynamics of the PKD parasites.

Brown trout are particularly hard hit by high water temperatures.

Clams under stress

In experiments involving natural populations, we analysed how two severe stress factors – anoxia and starvation – affect the susceptibility of the freshwater clam *Anodonta piscinalis* to disease. Anoxia may develop in eutrophic lakes and ponds, and clams may suffer starvation as a result of seasonal fluctuations in food resources. At the same time, we evaluated the effects of two parasite species with different exploitation rates. We found that clams infected with parasites died markedly faster under both stress conditions. Stress combined with infection thus appears to substantially reduce the clams' chances of survival [3].

Both studies fall within the emerging field of aquatic epidemiology, which is concerned with the ecology, evolution and environmental drivers of aquatic diseases. The key question is: how do (parasitic) diseases vary over time, and how does this affect the biodiversity and ecosystem of aquatic habitats. Therefore, as well as investigating the evolutionary and transmission dynamics of the parasites, we are attempting to predict future trends.



Annual average temperatures of some Swiss rivers (adapted from FOEN Environmental publication series no. 369 – impacts of the hot summer of 2003 on waterbodies).
Squares = annual average, curves = running 7-year average

[1] Burkhardt-Holm P., Giger W., Güttinger H., Ochsenbein U., Peter A., Scheurer K., Segner H., Staub E., Suter M.J.F.: Where have all the fish gone? Environmental Science & Technology, 2005, 39, 21, 441A–447A.
[2] Wahli T., Knuesel R., Bernet D., Segner H., Pugovkin D., Burkhardt-Holm P., Escher M., Schmidt-Posthaus H. (2002): Proliferative kidney disease in Switzerland: current state of knowledge. Journal of Fish Diseases 25, 491–500.
[3] Jokela J., Taskinen J., Mutikainen P., Kopp K. (2005): Virulence of parasites in hosts under environmental stress: experiments with anoxia and starvation; Oikos, 2005.
www.fischnetz.ch

Temporary rivers: not always detrimental

As glaciers recede, temporary streams are becoming increasingly common even in alpine regions. Dry reaches of watercourses have previously been regarded as biologically inactive. We have shown that temporary waters can influence biodiversity by enhancing population dynamics. Christopher Robinson, Lisa Shama, Scott Larned[1], Thibault Datry[2]

The survival of populations in ephemeral habitats can be assured by two processes: specialization (local adaptation) or changing morphological and physiological traits in response to environmental cues (phenotypic plasticity). In the absence of such a strategy, the species will suffer local extinction, and recolonization from other populations will be required.

The River Selwyn near Christchurch (New Zealand) before and during a dry period. Parts of the riverbed may dry up for over a year.

Adapting to temporal constraints

In the Roseg valley, using the alpine caddisfly *Allogamus uncatus* as a model system, we studied how population development and genetic structure respond to dry stress conditions. In experiments involving dry stress, larvae from permanent streams grew more slowly than those from temporary streams. Larvae from both temporary and permanent streams accelerated their development when the approach of winter was simulated via artificially shortened days. Populations from permanent streams exhibit adaptations to local conditions, whereas no consistent picture emerged for populations from temporary streams, with major differences observed between males and females. Local extinction and subsequent recolonization from neighbouring populations in the valley is a normal occurrence for species in ephemeral waters. This population turnover influences genetic variation and hence species evolution. If large numbers of individuals from many different source populations are present, turnover has a homogenizing effect. If the number of colonists is small and individuals originate from only a few sources, turnover may result in differentiation of the population genetic structure. If recolonization is prevented, e. g. by major floods, genetic diversity is reduced, harmful mutations are transmitted, inbreeding increases, and the adaptive potential of the population declines.

Metapopulation structure

Using microsatellite markers, we investigated the genetic structure of *Allogamus uncatus* populations before and after an extreme dry period (summer 2003). Connectivity with neighbouring areas was also taken into consideration. It was shown that gene flow (disperal) must occur frequently, since none of the populations was significantly differentiated from the others. Overall, *Allogamus uncatus* displays a metapopulation structure: the caddisflies form a network of populations characterized by migration, local extinction and recolonization. Adaptation to selection pressures in temporary waters rarely occurs, as survival is assured by the gene flow from neighbouring permanent streams.

Shama L.N.S., Robinson C.T.: Sex-specific life-history responses to seasonal time constraints in an alpine caddisfly. Evolutionary Ecology Research 2006(1)

Robinson C.T., Matthaei S., Logue J.B.: Rapid response of alpine streams to climate induced temperature change. Verh. Internat. Verein. Limnol., 2006, 29, 1565–1568.

[1] National Institute of Water and Atmospheric Research (Niwa), Christchurch

[2] Institut Cemagref. Lyon

Length of dry period is decisive

In fluvial landscapes, temporarily flooded transitional zones between land and water increase habitat heterogeneity and generally exhibit a high degree of biodiversity. Inundation triggers brief periods of significant biogeochemical and biological activity: nutrients and organic matter suddenly become available, algal and microbial growth begins, and invertebrate eggs hatch. At the same time, inundation also kills and displaces terrestrial organisms, or forces them to enter resistant stages.

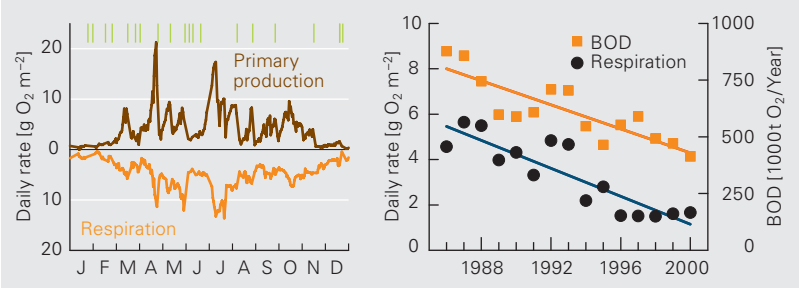
We investigated the effects of a 17-day inundation on invertebrates and microbes in sediments from the River Selwyn in New Zealand. Before the samples were collected, the sediments had been dry for 1–592 days: the richness and density of invertebrate species decreased rapidly with the length of the preceding dry period. Likewise, microbial activity – determined using measures of sediment respiration and esterase activity – decreased exponentially. Only small numbers of individuals from a few resistant invertebrate species survived prolonged dry periods. Dry periods that are longer than invertebrate generation times reduce the efficacy of certain adaptive traits. Survival is only possible through the development of desiccation-resistant eggs or pupae. Conversely, certain terrestrial species are able to survive periods of inundation as a result of traits such as plastron respiration and water-resistant eggs. Thus, natural flow dynamics also increase biodiversity in ephemeral rivers, whereas water abstraction or flow regulation causing long-term drying of river channels will lead to a loss of species.

Floods and wastewater treatment plants influence energy and oxygen balance

Oxygen concentration curves can be used to calculate primary production and oxygen consumption in watercourses. Due to a unique long-term measurement at the river Thur, it is possible to suggest natural and anthropogenic changes in the river basin, specially the improved performance of the wastewater treatment plants. Urs Uehlinger

Primary production and oxygen consumption are key processes in the energy balance of watercourses. Primary producers (algae, mosses and higher aquatic plants) use light energy to synthesize organic matter from inorganic compounds, with oxygen being released in the process. Primary products and organic matter from the area adjoining the watercourse are decomposed by non-primary producers – microorganisms and invertebrates – with oxygen being consumed in the process (respiration). Despite aeration, low oxygen concentrations and a poor water quality could be the consequences. In the course of a day, primary production and respiration lead to variation in the concentrations of oxygen in water. Accordingly, the 24-hour (diel) oxygen curve can be used to calculate the primary production and respiration for a reach of river.

High nutrient concentrations and abundant light promote rapid algal growth after a flood.



Left: Primary production and respiration in 1995. Green lines = bedload moving spates.
Rignt: Trends for annual respiration rate and annual discharges of biodegradable organic matter (measured as biochemical oxygen demand) from the five major wastewater treatment plants upstream of the study reach.

Unique long-term measurement series

On the lower reaches of the River Thur, a prealpine tributary of the upper Rhine, oxygen concentrations have been continuously recorded at the NADUF[1] station of Andelfingen since 1986. On the basis of this unique measurement series, it was possible to determine primary production and respiration values for the 28 km stretch upstream of the gauging station at a high temporal resolution.

On the Thur, floods involving bedload transport are frequent disturbances, occurring on average 15 times per year. Such events cause substantially greater damage to primary producers (algae), which grow on the surface of the river bed, than to non-primary producers, whose habitat includes the deeper and relatively well protected bed layers. Thus, floods reduce primary production on average by 50%, but respiration by only 20%. On the other hand, primary production recovers rapidly (within 20 days) between spring and autumn, while respiration only rises slowly again after a flood (Figure). The rapid recovery of primary production is promoted by relatively high concentrations of the nutrients nitrogen and phosphorus, high water temperatures and favourable light conditions.

Effects of wastewater treatment

Over the period 1986–2000, no trend was apparent in annual primary production. While average phosphate concentrations declined in the same period from 0.187 to 0.047 mg P/l, the latter value is still 3 to 15 times higher than the threshold below which algal growth and primary production are limited by phosphorus concentrations. In contrast to primary production, the average annual respiration rate fell by around 50%. This decrease coincides with a marked reduction in the readily biodegradable organic matter – measured as biochemical oxygen demand (BOD) – discharged into the Thur from the five major wastewater treatment facilities lying upstream of the study reach. It is reasonable to conclude that the reduction of annual oxygen consumption in the study reach – a decrease of no less than 1133 t O_2 over 15 years – is mainly attributable to improved elimination of organic compounds at the wastewater treatment plants. ○○○

[1] NADUF: National River Monitoring and Survey Programme; www.naduf.ch.

Uehlinger U. (2006): Annual cycle and inter-annual variability of gross primary production and ecosystem respiration in a floodprone river during a 15-year period. Freshwater Biology 51, 938–950.

Jakob A., Binderheim-Bankay E. et al. (2002): «National long-term surveillance of Swiss rivers». Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie 28, 1101–1106.

Lake resident brown trout spawn again in the Anterior Rhine

The installation of a fish ladder at the Reichenau hydropower plant restored access to the lake resident brown trout spawning grounds of the Posterior (Hinterrhein) and Anterior Rhine (Vorderrhein). Our radiotelemetry studies showed that lake resident brown trout are actually taking advantage of this connectivity. In addition, we documented the spawning site requirements of the endangered fish species. Reto Caviezel, Armin Peter

Historical sources indicate that lake resident brown trout from Lake Constance used to migrate for reproduction along the Anterior Rhine as far as Disentis. However, the important spawning areas of the Anterior and Posterior Rhine were cut off from Lake Constance by the construction of the Reichenau hydropower plant in 1959. Around 40 years later, in 2000, a fishladder was integrated into this facility.

126 kilometres from Lake Constance

Initial evidence of upstream migration by lake resident brown trout was provided by our radiotelemetry studies performed in 2001 and 2002. In 2005–2006, we specifically investigated how the newly accessible spawning areas of the Posterior and Anterior Rhine are used, and we also studied the spawning site requirements of the endangered species. In October 2005, 19 up-migrating trout measuring 53–73 cm in length were caught in a trap in the Reichenau fish ladder – 90 km upstream of Lake Constance. The fish were anaesthetized, measured and implanted with a transmitter. With the aid of directional antennas and receivers, they could then be continuously and precisely tracked.

Four fish migrated to the Posterior and 15 to the Anterior Rhine. On average, the trout swam up the Anterior Rhine at a rate of 5 km per day. Ten days after being captured in the fish ladder, almost all of them had reached their spawning sites. The mean migration distance from the Reichenau dam was 20 km (minimum 8.7 km, maximum 35.8 km). In the Posterior Rhine, a female swam 16 km upstream to where the Albula River enters the river. The spawning sites used in the Anterior Rhine are distributed along the reach between Trin (6 km above Reichenau) and Tavanasa (36 km above Reichenau). None of the radiotagged trout migrated further upstream than the Tavanasa hydropower plant. The maximum migration distance observed for a trout from Lake Constance was 126 km. Migrations of this length are no longer possible in any other Swiss watercourse.

Good chance of survival

The preferred rate of flow over the spawning habitats is 55 cm/second (range 28–85 cm/second), with a water depth of 32 cm (range 18–50 cm). The favoured spawning substrate is gravel with a particle size of 15–65 mm. The spawning sites inventoried comprised several redds (5–6 at most). Egg survival in the gravel was documented in an incubation experiment. In the Anterior Rhine, trout eggs were buried in plastic boxes. Of the 200 eggs exposed at the beginning of December 2005, 174 (78%) survived until April 2006. Thus, natural reproduction is successful in this spawning area, and presumably also in many other parts of the Anterior Rhine. No firm conclusions can be drawn as to the situation in the Posterior Rhine, as we were not able to observe sufficient numbers of fish. Another question requiring closer examination is the effect of hydropeaking – rapid changes in water levels due to hydropower operations – on natural spawning.

The migration back to Lake Constance appears to be difficult: of the 38 lake resident brown trout tracked in 2001 and 2002, only 7 fish (18%) managed to swim back to the lake. Nonetheless, the results provide grounds for hope that populations of the endangered lake resident brown trout may recover in the coming years. ○ ○ ○

A (male) lake resident brown trout from Lake Constance, captured in the Alpine Rhine.

The radiotelemetry transmitter, encapsulated in resin, is implanted in the body cavity of the trout

[1] Caviezel R. (2006): Reproduktion der Seeforelle im Vorderrhein; Diplomarbeit ETHZ betreut von Armin Peter. www.rhone-thur.eawag.ch > Publikationen.

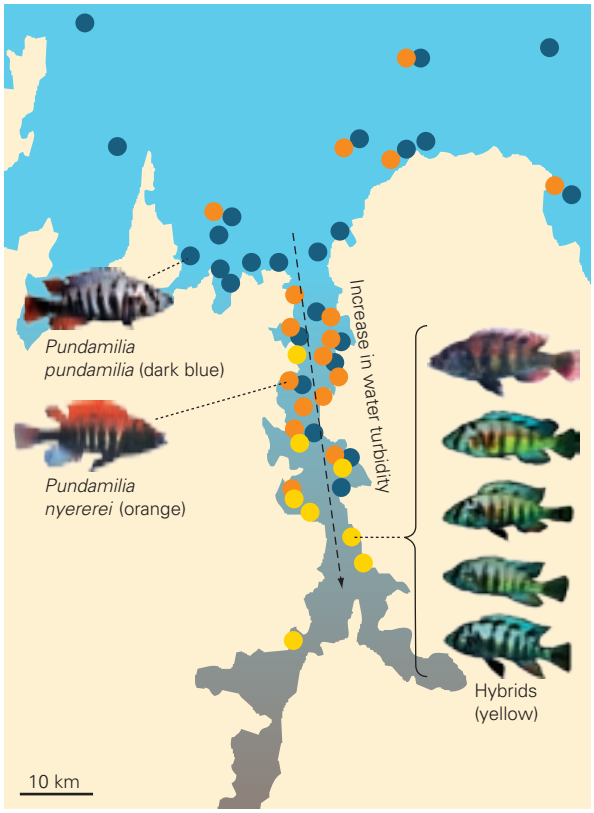
[2] Klunzinger C.B. (1881): Die Fische in Württemberg, faunistisch-biologisch betrachet, und die Fischereiverhältnisse daselbst. Jahreshefte des Vereins für vaterländische Naturkunde in Württemberg 37, 172–304.

Increased turbidity reduces fish diversity

Manmade changes in ecosystems strongly influence the processes that lead to the formation, change and disappearance of species. In Lake Victoria for instance, deepened turbidity changed the ecology of cichlids, which in turn lead to increased hybridization and genetic merging of originally differently adapted species to fewer hybrid populations. Vicky Schneider, Ole Seehausen

Sometimes, diving in Lake Victoria, one of the Great Lakes of Africa is like diving in a tropical aquarium: An astonishing variety of cichlids – common aquarium fish and the tropics most important food fish – in different sizes, shapes and colours inhabits this large freshwater body. But this ecosystem is not a mere diver's delight. It actually provides a unique setting for scientists interested in biodiversity dynamics. Scientist in the department Fish Ecology and Evolution repeatedly return to Lake Victoria to study the mechanisms that lead to the formation and the loss of species diversity.

Less picky fish gain a selection advantage in turbid water.



Map of the Mwanza golf, from which we took two cichlid fish species *Pundamilia nyererei* and *Pundamilia pundamilia*. In clear water, both species were present (blue and orange dots); in turbid water an increased number of hybrid phenotypes can be found (yellow dots).

Picky fish die out

Lake Victoria is unique: In a few thousand years, 500 endemic species were formed in this lake. Unfortunately, it is also the site of the largest mass extinction of animal species in history. With eutrophication and the introduction of a predator fish – the Nile perch – the Lake Victoria ecosystem underwent a dramatic transformation and approximately 200 endemic cichlid species disappeared in the last 25 years. Over the last 15 years, we have studied this process and showed that increased water turbidity directly affected the coexistence of cichlid species. We found more than 30 genetically and ecologically diverse species in any one clear water location, whereas in turbid water only a few species persisted, of which some shared the characteristics of several species. Bad visibility constrains the cichlids' ecology and the effort to find the right mate and food increases. Less picky fish then gain a selection advantage because they spend less time and incur less risk when looking for a mate or food. Random mating then turns multiple ecologically specialized species into fewer unspecialized populations of hybrid origins.

The cichlid ancestor

On the other hand, we analyzed how ecological selection pressure and genetic exchange between populations can interact to generate biodiversity. Salome Mwaiko and colleagues recently studied mitochondrial DNA (mtDNA) and nuclear DNA of different species from all drainage systems that historically were connected to Lake Victoria. When looking at nuclear DNA, inherited from both parents, their results show that the diversity of cichlids descends from at least four different river cichlids. However, when looking at the maternally inherited mtDNA, all cichlids had the same single ancestor. This seeming contradiction indicates that originally at least four unrelated species populated the rivers of the region. Upon colonizing Lake Victoria, these species appear to have hybridized and through a variety of adaptations in a very heterogeneous environment several hundred endemic species developed from the hybrid ancestor.

Variety of environments is crucial

Taking into consideration both aspects outlined above, our work shows that hybridization between species can contribute to the formation of biodiversity, as long as evolution occurs in a heterogeneous environment. However, if the environment loses its heterogeneity (e.g. through increased turbidity), hybridization can cause a quick collapse of species diversity. Therefore, we are currently analyzing whether and how similar processes influence the origin and loss of diversity of whitefish in Swiss Lakes.

Seehausen (2006): Conservation: Losing biodiversity by reverse speciation. Current Biology Vol 16(9).
www.fishecology.ch

Greenhydro goes international

Six years after the completion of the Green Electricity project, it is increasingly clear that the *greenhydro* certification procedure developed by Eawag is a powerful tool, with the potential to become an international standard. It would be feasible to apply these requirements for environmentally sound hydropower production in Germany, and China is now also taking an interest in the *greenhydro* standard. Annette Ruef, Jochen Markard, Cirus

In Switzerland, sales of green power products certified to the naturemade star quality standard are booming. Leading the field is the Municipal Electric Utility of Zurich (ewz), where sales rose more than tenfold in 2006 to about 180 GWh – or 6% of total power sales. The main source of certified green electricity is still hydropower. More than 80% of the green power consumed in Switzerland is generated by hydroelectric plants certified according to Eawag's *greenhydro* procedure. But since hydropower also accounts for the lion's share of green electricity abroad, efforts are under way at the international level to define consistent quality standards for green hydropower. As part of the CLEAN-E project, Eawag took part in preparatory work on transferring the *greenhydro* standard to other countries. At the same time, a feasibility study for Germany was carried out in collaboration with partners from academia and the electricity sector.

Competition from feed-in tariffs

Experience at four pilot facilities showed that the basic requirements are readily applicable to German power plants. However, difficulties are posed by the legal and economic framework existing in Germany: while the *greenhydro* procedure is fully compatible with – and indeed goes well beyond – the water protection regulations, new challenges arise from the Renewable Energy Sources Act (EEG), which is designed to promote environmentally sound power generation. The EEG specifies tariffs for electricity produced by small or renovated hydropower plants. Accordingly, operators of such plants have little interest in additionally meeting the stringent *greenhydro* criteria. Thus, certification is an attractive option primarily for hydropower plants not eligible to receive payments under the EEG. These include existing run-of-the-river plants with an output of more than 5 MW and all storage plants.

An additional challenge stems from the fact that German eco-labels have accepted hydropower to date without imposing strict conditions: for plants that are currently in a poor ecological condition but still sell green power, tightening of the criteria would entail substantial costs. For this reason, the *greenhydro* standard is opposed by a number of established green power suppliers and plant operators. They doubt that their customers are prepared to pay a higher price for more stringent environmental requirements. This conflict of interests will need to be resolved by the organizations that issue eco-labels, such as "ok-power".

Compatible with the Water Framework Directive

However, the *greenhydro* procedure is relevant not only to eco-labelling programmes but also to the implementation of the EU Water Framework Directive (WFD). Our studies have shown that the *greenhydro* standard is essentially compatible with the aims and quality criteria of the Directive. In various respects, the basic requirements of *greenhydro* go beyond those of the WFD. In addition, the Eawag procedure offers complementary approaches for local implementation of the WFD, e.g. the involvement of local stakeholders in the definition of environmental support measures. ○ ○ ○

Wanlin Tang

The *greenhydro* procedure is attracting growing international interest. In addition to German and English versions, the key publication is now also available in French, Italian and Chinese.

EnBW

Bypass channels reduce the impact of a hydropower plant on connectivity and meet the *greenhydro* criteria by facilitating upstream fish migration.

Bratrich C., Truffer B. (2001): Green electricity certification for hydropower plants – Concept, procedure, criteria. Eawag, Kastanienbaum. Green Power Publications Issue 7.

Ruef A. and J. Markard (2006): Transfer of the greenhydro standard to Germany – Feasibility study. Report prepared as part of the EIE project "Clean Energy Network for Europe (CLEAN-E)". http://www.eugenestandard.org > news&facts > publications

www.greenhydro.ch

www.naturemade.ch

www.eugenestandard.org

Cloud cover influenced by cosmic rays?

Water plays a fundamental role in the climate system. One of the factors influencing the amount of solar radiation reflected back into space is the extent of cloud cover. We have found no evidence for a hypothesis representing global cloud coverage as a direct function of the intensity of cosmic rays. Jürg Beer, Jasa Calogovic, Laurent Desorgher[1], Erwin Flückiger[1], F. Arnold[2]

As a greenhouse gas, water vapour inhibits infrared emissions into space. Conversely, in the form of clouds, snow and ice, water causes a portion of incoming solar radiation to be reflected, rather than contributing to warming. In addition, through ocean currents, evaporation and condensation, it plays a key role in the transfer of energy from equatorial to polar regions.

Condensation nuclei from space

A hypothesis proposed several years ago created quite a stir among climatologists. It contends that global cloud coverage is controlled by the intensity of cosmic rays [1]. As the extent of cloud cover in turn affects the climate, this hypothesis takes on great significance both for climate forecasting and for the assessment of human influences on the climate. The underlying mechanism appears to be simple: as the high-energy particles of cosmic rays penetrate the earth's atmosphere, they produce ions, which grow into aerosols, giving rise to condensation nuclei for cloud droplets [2]. Changes in the cosmic ray flux thus cause changes in cloud cover. The evidence put forward was a comparison of cosmic rays and global cloud coverage, which indeed shows a good correlation for the period from 1980 to 1995 [3].

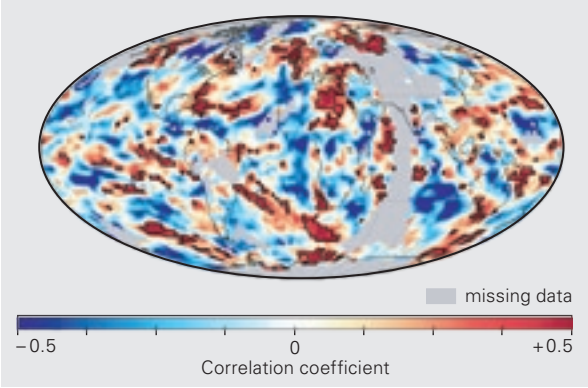
We were not able to demonstrate a significant correlation between cosmic rays and cloud cover.

Extensive correlation study

We examined this hypothesis in collaboration with the University of Bern and the MPI Heidelberg [4]. For our study, we selected six 20-day periods from the last 30 years during which interplanetary transients produced fluctuations in cosmic rays similar in amplitude to those occurring during the 11-y solar cycle between 1980 and 1995. For each event, the ion production rate in the atmosphere was calculated as a function of altitude, latitude and longitude, with a temporal resolution of 3 hours. The changes in ionization were then compared with satellite data on clouds. Delays (0–9 days) were permitted between ionization and cloud formation, to allow for the production of condensation nuclei. Altogether, several million correlations were computed.

Distribution is random

By way of example, the Figure shows the results for low clouds (up to 3.5 km above sea level), for which the proponents of the hypothesis found a strong positive correlation. There are equal numbers of positive and negative correlations, and the distribution is random. In a previous study, we had – unsuccessfully – sought evidence of climate changes, taking the example of a marked decrease in geomagnetic field strength that occurred 40000 years ago (Laschamp excursion), triggering a massive drop in the intensity of cosmic rays [5]. Numerous additional analyses also lead to the conclusion that, on a global scale there is no significant association between the intensity of cosmic rays and low cloud coverage. Accordingly, global warming – involving changes in the hydrological cycle, such as droughts and flooding, and in the long term changes in groundwater and sea levels – cannot simply be attributed to a natural mechanism such as cloud forcing. ○○○



The distribution of correlations between ionization and cloud formation is random. Positive correlations are shown in red, negative in blue. Grey regions are not covered by the satellites and therefore cannot be studied. Grid cells = 3°×3°.

[1] Bern University
[2] MPI Heidelberg

[1] Svensmark H., Friis-Christensen E. (1997): Variation of cosmic ray flux and global cloud coverage – a missing link in solar-climate relationships, Journal of Atmospheric and Solar-Terrestrial Physics 59, 1225–1232.
[2] Yu F., Turco P.R. (2001): From molecular clusters to nanoparticles: Role of ambient ionisation in tropospheric aerosol formation, Journal of Geophysical Research 106.
[3] Marsh N.D., Svensmark H. (2000): Low cloud properties influenced by cosmic rays, Phys. Rev. Lett. 85, 5004–5007.
[4] Calogovic J. (2006): Forbush decrease und Wolkenbildung: Gibt es einen Zusammenhang? Diplomarbeit an der Eawag; Betreuung: Beer J., Flückiger E.
[5] Wagner G. et al. (2001): Some results relevant to the discussion of a possible link between cosmic rays and the Earth's climate, J. Geophys. Res. 106, 3381–3387.

Substantial nitrogen losses due to the anammox process

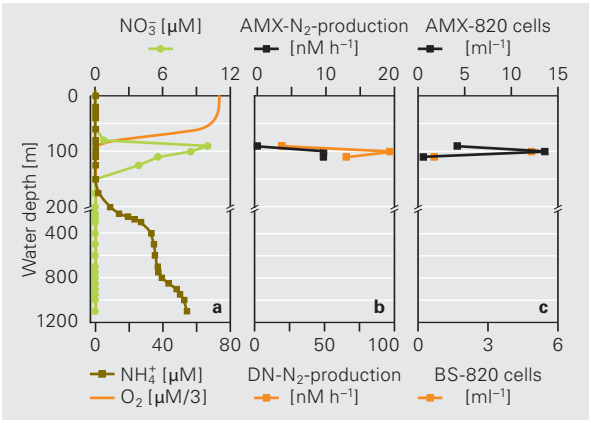
Microbial nitrogen fixation is one of the major sources of nutrients in surface waters, while denitrification has traditionally been regarded as one of the largest sinkers. Recent studies have shown that a further process needs to be taken into consideration in the overall balance of substance flows for a waterbody – anaerobic ammonium oxidation (the anammox process).

Carsten Schubert, Edith Durisch-Kaiser, Bernhard Wehrli, Bo Thamdrup, Phyllis Lam, Marcel Kuypers

In the anammox process, ammonium is oxidized directly with nitrite by bacteria, producing nitrogen gas (Fig. 1a). This reaction was first described in a wastewater treatment plant, but in recent years it has also been found to occur in marine sediments and in the water column of the Black Sea [1, 2]. As this process had yet to be described in freshwater environments, we undertook an expedition to the tropical Lake Tanganyika. We measured the concentrations of oxygen, sulphide and various nutrients (nitrate, nitrite and ammonium) over the entire depth range. In addition, we carried out tracer studies using stable isotopes (^{15}N-labelled substances). We were thus able to demonstrate the anammox process in a lake water column for the first time (Fig. 1b).

Anammox process localized

Having established that oxygen was not detectable from a depth of around 90 m, and that nitrate only occurred in a zone extending from 60 to 140 m, we added isotopically labelled nitrate to culture flasks at depths of 90, 100, and 110 m. After an incubation period of one day at in situ temperature, the isotope signal of the nitrogen produced was measured in a mass spectrometer. The production of nitrogen with a mass of 29 provided clear evidence of the occurrence of the anammox process in the water column of Lake Tanganyika. In addition, with the aid of fluorescence in situ hybridization – which allows microorganisms present in a water sample to be dyed and identified under the microscope – it was possible to quantify the anammox bacteria. Up to 13000 cells per millilitre or 1.4% of the total cell count were anammox bacteria (Fig. 1c). We subsequently sequenced the genetic material in the cells and demonstrated that the anammox bacteria in Lake Tanganyika are closely related (95.6% similarity) to the bacterium *Candidatus "Scalindua sorokinii"* which has been detected in the Black Sea.



Lake Tanganyika:
a) Concentrations of oxygen, nitrate and ammonium.
b) Nitrogen production rates for the anammox process and denitrification.
c) Number of anammox bacteria cells (hybridization with Amx-820 and BS-820 probes).

Significant element in the overall balance

For waterbodies and the resident organisms, nutrients are of vital importance. They can be obtained from nitrogen fixation, external inputs or internal transformation (nitrification). At the same time, however, nutrients are also converted to dinitrogen and lost through gas emissions. Previously, it was assumed that such losses only occur via denitrification. It is now clear that the anammox process also needs to be taken into account in the overall balances. Specifically, in the case of Lake Tanganyika, denitrification accounts for 87% of nitrogen losses and the anammox process for the remaining 13%. This proportion amounts to no less than 200 million tonnes of nitrogen per year. In areas such as the South Atlantic upwelling zone off the coast of Namibia, it is even possible for denitrification to be almost completely eclipsed by the anammox process.

The results of our research once again illustrate the need for conventional textbook knowledge to be constantly revised.

The in situ pumps are attached to a steel cable, which is lowered into the water column.

[1] Thamdrup B. and Dalsgaard T. (2002): Production of N_2 through anaerobic ammonium oxidation coupled to nitrate reduction in marine sediments. Appl Environ Microbiol 68, 1312–1318.
[2] Kuypers M.M.M., Sliekers A.O., Lavik G., Schmid M., Jorgensen B.B., Kuenen J.G. et al. (2003): Anaerobic ammonium oxidation by anammox bacteria in the Black Sea. Nature 422, 608–611.
[3] Schubert C.J., Kaiser-Durisch E., Wehrli B., Thamdrup B., Kuypers M.M.M. (2006): Anaerobic ammonium oxidation in a tropical lake (Lake Tanganyika). – Environmental Microbiology 8 (10), 1857–1863.

Chemicals and their impacts

In the field of chemicals and their impacts, Eawag's research on the quality of water and waterbodies emphasizes dynamic environmental risk assessment. This involves combining research on spatial and temporal variations in exposure with studies on the effects of individual substances and mixtures. Also considered are non-chemical stress factors such as rising temperatures or increased ultraviolet radiation.

A certain concentration of a single pollutant in water will cause harmful or lethal effects in a fish. That, at least, is the classical view of toxicology, as traditionally practised and enshrined in many regulations, such as those governing the approval of chemical products. However, the dead fish – generally a result of experiments – provides only a limited reflection of real-life conditions. It tells us nothing about how the pollutant is absorbed or about what internal concentrations trigger specific effects in the organism. This approach also disregards the fact that natural waters are almost always subject to the effects of cocktails of substances, and that low concentrations in the long term may be just as decisive as short-term peaks.

Dynamic risk assessment

By focusing on dynamic risk assessment in its research on the impacts of chemicals, Eawag is helping to shape modern ecotoxicology. Assessment that is dynamic in terms of space and time considers, for example, substances deriving from urban areas (page 49) in conjunction with agricultural inputs (page 43) and takes into account whether inputs of water pollutants are seasonal or determined by individual rainfall events. Such surveys can be used to generate exposure scenarios and develop models permitting a realistic evaluation of actual exposure levels for organisms and ecosystems. Integrated risk assessment requires a combination of exposure and impact research. Studies of internal exposure – both experimental and with the aid of models – are crucial here. Knowledge of how individual pollutants or mixtures are distributed within the organism and how they behave at the target site will make it easier to explain and predict effects.

ances er

Interaction with practitioners

In the area of realistic exposure scenarios, Eawag has focused its efforts and is not only participating in several EU projects but also collaborating in projects of the Competence Centre for Environment and Sustainability (CCES) – notably in the education and research units "Sustainable Land Use" and "Food, Environment & Health" (page 5). In the field of chemicals and their impacts, foundations are being established which should help to modernize legal regulations concerning environmental toxicology and chemistry, permitting, for example, a more sophisticated treatment of the question of limit values. The specific methods of chemical and biological analysis required for this research are, like the underlying methodology, being constantly adapted. In addition, Eawag is developing action-oriented concepts for the reduction of inputs to waters or the management of existing contamination. These are illustrated in the articles on biocides released from facades and on antimony in soil at shooting ranges. Exchanges between researchers and practitioners will be further strengthened from 2008, when a Centre for Applied Ecotoxicology is established by Eawag and the Federal Institute of Technology (EPF) Lausanne in accordance with a recent decision by the federal government.

Contaminants of natural origin

Humans are not always responsible for the presence of problematic or even dangerous substances in water. Worldwide, drinking water consumed by hundreds of millions of people is contaminated by high salt concentrations or substances such as fluoride, arsenic and selenium from natural sources. Accordingly, Eawag's cross-cutting project "Water Resource Quality" (WRQ) focuses on geogenic contaminants in groundwater. WRQ aims to identify high-risk regions at an early stage and to estimate the impacts of geochemical processes on drinking water quality. Here, too, Eawag is concerned with practical applications, conducting research on methods suitably adapted to the sociocultural characteristics of the regions concerned. Typical of these efforts is the collaboration on fluoride removal with the Water Quality Programme of the Catholic Diocese of Nakuru in Kenya (page 52).

Medicines: new approaches to risk assessment

The issue of medicines in surface waters is frequently covered in the media. The regulatory guidelines on environmental risk assessment of these compounds are relatively new and are partly based on very rough estimates. As part of the EU project ERAPharm, we are developing improved modelling methods to facilitate risk prediction. The aim is to obtain a picture of the environmental fate and effects of veterinary and human medicines which is as realistic as possible. Kathrin Fenner, Manuel Schneider, Beate Escher, Mats Larsbo

In recent years, harmonized guidelines for the registration of human and veterinary medicines have been developed and adopted across the EU [1, 2]. These include guidance on how the environmental risk assessment is to be carried out and weighted within the approval process. While for other substances – such as industrial chemicals and pesticides – guidelines have long been in force and methods have been continually refined, environmental risk assessment for medicines is a relatively new undertaking. In some cases, the standardized assessment procedures rely on very rough estimates, for the simple reason that not enough is known about the behaviour and effects of these substances in the environment. As part of the EU project ERAPharm (see box), we are pursuing the goal of refining these methods so as to allow the environmental risks to be assessed with greater regard for regional and seasonal factors and to provide a more realistic account of actual environmental exposure. These efforts are illustrated in the present article by describing four Eawag projects in the area of veterinary medicines.

Traces of veterinary medicines from grazing animals or in manure spread on fields ultimately enter surface waters. At Eawag, we are investigating the pathways involved and developing tests to assess the ecotoxicological effects of the substances concerned (Eawag/Keystone).

From cow to water

One possible source of inputs of medicines to surface waters is the use of manure or sewage sludge[1] on agricultural land – but a wide variety of processes and pathways are involved. Thus, the extent of inputs via surface run-off or drainage flows depends not only on the chemical properties of the medicines but also on site-related factors. The applicable regulatory guidelines recommend the use of process-based soil transport models to predict the transport of veterinary medicines to surface waters. These models were originally developed for pesticides, and their suitability for medicines has been scarcely investigated to date. One notable difference, for example, lies in the fact that pesticides are generally applied in aqueous solutions, whereas medicines are released onto the soil in sewage sludge or manure. The organic material applied influences not only the behaviour of the substances but also the physical and chemical properties of the soil. For example, slurry promotes sealing of the soil, thereby increasing surface run-off. In our project, therefore, we used available data from field studies of veterinary and human

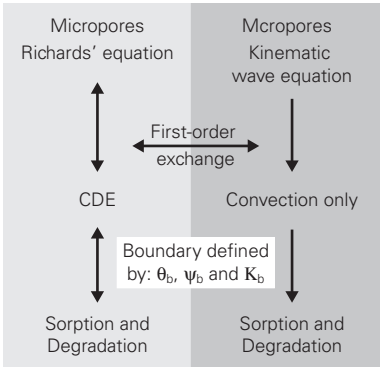


Fig. 1: Representation of key processes in the Macro model. CDE, convection dispersion equation; Θ_b. Ψ_b und K_b stand for soil water content, soil water pressure head and hydraulic conductivity at the boundary between the macropore and micropore flow domains.

medicines to evaluate a number of different models, focusing in particular on the suitability of "Macro" [4]. This model was developed to simulate transport in macroporous soil (Fig. 1). Using global optimization methods and Bayesian statistics, we estimated the uncertainties in the model parameters and the predictions. The results show that Macro provides a good representation of the losses of various sulphonamide antibiotics via surface run-off and drainage (Fig. 2). Using an add-on module with modified parameters for the uppermost soil layer, we were able to simulate the physical sealing of the soil by slurry. However, the results still exhibit substantial uncertainties, indicating that the field data were not ideal for model evaluation purposes. To permit further improvements, specially designed field studies will therefore need to be carried out.

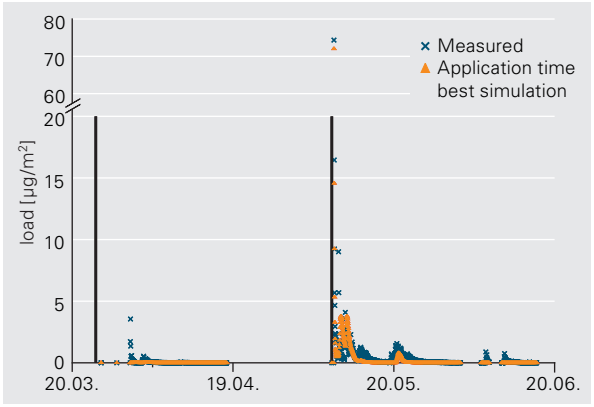


Fig. 2: Comparison between measured and simulated rates of loss of sulphonamide antibiotics from a study area. The peaks are associated with rainfall events.

Major regional variation

In the EU, applications for approval of veterinary medicines are increasingly handled via a centralized procedure, meaning that they are either carried out by a member state or the EMEA[2]. The resulting decisions are frequently also adopted by Switzerland. However, regulatory reviews can only be focused on the most relevant and critical scenarios if it is clear under what conditions medicines enter the environment and how critical these scenarios are. Our study was concerned with the major regional differences that exist within Europe. The starting point, once again, was the existing scenarios for the evaluation of pesticides, which are also to be applied for veterinary medicines.

We concentrated on critical conditions for inputs of veterinary medicines into surface waters from slurry or manure. For this purpose, we compiled georeferenced information on factors influencing releases from soil into receiving waters – animal densities and climatic and soil characteristics favouring input processes. In a cluster analysis, groups of areas with similar characteristics were then identified and ranked by risk of inputs with the aid of an evaluation scheme (Fig. 3).

It was shown that the existing scenarios for pesticides also cover the most critical situations with regard to veterinary medicines fairly well (Fig. 3). In addition, critical scenarios for veterinary medicines are to be found in hilly areas of the Central Uplands and in plains of the Mediterranean region [5]. The pesticide scenarios thus need to be supplemented if they are to be used for veterinary medicines. For the additional scenarios, it will be necessary to calibrate detailed transport models such as Macro so that environmental concentrations can be predicted.

Not all effects detected by test battery

Grazing animals in particular are often treated with parasiticides. These agents are excreted with urine and droppings and may pose risks to organisms such as dung flies and dung beetles. In addition, parasiticides also enter surface waters – through rainwater run-off or direct excretion into streams – where they may affect further non-target organisms. As part of ERAPharm, a comprehensive environmental risk assessment was carried out for ivermectin, with a number of different project partners investigating the effects of the substance on a wide variety of terrestrial and aquatic organisms. A test battery was specially developed by Eawag to detect ecotoxicological effects. This focuses in particular on the interactions between toxic substances and biologi-

ERAPharm

The EU project Environmental Risk Assessment of Pharmaceuticals (ERAPharm) is designed to fill gaps in our knowledge and in the methods used for assessing the environmental risks of human and veterinary medicines. It includes studies on the fate and effects of substances in the environment, and on the improvement of predictions based on models. The project consortium consists of 14 partners from 7 European countries and Canada. Authorities and the pharmaceutical industry are also involved. Two of the eight work packages are led by Eawag. ERAPharm, a 3-year project, is to be completed in October 2007. The two last-mentioned examples of Eawag's research illustrate how important cooperation between different groups is to the success of the project: while our test battery cannot cover all possible ecotoxicological effects, the studies on the membrane permeability of the ivermectin compound make a significant contribution to our understanding of the effects observed in invertebrates.

Confounded by foragers
Sometimes life is not easy for researchers. In order to obtain results that would be as precisely comparable as possible, scientists carrying out ERAPharm research painstakingly applied cow dung to a study field in portions that had been exactly weighed out and chemically analysed. Measurements to be carried out after the next rainfall were to reveal whether ivermectin had been degraded or had migrated into the soil. But one point had been overlooked: in the shed, the cows had been given fodder maize, and undigested grains in the standardized cowpats attracted foraging birds. These disrupted not only the mass balance but also the physical structure of the dung – thereby preventing an accurate scientific investigation on this occasion.

cal compounds and the resultant primary effects. All the results from this test battery indicate that ivermectin has non-specific toxicity. Only algae exhibited specific toxic reactions, showing effects at concentrations well below effect concentrations for non-specific toxicity. However, studies performed by other project partners demonstrate that ivermectin has highly specific effects on invertebrates such as water fleas – presumably through the same mechanism of action as the antiparasitic effect, i.e. interference with chloride ion channels in nerve cells. This highly specific effect is not covered by our test battery.

Higher-than-expected bioavailability

Ivermectin is a semi-synthetic lactone, which is isolated from a natural product and then undergoes further processing. It is a bulky and poorly water-soluble compound, with physicochemical properties that are unusual for environmental chemicals. In addition to the studies on ecotoxicological modes of action, therefore, research on the bioavailability of ivermectin was also carried out as part of the ERAPharm programme. However, owing to the unusually low solubility and presumed colloid formation, distribution in biological membranes could not be measured by standard methods. At Eawag, we therefore applied a new method known as Pampa – parallel artificial membrane permeability assay. This assay was originally developed by the pharmaceutical industry to simulate the absorption of medicines in the gastrointestinal tract and is currently being adapted at our institute for the assessment of bioaccumulation potential. Using this test, we were able to show that, despite its size, ivermectin is a membrane-permeable compound. Thus, a high molecular mass is not necessarily associated with reduced bioavailability.

Dynamic process

In prospective environmental risk assessment, modelling plays a key role, as the substances studied have yet to enter the environment. The aim is to predict both, the behaviour of a substance and the environmental concentrations to be expected, or the potential for adverse impacts in the longer term. The applicable guidelines

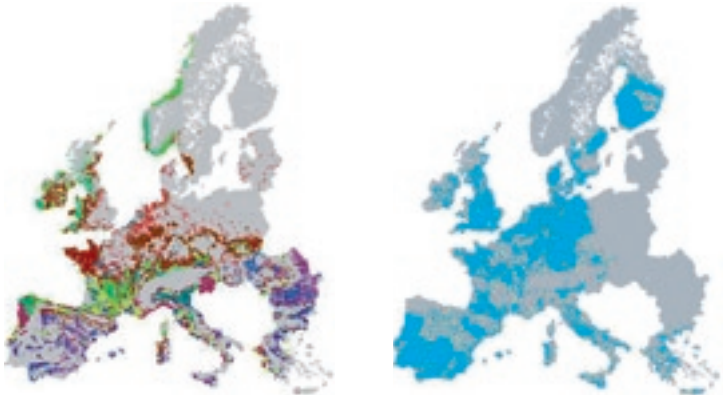


Fig. 3. Areas covered by scenarios for exposure of surface waters to veterinary medicines via surface run-off (randomly selected colours), compared with coverage by existing scenarios for pesticides (blue).

suggest that exposure should be estimated using relatively simple, static models, which already yield results with a small set of measured chemical properties. In line with the precautionary principle, the assumptions underlying these models seek to cover the "worst case", although it is not always clear how this is to be defined. The examples from Eawag's research show that there is room for improvement of the evaluation schemes for veterinary medicines, and that sound environmental risk assessment is a dynamic process. Not only the specific properties of substances but also the exposure situations – which show a high degree of regional and temporal variation – could be more realistically evaluated. This should also be taken into account by those who apply the regulations. We are in contact with the bodies responsible at EMEA and EFSA[3] to ensure that our findings are considered in the revision of the guidelines. ○ ○ ○

[1] In Switzerland, the application of sewage sludge has been restricted since 2003 and completely prohibited since 2006.
[2] EMEA European Agency for the Evaluation of Medicinal Products.
[3] EFSA European Food Safety Authority.
[4] VICH: International Cooperation on Harmonization of Technical Requirements for Registration of Veterinary Products.

[1] VICH[4] (2006): Environmental impact assessment for veterinary medicinal products – Phase II VICH GL 38. Final Guidance, London, UK.
[2] EMEA (2006): Guideline on environmental impact assessment for veterinary medicinal products in support of the VICH guidelines GL6 and GL38; EMEA/CVMP/ERA/418282/2005-CONSULTATION. London, UK.
[3] Escher B.I., Bramaz N., Richter M. (2007): Bioavailability, membrane-water partitioning and non-target modes of action in aquatic organisms of the parasiticides ivermectin, albendazole and morantel. Environ. Tox. Chem. (submitted).
[4] Larsbo M., Jarvis N. (2003): MACRO 5.0. A model of water flow and solute transport in macroporous soil. Technical description. Emergo 2003/6; Swedish Univ. of Agric. Sci, Dep. of Soil Sci, Uppsala, Sweden.
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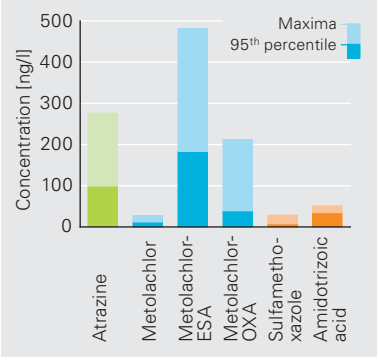
Pharmaceuticals and pesticides in groundwater

As groundwater is Switzerland's main source of drinking water, it is extremely important to prevent the pollution of groundwater resources as far as possible. In particular, there is a need to avoid contamination with substances – such as pharmaceuticals or pesticides – that have specific effects on organisms. Irene Hanke, Heinz Singer, Christa S. McArdell

About 80 % of Switzerland's drinking water is sourced from groundwater. To monitor the quality of these resources, measurements are carried out at numerous stations forming part of the NAQUA[1] network. While a large number of pesticides are covered on a regular basis by the existing programmes, measurements are lacking for certain highly mobile pesticide metabolites. Likewise, routine groundwater measurements are not performed for human and veterinary pharmaceuticals that have already been detected in surface waters.

Transport pathways

Pesticide active substances can enter surface waters with rainwater via runoff or drainage from treated surfaces and materials, or be transported through the soil into groundwater. Pharmaceuticals, after ingestion, are excreted unchanged or in the form of metabolites. Human medicines enter wastewater treatment plants in sewage. However, as the substances can only be partly eliminated, they are subsequently released into surface waters. Finally, these substances may also enter groundwater via defective sewer pipes or as a result of infiltration from contaminated surface waters.



Concentrations of selected pesticides and pharmaceuticals in the groundwater samples analysed. In the Water Protection Ordinance (GSchV), a limit of 100 ng/l is specified for pesticides in groundwater that is used, or intended for use, as drinking water.

Contamination with metabolites

On behalf of the Federal Office for the Environment and in cooperation with the Food Control and Environmental Protection Office of Canton Schaffhausen (ALU) and the Water Technology Centre (TZW) in Karlsruhe, we analysed groundwater samples for pesticides and pharmaceuticals. In the case of routinely measured pesticides, the concentrations observed were comparable to those recorded in the NAQUA monitoring programmes. Altogether, triazine compounds and their metabolites accounted for about three quarters of the pesticides detected. At 10 % of the measurement stations included in the study, the concentration of at least one of the analytes exceeded the limit of 100 ng/l specified in the Water Protection Ordinance (GSchV).

The two metabolites of the pesticide metolachlor – determined for the first time in Naqua – showed maximum concentrations of 480 ng/l (metolachlor-ESA) and 210 ng/l (metolachlor-OXA). Overall, the metabolites occurred more frequently and in higher concentrations than the parent compound. Although metabolites are generally less problematic toxicologically, their occurrence is a matter of concern, as they are often more mobile than the pesticides applied and can therefore be transported further.

Limits also required for pharmaceuticals

As well as pesticides, a wide variety of pharmaceuticals were studied. Of a total of 77 active substances, 8 were found in groundwater – 4 antibiotics, 2 radiocontrast agents, 1 antiepileptic and 1 metabolite of a lipid-lowering agent. The concentrations were between 10 and 90 ng/l and thus on average lower than those of the pesticides. The highest concentrations measured were for the radiocontrast agents amidotrizoic acid and iopamidol. The pharmaceutical occurring most frequently was the antibiotic sulfamethoxazole, which was found at almost one in five sites. As this substance is used exclusively in human medicine, its occurrence indicates that some of the groundwaters investigated are affected by wastewater or by surface waters contaminated with wastewater.

Our measurements show that effective groundwater monitoring requires consideration of metabolites as well as pesticides. In addition, the inclusion of selected pharmaceuticals in the routine measurement programme would facilitate the evaluation of inputs from urban areas. Limits should be specified both for pesticide metabolites and for pharmaceuticals.

[1] NAQUA: National Groundwater Quality Monitoring Network

NAQUA – Grundwasserqualität in der Schweiz 2002/2003. Bundesamt für Umwelt, Wald und Landschaft/Bundesamt für Wasser und Geologie (Hrsg.); Bern 2004.

Hanke I., Singer H., McArdell C., Traber D., Brennwald M.S., Herold T., Muralt R., Oechslin R., Kipfer R. (2007): Arzneimittel und Pestizide im Grundwasser. Gas, Wasser, Abwasser (GWA), 2007 (3), S. 187–196.

The search for unknown estrogenic compounds

Looking for unknown compounds that cause effects in waterbodies even at trace concentrations is a laborious process. The more sensitive the analytical methods, the narrower is the analytical window preventing analysis of non-target compounds. With high-resolution tandem mass spectrometery, it is possible to determine the elemental composition of unknown compounds and to draw conclusions about their structure. Marc J.-F. Suter, A. Christiane Vögeli, Anja Liedtke

The issue of gonadal malformations in whitefish from Lake Thun first came to public attention in 2000, and it is being studied at the cantonal and national level ever since. What makes this case unique is the nature and frequency of the malformations detected. In addition to genetic and infectious factors, two possible "suspects" were soon identified – munitions disposed of in the lake and the construction chemicals used in the excavation of the Lötschberg base tunnel (2001–2004). To date, however, neither of these has been confirmed as the cause of the effects observed.

Known steroid hormones ruled out

One possible explanation is the presence of environmental hormones that impair reproductive development (endocrine disruptors). Sediment and plankton samples were therefore analysed for hormonal activity, and aqueous extracts of plankton were found to contain estrogenic compounds. The question of whether these are natural substances or bioaccumulated chemicals that enter fish via the food chain is still under investigation. Chemical analysis of fractionated samples showed that the estrogenic activity is not attributable to the steroid hormones estrone, estradiol or ethinyl estradiol. This activity must therefore be due to other as yet unknown compounds.

Narrow analytical window

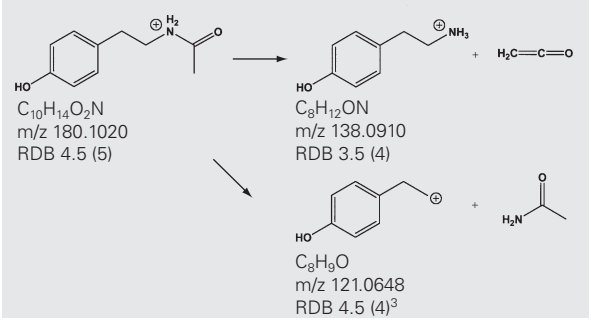
Efforts to identify those compounds found only in samples from Lake Thun (and not in Lake Brienz) soon reveal the limits of trace analytical methods. For example, in order to determine the steroid hormones with maximum sensitivity, the analytical method needs to be so specific that only a limited number of target substances can be measured at the same time – in other words, the analytical window is narrow. This makes it practically impossible to identify unknown compounds at low concentrations. In this situation, help is provided by experiments with Eawag's Orbitrap mass spectrometer, which uses the latest ion trap technology. This permits simultaneous recording of mass spectra at high resolution, together with the analysis of selected fragment ions.

Using this method, a compound was detected in plankton from Lake Thun that does not occur in Lake Brienz. It forms a positive ion of mass 180.1020. A conventional mass spectrometer provides at best a mass accuracy of ±0.2, which would yield almost 1000 potential sum formulae for the mass 180.1, if the elements H, C, N, O, F, Si, P, S and I and the nitrogen rule[1] are taken into account. Cl and Br were excluded from the outset on the basis of the isotopic pattern. Given the accuracy of the high-resolution Orbitrap system – ±0.0004 or 2 ppm – the possible candidates are reduced to $C_{10}H_{14}O_2N$ and $C_2H_{14}ON^{28}Si$. Substances that activate a signal at the estrogen receptor typically have a phenol group, which makes the first candidate considerably more likely. The compound exhibits similarities to nonylphenol isomers and could thus very likely show estrogenic activity. Unfortunately, as it is not commercially available, this hypothesis has yet to be tested. ○ ○ ○

[1] For an ion M^+H^+, an even mass indicates an odd number of nitrogen atoms.

m/z 180.1020 Sum formula	RDB[2]	Theoretical mass	Difference [mmu]	Difference [ppm]
$C_{10}H_{14}O_2N$	4.5	180.1019	0.095	0.53
$C_2H_{14}ON_7{}^{28}Si$	0.5	180.1024	–0.363	–2.02
$C_7H_{16}N_1F_2{}^{28}Si$	0.5	180.1015	0.539	2.99
$C_3H_{14}N_7{}^{32}S$	0.5	180.1026	–0.592	–3.29
$C_7H_{15}O_3NF$	0.5	180.1030	–1.048	–5.82
$C_4H_{15}ON_5P$	0.5	180.1009	1.125	6.25
$C_6H_{19}NF^{28}Si_2$	–0.5	180.1035	–1.461	–8.11
$C_3H_{11}ON_7F$	1.5	180.1004	1.637	9.09
$C_8H_{13}NF_3$	1.5	180.0995	2.539	14.10
$C_6H_{10}N_7$	5.5	180.0992	2.78	15.44

The ten sum formulae that meet the selected criteria and deviate from the experimentally determined mass by no more than ±3 mmu (Milli mass units). [2] Double bond equivalents (number of rings/double bonds); the halves are due to the additional proton H^+, which accounts for –0.5, so that 4.5 DBE actually corresponds to 5 equivalents for the uncharged compound.



In a tandem mass spectrometry experiment, the fragments 138.0910 and 121.0648 are generated from the ion 180.1020 via collision-induced dissociation. The exact mass is used to narrow down the possible sum formulae of the fragments. The para-substituted alkyl phenol shown on the left represents the most likely structure both for the precursor compound and for the fragment ions. The value in parentheses corresponds to the unprotonated molecule. [3] The neutral form of the carbocation requires an additional H^-.

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NRP50 – Endocrine Disruptors: Relevance to Humans, Animals and Ecosystems; Project 23: Gonad malformations in white fish (Coregonus lavaretus) in Lake Thun: are they induced by endocrine disruptors?

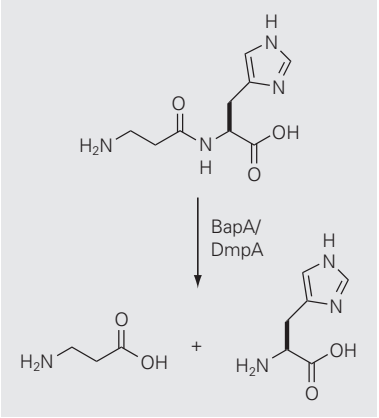
β-Peptides: new pharmaceuticals or future pollutants?

β-Peptides are of pharmaceutical interest, as they can reach a target site in the body unchanged. However, their stability could make them ecotoxicologically problematic, since they tend to accumulate rather than being broken down in the environment. We have now shown that β-peptides can be degraded by specific enzymes from novel bacterial strains. Birgit Geueke, Tobias Heck, Hans-Peter E. Kohler

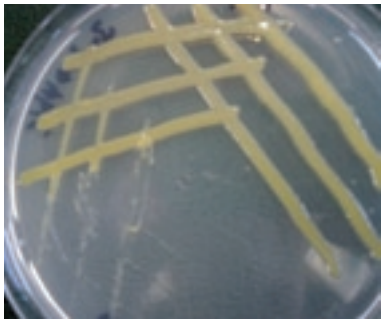
β-Peptides are chemical compounds that show great potential for development as new pharmaceutical agents, based on their structural similarity to natural α-peptides and their extraordinary resistance to enzymatic degradation. For medicines, a high level of biological stability is required to enable them to reach their target site in the body before they are metabolized by enzymes. However, this property can also be a major disadvantage because stable bioactive substances may accumulate in the environment.

The new enzymes could play an important role in the synthesis of β-peptides.

We are studying bacterial strains from various habitats which are able to convert and degrade β-peptides. These microorganisms are the first biological systems shown to have the enzymatic capacity for β-peptide degradation. We demonstrated that these bacteria belong to the recently identified genus *Sphingosinicella*. Their unique characteristic is the ability to degrade β-peptides, with these substrates representing the sole carbon and nitrogen source for their growth.



Enzymatic cleavage of the mixed β,α-dipeptide carnosine by BapA/DmpA into the amino acids β-homoglycine (left) and α-histidine (right).



Growth of *Sphingosinicella xenopeptidilytica* bacteria on a culture plate.

Single enzyme as catalyst

We showed that β-peptide degradation is catalysed by a single enzyme (BapA), which cleaves β-amino acids from the N-terminus of the β-peptide. The enzyme in question exhibits structural similarities to the aminopeptidase DmpA from the genus *Ochrobactrum*. In cooperation with the Laboratory of Organic Chemistry at the ETH Zurich (Professor Dieter Seebach's research group), we characterized these enzymes biochemically so that conclusions could be drawn concerning the physiological function of the peptidases. It would appear that BapA is able to cleave a broad range of β-peptides, while α-peptides are not accepted as substrates. In contrast, DmpA can hydrolyse both β-peptides and α-peptides. However, the precise nature of the side chain of the N-terminal amino acid is crucial to successful cleavage by DmpA.

Biotechnological application

Our studies show that the stability of β-peptides in the environment, though high, is by no means unlimited. However, new questions are raised by the fact that pure β-peptides such as those used for our degradation experiments do not occur naturally. Our future investigations will therefore seek to elucidate the natural functions of the enzymes in the degradation of β-peptides and the distribution of these degradation pathways in the environment. Another focus of our research will be the application of the new enzymes in biotechnology. ○ ○ ○

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Biocides and additives in building envelopes: a risk for waterbodies?

Problematic substances can be washed out of facade and roofing materials by rainwater and enter surface waters. In the URBIC project, the release of biocides and additives, and their transport in the sewer system, is being systematically studied for the first time.

Michael Burkhardt, Thomas Kupper, Jakob Eugster, Luca Rossi, Markus Boller

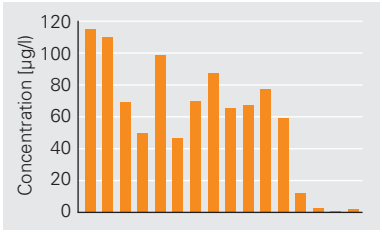
Recent years have seen an increase in the growth of fungi and algae on facade surfaces as a result of improved thermal insulation (increased condensation) and changing architectural trends (short or non-existent roof overhangs). The main control method is the application of biocides. In bituminous roof sealing membranes, mecoprop-based agents are used to prevent root penetration. In addition, plastic roofing materials of various kinds – e.g. PVC, flexible polyolefin (FPO) and ethylene propylene diene monomer (EPDM) rubber – may contain biocides, UV filters, flame retardants, antioxidants and plasticizers.

A property shared by agents such as diuron, carbendazim and mecoprop is that they are only active in the aqueous phase. They can thus leach into rainwater and enter surface waters.

Building envelope agents detectable

Flows of substances from facades and flat roofs via rainwater into receiving waters are the subject of the ongoing URBIC project. This work is being supplemented by laboratory studies. Runoff from new and ageing facades at a site in Volketswil (Canton Zurich) is currently being analysed, as well as rainwater from a separate sewer. Initial data show that active substances such as s-triazines (terbutryn, Irgarol 1051), carbendazim or mecoprop are detectable in rainwater and can be tracked to the point where they are discharged into receiving waters.

In laboratory tests on the leaching of additives from bitumen sheets, more recent products performed better than materials of a type still produced ten years ago. In addition, that fact that concentrations differ by a factor of 100 among the 16 products tested suggests that optimized formulations could contribute to a considerable reduction in contamination of roof runoff and waterbodies. Through our URBIC project, we intend to make available further scientific foundations concerning the material dependence of water pollution and environmentally relevant processes. We believe that measures taken at source represent the most sustainable approach for effective water pollution control.



Leaching of three root protection agents from 16 different bitumen sheets. The products differ in the concentrations applied and in their material properties (formulation, surface coating, thickness).

Cooperation with manufacturers

The URBIC project is to continue until mid-2008. With regard to methodology and analysis, the Eawag Urban Water Management and Environmental Chemistry departments, together with project partners from Empa and other institutions, are breaking new ground in many respects. One special feature of the project is the involvement of numerous manufacturers and associations. This represents a considerable challenge, as the findings are intended to support decisions on additional measures to be taken by manufacturers and authorities. The project will help to improve our understanding of the significance of previously neglected inputs of substances from urban areas, and to keep water pollution to a minimum. ○○○

Biocides leaching from facades and roofs can enter waterbodies directly in rainwater.

The URBIC project is supported by Eawag, Empa, FOEN, AWEL Zurich, and uwe Lucerne.

Additives

Additives are substances added to products in small quantities to confer or enhance certain material properties. This general term encompasses e.g. antioxidants, UV filters and flame retardants. Although biocides are also additives, they are regulated – in view of their specific effects against organisms – by the Biocidal Products Directive (VBP). This legislation contains detailed provisions concerning the approval procedure, use in products and product labelling. The Swiss VBP, which has been in force since 2005, is in line with the European Biocidal Products Directive (98/8/EC).

Sampling in a rainwater drain in a new residential area in Volketswil.

www.eawag.ch/urbic

Burkhardt M., Kupper T., Rossi L., Chèvre N., Singer H., Alder A., Boller M. (2005): Biozide in Fassadenbeschichtungen: Auswaschung mit Folgen. COVISS 2 (7), 6–9.

Burkhardt M., Kupper T., Rossi L., Boller M., Hean S., Haag R., Kohler M., Mattrel P., Schmid P. (2006): Umweltrelevante Stoffe in Flachdachabdichtungen. SIA Tec21, 31–32, 27.

Burkhardt M., Kupper T., Rossi L., Seehafer P., Boller M. (2006): Einsatz von Bioziden in Fassaden – Ergebnis einer Umfrage beim SMGV. Applica 12, 8–14.

Glyphosate herbicides in surface waters

Glyphosate is by far the most commonly used herbicide – worldwide and also in Switzerland. Given its importance, however, relatively little data is available on its occurrence in the aquatic environment since the substance is difficult to detect analytically. A reliable method for the determination of glyphosate and its degradation product AMPA in water has now been developed by Eawag and applied to environmental samples. Irene Hanke and Heinz Singer

Glyphosate is a broad-spectrum herbicide with low toxicity to humans and the environment. Worldwide and in Switzerland, it is among the most widely used pesticides. In recent years, use of the agent has risen sharply around the world as a result of the increased cultivation of crops such as maize and soya that are genetically modified to be resistant to this herbicide. Sales of glyphosate in Switzerland currently amount to approx. 190 t per year, which is equivalent to about 14 % of the total quantity of pesticides used. The bulk of this product is applied as a non-selective herbicide in the agricultural sector. Around 4 t is used by Swiss Federal Railways (SBB) for vegetation control on the rail network (see the article on p. 14). Use of glyphosate as a weedkiller by public institutions, industry and private individuals accounts for an unknown proportion of the total. Because glyphosate is strongly adsorbed to soil minerals and readily biodegradable, it is assumed that – even though the substance is highly soluble in water – only a small fraction enters surface or groundwaters.

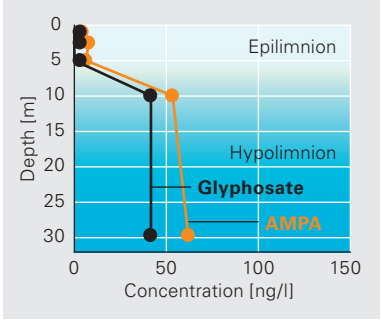
Although the mobility of glyphosate is expected to be low, we measured concentrations similar to those of atrazine.

Difficult to detect

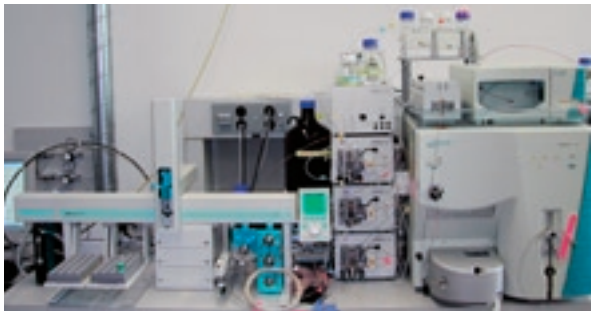
The properties of glyphosate – a small, polar, zwitterionic and strongly sorbing compound with a propensity for complexation – and its major metabolite aminomethylphosphonic acid (AMPA) make reliable detection of trace levels difficult with the analytical methods currently available. At Eawag, therefore, we have chosen a method in which the analytes are first converted in an aqueous solution with the aid of the derivatization reagent FMOC-Cl to a product which permits efficient enrichment from the water sample, unproblematic liquid chromatographic separation and highly sensitive detection by mass spectrometry. Although the method was essentially already known, certain refinements were required; in particular, these related to optimization of the yield and speed of derivatization, the removal of undesirable by-products and the inhibition of metal complexes.

Environmental measurements

The analysis of samples from various lakes, rivers and groundwaters demonstrated the robustness of the method and revealed interesting initial environmental data. None of the groundwater samples analysed contained detectable concentrations of glyphosate or AMPA (<10 ng/l). In contrast, glyphosate and AMPA were detected in all the lakes and rivers investigated. In the samples withdrawn from the tributaries of Lake Greifen, up to 390 ng/l glyphosate and 180 ng/l AMPA were detected. The Rhine at Weil contained about 30 ng/l glyphosate and 50 ng/l AMPA. These concentrations of glyphosate – a substance considered to be of low mobility – are thus in a range similar to that observed for the widely used and more mobile compound atrazine. The depth profile of the contentration for Lake Greifen shows that glyphosate and AMPA appear to be degraded in the uppermost water layer (epilimnion). Using the newly developed analytical method, possible sources, input pathways and the degradation of glyphosate are now to be studied in more detail. ○○○



Concentration/depth profiles of glyphosate and AMPA in Lake Greifen in August 2006. Glyphosate and AMPA are detectable in the lower layer of the lake (hypolimnion).



Analysis of enriched water samples by mass spectrometry.

Hanke I., Singer H., Hollender J. (2006): Quantification of Glyphosate and Aminomethylphosphonic Acid in Water using Solid Phase Extraction-Liquid Chromatography-Tandem Mass Spectrometry. Proceedings of the IAEAC European Conference on Pesticides, November 26–29, Almeria, Spain.

How does antimony enter groundwater?

Increased concentrations of antimony have been detected in groundwater close to the stop butts of shooting ranges. However, the processes that influence the mobility of this toxic metalloid are not fully understood. Our research indicates that iron plays an important role. A newly developed method aids in the identification of geochemical processes in soil. Ann-Kathrin Leuz, Alexander Englert, Hermann Mönch and Annette Johnson

When a shooting range is closed – if not earlier – the question arises as to whether soil remediation is required in the stop butt area. This is because soluble heavy metals and metalloids from ammunition, primarily antimony (Sb), may pose a risk to groundwater. Antimony is used as a hardening agent for lead and has chemical and toxic properties similar to those of arsenic. It is also increasingly used in industrial products, e.g. flame retardants for plastics, brake linings, and lead alloys for car batteries. According to a material flow analysis carried out at Eawag, the element is mainly released into the environment in Switzerland through brake wear and from ammunition [1].

Mobility promoted by oxidation

Around 400 tonnes of lead bullets are discharged at Swiss shooting ranges every year. These contain 2–5% metallic antimony [Sb(0)] by weight, which is released by weathering of the bullets. Sb(0) is only mobilized in the soil as a result of oxidation to Sb(III) and Sb(V), with Sb(V) compounds being more readily soluble in water and more poorly bound to soil particles than Sb(III) compounds. Oxidation processes in the stop butt were detected with the aid of spectroscopic methods. These processes are probably pH-dependent, as Sb(0) is prevalent in an acidic, organic-rich soil, while Sb(V) bound to iron oxides prevails in a neutral soil [2, 3].

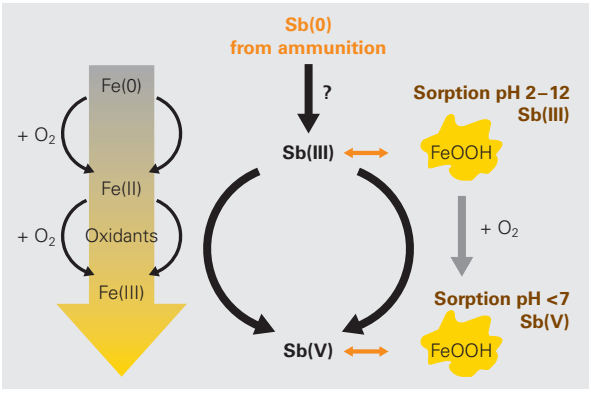
Laboratory experiments show that iron plays a key role both in the oxidation and in the binding of Sb. Thus, Sb(III) is oxidized following the corrosion of iron in the bullet jacket or when Sb(III) is bound to iron oxides. At the same time, iron oxides bind Sb, although Sb(V) compounds are only partly adsorbed above pH 7 [4].

Simplified monitoring

To make it possible to observe oxidation processes in the soil and to determine the factors influencing these, a method is required which allows low concentrations of antimony to be measured and permits numerous samples to be analysed at low cost. This is not possible with the complex spectroscopic methods that are generally used. We have therefore developed a simple extraction method capable of distinguishing between Sb(0) + Sb(III) and Sb(V) compounds. Initial results indicate that the ratio of Sb(V) to Sb(0) + Sb(III) increases with depth. This suggests that the Sb(V) compounds migrates to a greater extent [5].

Filter systems under evaluation

In isolated cases, increased levels of antimony have been measured in groundwater below shooting ranges.



Important oxidation reactions of antimony with iron. While the predominant oxidation states in the stop butt are both Sb(0) and Sb(V), in leachate water in contrast, more than 90% of Sb occurs as Sb(V).

With an improved understanding of the processes involved and a simplified analytical procedure, we are now in a better position to predict which sites require closer monitoring. In addition, Eawag and the HSR (Rapperswil) are currently evaluating filter systems for the removal of antimony and lead from stop butt leachate water. ○○○

Withdrawal of soil samples and depth profiles from the stop butt of a shooting range, in cooperation with the ETH Zurich. Inset: spent bullet.

[1] Mathys R., Dittmar J., Johnson C.A. (2007): Antimony in Switzerland: a Substance Flow Analysis. FOEN report (in press).
[2] Scheinost A.C., Rossberg A., Vantelon D., Xifra I.O., Kretschmar R., Leuz A.-K., Funke H., Johnson C.A. (2006): Quantitative Antimony Speciation in Shooting-Range Soils by EXAFS Spectroscopy. Geochimica Et Cosmochimica Acta 70, 3299–3312.
[3] Eichinger F. (2005): Geochemistry and Mineralogy of Antimony in Soils of Shooting Ranges. Diploma Thesis, Albert-Ludwigs-Universität Freiburg i. Br.
[4] Leuz A.-K. (2006): Redox reactions of antimony in the aquatic and terrestrial environment. Ph.D. Thesis, Swiss Federal Institute of Technology Zürich.
[5] Englert A. (2006): Untersuchung der Antimonspeziierung in Kugelfängen von Schiessanlagen mit nasschemischen Extraktionen. Diploma Thesis, Fachhochschule Weihenstephan/Triesdorf.

Fluoride removal in developing countries

Excessive fluoride intake leads to fluorosis – an incurable disease, which can only be combated by preventive measures, such as treatment of drinking water. In cooperation with the Catholic Diocese of Nakuru (CDN), a Kenyan organization, Eawag is researching alternative treatment materials and promoting the use of simple and effective bone char filters.

Kim Müller, Hillary Korir[1], Annette Johnson, Regula Meierhofer and Martin Wegelin

Small amounts of fluoride help to protect against caries and strengthen bones. In many parts of the world, however, consumption of groundwater with high levels of naturally occurring fluoride causes fluorosis. This condition is characterized by marked staining and pitting of the teeth (dental fluorosis) and bone deformities and brittleness (skeletal fluorosis). According to UNESCO estimates [1], more than 200 million people worldwide are exposed to this risk.

Even the best methods are useless if they are not accepted by users.

Bone char: an effective material

CDN has already been working for eight years on the use of bone char for effective fluoride removal. Although this method of treating drinking water is relatively simple to apply, the production of high-quality bone char requires a great deal of experience: the quality of the end product is significantly influenced by the temperature, oxygen levels and duration of the animal bone charring process. In recent years, CDN has produced and sold around 900 household and more than 70 community filter units. With the support of Eawag, the valuable defluoridation experiences of CDN could be analyzed and documented. A joint study on the effectiveness and usability of household units showed that, while fluoride is effectively adsorbed on bone char, the saturated filter material has, in some cases, not been replaced (Figure). Therefore, to ensure sustainability of this type of drinking water treatment, technical optimization is not sufficient – sociocultural and user-specific factors also need to be taken into account. The results of the analysis were presented and discussed at a workshop, with the participation of fluoride specialists and stakeholders from Ethiopia, Tanzania, Kenya and Switzerland.

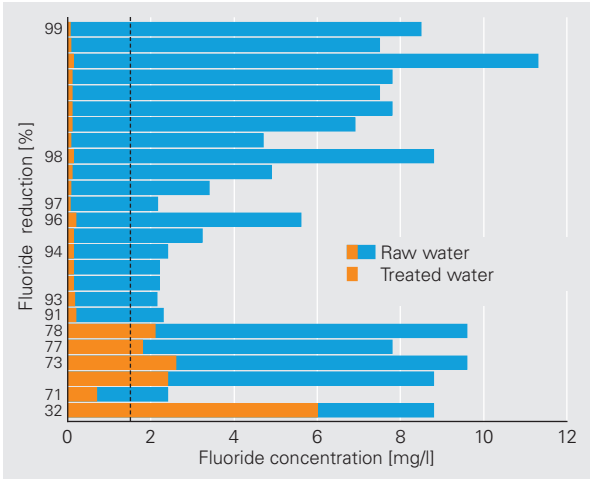


Figure: Fluoride reduction in 25 CDN household filter units. The vertical line indicates the Kenyan national standard for fluoride in drinking water (1.5 mg/l). Increased fluoride concentrations were found in treated water in those cases where the filter medium had never been replaced (2006).

Not universally accepted

Further research is required in particular to elucidate and optimize the fluoride removal mechanisms of a more recent treatment method – contact precipitation – in which calcium and phosphate are added to the bone char filter to precipitate fluoride. To avoid the need for daily addition of chemicals, CDN has developed pellets which dissolve in water, slowly releasing the required chemicals. As processed animal bones are not acceptable to certain social groups for religious reasons, we are also investigating the synthesis and defluoridation properties of synthetic apatite, a calcium phosphate mineral. Initial studies [2] have demonstrated that synthetic apatite can also adsorb fluoride. Together with CDN, we also intend to promote the installation and correct use of bone char filters, and to study in more detail the above-mentioned acceptance problems, e. g. in Ethiopia.

As part of the workshop, the community provides feedback on its experience with defluoridation. The filter unit can be seen on the left in the background.

[1] CDN Water Quality Programme, Nakuru, Kenya

[1] UNESCO Ground water briefing: Trace elements in groundwater and public health, www.iah.org/briefings/Trace/trace.pdf (Stand 10.12.2006)
[2] Hubaux N. (2006): An Investigation of Calcium Phosphate for Drinking Water Defluoridation, Diplomarbeit, EPFL.

www.eawag.ch/fluoride_removal

Preparing for hard times

Organisms in the environment are regularly confronted with natural and anthropogenic stresses, which stimulate a genetic defence response in the cell. The glutathione peroxidase homologous *(Gpxh)* gene of the green alga *Chlamydomonas reinhardtii* is activated by intense light intensities, even before damage can occur. Any damage that occurs despite this first response leads to a further increase in *Gpxh* activation, thus prolonging the defence reaction.

Beat Fischer, Régine Dayer, Manuela Wiesendanger, Rik I.L. Eggen

Natural life already places great demands on all organisms, and their survival depends on adaptability and instinct. In addition, organisms are also frequently exposed to environmental stress factors, such as heat, drought or high light intensities, which call for rapid and effective defence mechanisms. Such mechanisms, operating in every cell, are generally based on a genetic response. Defence genes that are otherwise quiescent are activated, and the resultant proteins make the cell more resistant to the stress.

Indicators of environmental stresses

In photosynthetic organisms such as the single-cellular green alga *Chlamydomonas reinhardtii*, high light stress is particularly common since full sunlight exceeds the organism's capacity for photosynthesis, leading to the formation of reactive oxygen species (e.g. $^1O_2$). These molecules are highly aggressive and cause cell damage. Many anthropogenic stress factors produce similar effects or may aggravate the natural stress. Therefore, if the genetic defence systems and associated regulatory mechanisms in *Chlamydomonas* are elucidated, it may be possible for these algae to be subsequently used as indicators for the presence of environmental stresses.

One of the initial effects of high light stress on plants and algae is the formation of singlet oxygen ($^1O_2$). We have isolated a defence gene, known as *Gpxh*, that is activated highly specifically by $^1O_2$ (Fig. 1). *Gpxh* can also be switched on by organic peroxides, including fatty acids in the cell membrane that can get damaged by $^1O_2$ at high light intensities. However, the latter activation is much slower and weaker. As the *Gpxh* protein is probably directly involved in the degradation of such fatty acid peroxides, we investigated why *Gpxh* is so strongly activated by $^1O_2$ and how regulation proceeds under high light stress.

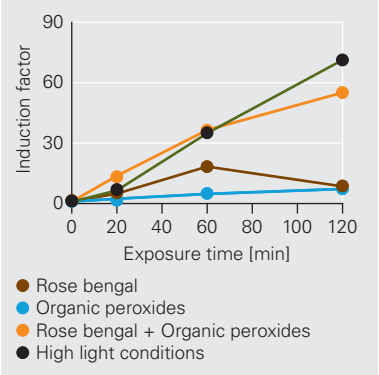


Fig. 1: Different *Gpxh* stress response profiles. Activation due to rose bengal-induced $^1O_2$ formation causes an early but transient response; in contrast, organic peroxides trigger slow and sustained activation. Exposure to a combination of rose bengal and organic peroxides produces a response similar to that observed under high light conditions.

Prevention and stabilization

We demonstrated that under high light conditions, *Gpxh* is very rapidly and strongly activated via the formation of $^1O_2$, which leads to increased concentrations of *Gpxh* mRNA (messenger for protein synthesis) (Fig. 1) [1]. As $^1O_2$ can lead directly to the formation of fatty acid peroxides in cell membranes, this early stress response appears to be a preventive reaction to expected damage. This activation involves stimulation of *Gpxh* transcription, i.e. the formation of new mRNA. In contrast, peroxide-induced activation involves stabilization of the mRNA formed. This leads to a gradual accumulation of *Gpxh* mRNA and thus to more prolonged defence via the proteins produced [2].

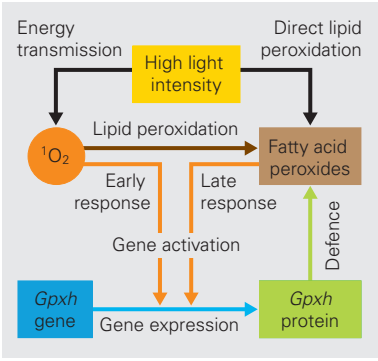


Fig. 2: Schematic view of the processes in the cell leading to activation of the *Gpxh* gene under high light conditions.

Under high light conditions, these two mechanisms are combined: the formation of $^1O_2$ leads to preventive synthesis of new *Gpxh* mRNA and the establishment of defences. If cell damage occurs and fatty acid peroxides are formed, this defence response can be further strengthened and prolonged by mRNA stabilization. The cell is thus able to combat peroxides rapidly (Fig. 2). This provides an example of how even the simplest organisms have "learned" to prepare in advance for bad times ahead. ○○○

Even the simplest organisms appear to have learned to prepare for bad times ahead.

[1] Fischer B., Eggen R., Trebst A., Krieger-Liszkay A. (2006): The glutathione peroxidase homologous gene *Gpxh* in *Chlamydomonas reinhardtii* is upregulated by singlet oxygen in photosystem II upon photoinhibition. Planta 223, 583–590.

[2] Fischer B., Dayer R., Wiesendanger M., Eggen R. (2006): Mechanisms for the independent regulation of gene expression by the cause and the effect of photooxidative stress during high light conditions. Physiologia Plantarum, in press.

Eawag review of 2006

The key events of 2006 were the appointment of Janet Hering as the new Director and the opening of the new building "Forum Chriesbach". The groups within the Aquatic Ecology department were reorganized, and social science research was strengthened with the establishment of the new Cirus department. Here we look back over a selection of other notable events. Andri Bryner

Success with arsenic biosensor

A biosensor used to detect arsenic in water has been successfully applied in the field for the first time by a team of researchers from Eawag and the universities of Hanoi (Vietnam) and Lausanne. The newly developed test provides significantly more reliable results than the chemical kits previously used in the field. It permits rapid analysis of large numbers of samples, is inexpensive and can be used directly in the regions concerned without the need for sophisticated laboratory equipment. In February, the article published by the research team in Environmental Science and Technology was selected as the ES&T top technology paper for 2005. www.eawag.ch/arsen

Urgent need for restoration

Flood control needs to go hand in hand with rehabilitation, as hopes of achieving protection against floods by straightening and damming rivers have proved illusory. The flooding that struck in 2005 was the most costly natural disaster experienced by Switzerland in the last 100 years. At the same time, habitats and connectivity elements urgently required to ensure the functioning of watercourse ecosystems have disappeared. Accordingly, numerous research partners, together with federal and cantonal agencies, sought in the Rhône-Thur project to develop scientific foundations and methods enabling river engineering projects to be carried out which provide ecological benefits and are successful for all concerned. On the Info Day held on 8 March, the latest research findings were presented to almost 400 experts and interested parties from academia, hydrology, and engineering and environmental consultancies, as well as administration officials and policymakers. www.rivermanagement.ch

Committed to sustainability – at home and abroad. Top: Swiss President Moritz Leuenberger with interim Director Ueli Bundi on a tour of the widely admired new building Forum Chriesbach. Bottom: Preparations for a workshop on the introduction of a faecal sludge management system optimized by Eawag in Togo.

Workshop in Hanoi on the use of the new biosensor for arsenic-contaminated water.

All-clear on asbestos

Before the start of renovation work at the old office building in Dübendorf, material tests suggested the presence of friable asbestos. Happily, in the air quality tests that were immediately arranged, none of the samples contained detectable concentrations of respirable fibres. The rapid action taken by the Directorate and the open communication on the suspected hazard were greatly appreciated by staff. ○○○

ETH-Rat

How does river restoration affect biodiversity? Capturing fish as part of the Rhône-Thur project.

Red Cross Prize for SODIS

On 24 June, Eawag's SODIS project, directed by Martin Wegelin, was awarded the inaugural Red Cross Prize by the Swiss Red Cross (SRC). The award is designed to recognize special humanitarian efforts. The jury was impressed by the personal commitment of the project's initiator Martin Wegelin, who "seeks to put his research and development work into practice himself, and personally endeavours, through partnerships and fund-raising, to help improve living conditions for the disadvantaged". Solar water disinfection using PET bottles was judged to be a "striking" way of helping to reduce diarrhoeal diseases and mortality in developing countries. www.sodis.ch

Distinguished visitors

Swiss President Moritz Leuenberger, Head of the Federal Department of the Environment, Transport, Energy and Communications, visited Eawag on two occasions in 2006. Together with his staff, he was impressed by the variety of aquatic research conducted at Eawag and especially by the active commitment to sustainability that Forum Chriesbach represents. On 14 September, the National Council Committee for Science, Education and Culture (WBK) had a guided tour of the new building, and in March the Lucerne cantonal government council visited the Kastanienbaum site. One of the points emphasized in the discussions with the Directorate, heads of

SRK

Presentation of the inaugural Red Cross Prize to SODIS project leader Martin Wegelin in the National Council Chamber, Bern. From left to right: SRC President René Rhinow, Jury Chair Anja Bremi, Martin Wegelin.

department and project leaders was that policymakers recognize the critical nature of water issues and see Eawag's problem-oriented research as a significant contribution to their resolution. ○○○

Swiss President Moritz Leuenberger in conversation with Roland Schertenleib.

Childcare centre "stormed"

The media spotlight on the new Forum Chriesbach (page 62) left another development in the shade – the opening of the new childcare centre (KiPa) on 2 August. According to the centre manager, Eveline

Sandra Neuhaus

Popular with children and carers – the new Eawag/Empa childcare centre with a large outdoor area.

Vonlanthen, the children "stormed" the new building. The facility – open to children of Empa and Eawag staff – is a modular timber construction, designed by Hornberger Architekten AG. Three "living units" with a total area of 270 square metres and accommodating 33 children are connected by a bright play corridor – perfect for racing up and down on a pedal fire engine. The spacious outdoor area offers a variety of swings, slides and other equipment.
www.kinderpavillon.eawag-empa.ch

Awards for new building

The new building Forum Chriesbach came into operation at the beginning of June. On 7 June, the keys were officially handed over by the contractor Implenia Generalunternehmung AG to the clients Eawag and Research Facilities/BaFA. On 19 October, the building was awarded a Swiss Solar Prize. Other awards have followed – the Swisspor Innovation Prize, the Federal Office of Energy's "Watt d'Or", and the Daylight Award sponsored by the Velux Stiftung. The architects Bob Gysin + Partner AG, can be proud of their achievement, as can Eawag, Empa and BaFa.
www.forumchriesbach.eawag.ch

Recipients of the Solar Prize 2006 for Forum Chriesbach (from left to right): Daniel Bührer (3-Plan), Bob Gysin (BGP Architekten + Planer) and Ueli Bundi.

Erika Vieli, who managed the Eawag cafeteria until the end of 2006.

aQa takes over from IG Cafeteria

The opening of the Forum Chriesbach staff canteen "aQa", run by the catering company DSR, marked the end of an institution at the Dübendorf site. For 23 years, the IG Cafeteria had been an asset to Eawag. For the last 6 years, Erika Vieli was the driving force on the top floor of the office building. She took an active part in planning, purchasing, preparing and serving meals, and also managed to restore the IG to financial health within a short time. The IG Cafeteria was dissolved at the end of 2006, and the team was taken on by DSR. Erika Vieli took up a new challenge in January 2007. We are indebted to her and to all those who dedicated themselves to this internal organization over the years. ○○○

International Water Management Forum

On 8–10 November, 26 external water experts, directors and departmental heads of water and wastewater utilities, engineering consultancies, environmental technology firms and water protection authorities from German-speaking countries met with Eawag scientists for the International Water Management Forum (IWMF). In their discussions, the researchers and decision makers jointly evaluated challenges and strategic options for action in the area of micropollutants. With this new type of event, Eawag is seeking to promote a shift away from a sectoral approach to the management of problems towards the development of long-term solutions through exchanges among all the relevant stakeholders. The IWMF 2007, to be held on 4–6 September, is entitled "River Restoration: Decision Making Process and Success Evaluation". www.iwmf.eawag.ch

Close dialogue between practitioners and researchers: a workshop at the IWMF 2006.

Annual outing: Eawag staff visit the NEAT construction site in the Kander valley.

Tunnel construction site and sturgeon farm

The "works outing" took place on 19 September in glorious late summer weather. At Mitholz in the Kander valley, Eawag staff attended a lecture on the AlpTransit Lötschberg base tunnel, now nearing completion. They then hiked to the crystal-clear Blausee. Finally, they visited the experimental sturgeon farm at Frutigen. In warm (20 °C) spring water discharged from the new tunnel and analysed by Eawag, the threatened fish are obviously thriving. Smoked sturgeon from the Bernese Oberland can already be bought, and the first caviar should be available soon. ○○○

Who owns the water?

According to a UN report, "The shortage of fresh clean water is the greatest danger to which mankind has ever been exposed." Published in September 2006, a new book entitled "Who owns the water" examines the "wonder called water" and investigates the risks and opportunities associated with this vital resource. As well as discussing key questions concerning drinking water supplies and food production, it considers the destructive force of water and explores the chemical properties of the molecule. Accessible to lay readers and including in part disturbing pictures, the book explains why water cannot belong to anyone. This new standard work on water, scientifically and financially supported by Eawag, is available in German and English editions.
www.lars-mueller-publishers.com

Personnel news

Retirements

Hans Jürg Meng: Hans Jürg Meng first came to Eawag in 1973 as a doctoral student at Kastanienbaum, where he investigated the causes of Saprolegnia infections (water mould diseases of fish) in Swiss surface waters. In 1980 he became a permanent employee. His colleagues soon realized that his scientific and electrotechnical training fitted him for particular tasks: as a researcher, he specialized in electrofishing and echo sounding for fish shoal detection. The fact that fish-for-eating were an occasional by-product of his work enhanced his popularity. Thanks to his technical expertise, Meng recognized the significance of the PC for scientific research at an early stage. Alongside his official duties, he constructed, managed and expanded a computer network at Kastanienbaum. Having initially been "only" a member of the Computer Committee, he officially joined the IT department at the time of the Eawag reorganization in 2000.

Eva Molnar: From 1975, the newly qualified ETH chemist Eva Molnar was one of the main pillars of the organic single-substance analysis group in the Chemistry department. In early studies of traces of chlorinated solvents in groundwater and drinking water, she carried out excellent pioneering work. After a prolonged family-related career break, she returned to Eawag in 1991 to work on organic water pollutants, using the latest concentration, separation and detection methods. In recent years, she earned a reputation as a reliable analytical chemist in ETH and Swiss National Science Foundation research projects. She measured concentrations of antibiotics both in hospital and municipal wastewater and in rivers and groundwater. She will now be able to devote more time to her leisure interests – sport and nature.

Christian Schaffner: When Christian Schaffner began his career at Eawag as a young chemical laboratory technician 42 years ago, it was still physically part of the ETH. In the early 1970s, he joined the organic single-substance analysis group and played a key role in the introduction of the latest instrumental analytical methods (gas chromatography-mass spectrometry, etc.). His technical skills enabled him to master challenging tasks such as the production of glass capillaries. Over the years, Christian Schaffner developed analytical methods for the determination of a large number of water pollutants. He was particularly enthusiastic about the application of these methods in field studies – his involvement in a project was sure to increase the chances of success. He was also a highly proficient photographer, and we hope that he will now find more time for this hobby.

Martin Strauss: As a sanitary engineer, Martin Strauss worked in development cooperation projects in

Tanzania and Nepal before becoming a full-time researcher. Having joined Eawag in 1977, he collaborated with research partners in Latin America, Africa and Asia, earning a reputation as one of the world's leading experts on the management of human excreta and waste. He specialized in the reuse of organic municipal waste and faeces for aquaculture and periurban agriculture in developing countries. He was a member of several scientific committees, including those responsible for the WHO wastewater and excreta reuse guidelines issued in 1989 and revised in 2006. In his teaching and in several publications, he argued that sanitation and ultimately effects on human health should be the priorities in waste and excreta management. However, he never lost sight of economic aspects and developed low-cost methods, particularly for safe treatment of faecal sludge in cities lacking sewage infrastructure. In May 2006, he organized, with great success, the first symposium on faecal sludge management, held in Dakar (Senegal) and supported by the UN, the World Bank and the Swiss Agency for Development and Cooperation. Happily, Martin Strauss will remain active as an expert after his retirement.

Michael Sturm: Mike Sturm studied and obtained his doctorate in geology in Vienna and Salzburg. In 1969, he moved to the University of Bern and, in 1977, to Eawag – working first in Limnology and then as Head of the Sedimentology group in the newly established Environmental Physics Department. He was one of the first researchers to focus on lacustrine sediments, and there is now scarcely a Swiss lake from which he has not collected bottom sediment samples. His publications from EU projects and in particular on Lake Baikal testify to the international links that he developed with researchers in this field. He was especially interested not only in the information stored in sediments, but also in how they are formed. Using sediment traps, he studied sedimentation processes and dynamics, and not least the new developments arising from climate change (see page 29). Mike Sturm has always been a researcher who pays attention to the practical aspects of his experimental work. He offers advice and even hands-on assistance in the field to anyone concerned with sediments – the list of dissertations and scientific papers in which his help is acknowledged is thus at least as long as the list of his own publications.

Jürg Zobrist: In the 1970s, Jürg Zobrist built up Eawag's analytical chemistry laboratory. In cooperation with the National Hydrological Survey and what was then the Environmental Protection Office, he initiated the National River Monitoring and Survey Programme (Naduf). This was a pioneering initiative, combining wide-ranging chemical studies with discharge measurements for the first time, and the programme has produced important findings on water protection in Switzerland. In the 1980s, Jürg Zobrist turned his attention to studies of atmospheric precipitation – a question of increasing importance in the context of the acid rain issue. At the same time, he devoted greater attention to groundwater, and geochemical processes in particular. His studies on biogeochemical transformation following infiltration of river water are now regarded as classics. Serving most recently (from 2000) in the Water Resources and Drinking Water department, Jürg Zobrist was always able to interest younger researchers in biogeochemical questions, and until his retirement, he remained committed to the Naduf programme.

Death

Stefano Gianella: On 3 November, Stefano Gianella succumbed to severe injuries sustained in a sailing accident. He had worked in the Environmental Engineering department since 2000, first as a doctoral student and then as a post-doc. His dissertation was a fine example of his systematic and single-minded approach. For his chosen subject – "Strategic information management in urban drainage" – he established a large network of practitioners and researchers within a short time, which enabled him to test and implement highly abstract information theory approaches in practice. In 2005, he helped to develop the new "Water Infrastructure Management" group. Outside work, he also found time to tend fruit trees in the Blenio valley (his home region), to go mountain-biking in the Alps and to gain his ocean sailing licence. Aboard a yacht during a storm between France and the Balearic Islands, he was struck by the boom and received life-threatening head injuries. Owing to the difficult conditions at sea, he was not able to be rescued from the yacht by the emergency services and could only be admitted to hospital the next morning after the boat reached Mahon harbour in Minorca. He was declared dead that evening. Stefano Gianella will always be fondly remembered for his modesty, his determination and his dry humour. ○○○

European ES&T Office based at Eawag

Environmental Science & Technology (ES&T) is considered to be a leading journal in the environmental field. Many people are not aware that Eawag is home to the European Office of this American Chemical Society publication. One of the Associate Editors is Eawag Director Janet Hering.

Anke Schäfer, Marie-Jeanne Weyrich, Lucia Valle, Janet Hering, Laura Sigg, Walter Giger

The European Editorial Office of *ES&T* was established in January 2000 by the Associate Editors Alexander Zehnder (who served in this capacity until 2004), Walter Giger and Laura Sigg, together with the then-Editor Bill Glaze. The aim was to advance the internationalization of the journal. Eawag represented an ideal location, not least as a result of the cooperation of the institute's former Director Werner Stumm with the first Editor of *ES&T* Jim Morgan. Anke Schäfer, a former doctoral student at Eawag, was appointed as Office manager, and in 2001 she was joined by Marie-Jeanne Weyrich. Since January 2007, the staff of the European Office has also included Eawag Director and Associate Editor Janet Hering, supported by her assistant Lucia Valle.

Among the ten most cited Eawag publications since 2000 are four *ES&T* papers.

Not a dream job

It is not always easy for Editors and reviewers to get their message across to the submitters of manuscripts. Faced with critical reviewers, frustrated authors do not pull their punches. Reviewers are accused of failing to focus on crucial details of the method – if they even understand the scientific background – and instead pursuing personal interests. But, equally, reviews are not always worded in the most diplomatic terms: comments such as "the worst paper I've ever read", "not even dissertation quality" or "I would be ashamed to submit a paper like this for publication" are frequently encountered and are suitably toned down before manuscripts are returned to the authors. On a lighter note, the following response was received from one researcher: "As recommended, we have shortened the paper by five pages. We agree that the paper has gained considerably as a result." In fact, nothing whatsoever had been cut, the author had merely shifted the margins and used a smaller typeface ...

The Office puts all the manuscripts allocated to one of the Associate Editors through the peer review process. The submissions are sent to several reviewers for expert comments. Considerable powers of persuasion are often required to motivate these reviewers, as their efforts are not rewarded by compensation or additional publications and the deadlines for this time-consuming work are tight. Being personally acquainted with a reviewer can be an advantage, as it is difficult to say no when a manuscript is delivered by hand to the office of the expert concerned.

60% rejection rate

In 2006, more than 60% of the drafts submitted to the European Office were rejected. In many cases, this is due to a lack of originality or environmental relevance, or to technical deficiencies identified by the Editor or reviewers. Each year, 200–250 manuscripts per Associate Editor are considered and sent to more than 500 different reviewers. Thus, since January 2000, the *ES&T* Office at Eawag has already reviewed more than 3000 manuscripts. In 2006 alone, the total was 547 – compared with 256 in 2000. During this period, the Eawag Office was also responsible for the preparation of two special issues, on the topics of "Ecotoxicology" and "Emerging Contaminants". In addition to the work on the scientific papers, a whole series of articles were produced by Anke Schäfer for the "News and Features" section.

Good reputation

For many Eawag researchers, especially in the field of environmental chemistry, *ES&T* is the journal of

Topics studied by Eawag researchers frequently feature prominently in ES&T, such as this report on arsenic-tainted groundwater and drinking water in Vietnam.

choice for their own publications. In 2006, no fewer than 24 papers authored by Eawag staff were published in this journal, which appears twice monthly. One reason is doubtless the good reputation enjoyed by *ES&T*, which has an impact factor of 4.1 – considerably higher than those of comparable journals in the environmental field. A paper on the application of arsenic biosensors in Vietnam, written by Eawag researchers Michael Berg and Jan Roelof van der Meer, was selected in 2006 as the *ES&T* top technology paper for the previous year.

The online edition of *Environmental Science & Technology:*
http://pubs.acs.org/journals/esthag/

In the public eye

"Eawag? They look after our water, don't they? A good idea!" This response is often encountered by Eawag employees. In 2006, various activities helped to reinforce the significance of aquatic research in the public mind and in political circles, and to raise the profile of our institute even further. Foremost among these was the opening of our new headquarters – Forum Chriesbach – on 1/2 September. This occasion not only attracted numerous visitors to the "blue-fin building" but also – together with announcements of several awards – kept Eawag in the media spotlight (see page 62). In February, the results of research activities contributing to the Millennium Development Goals were presented at a media conference held in Bern with the Swiss Agency for Development and Cooperation, and with support from National Councillor Rosmarie Zapfl and the President of the ETH Board Alexander Zehnder. In July, the findings of the Lake Brienz project – a study commissioned by Canton Bern which had been running for several years – were made public. Another event widely covered by the specialist and general media was the Eawag Info Day on flood control and rehabilitation, which took place on 8 March with almost 400 attendees.

Altogether, the external media monitoring service registered 868 articles and broadcasts dealing with Eawag research – 7% more than in the previous year. Website usage rose by 30% over 2005 to 750000 visitor sessions – the redesigned site is widely appreciated. Thirty-six groups visited Eawag in Dübendorf or Kastanienbaum – from school students to a delegation of Chinese officials. The communication of research findings to a non-academic readership was aided by three issues of *Eawag News*, focusing on biofilms (60), flood protection and rehabilitation (61), and material flows in developing and emerging countries (62). ○ ○ ○

Sustainable energy supplies for Eawag

Thomas Lichtensteiger, with the Eco-Team

According to the Guidelines for Environmental Protection at Eawag issued in 1994, consumption of non-renewable energy was to be reduced to 20% of 1990 levels by 2025. The target of 1.3 TJ per year for non-renewable sources of heating energy will probably already be met in 2008 when the renovated office building in Dübendorf is occupied and the rented Chriesbach property is no longer used. Further efforts are required in the areas of transport and electricity consumption. A substantial reduction in the demand for power from the current level of more than 8 TJ per year (2.2 million kWh) to the target of 5 TJ has been shown to be unrealistic. The Eco-Team therefore asked the Directorate to set new energy goals, taking into account experience with the new building Forum Chriesbach and the requirements of the 2000-watt society. New goals were approved by the Directorate on 4 December:

▶ Eawag is to take all necessary measures to meet its entire electricity and heating requirements with renewables and in an environmentally sound manner as soon as possible, but by 2025 at the latest.

▶ Electricity purchasing is to be gradually switched over to *naturemade star* green power supplies from 2007, with this source to cover all requirements from 2010.

▶ Work-related travel undertaken by Eawag staff is to be carbon-neutral.

In the process, the potential for savings is to be fully exploited when property and equipment is renewed and in the organization's operations. In addition, CO_2 emissions are to be offset through contributions and funding of appropriate projects not only in the case of air travel, as hitherto, but for all types of travel. In switching to renewables, the production of solar power on Eawag's own buildings is to be consistently expanded. Wherever possible and reasonable, co-generation is to be used. The remaining requirements are to be covered by green power with the *naturemade star* label, which was partly developed by Eawag (cf. page 37). This certification guarantees that hydropower generation complies with ecological requirements and is in line with sustainable development. As *naturemade star*-labelled power cannot be purchased directly in Dübendorf, it will be obtained indirectly through the purchase of certificates. This means that green power will be supplied elsewhere at standard rates in the quantities financed by our procurement.

www.umwelt.eawag.ch

The solar panel on the roof of Forum Chriesbach. A photovoltaic system is also to be installed on the roof of the old office building (back) when the refurbishment and upper storey addition is complete.

The frugal-energy building

"Blue bastion of sustainability", "The futuristic building", "A step towards the 2000-watt society", "Showpiece of zero-energy architecture" – the Forum Chriesbach attracted wide media coverage. The theme underlying all the reports was that Eawag, which conducts research on sustainable use of water resources, has now demonstrated its own commitment to sustainable development. Andri Bryner

Eawag's new headquarters was officially opened on 1 September 2006. The following day, around 2500 members of the public took the opportunity to have a closer look at the building, which has a striking facade consisting of blue glass fins. On guided tours, the visitors learned a great deal not only about the workings of the building but also about how Eawag's research projects help to tackle current water-related problems.

"We want to stick to our core competency, which is architecture. But as architects, we should not just leave the question of energy efficiency to the engineers. Good architecture, sustainable building, energy-efficient design and cost-effectiveness are certainly compatible."
Bob Gysin. Bob Gysin + Partner BGP Architekten ETH SIA BSA

No heating installed

What makes Forum Chriesbach special is the consistent application of available knowledge on sustainable building practices. Essentially, the design involves the integration of established technologies, rather than the radical or experimental use of individual elements. Apart from the ground floor (staff canteen, reception and library), the building requires no conventional heating. With a 45-centimetre-thick outer wall (including a 30 centimetre layer of rock wool) and high-quality windows, it is so well insulated that heat losses are minimal.

Gaëtan Bally. Keystone

The new building's characteristic blue fins are adjusted according to the position of the sun, providing shade in the summer months and as much sunlight as possible during the winter.

All sources of heat are utilized, from that given off by computers and lighting to employees' body heat. In the winter, incoming air is pre-heated in 80 20-metre-long underground pipes and further warmed in a heat exchanger, using heat from exhaust air and the server room. In addition, heat from the hot water storage system can be supplied to incoming air. Water in this system is heated by solar collectors on the roof of the building (50 m^2, vacuum tube system) and by exhaust heat from refrigeration units in the kitchen. To meet peak demand during particularly cold periods, heat can be obtained from the Empa-Eawag site network. It has been calculated that supplies from this source will not exceed the equivalent of 2500 litres of oil per year – i.e. barely as much as is required by a conventionally built detached house.

Pleasantly cool in the summer

Providing an aesthetically innovative alternative to blinds are 1232 silkscreen-printed glass fins. Along each facade, these are adjusted according to the position of the sun: in the winter the amount of sunlight reaching the building is maximized, and in the summer exposure to the sun's rays is minimized to prevent the windows and interior from heating up. On hot days, the entire building is cooled overnight by the opening of office windows and skylights in the roof. Heat escapes via the atrium as if through a chimney, and cool night air enters the offices. Concrete ceilings promote heat absorption, while clay partitions help to regulate interior humidity. Even during the July heatwave, with outdoor temperatures reaching 35 °C, temperatures inside the Forum Chriesbach building remained below 26 °C – without any energy-intensive air-conditioning.

Taking grey energy into consideration

Sustainable construction means that the entire life cycle of a building needs to be considered, and in particular the embodied or "grey" energy. This fraction becomes all the more important as operating energy efficiency is increased. Accordingly, resource-conserving materials were used, e.g. recycled concrete, wood-clay partitions and magnesite flooring. The use of non-recyclable composites was avoided as far as possible, and more energy-intensive components were required to have a long useful life. A third of the electricity requirement is met by solar

Sandra Neuhaus

Open house on 2 September. Extending in the atrium on the left and right two meeting rooms.

panels covering an area of 460 square metres on the roof. After 25 years, this system will have produced about 7.5 times as much energy as was required to manufacture it. With per capita power consumption of around 190 watts for electricity and heat and 240 watts for grey energy, Forum Chriesbach demonstrates that, in the building sector, the "2000-watt society"[1] is no longer a vision but can already be implemented today.

"In-house" research

Particular importance is attached to the management of water and wastewater. Roof water is stored in a reservoir with a capacity of 80 m^3 and used for toilet flushing. Rainwater from other hard surfaces is allowed to infiltrate on extensively vegetated areas. Urine is separately drained from all toilets and centrally collected for research purposes. Practical experience can thus be gained with the NoMix (urine source separation) technology, and new research questions can be addressed within the building itself (see pages 8–13). In addition, there are plans to rehabilitate the Chriesbach river, which flows through the Eawag site. The entire location, including the new Eawag-Empa childcare facility, is increasingly being transformed into a "sustainable campus".

Not a luxury project

Forum Chriesbach – the competition-winning project – was designed by the architectural firm Bob Gysin + Partner (BGP), with Implenia serving as the general contractor. The six-storey building accommodates 150 office workplaces, an auditorium for 140 people, two 40-seater seminar rooms, meeting rooms and communication areas. It also houses the joint Empa-Eawag library and the staff canteen "aQa", which has been awarded the "Goût Mieux" label. The building has been occupied since June 2006. Experience to date has been favourable, and isolated weak points or teething troubles, such as defective temperature sensors or incorrect control signals, are being progressively ironed out. The preconceived idea that only the state could afford a construction project of this kind has not been borne out. By deliberately forgoing luxurious interior design and complete energy self-sufficiency (which would not have been economically justifiable), it was possible to keep the project costs significantly below the federally approved credit of CHF 32.7 million. The price per cubic metre – CHF 572 (SIA, BKP2) – bears comparison with conventional construction projects.

"Our research on sustainable water use requires practical demonstration. The vision and philosophy underlying Forum Chriesbach have proven to be viable. This makes me happy for Eawag and optimistic about our society's progress along the challenging path towards a more sustainable future."
Ueli Bundi, interim Director of Eawag from 2004 to the end of 2006

Further information and details of public viewings are available at: www.forumchriesbach.eawag.ch/

The new childcare centre and playground – open to Eawag and Empa employees' children.

[1] Continuous consumption of 2000 watts per capita relates to all sectors, not just employment. At present, total consumption in Switzerland is 5000–6000 watts per capita.

Organization

Directorate
Ueli Bundi (Interim Director)
Rik Eggen
Willi Gujer
Peter Reichert
Roland Schertenleib
Bernhard Wehrli

CCES
Competence Centre Environment + Sustainability of the ETH Domain

Staff of the Directorate
Further education, knowledge transfer, communication
Peter Häni

Research departments

Research topic: Aquatic ecosystems

- **Surface Waters** – Alfred Wüest
- **Aquatic Ecology** – Jukka Jokela
- **Fish Ecology + Evolution** – Ole Seehausen

Research topic: Chemicals and effects

- **Environmental Chemistry** – Juliane Hollender
- **Environmental Microbiology** – Thomas Egli (a.i.)
- **Environmental Toxicology** – Marc Suter (a.i.)

Research topic: Urban water management

- **Water Resources + Drinking Water** – Rolf Kipfer
- **Environmental Engineering** – Hansruedi Siegrist
- **Urban Water Management** – Markus Boller
- **Water + Sanitation in Developing Countries (Sandec)** – Chris Zurbrügg

- **Systems Analysis, Integrated Assessment + Modelling** – Peter Reichert
- **Comprehensive Innovation Research in Utility Sectors (Cirus)** – Bernhard Truffer

Support

- **IT Services** – Gabriel Piepke
- **HR + Finances** – Pamela Graves (until Sept.), Rik Eggen, Peter Häni (from Oct.)
- **Vocational Training** – Max Reutlinger
- **Technical Services** – Max Mauz
- **Gender Activities** – Gabriella Meier

Eawag / Empa

- **Library** – Bas den Brok
- **Nursery** – Arianne Maniglia

As at 31.12.2006

Beratende Kommission

André Bachmann (President)
Executive Director, BMG Engineering Inc, Schlieren

Ursula Brunner
Lawyer, Ettler Brunner Suter Bächtold, Zurich

Erika Forster (from June 2006)
State Councillor, St. Gallen

Günter Fritz
Head of Environment, Health and Safety, Ciba Specialty Chemicals, Basel

Claude Martin (until November 2006)
Director-General WWF – World Wide Fund for Nature, Gland

Jürg Meyer
President, Swiss Water Pollution Control Association, VSA, Zurich

Bruno Oberle
Director, Federal Office for the Environment (FOEN), Bern

Directorate

Ueli Bundi (Interim Director.)

Rik Eggen

Willi Gujer

Peter Reichert

Roland Schertenleib

Bernhard Wehrli

Direktionsstab

Peter Häni
Leader

Herbert Güttinger
Further education

Isabel Wiedmer
Knowledge transfer

Andri Bryner (a.i.)
Communication

Research departments

Alfred Wüest

Jukka Jokela

Ole Seehausen

Juliane Hollender

Thomas Egli (a.i.)

Marc Suter (a.i.)

Rolf Kipfer

Hansruedi Siegrist

Markus Boller

Chris Zurbrügg

Peter Reichert

Bernhard Truffer

Support

Gabriel Piepke

Pamela Graves
(until 30.9.2006)

Max Reutlinger

Max Mauz

Gabriella Meier

Bas den Brok

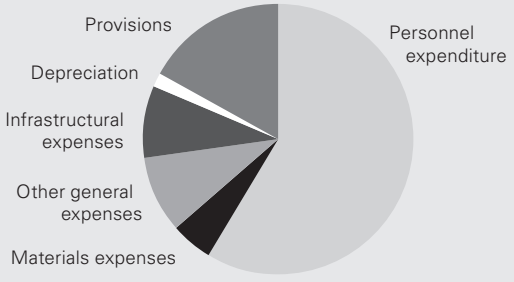
Arianne Maniglia

Finances

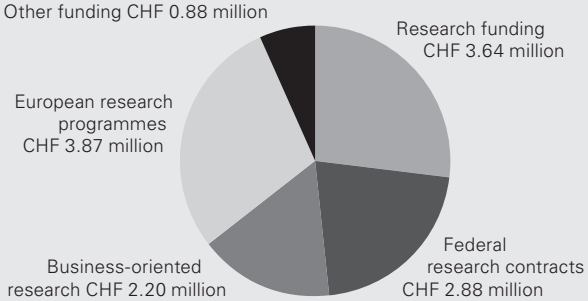
Financial statement (in CHF)	2004	2005	2006
Personnel	33 176 228	33 136 459	35 203 743
Materials	2 010 300	2 310 907	2 911 752
Other general expenses	4 836 881	5 051 942	5 556 131
Infrastructural expenses	3 296 021	3 399 665	5 160 395
Depreciation	1 198 857	1 029 614	871 718
Provisions	7 068 173	19 660 190	10 088 456
Expenditure	**51 586 460**	**64 588 777**	**59 792 195**
Federal government funding	46 645 700	46 624 468	49 795 822
Third-party resources	9 366 328	10 293 942	13 481 019
Miscellaneous revenue	620 832	1 110 280	1 010 742
Release of provisions	0	0	0
Income	**56 632 860**	**58 028 690**	**64 287 583**
Result	**5 046 400**	**–6 560 087**	**4 495 388**

Investments (in CHF)	8 306 818	20 929 645	9 370 632
Real estate	6 809 532	18 463 636	6 883 301
Movables	1 305 748	2 259 269	2 439 510
IT	191 538	206 740	47 821

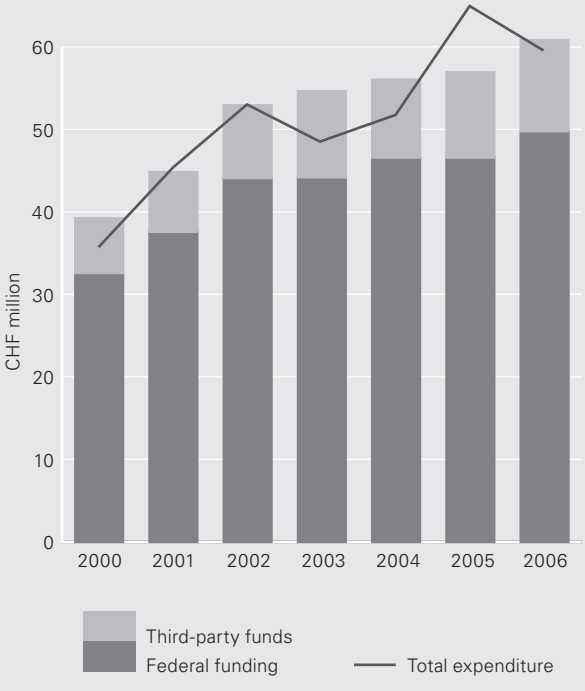
Breakdown of expenditure 2006



Third-party resources 2006



Development 2000–2006

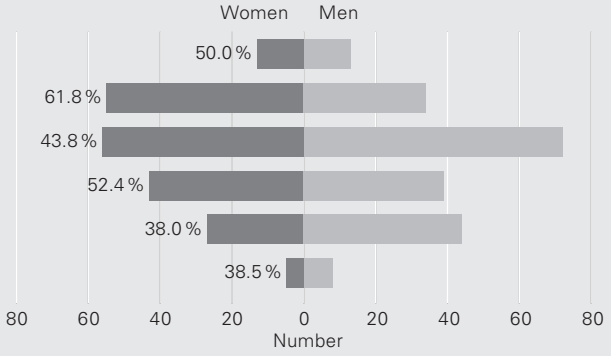


People

Personnel	People	Whereof women	Whereof non-Swiss	Full-time equivalents
Full professors [1]	4	0	2	4
Titular professors	13	2	5	13
Scientific staff (academic staff)	155	56	80	123
PhD students	71	35	36	66.6
Technical staff	82	41	10	63.9
Administrative staff	61	51	7	38.9
Apprentices	27	14	1	27
Trainees [1,2]	14	8	11	13.8
Affiliated staff (nursery) [1]	12	12	0	10.4
Total	439	219	152	360.6

[1] Not directly employed by Eawag
[2] Only traineeships funded by Eawag; total for 2006: 61.

Age structure	Women	Men	Total
15–19	13	13	26
20–29	55	34	89
30–39	56	72	128
40–49	43	39	82
50–59	27	44	71
60–65	5	8	13
Total	**199**	**210**	**409**



Percentage employment	Women	Men	Total
1–49%	26	10	36
50–79%	48	16	64
80–99%	34	17	51
100%	91	167	258

Origin	Women	Men	Total
Switzerland	132	138	270
EU	52	54	106
Other	15	18	33

Activities

	2004	2005	2006
Supervised dissertations	117	105	107
Supervised diploma theses	51	97	104
Publications in refereed journals	142	186	194
Publications in non-refereed journals	52	47	49
Spin-offs	2	–	1
Patents, licence agreements	2	–	–
Service contracts	41	39	38
Prizes	15	8	24
Teaching programmes at ETHZ, EPFL	81	85	93
Teaching programmes at other universities	20	31	37
Teaching programmes at universities of applied sciences	11	10	10
PEAK courses (further education)	8	9	6
Conferences	28	39	45
Committee memberships	162	180	201

Further details and annual reports in pdf format are available at: www.eawag.ch/annualreport

This Annual Report presents only a small selection of Eawag's research, teaching and consulting activities. It is also available in German. All publications by Eawag staff can be viewed online or ordered by e-mail.
http://library.eawag-empa.ch
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