

Annual Report 2007





Eawag, the Swiss Federal Institute of Aquatic Science and Technology, is part of the ETH Domain. This comprises the Swiss Federal Institutes of Technology in Zurich (ETHZ) and Lausanne (EPFL), Eawag and three other independent, application-oriented research institutes – the Paul Scherrer Institute (PSI), the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) and the Materials Science and Technology Research Institution (Empa). Nationally rooted and internationally networked, Eawag is concerned with 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 harmonize 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.

Cover photo

Pilot plant for the ozonation of treated wastewater at the Regensdorf wastewater treatment plant near Zurich. Ozonation can reduce the remaining toxicity by 90 %. In the Micro-Poll project, initiated by the federal authorities, Eawag – in cooperation with various partners – is assessing whether an additional treatment step of this kind is worthwhile.
Photo: Andri Bryner. Article: page 9.

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Water research with high scientific and societal impact



In most industrialized countries, gross pollution, such as foaming rivers, is a thing of the past. However, newly-introduced or newly-detectable chemicals pose novel challenges for water researchers and the water management sector. Developing countries face more acute issues of safe water supply and sanitation. Eawag is supporting the UN Millennium Development Goals through its research and its new partnership program. Janet Hering

Water is one of the prerequisites of life on our blue planet. Across the continuum from relatively unperturbed aquatic ecosystems to fully engineered wastewater treatment systems, water affects many areas of our lives – and offers many fascinating topics for research.

Water quality issues in developed countries

In developed countries, the acute water quality problems of the 20th century, such as eutrophication and uncontrolled releases of industrial effluents, have been largely solved. The increasingly widespread use of synthetic chemicals has, however, led to the ubiquitous occurrence in the aquatic environment of xenobiotic compounds, many of which act as endocrine disruptors (e.g. damaging reproductive organs or processes in fish). Eawag researchers have therefore been studying options for improving the efficiency of micropollutant removal in municipal wastewater treatment plants (p. 9) and for implementing localized wastewater treatment at hospitals (p. 14).

Improving human welfare

The UN-sponsored International Year of Sanitation in 2008 highlights the critical importance of good sanitation to human health. Eawag has a long history of engagement in improving sanitation, safe drinking water supply and waste management in developing countries, particularly through the activities of the Department of Water and Sanitation in Developing Countries (Sandec). Our guide-

lines for household-centred environmental sanitation are an important contribution to realizing the UN Millennium Development Goals (p. 39).

In recent years, research activities in developing and emerging countries have expanded beyond Sandec to other Eawag departments. For example, Eawag researchers have studied groundwater quality in South and Southeast Asia, surface water quality in China, and the opportunities and risks associated with energy generation from naturally occurring methane in Lake Kivu in Africa (pp. 25, 35). The Eawag Partnership Programme (EPP) will facilitate and promote collaboration with students and researchers from developing and emerging countries (p. 4).

Engaging with stakeholders and the public

Because water is such an integral part of our everyday experience, Eawag's activities must incorporate effective engagement and outreach to individuals. The cross-cutting Novaquatis project concluded with a well-attended and successful Information Day in March. In the same month, the "Sound of Rivers" (p. 29) was part of a popular exhibit at the Muba Fair in Basel, and a beautifully illustrated book on the Vierwaldstättersee and its surroundings was published with support from Eawag in October. The Forum Chriesbach building continues to be a source of great interest to the public and was visited by two members of the Federal Council in 2007.

Emerging areas of activity

Eawag researchers are constantly identifying new areas for research and new opportunities to address the problems facing society. The questions of how climate change will affect water resources, water supply and aquatic ecosystems, and of how ecosystems and societies will adapt to these pressures, are emerging topics of research at Eawag. Another emerging topic is the fate and environmental effects of engineered nanomaterials. These research areas will be the subject of active investigation in the coming years. In 2008, Eawag will also initiate a new type of activity, with the opening of the Centre for Applied Ecotoxicology. This centre is designed to meet the critical needs of society, industry and regulators by providing practice-oriented continuing education, contract research and ecotoxicological evaluation of chemicals.

Eawag staff can be justifiably proud of their many contributions to fundamental and applied research in aquatic science and technology. Publications by Eawag researchers appear in leading scientific and engineering journals and have a wide-ranging impact on the development of novel concepts and technologies. Eawag researchers are also leaders within the environmental science and engineering communities, where they are active as organizers of technical meetings and symposia, experts on advisory boards, invited speakers and reviewers, once again receiving many honours and awards in 2007.

Although these activities may seem rather distant from the daily water-related concerns of individuals, the strength of fundamental and applied research in aquatic science and technology at Eawag also positions it to address problems of broader societal impact. The function of *bridging between theory and practice* is a key part of Eawag's mission and mandate. Knowing that our work is put into practice to improve human well-being and environmental quality is a strong motivation for all of us at Eawag.

The strength of our research in aquatic science and technology enables us to address problems of broader societal impact.



Handwritten signature of Janet C. Avering in blue ink.



Promoting partnership

For many years, Eawag – through the Department of Water and Sanitation in Developing Countries (Sandec) – has been actively engaged in research in and for the benefit of countries where clean drinking water and safe disposal of wastewater and faecal matter cannot be taken for granted. Recently, other departments have also been increasingly concerned with water-related problems in various regions of the developing world. To further strengthen this commitment, Eawag has launched a Partnership Programme for Developing Countries. Andri Bryner, Christoph Lüthi, Tom Gonsler

For Eawag, research in developing countries is an important task. Water scarcity, environmental pollution, over-exploitation of resources and loss of biodiversity are just some of the issues of growing concern in the developing world. Thanks to its multidisciplinary approach and its network of scientific partners and research centres in the South and East, Eawag can increasingly provide practice-oriented solutions.



Fabrice Amisi is an MSc student from the Democratic Republic of the Congo. He is working in the Surface Waters Department on the quantification of external nutrient inputs to Lake Kivu. This requires the measurement of and collection of samples from tributaries, as shown in the photograph (see also page 35).

Fellowship Programme

Existing research and training activities in this area are now being expanded with the launching of the Eawag Partnership Programme (EPP), which is mainly designed to build academic, professional and research capacity in developing countries. A key element of the EPP activities is the Fellowship Programme, which each year offers six talented (preferably PhD) students from the developing world, the opportunity to carry out research at Eawag for 3–4 months. The other components of the EPP are a Visiting Scientist Programme for experienced researchers and professionals, the partnership with the UNESCO-IHE

Institute for Water Education in Delft (the Netherlands), and a module providing support for curriculum development.

To ensure that exchanges are mutually beneficial, each fellowship must be linked to a departmental project or a senior scientist at Eawag. In addition, the research topic has to be of relevance within a development context, and candidates are to be selected on the basis of the scientific quality of the proposed project. The EPP Selection Committee includes representatives of six Eawag departments and Director Janet Hering. In March 2008, the first three fellowships were awarded to an MSc student from the Democratic Republic of the Congo and two PhD students from Ghana and China.

Visiting Scientist Programme

The Visiting Scientist Programme will enable pre-eminent researchers and sector specialists from developing countries to present their projects and discuss their findings with researchers at Eawag. This will also give Eawag staff



Noah Adamtey is completing his doctoral thesis on "Enrichment of co-compost for periurban maize cultivation in Ghana" in the Department of Water and Sanitation in Developing Countries. In co-composting, organic wastes are composted together with faecal sludge. In this process, pathogens are rendered harmless under controlled conditions, so that the compost can finally be safely used in agriculture. In cooperation with the local university and the municipal authorities Eawag has launched a co-composting plant in Kumasi (Ghana) as a pilot project (see also pages 42, 43).



Tao Zhang has previously carried out research at Nankai University in Tianjin (China). At Eawag's Environmental Chemistry Department (in cooperation with Empa), he will continue with his thesis on perfluorinated compounds (PFCs) in wastewater and in natural waters. PFCs originate, for example, from stain-, grease- and waterproof coatings or breathable fabrics. They have toxic effects, persist in the environment and are scarcely degraded by wastewater treatment.

the opportunity to prepare new projects relevant to developing and transition countries, and to establish contacts with potential research partners.

Continuing the long-standing IHE partnership

Eawag's partnership with the UNESCO-IHE Institute for Water Education in Delft, which began 14 years ago, is now to be integrated into the EPP. Each year, three students from developing countries taking an MSc at the IHE are to pursue their studies at Eawag. These exchanges will generally last half a year and also include fieldwork in the participant's home country. Here, too, it is a requirement that the research topic should be of practical relevance to the student's country of origin. A first-hand account of how this scheme can work is given by former MSc student Mingma Sherpa, who is now applying the knowledge he acquired through Eawag in his home country Nepal (see Box).

Supporting education

The fourth component of the EPP is support for the education of local specialists. For this purpose, the large number of Eawag scientists involved in teaching represents a broad pool of expertise. Support may be provided in the development of training modules or the production of course material; equally, Eawag researchers may give a course or series of lectures themselves at a partner institution. Ultimately, this kind of capacity building should also promote research collaboration (see also page 43). ○ ○ ○

Mingma Sherpa describes his experience

My first contact with Eawag was in 2002, when the Sodis programme (solar water disinfection using PET bottles) was implemented in Nepal. I helped to test the effectiveness of Sodis at various altitudes in Nepal – from the slopes of the Himalayas down to the plains of the south. I worked initially as a researcher and later as a project coordinator for a Nepalese aid agency's Sodis promotion programme. In 2003, I had the opportunity to take a Master's degree in Environmental Science at the UNESCO-IHE Institute for Water Education in Delft (the Netherlands).

For my Master's thesis, I once again collaborated with Eawag, as the topic was faecal sludge management in Kathmandu Valley. I successfully completed my MSc at the IHE thanks to expert supervision by Martin Strauss and Doulaye Kone at the Department of Water and Sanitation in Developing Countries, and with assistance from my advisor, Roshan Shrestha of the UN Human Settlements Programme (UN-Habitat) in Nepal. This cooperation between the IHE, Eawag and the UN offers many advantages: it meant that, although I was enrolled at an Institute in the Netherlands, I had the support of the leading experts in the field of faecal sludge management. I was able to work on a topic which I find very interesting and which had previously been scarcely studied in my home country. My work is now gradually bearing fruit: for example, some of the results have been incorporated by UN-Habitat into a faecal sludge management strategy for the Bagmati region. In 2006, I started working for the same organization in Nepal again, as a wastewater and sanitation programme manager. I'm involved in the planning of a water supply system and an integrated programme to improve sanitation for a community of 6000 people living near Kathmandu. Thanks to an intensive campaign carried out in partnership with the community – involving more than 100 composting toilets and other toilet facilities – we have reached the point where people no longer defecate in the open. We have also distributed composting buckets to households, where they are consistently used. I am now also jointly responsible for coordinating other water and sanitation programmes run by our organization and for the budget in this sector, and at the same time I'm trying to press on with my thesis at the Asian Institute of Technology in Bangkok.



Mingma Sherpa at a workshop on improving sanitation in Nepal.

Subst

Chemicals and their impacts

Herbicides, fungicides, algicides, disinfectants, cleaning agents, pharmaceuticals and nanoparticles – the list of substances detected in surface waters is growing longer and longer. But very often it is unclear where exactly the substances come from and what effects they have in the environment. Aquatic research at Eawag explores these questions, but even when answers have been found, the problems are not necessarily solved. For example, is it worthwhile upgrading wastewater treatment plants with additional technologies? Or could other measures be more effective for avoiding releases of problematic substances? Here, there is a need to consider economic, social and frequently also political aspects – in the light of our scientific findings.

Some people are content when they see that something works, but chemist **Stephan Hug** (50) is not one of them: he wants to know how it works. While this may be normal for a researcher, Hug is not satisfied either with theories developed under sterile laboratory conditions, as commonly found in academic research. Hug is convinced that “The key to understanding lies in studying the actual environment,” and this he considers to be one of Eawag’s great strengths. Often, as Hug points out, the crucial processes occur at interfaces – for example, on ultrafine particles suspended in water: “If you only work with pure substances, you’ll never really understand what’s going on.” Hug originally trained as a chemical laboratory technician, before studying at a university of applied science and at Bern University. Having obtained his doctorate at the University of California, he was a post-doctoral fellow at Stanford University. Throughout his career, while specializing in photochemical and surface chemical processes, he has never lost sight of his goal: scientific understanding must



ultimately lead to practical applications. As well as leading to the release of problematic substances, photochemical and surface reactions may eliminate the toxicity of chemicals. Accordingly, Hug’s research at Eawag has focused not only on how UV light kills microorganisms (as in the Sodis method of solar water disinfection), but also on how it can render contaminants such as arsenic or hexavalent chromium harmless. While photochemical water treatment still requires further development, other processes investigated by Hug’s group are being applied in practice – for example, the use of sand filters to remove arsenic from drinking water in Bangladesh, Vietnam and Greece (pages 19, 20).

Environmental engineer **Nathalie Vallotton** (30) hails from Lausanne and (as she is frequently asked) is related to the painter Félix Vallotton. She specializes in risk assessments – a topic she had already chosen for her dissertation at the Federal Institute of Technology (EPFL), which was concerned with leachate from a land-fill in Ho Chi Minh City (Vietnam). In the Environmental

Toxicology Department at Eawag, Vallotton subsequently wrote her doctoral thesis on the effects of peak exposures of herbicides on algae (*page 13*). Although she had not been intent on obtaining a doctorate from the start, she says, she realized that a disser-

tion was the best way of learning more about environmental toxicology. She is now an expert in this field and, as she puts it, “a bit closer to being able to assess these effects, with a view to understanding the effects observed and the quality of waterbodies”. As it is difficult even to detect peak exposures by means of sampling, scant reliable data have been available so far on the effects of such pulses, which may derive, incidentally, not only from agriculture but also from traffic or urban sources. For Vallotton, scientific insights are not enough: thanks to Eawag’s cooperation with authorities and agricultural research institutes, measures designed to reduce agrochemical pollution of surface waters have already been taken – including increased training for farmers on the management of these substances. Finally, Vallotton mentions another practical concern: “People should speak more French at Eawag.”



Agricultural engineer **Christoph Ort** (33) was repeatedly told that it was barely possible to predict when, and in what concentrations, pollutants flow through sewers. “Not even daily loads were considered to be predictable,” he says. However, by skilfully combining analytical chemistry with a stochastic model, Ort managed to remedy this deficiency in his dissertation. In doing so, he sought support from various departments at Eawag: “The open doors were extremely helpful.” His predictions agree closely with the results of costly individual measurements and can even reveal peaks at a temporal resolution in the minute range. In the MicroPoll project sponsored by the Federal Office for the Environment (FOEN), Ort now has the opportunity, as an Eawag post-doc, to apply his

interdisciplinary approach on a large scale: using a national material flow model (*page 9*), he has predicted what micropollutant loads are to be expected for all wastewater treatment plants, and where critical inputs of effluent into streams could occur under dry weather conditions – with more than a hundred plants affected. Do all of these plants now need to be upgraded with additional technology? Ort cites the principle “As simple as possible, as complex as necessary.” He adds that, alongside technical measures, efforts are needed to promote more careful management of substances potentially hazardous to the environment. Ort is already involved in the FOEN pilot study at the Regensdorf wastewater treatment plant. Here, treated wastewater undergoes ozonation before being discharged into a small stream. With the scientist’s curiosity, he admits: “It’s fascinating to be among the first to be able to try out this process at full scale – whether or not it will later become common practice.”





Closing gaps in wastewater treatment

Organic micropollutants, such as ingredients of cleaning agents or active substances of medicines, are not completely eliminated at wastewater treatment plants (WWTPs). This means that they are discharged into creeks, rivers and lakes, where they may have adverse effects on the ecosystem. In the MicroPoll project, researchers are assessing possible countermeasures – including an additional treatment step at WWTPs, which has already produced encouraging initial results. Christoph Ort, Hansruedi Siegrist, Juliane Hollender und Beate Escher

Representative sampling and quantification of a wide variety of organic micropollutants is extremely costly. If efforts are restricted to a reasonable and financially acceptable level, it is only possible to obtain a “snapshot”, limited in space and time. Online analytical instruments capable of measuring these substances directly and continuously in surface waters do not (yet) exist – and even if they were available, they could be used only to record existing conditions, and not to make predictions.

We therefore developed a national material flow model [1], which describes current loads of selected micropollutants in surface waters downstream of the 742 WWTPs serving more than 500 population equivalents. In addition, the model can be used to calculate future scenarios and carry out cost/benefit analyses. The key input variables for our model are the quantities of a given substance consumed and data on the WWTPs, including the number of inhabitants served, the sites where effluent is discharged to receiving waters and the elimination performance for

the substance concerned. We also take into account information on the use and fate of substances, e.g. prescribed doses and known rates of excretion.

Case of carbamazepine

A number of studies, including our own, have shown that elimination of the antiepileptic agent carbamazepine at WWTPs is currently minimal. Under the assumption that on average almost 10 % of the carbamazepine ingested is excreted from the human body in unchanged form, and that the substance is not degraded in natural surface waters, the model calculates the average annual mass flows to be expected. In Fig. 1, the values predicted by the model for 26 catchments of different sizes are plotted against the loads measured. With only a few exceptions, the results generated by the model are in close agreement with reality. For household chemicals and medicines, deviation by a factor of 2 is not unusual and reflects the variability over time that is to be expected at a given site [3].

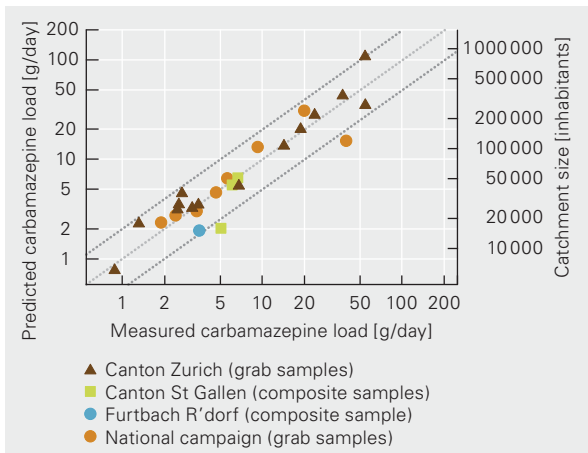
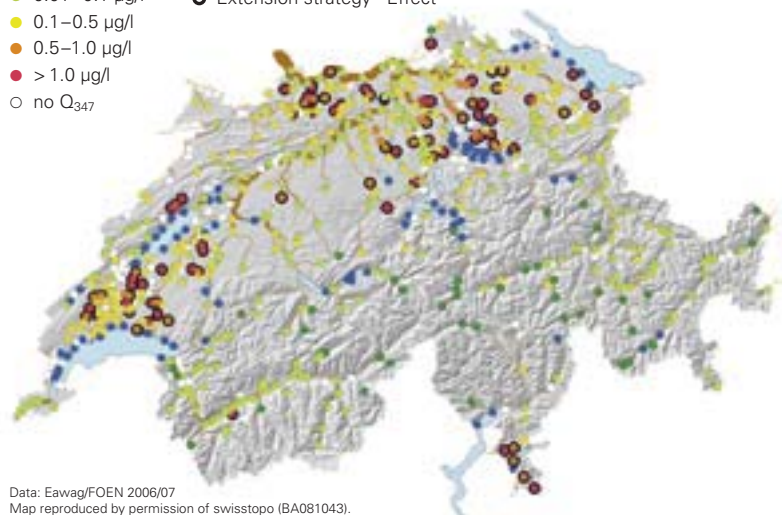


Fig. 1: Daily loads of carbamazepine in 26 river sections, by catchment size. The dotted lines indicate a deviation by a factor of 2 from the values predicted by the model.

Figure 2 provides an overview of the total hazard potential predicted for carbamazepine in rivers at base flow Q_{347} (i.e. the flow rate attained or exceeded 95 % of the time). If no measurements of flow rates below a WWTP were available, values were interpolated. The results show that the quality standard of $0.5 \mu\text{g/l}$ proposed for carbamazepine by the German Working Group of the Federal States on water issues (LAWA) is exceeded in rivers and streams below almost 100 of the 742 major Swiss WWTPs. The base flow Q_{347} represents a “worst case” since dilution of the effluent in receiving waters is low under such conditions. The period during which the quality standard is actually exceeded in specific cases depends largely on the annual flow regime in the individual water-

Carbamazepine + metabolites at base flow Q_{347}

- $< 0.01 \mu\text{g/l}$
- $0.01 - 0.1 \mu\text{g/l}$
- $0.1 - 0.5 \mu\text{g/l}$
- $0.5 - 1.0 \mu\text{g/l}$
- $> 1.0 \mu\text{g/l}$
- no Q_{347}
- Discharge to lake
- Extension strategy “Effect”



Data: Eawag/FOEN 2006/07
Map reproduced by permission of swisstopo (BA081043).

Fig. 2 Modelled carbamazepine hazard potential in rivers at base flow Q_{347} . Black rings indicate wastewater treatment plants that would need to be upgraded to ensure that concentrations of carbamazepine (including metabolites) do not exceed $0.5 \mu\text{g/l}$ in any surface waters.



Ozonation of previously treated wastewater can reduce the remaining toxicity by 90 %.

course. The material flow model was tested in a measurement programme involving the collection of samples from 10 rivers and 15 WWTPs. The results obtained for three of these rivers (Töss, Ergolz and Seyon) are shown in Fig. 3. Here, the carbamazepine loads expected on average lead to exceedance of the quality standard for periods ranging from no or only a few days to several months per year. The duration of exceedance varies widely from year to year. Peaks occur in years with prolonged dry periods, such as the summer heat wave of 2003.

Extension strategies

If the periods during which excessive loads are expected to occur in surface waters are to be reduced, an additional treatment step would need to be implemented at the WWTPs concerned. Pilot studies on a small scale have shown that, for many micropollutants, elimination rates

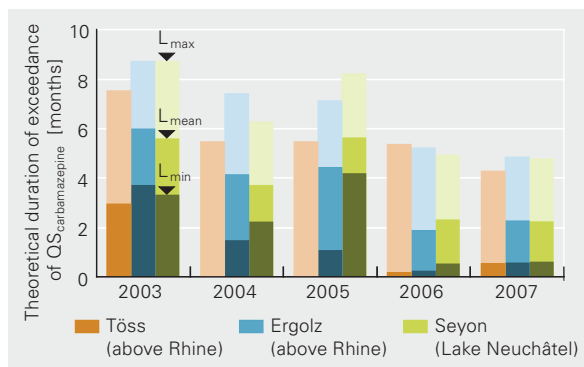


Fig. 3 Periods during which carbamazepine concentrations theoretically exceeded the quality standard (QS – suggested by the LAWA) of $0.5 \mu\text{g/l}$. The duration of exceedance is also shown for carbamazepine loads of twice (L_{max}) and half (L_{min}) the expected value (L_{mean}).

of 95% or more could be achieved through the use of activated carbon filtration or advanced oxidation of treated wastewater. Assuming that inputs of substances to wastewater cannot be prevented by means of prohibitions or other at-source measures, the following strategies are conceivable:

► *“Effect” strategy:*

Additional treatment processes would be implemented at the minimum number of WWTPs required to ensure that the desired quality standard at base flow is no longer exceeded in downstream river sections. This would involve at least 80 plants, serving around 10% of the population (see Fig. 2).

► *“Load” strategy:*

In line with the precautionary principle, the aim would be to achieve the greatest possible load reduction nationwide, with measures only being considered for WWTPs serving at least 10,000 population equivalents. In this case, more than 250 plants would be involved (serving around 90% of the population). However, the quality standard for carbamazepine would still be exceeded at about 40 smaller WWTPs.

What we have shown in the case of carbamazepine is also applicable for other micropollutants: in the case of the anti-inflammatory agent diclofenac (average consumption approx. 4000 kg per year in Switzerland, according to IMS Health GmbH), we calculated that concentrations in receiving waters at base flow would exceed the quality standard of 0.1 µg/l at more than 170 WWTPs.

Full-scale trial in Regensdorf

To determine whether the results achieved in pilot studies can be reproduced with a full-scale system, an ozonation process is currently being tested at the Wüeri WWTP in Regensdorf (Canton Zurich). The trial is also designed to determine how much energy is required for full-scale operation of an additional treatment step and what demands it places on staff at a municipal WWTP.

The Wüeri WWTP was chosen as the test site because the plant is technologically advanced and is situated on the small Furtbach stream. With substantial fluctuations over

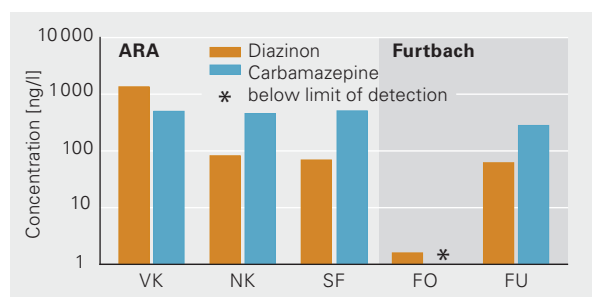


Fig. 4: Concentrations of diazinon and carbamazepine measured over a 1-week period at the Wüeri WWTP in Regensdorf. VK = primary clarifier, NK = secondary clarifier, SF = sand filter effluent, FO = Furtbach above WWTP, FU = Furtbach below WWTP. Modified from [5].

MicroPoll

Aquatic micropollutants currently feature prominently in discussions of surface water assessment, drinking water processing and wastewater treatment. But do organic micropollutants really pose a problem at concentrations ranging from millionths to billionths of a gram per litre (e.g. compounds found in detergents and cosmetics, or active ingredients of pharmaceuticals)? As part of the “MicroPoll strategy” – an interdisciplinary project launched by the Federal Office for the Environment (FOEN) – research is focusing on the question of micropollutants from urban drainage. Ecotoxicologists are seeking ways to identify problematic substances and to determine the concentrations at which these pollutants have (adverse) effects on organisms. Chemists are developing methods to allow water samples to be screened as accurately as possible for such compounds. Efforts in both of these areas are providing valuable information on the current state of our surface waters. The overall aim is to formulate a national strategy for reducing inputs of micropollutants to receiving waters. Also participating in the MicroPoll project, alongside the FOEN and Eawag, are the Federal Institute of Technology Lausanne (EPFL), cantonal environmental protection agencies and the Swiss Water Pollution Control Association (VSA). Further details are available at www.umwelt-schweiz.ch/micropoll [2].

a 24-hour period, the average proportion of wastewater in the stream just below the plant is 60%; in other words, the effluent discharged by the WWTP is only diluted by a factor of 1.7. Taking the examples of carbamazepine and diazinon, Fig. 4 shows the correspondingly sharp increase in concentrations of micropollutants in the Furtbach stream after the release of treated wastewater. At the WWTP, carbamazepine is scarcely eliminated at all, while the insecticide diazinon is only partly eliminated.



The treated wastewater discharged into the Furtbach stream is only weakly diluted, particularly during low-flow conditions.



Clarifier at the WWTP Regensdorf. The tank containing liquid oxygen for ozone production can be seen in the background.

In general, given the high costs involved, samples can only be analysed for a limited number of micropollutants, and the effects of mixtures are largely unknown. However, ecotoxicity tests covering various modes of toxic action make it possible to obtain a more comprehensive assessment of the treatment performance of WWTPs (see also the "Hazard potential" Box). At the plant in Regensdorf, Eawag applied an ecotoxicological test battery [6].

Figure 5 shows how the toxicity of micropollutants in wastewater was reduced as a result of the treatment processes – by more than 90% overall, although major differences were seen, depending on the substance and mode of action. The first measurements performed after the implementation of ozonation demonstrate that this additional treatment can reduce the remaining toxicity by a further 90%. Just as importantly, the ecotoxicity tests did

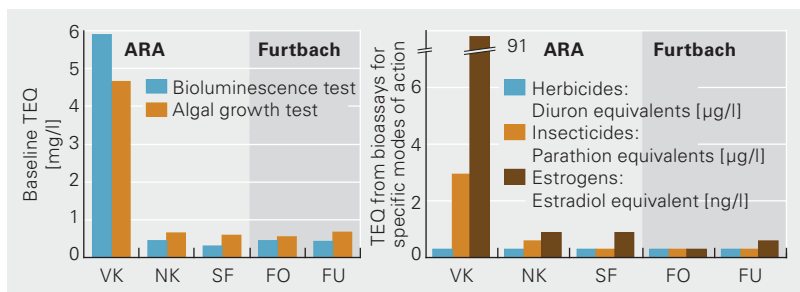


Fig. 5: Average toxicity values (toxic equivalents/TEQ) determined at the Wüeri WWTP in Regensdorf using an ecotoxicological test battery over a 1-week sampling period [6]. Left: Baseline TEQ for a large group of compounds (including carbamazepine). Right: TEQ from bioassays for specific modes of action, e.g. parathion equivalent concentrations (including the contribution of diazinon). VK = primary clarifier, NK = secondary clarifier, SF = sand filter effluent, FO = Furtbach above WWTP, FU = Furtbach below WWTP.

Hazard potential

In order to draw conclusions about the risk posed to surface waters by measured or predicted concentrations, it is necessary to know the hazard potential of the substance under investigation. This value is determined experimentally in the laboratory with the aid of elaborate ecotoxicity tests involving, for example, algae, daphnia (water fleas) or fish. The results of these studies are used to derive a concentration below which no adverse effects are expected to occur in the ecosystem concerned – the PNEC (predicted no effect concentration). It is important that biotransformation products (metabolites) should be taken into account as well as the parent compound. In the case of carbamazepine, about 40% of the active substance is excreted as metabolites formed in the body. These compounds increase the hazard potential by around 25% [4].

In addition, it is necessary to distinguish between the baseline toxicity of a compound or group of compounds and specific modes of toxic action – e.g. endocrine disruption or insecticidal effects (see Fig. 5).

not reveal any increases in toxicity, which suggests that the process does not give rise to any toxic by-products. These findings, which were confirmed by chemical analysis for individual substances, are highly encouraging. The trial in Regensdorf is to run until the end of 2008. During this period, different modes of operation are to be tested and, in particular, control systems are to be further optimized. The combined efforts of water pollution control authorities, ecotoxicologists, environmental chemists, research engineers and practitioners, and WWTP staff will allow valuable experience to be accumulated, facilitating future decisions in the area of centralized wastewater treatment. ○ ○ ○

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Taking peak exposures into account

Herbicides used in crop production may enter aquatic ecosystems via surface runoff, especially after heavy rainfall. Wide variations in concentrations are generally not detected by routine measurements. However, peak exposures have toxic effects, for example on algae. The existing non-specific quality criteria need to be amended. Nathalie Vallotton, Rik I.L. Eggen, Nathalie Chèvre¹

Under the Swiss Water Protection Ordinance, concentrations of organic pesticides in surface waters are required not to exceed 0.1 µg/l per individual substance. From an ecotoxicological viewpoint, this limit is unsatisfactory since substances with quite different modes of action are all assessed by the same standard, and the effects of mixtures of pesticides are not taken into consideration. In addition, peak concentrations in streams frequently – albeit temporarily – exceed not only the chronic water quality criteria (CQC) applicable to all pesticides, but also the limits recently proposed for specific substances.

Widely used products

Conventional laboratory tests usually assess toxic effects in algae or aquatic plants exposed to constant concentrations for several days. Effects caused by single or multiple peak exposures are not evaluated. We therefore investigated how the green alga *Scenedesmus vacuolatus* reacts to various exposure scenarios and how well it recovers after each exposure. We selected three herbicides with different modes of action – the photosystem II (PSII) inhibitors atrazine and isoproturon, and

the chloroacetanilide S-metolachlor, which inhibits fatty acid biosynthesis. All three products are widely applied in agriculture on cereals and corn crops and are commonly detected in surface waters.

Varying effects

For all the herbicides studied, toxic effects on growth increased with increasing exposure duration and concentrations. However, the rise in toxicity varied widely, depending on the type of herbicide. Considerable differences were also observed in the time to onset of toxic effects and in the recovery of algae following pulse exposure: with the PSII inhibitors, algal growth inhibition occurred within only a few hours, but algae recovered again almost as rapidly in clean water. In the case of S-metolachlor, on the other hand, effects on algal division were only observed if exposure coincided with a specific development stage, while recovery was seen after a delay of 29 hours. These differences may be attributable to the mode of action of the herbicide and the type of binding at the target site.

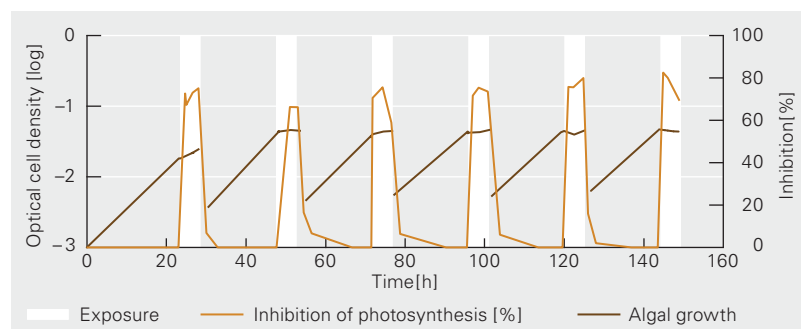
The effects of repeated exposure to the PSII inhibitor isoproturon are shown in the Figure. While the



The ecotoxicological effects of herbicides depend on a variety of factors.

effects on growth and photosynthesis were reversible after each exposure, the cumulative decrease in biomass production may affect the composition of algal communities in the environment.

As peak herbicidal exposures have been shown to induce toxic effects in algae, the level and the number of exceedances of the CQC should be limited. In addition, more stringent requirements should be specified for herbicides with delayed effects. ○ ○ ○



The growth and photosynthetic yield of algae are strongly inhibited during each exposure (5 hours/day) to the herbicide isoproturon; however, they recover between exposures. The decrease in cell density after each exposure is due to the experimental procedure – the algal cultures have to be diluted to permit renewed growth.

¹ University of Lausanne.

This study was funded by the Velux Foundation and the Swiss National Science Foundation.

Vallotton N. (2007): Effect assessment of fluctuating exposure of herbicides with different modes of action on algae. PhD thesis, ETHZ.

Vallotton N., Eggen R.I.L., Escher B.I., Krayenbühl J., Chèvre N. (2008): Effect of pulse herbicidal exposure on *Scenedesmus vacuolatus*: a comparison of two photosystem II inhibitors. Environmental toxicology and chemistry, accepted.

Chèvre N. (2006): Pestizide in Schweizer Oberflächengewässern: Wirkungsbasierte Qualitätskriterien; Gas Wasser Abwasser 4, 297–307.

Where should hospital wastewater be treated?

Hospitals are generally regarded as point sources for pharmaceuticals. A study performed at Winterthur Cantonal Hospital showed that concentrations in wastewater vary widely, and that by no means all the substances dispensed are also excreted at the hospital. In view of these findings, the question whether separate treatment of hospital wastewater is worthwhile requires further investigation.

Christa S. McArdell, David Weissbrodt, Lubomira Kovalova, Juliane Hollender, Hansruedi Siegrist

It cannot yet be said whether separate treatment of hospital wastewater is worthwhile.

According to estimates of the consumption of pharmaceuticals drawn up as part of the MicroPoll project (see page 9), about 18% of all medicines sold in Switzerland are dispensed in hospitals. However, the percentage for hospital use is much higher in the case of certain types of substance, e.g. X-ray contrast media or cancer drugs (cytostatics).

Dispensing ≠ excretion

The quantities of medicines dispensed cannot simply be equated with those subsequently found in hospital wastewater. The proportion excreted varies widely from one substance to another and, moreover, medicines are also dispensed to hospital outpatients. To determine the actual proportion of pharmaceuticals in hospital wastewater, we therefore collated statistics on consumption and known data on rates of excretion.

In addition, we analysed samples for selected agents and quantified the corresponding mass fluxes in hospital wastewater.

Initial analyses were carried out at Winterthur Cantonal Hospital in May 2007. Over a 1-week period, samples were collected from the sewer in proportion to the volume of effluent. The agents studied were representatives of the class of cytostatics, which are undesirable in the environment on account of their frequently carcinogenic effects, and contrast media. Although the latter are of less toxicological concern, they are environmentally persistent.

Numerous outpatients

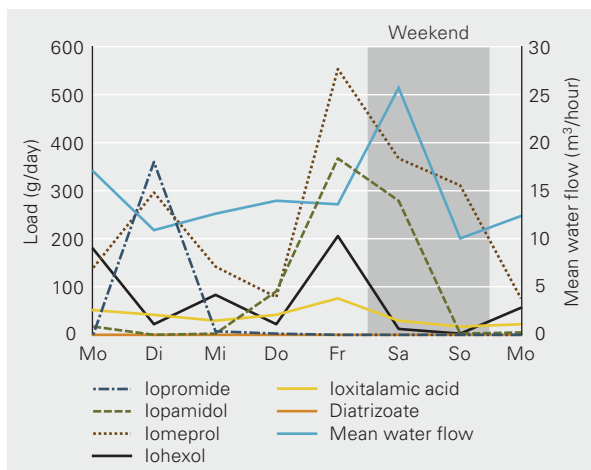
The results show that the loads vary widely both in the course of the day and from one day to another, depending on the quantities consumed at the hospital. The highest concentrations – up to 1700 µg/l – were found in the case of the contrast medium iomeprol, while the maximum concentrations detected for the cancer drug 5-fluorouracil were only 30 ng/l. The concentration profile for the 3-hour composite samples reflects the predicted excretion rates. The fraction of contrast media excreted within 2 hours is 50%; accordingly, after administration in the morning, a peak concentration is found around midday.

Comparison with the 2006 consumption statistics for contrast media shows that the loads measured correspond to 25–50% of average consumption. In the case of cytostatics, precise consumption figures are available for the measurement period. However, we found only 1–4% of the expected amounts of

5-fluorouracil and gemcitabine in the wastewater. This can be partly explained by the high proportion of these agents (70%) dispensed to outpatients.

No “best available technology”

Various strategies are conceivable for preventing pharmaceuticals in hospital wastewater from entering the environment. Under the leadership of Eawag, a working group on “Hospital wastewater” has therefore been established, comprised of experts from the Federal Office for the Environment, cantonal authorities and engineering consultancies. One of the main goals is to reach scientifically based conclusions as to whether hospital wastewater requires separate treatment, and if so, whether this would be best carried out on site or in additional treatment steps at wastewater treatment plants. A pilot plant combining a membrane bioreactor with advanced oxidation is currently being installed at Baden Cantonal Hospital in order to accumulate further experience, since no “best available technology” exists as yet for hospital wastewater treatment. ○○○



Mass fluxes of X-ray contrast media in wastewater from Winterthur Cantonal Hospital over a 1-week period.

This project is supported by the State Secretariat for Education and Research, the EU project Neptune, the Federal Office for the Environment, Cantons Bern, Basel District, Geneva, St. Gallen, Schaffhausen, Solothurn, Schwyz, Thurgau, Vaud and Zurich, and the Holinger (Liestal) and Hunziker (Winterthur) engineering consultancies.

Moser R., McArdell C.S., Weissbrodt D. (2007): Mikroverunreinigungen: Vorbehandlung von Spitalabwasser. GWA 11, 869–875.

Nitrosamines in water resources

Carcinogenic nitrosamines can enter surface waters – and possibly also groundwater – via wastewater. Eawag has developed an analytical method capable of detecting these unwanted compounds in wastewater samples and measuring concentrations in the nanogram range. The results obtained at Swiss wastewater treatment plants are reassuring. Martin Krauss, Philipp Longrée, Juliane Hollender

The discovery of carcinogenic nitrosamines, especially *N*-nitrosodimethylamine (NDMA), in wastewater and drinking water has raised concerns, initially in North America and more recently also in Europe. In North America, nitrosamines mainly arise as a by-product of chlorine or chloramine disinfection of wastewater and drinking water. However, as these unwanted substances also derive from industrial and household sources, they may likewise occur in countries such as Switzerland that rely primarily on other methods of water disinfection. At Eawag, a sophisticated analytical method has been developed for the determination of nitrosamines.

Analytical challenges

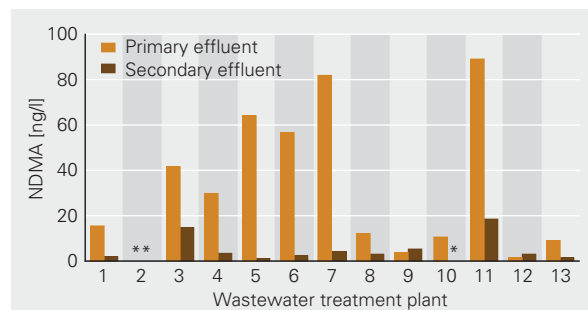
The detection of NDMA and other nitrosamines in the low nanogram per litre range is a highly demanding analytical task. Enrichment of the small, uncharged and highly soluble compounds from water requires the use of specific adsorbents. Particu-

larly in wastewater samples, reliable measurement is hampered by the presence of a large number of interfering matrix compounds, so that not only high sensitivity but also high selectivity is necessary to ensure unequivocal quantification. Our method allows nitrosamines to be measured in concentrations as low as 1 ng/l. It involves pre-concentration of the water sample by a factor of 500 by solid-phase extraction, followed by separation using liquid chromatography and measurement of nine nitrosamines by high-resolution tandem mass spectrometry (LTQ Orbitrap system).

Measurements at Swiss WWTPs

To gain an overview of nitrosamine concentrations in wastewater in Switzerland, we analysed 24-hour composite samples from 13 more or less technologically advanced wastewater treatment plants. In the primary effluent, concentrations of NDMA approaching 100 ng/l were found in some cases. At all the WWTPs, high levels of NDMA were markedly reduced by biological wastewater treatment, and in all cases concentrations were below 20 ng/l before the secondary effluent was discharged to receiving waters.

Among the other nitrosamines measured, *N*-nitrosomorpholine was found at all WWTPs in concentrations of up to 30 ng/l. For *N*-nitrosodiethylamine, *N*-nitrosopiperidine and *N*-nitrosodi-*n*-butylamine, individual samples showed concentrations of up to 20 ng/l. These four compounds were also largely eliminated by biological wastewater treatment, so that the concentrations in the secondary effluent were generally below 5 ng/l. On the basis of these findings, compared with the situation in North America,



Concentrations of NDMA in primary and secondary effluent at 13 Swiss wastewater treatment plants. * = below the detection limit of 1 ng/l.

contamination of treated wastewater with nitrosamines in Switzerland can be classified as low-level.

As part of the EU RECLAIM WATER project, we are currently monitoring the occurrence and elimination of nitrosamines in wastewater streams used for artificial groundwater recharge at facilities in Israel, Italy, Belgium and Spain. The results indicate that nitrosamines are largely eliminated in the course of wastewater treatment and aquifer passage. When groundwater was recovered, only NDMA was found in some cases at concentrations below 10 ng/l. ○ ○ ○



Martin Krauss working at the high-resolution tandem mass spectrometer (LTQ Orbitrap system).

Krauss M., Hollender J. (2008): Analysis of nitrosamines in wastewater: Exploring the trace level quantification capabilities of a hybrid linear ion trap/Orbitrap mass spectrometer. *Analytical Chemistry* 80, 834–842. www.reclaim-water.org

Caffeine: a marker indicating the need for water protection

Should concentrations of pharmaceuticals, biocides or caffeine be measured even when they are so low that there is no immediate threat to river ecosystems or individual species? Yes, they should, since these measurements provide valuable pointers to where water protection measures would be most effective – long before pollution starts killing fish. Alfredo C. Alder, Zaharie Moldovan

In recent years, numerous studies have been carried out in Europe and North America on the occurrence of pharmaceuticals and fragrances in effluents and surface waters. However, scant data are available from Eastern Europe and developing countries. This lack is worrisome for two reasons: firstly, it is scarcely possible to assess the local situation using data obtained elsewhere, since consumption levels vary widely from country to country. Secondly, it is not possible to conclude where untreated or poorly treated wastewater is being discharged into surface waters.

Medicines and caffeine

As part of the Swiss-Romanian research collaboration sponsored by the Swiss National Science Foundation (see Box), we determined the concentrations and loads of specific pharmaceuticals and fragrances in the Somes watershed in Transylvania. The substances studied were

the medicines carbamazepine, ibuprofen, diazepam and pentoxifylline, and the musk fragrances tonalide and galaxolide. In addition, samples were analysed for caffeine and for the biocide triclosan, which is used as an antimicrobial or preservative.

The Little Somes (Romanian: *Somesul Mic*) rises to the south of Cluj-Napoca and merges with the Great Somes (*Somesul Mare*) at Dej. The Somes then flows westward for 370 km to join the Tisza (a tributary of the Danube) in Hungary. Along the 250-km Romanian stretch of the river, we collected grab samples several kilometres upstream and downstream of wastewater treatment plants (WWTPs) and analysed these using directly coupled gas chromatography-mass spectrometry.

Concentrations lower than in Switzerland

The anticonvulsant carbamazepine is scarcely eliminated at WWTPs and is therefore a useful indicator of the level of discharges of municipal wastewater into a river. The concentrations measured in the effluents of Romanian WWTPs ranged from 210 to 770 ng/l. In the river, concentrations were relatively constant at 20–60 ng/l. They are thus an order of magnitude lower in the Somes than in the rivers of Switzerland or other Western European rivers. This may be due to two factors: either carbamazepine is less widely used in Romania, or the proportion of effluent in the river is lower (i.e. wastewater is highly diluted).

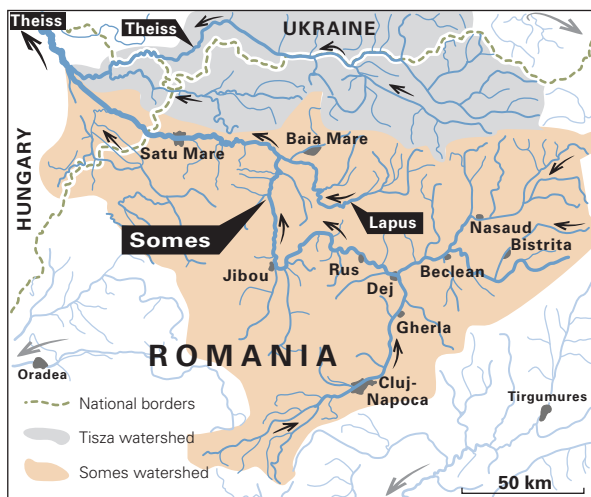
The daily loads varied between 78 g/day below Cluj-Napoca and 210–230 g/day after the confluence of the Little and Great Somes (Fig. 2).

In contrast to carbamazepine, caffeine is efficiently eliminated at WWTPs (>99%). Concentrations of caffeine in the river can therefore serve as a chemical indicator of untreated municipal wastewater. Caffeine concentrations in the effluent of most WWTPs varied between 24,000 and 42,000 ng/l. These very high levels suggest that the facilities are not operating effectively or are completely overloaded. One exception is the efficient plant at Cluj-Napoca, where caffeine concentrations of only 30 ng/l were measured in the treated wastewater. Caffeine levels in poorly treated or raw wastewater are thus around three orders of magnitude greater than in the WWTP effluent at Cluj-Napoca.

Caffeine concentrations in the Somes, varying between 110 and 330 ng/l, were comparable to those measured in Swiss rivers. Caffeine loads rose from less than 600 g/day in the Little Somes to 2400 g/day after the confluence with the Great Somes.

Wastewater inflows from Great Somes

At Dej, loads of the poorly biodegradable substance carbamazepine increased by a factor of 2–3 as a result of wastewater discharges into the river. The disproportionate increase in caffeine loads by a factor of 4 below Cluj-Napoca indicates inputs of untreated wastewater. As the rise is most marked at Dej, it must be due to inflows of untreated wastewater from the Great Somes – originating from the cities of Bistrita, Nasaud and Beclean (combined population of approx. 115,000). Downstream of Dej, despite inputs from further cities such as Jibou, Baia Mare and Satu



The population of the Somes watershed is 1.8 million. The main wastewater treatment plants are at Cluj-Napoca (350,000 inhabitants), Gherla (30,000), Dej (75,000), Baia Mare (200,000) and Satu Mare (150,000).



Top: River scene in Romania. Bottom: Sampling at a barely functional wastewater treatment plant in the Somes watershed.

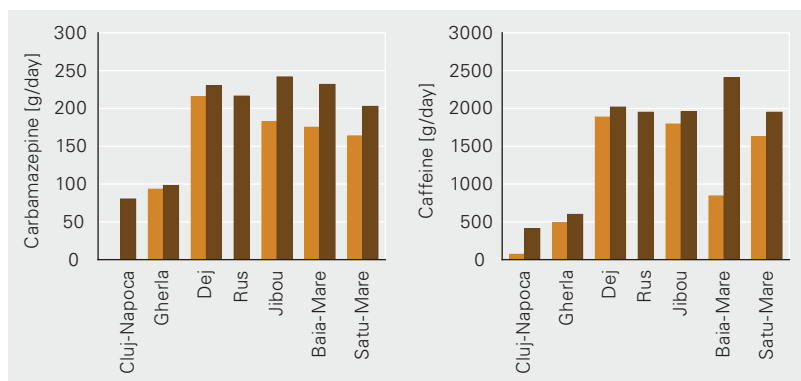
ESTROM – Swiss contribution to water research in Romania

The ESTROM (Environmental Science and Technology in Romania) research programme was jointly funded by the Swiss National Science Foundation, the Swiss Agency for Development and Co-operation, and the Romanian Ministry for Education and Research. The aim of the programme was to study the extent and impacts of water pollution at selected sites in Romania and to provide a basis for decisions on measures to protect ecosystems and human health. With a budget of CHF 1.5 million, nine projects were supported. Five Eawag researchers were involved as Swiss partners, and Professor Walter Giger (also of Eawag) chaired the ESTROM Steering Committee. The results of this research are to be presented to water protection professionals and officials at an international conference in Bucharest (3–5 September 2008). Further information is available at: www.estrom.ch and www.cntp.ro/estrom.php

Mare, the loads remained relatively constant since caffeine is partly degraded in the river.

Toxicologically, the concentrations of the substances measured do not give cause for concern. However, our

findings indicate that other substances and mixtures may also be entering the Somes with inputs of untreated wastewater. To improve water quality, therefore, the WWTPs along the Great Somes, in particular, need to be upgraded. The rapid rise in caffeine concentrations downstream of Baia Mare also suggests that the performance of the WWTP there is inadequate. ○ ○ ○



Mass fluxes of carbamazepine and caffeine in the Somes. The water samples were collected upstream (orange) and downstream (brown) of where tributaries or WWTP effluents enter the river.

Moldovan Z., Schmutzer G., Tusa F., Calin R., Alder AC. (2007): A first overview of pharmaceuticals and personal care products contamination along of the river Somes watershed, Romania. *J. Environ. Monit.* 9, 986–993.

A plastic disc to replace a fish?

New legislation for chemicals has created a strong international demand for information on the bioaccumulation potential of organic micropollutants. Studies with live fish are costly and also need to be reduced to a minimum for animal welfare reasons. Our laboratory method successfully simulates passive uptake across fish gills. Jung-Hwan Kwon, Beate Escher

Many organic micropollutants accumulate significantly in fish. This bioaccumulation is thus important not only for fish health and ecosystem integrity, but also for human health. For the registration of new chemicals, manufacturers are required to assess bioaccumulation in fish.

Need for more rapid tests

Bioaccumulation involves two pathways:

- ▶ bioconcentration, i.e. direct accumulation from ambient water, especially through passive diffusion across the gills,
- ▶ biomagnification, i.e. accumulation via the food chain.

Bioconcentration is generally evaluated using OECD Test Guideline 305. This procedure requires the killing of 40–60 fish per compound tested. A single test takes 2–3 months and can easily cost more than CHF 100,000. There is a pressing need for alternative methods.



The stir disc is placed in one half of the glass cell. The entire glass cell, with the PDMS membrane in the middle, is then mounted on a magnetic stirrer in which the discs are not just rotated but tumbled end-over-end. This ensures that only a wafer-thin water layer remains unstirred at the gill membrane.

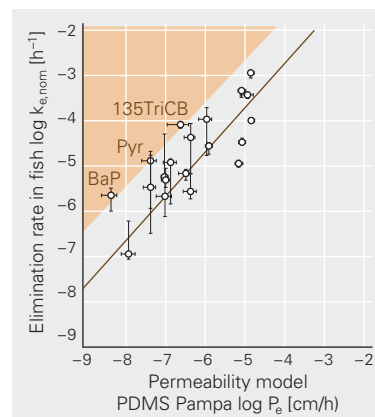
Pharmaceutical forerunners

Various laboratory methods have been developed to evaluate the passive absorption and elimination of pharmaceuticals with the aid of biological membrane models. One of these methods – the Parallel Artificial Membrane Permeability Assay (PAMPA) pioneered by Hoffmann-La Roche – has also been used for organic micropollutants [1]. Unfortunately, however, this method is not suitable for particularly problematic substances, as these are generally poorly soluble in water.

We modified this method to simulate the process occurring in fish gills. A polydimethylsiloxane (PDMS) membrane – serving as a gill membrane model – is placed between a pollutant-impregnated donor disc and a pollutant-free acceptor disc (both also made of PDMS). The decrease in pollutant concentrations is then measured in the donor, together with the increase in the acceptor. However, what determines the time required for equilibrium to be reached on either side of the membrane is diffusion not through the membrane itself, but through the unstirred aqueous boundary layer that forms between the membrane and well-stirred water. In gills well supplied with oxygen, this layer is only about 20 μm thick. Simulating this in the laboratory requires the use of a special stirring system.

Effective gill model

Using our experimental set-up, we tested 14 hydrophobic chemicals [2]. The permeability values correlated well with the elimination rates measured *in vivo*. The only exceptions were substances that are metabolized in fish and therefore have higher elimination rates than are predicted by the model. We now intend to add



The results obtained with the gill model are in close agreement with the elimination rates measured *in vivo*, with the exception of substances whose elimination rate is increased by metabolism e.g. benzo[a]pyrene, 1,3,5 trichlorobenzene (orange marked zone).

enzymes isolated from fish liver to the acceptor cell, so that the contribution of metabolism can also be predicted. However, the PDMS-PAMPA system can already be used for worst-case assessment of bioconcentration potential and thus as an aid to decisions on whether animal experiments are even necessary. ○○○

- [1] Kwon J.-H., Katz L.E., Liljestrand H.M. (2006): Use of a parallel artificial membrane system to evaluate passive absorption and elimination in small fish. *Environ. Tox. Chem.* 25, 3083–3092.
- [2] Kwon J.-H., Escher B.I. (2008): A modified parallel artificial membrane permeability assay for evaluating bioconcentration of highly hydrophobic chemicals in fish. *Environ. Sci. Technol.* (in press).

A climate record preserved in dripstone

Stalagmites in limestone caves, which develop over thousands of years, can be used by researchers to study the past climate. Unlike Arctic ice cores, for example, they also provide long-term information on conditions in temperate and continental zones. However, high-precision extraction of gases from microscopic water and air inclusions in stalagmites is extremely challenging.

Yvonne Scheidegger, Rolf Kipfer, Rainer Wieler¹, Dominik Fleitmann², Markus Leuenberger²

As a result of seasonal variation in drip rates, stalagmites exhibit distinct growth layers, which can be precisely dated. As stalagmites grow, minute quantities of drip water and cave air are trapped inside. These water and air inclusions are promising climate records, which remain largely unsearched.

Intact crystals

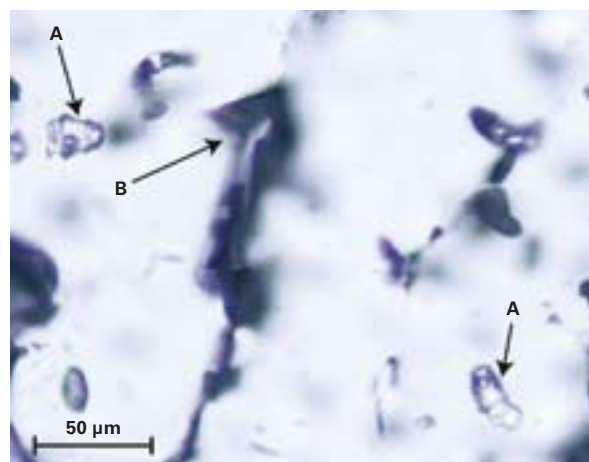
Dissolved noble gases in water inclusions provide a record of the climatic conditions prevailing at the time when they were enclosed in the stalagmite. This is because the solubility of noble gases (neon, argon and xenon) depends on the temperature and salt concentration of the water and on the atmospheric pressure during gas exchange. Applying a method familiar from groundwater analysis, the ratio of gas concentrations can thus be used to determine the cave temperature that must have prevailed when the water inclusions were formed.

The main difficulty involved in extracting the gases from the water inclusions is to avoid any mixing with noble gases from nearby air inclusions, since noble gases from the air yield no information on the past climate. We have developed a method that makes it possible to extract noble gases from water inclusions while keeping to a minimum any interference caused by noble gases from air inclusions. To this end, the stalagmite material is crushed, without the individual calcite crystals being destroyed. This allows the air between the crystals to be released – but not the water inside the crystals. Only in the next step are the gases dissolved in this water extracted by

heating. We tested the method by analysing samples taken from a stalagmite from Yemen, which is still active today. The temperatures calculated accord well with the present cave temperature. However, they still show large errors, as we have so far been unable to measure absolute concentrations. We are currently seeking to reduce the margin of error by determining the amount of water extracted from the sample manometrically, so that palaeotemperatures can be determined even more precisely.

More luxuriant growth 2000 years ago

To study the gases from the air inclusions, the composition of present-day and 2000-year-old samples from the same stalagmite was analysed. Initial findings show that the main components of the air occur at the same levels as in the free atmosphere. However, trace gases – especially CO₂ – are markedly elevated compared with atmospheric concentrations. The carbon isotopic composition is very light, suggesting that the CO₂ is of biogenic origin. This shows that the old air inclusions do indeed contain “old” cave air and can be used as an indirect indicator of biological activity in the soil above



Micrograph of a stalagmite from Oman. A: Water inclusion, B: Air inclusion

the cave. Comparison of the recent and the ancient sample suggests that biological activity was higher in the past. The climate of this arid country must therefore have been more humid at that time. ○ ○ ○



The last 7000 years' growth (approx. 20 cm) of a stalagmite from the Sofular Cave (Turkey). The entire formation contains growth layers dating back 50,000 years.

¹ ETH Zurich

² Bern University

Arsenic and uranium in Greek groundwater

In some regions of Greece, groundwater used for drinking contains elevated concentrations of arsenic and uranium. While uranium is below the guideline value in the areas studied, arsenic levels are above the new EU limit of 10 µg/l. Existing remedial measures now need to be rapidly expanded to ensure compliance with the tighter regulations, in force since January 2008. Ioannis Katsoyiannis and Stephan Hug

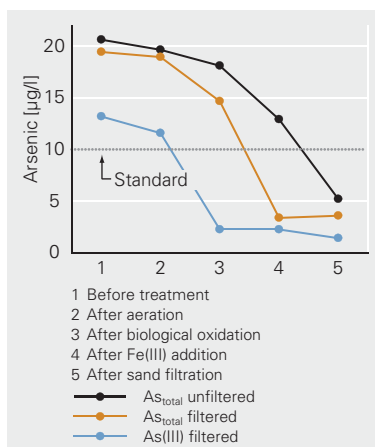
In view of its carcinogenic effects, the EU, WHO and US limits for arsenic in drinking water have been lowered to 10 µg/l. This limit is exceeded in many regions of Europe and elsewhere. In Greece, a transitional limit of 35 µg/l was applicable until January 2008. In an EU-funded project, we studied the situation in two regions of Northern Greece.

Three times the limit

In groundwater, arsenic occurs in two forms: the dominant species in oxic water is As(V), which is easier to remove. The main species in anoxic water is As(III), which generally has to be oxidized to As(V) to permit removal. In two regions on the Thermaic Gulf, we collected samples from 23 groundwater wells. The average arsenic concentrations for the two regions were around 30 µg/l, with values ranging from 10 to 70 µg/l. In the reducing groundwaters in the alluvial plain of the Axios and Loudias rivers, As(III) predominated and uranium concentrations were low. In the oxic groundwaters of the karstic region of Kalikratia, As(V) was the dominant form and uranium concentrations up to 10 µg/l were found (WHO guideline value for uranium: 15 µg/l).

Arsenic removal in four steps

In Malgara (Axios), the groundwater contains 20 µg/l arsenic (mainly



Arsenic concentrations in groundwater from Malgara (Axios) after each treatment step.

As(III)), 165 µg/l iron, 550 µg/l phosphate, 235 µg/l manganese and 1.2 mg/l ammonium. At a multi-step water treatment plant, which has been installed in Malgara in 2005, we studied the removal of arsenic in collaboration with the local operators. In step 1, the water is aerated and dissolved Fe(II) is oxidized to insoluble Fe(III), with formation of microscopic, suspended iron oxide particles ("red-orange water"). In the process, a small fraction of As(III) is oxidized to As(V) and bound to the

iron oxide. The second step involves a biological sand filter, in which naturally occurring bacteria oxidize dissolved manganese to manganese oxides, which are retained together with the iron oxides. As(III) is oxidized to As(V), but not removed, as the amount of the oxides formed is not sufficient to bind all the arsenic. In the third step, addition of Fe(III) salts results in arsenic sorption on the additionally formed iron oxide particles, which are removed by the sand filter in step 4. In areas with oxic groundwater containing As(V), a facility comprising steps 3 and 4 would be sufficient.

In laboratory tests and in pilot plants, we are currently developing simpler methods for arsenic removal for small-scale facilities. One promising option is the use of sand filters with iron filings, which continuously form dissolved Fe(II) and iron oxides in aerated water, thereby continuously oxidizing and retaining As(III). ○ ○ ○



Location of the two study regions in northern Greece: a) Axios, 30–40 km west of Thessaloniki and b) Kalikratia, 40–50 km south-east of Thessaloniki.

The situation in Switzerland

In Switzerland, the limit for arsenic in drinking water is still 50 µg/l, but in practice, water suppliers want lower concentrations. In areas where concentrations exceed 10 µg/l – particularly in the cantons of Ticino, Graubünden and Valais – the problem can generally be solved by dilution with uncontaminated water. The use of individual contaminated resources would require arsenic removal similar to that in Greece.

Katsoyiannis I.A., Hug S.J. et al. (2007): Arsenic speciation and uranium concentrations in the groundwaters in Northern Greece: Correlations with redox indicative parameters and implications for groundwater treatment. *Science of the Total Environment* 383, 128–140.

Katsoyiannis I.A., Zikoudi A., Hug S.J. (2008): Arsenic removal from groundwaters containing iron, ammonium, manganese and phosphate: A case study from a pilot plant unit in Northern Greece. *Desalination* 224, 330–339.

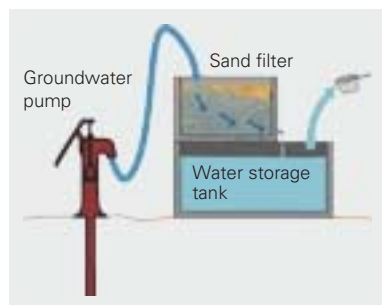
The psychology of sand filter use

Technological innovation is not in itself sufficient to solve real-world problems – solutions can only be effective if they are consistently and correctly applied in practice. This calls for campaigns tailored to target groups' material, social and psychological situation. Taking the example of sand filters used for arsenic removal, we sought to identify the key requirements. Robert Tobias, Hans-Joachim Mosler

Many problems concerning water supply and wastewater disposal can be solved with the aid of innovative technologies developed at Eawag – or rather, *could* be solved, since households first need to be encouraged to install, use and maintain these systems. This can be achieved through promotional campaigns devised and implemented by social scientists.

Arsenic in drinking water

Current estimates suggest that the health of more than 100 million people worldwide is threatened by drinking water contaminated with arsenic. Chronic exposure to arsenic concentrations of 50 µg per litre is enough to cause serious health problems after 10–15 years. The first sign of disease is a change in skin pigmentation, which may be followed by skin cancer and blackfoot disease – a condition typical of chronic arsenic poisoning. Sand filters developed by Eawag can help to mitigate the problem of contamination: using this simple method, 80% of the arsenic content on average can be removed by precipitation. However, for a household, the effort involved in installing and operating a sand filter is not insignificant.



With the aid of a simple sand filter, 80% of the arsenic content, on average, can be removed from pumped groundwater in Vietnam.

Vietnam: follow-my-neighbour

In order to assess the situation in Vietnam, we conducted representative surveys in villages around Hanoi and evaluated the responses statistically. It was shown that people's behaviour is strongly influenced by that of their peers. Accordingly, sand filters are used by almost all households in some villages, and by scarcely any in others. Surprisingly, however, the filters are generally not rated as expensive and are not constructed because of arsenic in drinking water but to remove the non-hazardous but unpalatable iron content. Maintenance is often not carried out frequently enough or is neglected altogether, even though the yellowish-brown colour of the water and the reduced flow rate seem to remind respondents that maintenance is required.

However, many people appear to be unaware of the importance of maintenance. To put the same point differently, proper maintenance is carried out significantly more frequently by those respondents who emphasized the health benefits of the filter in the survey.

Based on these results, campaigns can now be developed to promote the construction and maintenance of sand filters. For example, to raise public awareness, the arsenic issue could be highlighted by the mass media. Another possibility would be to offer a water-testing service, with households paying to have samples collected and analysed.

To take advantage of the social forces revealed by the survey to be particularly important, targeted efforts could be made to help interested households install and maintain sand filters. They would then serve as models and instructors for other households.



Sand filter for iron and arsenic removal, used by rural households in the Red River Delta (Vietnam).

These and other techniques can be used to ensure that effective innovations are actually implemented on the ground, thus contributing to the solution of real problems. ○ ○ ○

www.eawag.ch > Abteilung Systemanalyse und Modellierung > Gruppe Soziale Systeme

Berg M. et al. (2006): Arsenic removal from groundwater by household sand filters – comparative field study, model calculations, and health benefits. *Environ. Sci. Technol.* 40 (17), 5567–5573.

Water

Aquatic ecosystems

Lakes, rivers and streams are complex habitats. It is essential to understand the workings of these aquatic ecosystems if the goal of sustainable management is to be achieved – whether it is on the Yangtze River in China, on Lake Kivu in the heart of Africa, or on Lake Wohlen near Bern. At Eawag, methods and approaches are being developed to allow early detection of changes in these systems and in the organisms they support. Intact waterbodies are important not only for the preservation of biological diversity, but also in terms of the valuable “services” they provide for humans – for example, safeguarding water resources and water uses over the long term.

“Whenever I go to a new town, the first thing I need is a map,” says **Rosi Siber** (44). As an expert on geographical information systems (GIS), she is the first point of contact at Eawag for anyone who needs to evaluate, represent or obtain geographical data. She is currently working with the Agriculture and Water Protection Group on the development of a model that shows which areas of Switzerland are of particular relevance for inputs of pesticides to water resources. As well as site-related factors and climatic data, the model incorporates information on crops grown, pesticide use and other data. Naturally, it is not possible to include every single field. However, the results will support the authorities in decisions as to which zones require closer monitoring, also covering small streams. In this project, Siber has benefited from

her knowledge of agriculture, which derives not just from her experience in her own garden but from the fact that she originally trained as an agricultural technical assistant. She subsequently studied biology at Constance University and became

interested in water through limnology. Previously, she had explored streams mainly as a canoeist. Her cheerful nature means that she is ideally suited for the dual role of researcher and GIS specialist that she has played at Eawag since 2002 – as well as being interested in databases and aquatic ecology, she enjoys working with people. In the Rivers of Europe project (*page 31*), she not only handled the data processing and provided a lot of behind-the-scenes advice but also co-authored the chapter on the Danube.



Carsten Schubert (41) started out studying physics at Giessen University, but after two semesters he couldn't see the point of calculating rocket trajectories and switched to geology. As he now recalls, "I hadn't previously had anything to do with rocks, but I was enthusiastic from the very start." He then turned his attention

from hard rocks to softer deposits, analysing a sediment core from the Baltic Sea for his dissertation. The information preserved in the sample dates back 10,000 years – which provides the link to environmental research since the occurrence of the

heavy metals lead, zinc and cadmium in the core documented the beginning of industrialization. In 1991, Schubert had an opportunity to join an expedition on the German research vessel "Polarstern". He still has vivid memories of this voyage – the moment the compass needle started spinning round, the telegram of congratulation from the Federal Chancellor, going swimming at -1.7°C and the celebrations on board when the ice-breaker had reached the North Pole. At the Alfred Wegener Institute in Bremerhaven, Schubert subsequently wrote his doctoral thesis on Arctic Ocean sediments. After holding a fellowship at the University of British Columbia, he spent four years at the Max Planck Institute for Marine Microbiology in Bremen. Here, Schubert and his co-workers were the first to demonstrate and precisely describe the mechanism of anaerobic methane oxidation by archaea and bacteria. Their paper published in *Nature* in 2000 is still frequently cited. However, jaded by the publications rat race, he considered moving to Italy, where "the weather is fine and the food is good, but," he admits with a smile, "I wouldn't have earned anything." Instead, he settled for a position at Eawag, where he continues to work on methane – in Swiss lakes, rather than in the sea (page 34). A bad career move? "Not at all", says Schubert, a family man. "Here, I have the best job in the world – with a degree of freedom that I probably wouldn't have in Germany."



"At secondary school, my dream was to be a marine biologist and to work on a ship for Greenpeace," says **Christine Weber** (33), who comes from the Emmental region. At Bern University, she did indeed study biology. However, her only dealings with fish were during an internship at the Federal Veterinary Office, when she was concerned with imports and exports of ornamental species. Her first contacts with Eawag came with a subsequent internship in palaeoecology: at Kastanienbaum, she investigated the evidence of past climate conditions provided by pollen trapped in lake sediments. Having enjoyed this placement, she later applied – successfully – for a position as a doctoral student, to work on fish ecology and river rehabilitation as part of the Rhône-Thur project. She is particularly fond of research in the field. On one occasion, during fieldwork on the Rhône, she was standing on two rocks near the riverbank when a squeaking water shrew approached and swam round her – an experience of nature which she will never forget. "I learn most about biology when I'm outdoors," she says. But isn't she disillusioned when she sees how little really changes in practice following restoration projects? Weber demurs: "That's not true – a great deal happens, but we are too impatient and the measures are frequently still very localized." She is clearly referring to all those who would pronounce the project a failure if salmon have not returned to the Thur within a few years. As she points out, a variety of indicators – from the longer shoreline to the growing numbers of recreational visitors – show that certain changes can already be precisely measured (page 30). "Other things just take longer than the four-year electoral cycle in politics."





Swiss-Chinese cooperation on the Yangtze

As part of the Yangtze Freshwater Dolphin Expedition, Eawag collected water and sediment samples on a 1700-km-long stretch of China's largest river. Analysis of these samples showed that while concentrations of most pollutants are in the same range as in other major rivers around the world, the loads are immense. Beat Müller, Michael Berg, August Pfluger¹

Taming the waters of the Yangtze is a millennia-old project. Among the most important responsibilities of the early Chinese imperial rulers was to provide the country with beneficial rainfall, so as to ensure good harvests and avert famine, floods and droughts – disasters poignantly described in the works of the Nobel Prize-winning author Pearl S. Buck [1]. The Yangtze, which together with the Yellow River to the north forms the cradle of Chinese civilization, is thus simultaneously loved and feared.

Thousands of dams

Since the 1950s, however, the taming of the Yangtze – the 6300-km-long artery on which some 350 million people now depend – has assumed grotesque proportions: the flow regime and suspended sediment transport have been profoundly altered by 45,000 dams in the entire catchment basin. Of these, 143 have a storage capacity of more than 100 million m³, including the controversial Three Gorges Dam. Of the 500 million tonnes of

sediment per year formerly transported to the East China Sea, only about a third now reaches its destination. As a result, the Shanghai Delta is gradually disappearing. To date, 1.4 million people have been displaced by the Three Gorges Reservoir, which began filling in 2003. In the foreseeable future, another 4 million people will have to be resettled, as the banks of the 600-km-long reservoir are starting to erode in places.

Gigantic diversion project

Less well known is another large-scale project that has been under way since 2003. This is designed to transfer water northwards from the Yangtze river basin to the dried-up rivers of the thirsty industrial centres, where the intensification of agriculture, desertification and demand from the coal, cement and paper industries have led to increasingly acute water shortages. The world's largest diversion project is to cost the equivalent of around EUR 45 billion and redistribute 50 billion m³ of water per year

Mineral fertilizers, pesticides and untreated wastewater enter the Yangtze, which is also (mis)used for dumping refuse. Here, rubbish is fished out of the Three Gorges reservoir. (Photo: das-fotoarchiv.com/Xinhua). Top: Water samples were analysed for more than 280 substances, with some tests carried out directly aboard one of the two research vessels. (Photo: baiji.org Foundation)

¹ August Pfluger is the Director of the baiji.org Foundation, which has offices in Zurich and Wuhan.

First-ever survey by an international team

The Yangtze Freshwater Dolphin Expedition was jointly organized by the Swiss baiji.org foundation and the Wuhan Institute of Hydrobiology. Under the auspices of the Chinese Ministry of Agriculture, the enterprise brought together researchers from six different countries, including the authors of this article from Eawag. It was the first time that China had allowed an international team to carry out such a detailed study of the Yangtze. The main aim of the expedition was to investigate the reasons for the disappearance of the whitefin dolphin (Baiji, *Lipotes vexillifer*) and the likewise threatened finless porpoise *Neophocaena phocaenoides asiaorientalis*. Among those supporting the project were the Swiss Agency for Development and Cooperation (SDC), the globally active Société Générale de Surveillance (SGS) Group, the Pictet bank and companies such as Canon, Victorinox and Katadyn.

– an average of 1500 m³ per second. For comparison, the mean discharge of the Reuss from Lake Lucerne is 110 m³ per second.

Searching for the Baiji

In November 2006, Eawag took part in an international expedition searching for the whitefin dolphin in the Yangtze. This now almost legendary creature, known by the Chinese as “Baiji”, is comparable to the panda as a national symbol. The Baiji was nearly chosen as a mascot for the 2008 Olympic Games in Beijing. Our aim in joining the expedition was to collect water and particle samples on the 1700-km-long stretch of the Yangtze from the Three Gorges Dam to where the river enters the East China Sea, in order to investigate a possible link between water quality and the disappearance of the dolphin. As far back as 1979, the Bern zoology professor Giorgio Pilleri had predicted that the Baiji would be endangered by the ongoing destruction of its habitat. Pilleri, who visited the country at the invitation of Chinese colleagues, was the first foreign researcher to see the whitefin dolphin. In his personal scientific journal, he

A whitefin dolphin (baiji) in a Singapore aquarium.
Photo: baiji.org Foundation



the expedition was to collect water and particle samples on the 1700-km-long stretch of the Yangtze from the Three Gorges Dam to where the river enters the East China Sea, in order to investigate a possible link between water quality and the disappearance of the dolphin. As far back as 1979, the Bern zoology professor Giorgio Pilleri had predicted that the Baiji would be endangered by the ongoing destruction of its habitat. Pilleri, who visited the country at the invitation of Chinese colleagues, was the first foreign researcher to see the whitefin dolphin. In his personal scientific journal, he



At 6300 kilometres, the Yangtze is the longest river in Asia. From the Three Gorges Dam to the Shanghai estuary, it flows over a distance of around 1600 kilometres. The difference in elevation along this stretch is barely 35 metres.

gives a striking account of this adventure, undertaken at a time when individual travel was still restricted in “Red China”. [2]

The crew of cetacean researchers from China, the US, Canada, the UK and Japan who combed the river for six weeks on two vessels found that Pilleri’s gloomy prediction had come true: no whitefin dolphins were detected [3]. Each day, our team collected water samples and suspended solids. These samples were analysed for more than 280 substances, either directly on board or in the laboratories of the Swiss company Société Générale de Surveillance (SGS) in Shanghai and Perth, and at Eawag. This series of measurements – the most comprehensive ever carried out on the Yangtze – provides a good picture of water quality in one of the most important rivers in a country that is undergoing incredibly rapid change [4].

Surprising findings

The results were somewhat unexpected: the concentrations of almost all the substances investigated were surprisingly low, although the Yangtze is considered to be one of the world’s most polluted rivers. However, anyone who has seen the mighty Yangtze – which can be up to 2 km wide, even on the middle reaches – will understand that this is not necessarily a contradiction: the immense inputs from agriculture and discharges of industrial effluents and – generally untreated – domestic wastewater are highly diluted by the enormous masses of water flowing in the main channel. At the estuary, the yearly average discharge is around 32,000 m³ per second – more than 30 times as much as in the Rhine at Basel. Locally, however, the quality of water in tributaries and of ground and hence drinking water is severely affected by the high levels of pollution.



Tow nets were deployed overnight to collect suspended particles from the river. The samples were then analysed for heavy metals, nutrients and organic industrial chemicals in the laboratory.

Heavy metals	kg/day
Zinc	10 000
Chromium	6300
Arsenic	4600
Lead	3000
Antimony	900
Selenium	340
Cadmium	75
Thallium	54
Mercury	20

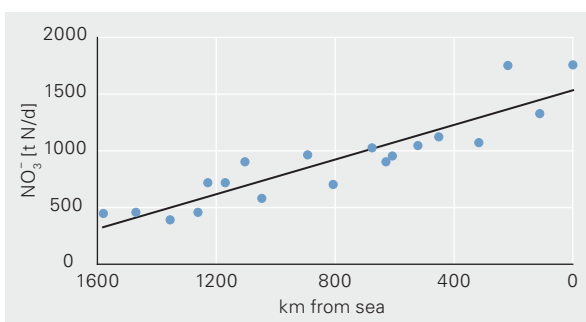
Low concentrations – heavy loads. The high rates of flow in the Yangtze are double-edged: on the one hand, they ensure that pollutants are so highly diluted that they rarely show acute toxicity. On the other hand, the relatively low concentrations obscure the fact that the total pollutant loads discharged into the East China Sea are immense.

Over long stretches, the Yangtze is canalized by 15-m-high embankments, and inflows are regulated by locks. Natural seasonal flooding of the plains is thus prevented, and huge areas have been drained for agricultural use on the middle and lower reaches. In many places, groundwater exchange and recharge is impaired, adversely affecting the quality of drinking water.

1500 tonnes of nitrogen per day

Despite the low concentrations, pollutant loads from the Yangtze have a major impact on the East China Sea: inputs of more than 1500 tonnes of nitrogen per day, particularly from mineral fertilizers and untreated household wastewater, are partly responsible for blooms of blue-green algae and for the increasingly common red tides. The latter are due to the explosive growth of dinoflagellates (especially the alga *Karenia brevis*), which may be toxic to all forms of marine life, including humpback whales and dolphins. In addition, decaying algae cause oxygen depletion at the bottom of the sea, depriving benthic organisms – a food source for many fish – of their habitat.

Heavy metal concentrations – though generally in accordance with Swiss and European guidelines – multiplied by the total volume of water yield enormous loads pouring into the sea from the Yangtze each day: 4600 kg of arsenic, 3000 kg of lead and 900 kg of antimony (see Box). These heavy metals, together with persistent organic herbicides and pesticides, enter the food chain and are found in fish and shellfish.



Increase in nitrogen load from the Three Gorges Dam to the East China Sea.



Heavy shipping traffic on the Yangtze probably contributed to the disappearance of the baiji.

One factor among many

Although on the basis of our study it is not possible to rule out synergistic effects of different chemicals, long-term effects, or impacts of endocrine disruptors, the deterioration of water quality in the Yangtze appears to have been only one additional adverse factor contributing to the extinction of the whitefin dolphin and to the decline of the Chinese sturgeon and an endemic porpoise. Other factors certainly include the destruction of habitats, extensive canalization, the cutting-off of side channels by dams and the drainage of shallow lakes (nurseries for many fish species), overfishing and unselective fishing methods, and the heavy shipping traffic on the Yangtze.

As flow rates and hence chemical water quality vary widely in the Yangtze over the course of the year, our data represent merely a snapshot. However, comparisons with earlier measurements demonstrate increases in concentrations of nitrogen, metals and organic compounds. This means that pressure is growing on the river ecosystem and the coastal waters of the East China Sea – and thus also on the quality of life for at least 350 million people. The extension of a reliable network of monitoring stations and concerted efforts now need to be pursued by China at an interprovincial level. One possible model could be the programmes and measures adopted by the riparian states within the framework of the International Commission for the Protection of the Rhine (ICPR/IKSR). ○○○

- [1] Buck Pearl S.: Die gute Erde (1931); Söhne (1933); Das geteilte Haus (1935).
 - [2] Pilleri G. (1980): Forschungsreise nach China zum Studium der Delphine des Chang Jiang (Yang Tze Kiang). Verlag des Hirnanatomischen Institutes, Waldau-Bern.
 - [3] Turvey S.T., Pitman R.L., Wang D. et al. (2007): First human-caused extinction of a cetacean species? Biol. Lett; doi: 10.1098/rsbl.2007.0292.
 - [4] Müller B., Berg M., Yao Z.P., Zhang X.F., Wang D., Pfluger A.: How Polluted is the Yangtze River? (eingereicht) Sci. Tot. Environ.
- www.iksr.org, www.baiji.org

River ecology enhanced by experimental floods

On a regulated section of the River Spöl in the Swiss National Park, artificial floods were used to create a more dynamic flow regime. This led to a marked improvement in the ecological status of the stretch below the dam. However, it took three years for an equilibrium to be established between the altered environmental conditions and the plant and invertebrate communities. Christopher T. Robinson & Urs Uehlinger

Habitat diversity has increased considerably.

The flow regime, temperature and bed structure of many rivers worldwide have been altered by over 45,000 large dams (more than 15 m high) worldwide. This regulation has adversely impacted the biodiversity of the rivers concerned. For this reason, criteria based on flow and temperature regimes are playing an increasingly important role in restoration projects. Artificial floods are now being used more widely to simulate a more natural flow regime in regulated rivers.

Since 2000, regime-based management has been implemented on the River Spöl in the Swiss National Park, with one to three experimental floods released per year. This management measure provided an opportunity to study the long-term effects of a flow regime shift on river ecology.

More fish redds

The experimental floods had no effect on the physicochemical condi-

tions of the river, since both the water released to maintain instream flows (1.2 m³/second) and the floodwater (10–55 m³/second) comes from the bottom layer (hypolimnion) of the Livigno reservoir. In the first year of flooding, the moss cover on bed sediments disappeared. Macroinvertebrate richness and biomass, but not density, were clearly reduced. After the third year, algal biomass and benthic organic matter persisted at a low level and macroinvertebrate density was reduced. Specific macroinvertebrate taxa showed different responses to the floods: a reduction or an increase in abundance, or an increase followed by a loss after the third year. The number of fish redds used by brown trout increased four-fold over the study period because of the increased porosity of bed sediments.

Better adapted community

The large variation observed in algal and macroinvertebrate biomass and density over time indicates that the biotic communities were not in equilibrium with the altered environmental conditions during the first three years. When individual floods are assessed, it can be seen that the immediate effects on macroinvertebrates were 30% greater at the beginning of the series of floods than today. The new community structure is evidently more resilient to flood disturbance.

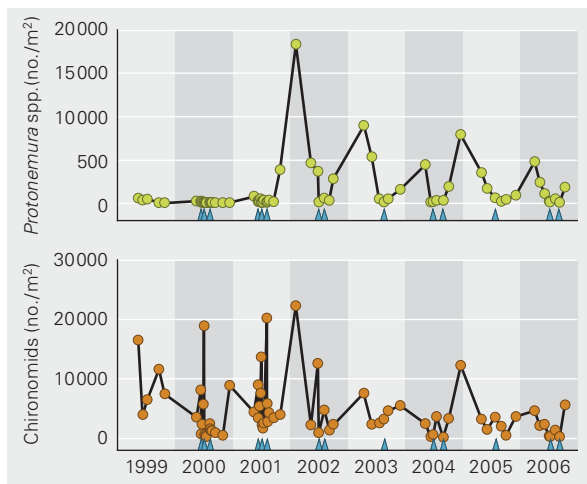
The flood programme has improved the ecological integrity of the regulated stretch of the River Spöl below Punt dal Gall dam. Habitat diversity has increased considerably, moss cover – not typical of alpine streams – has disappeared, the composition of the macroinvertebrate community



The artificial floods on the Spöl erode debris cones that otherwise constrain the main channel.

has shifted towards disturbance-resistant species, and spawning conditions for brown trout have been substantially improved.

In the present case, it took three years for the effects of the new flow regime to unfold. The natural dynamics of the River Spöl have only been partly restored, as residual flows are consistently low between each flood. However, this compromise solution – the result of an agreement among all stakeholders (National Park, hydropower generation, fisheries) – has benefited the Spöl ecosystem.



Changes in the abundance of stoneflies (*Protonemura* spp.) and chironomids in the Spöl over time. The artificial floods are indicated by blue triangles.

Robinson C.T., Uehlinger U.: Artificial Floods Cause Catastrophic Regime Shift in a Regulated River. *Applied Ecology*, im Druck.

Robinson C.T., Uehlinger U. (2007): Using artificial floods for restoring river integrity. *Aquatic Sciences* 65,181–182.

The sound of rivers

Although the sound of watercourses has never before been systematically studied, acoustic “fingerprinting” can help to assess the ecological condition of alpine streams and rivers in particular. At the same time, the sound can be used to rate their aesthetic quality, adding an objective element to discussions of the value of watercourse diversity. Diego Tonolla, Klement Tockner, Berit Junker (WSL), Kurt Heutschi (Empa)

Since time immemorial, the murmuring, babbling, raging and roaring of watercourses has been described by authors and poets. To date, however, the sound of streams and rivers has not been the subject of systematic research. We therefore decided to use methods from the natural and social sciences to investigate how the sounds of river habitats differ from one another, and whether changes in morphological quality can be detected acoustically.

Typical habitats

Four typical river habitats were characterized hydromorphologically and acoustically:

- ▶ Pools: deep, slow-moving stretches,
- ▶ Riffles: fords, with swiftly moving water at the surface,
- ▶ Runs: straight, non-turbulent stretches between pools and riffles, or channelized sections,
- ▶ Steps: small vertical drops over boulders in the riverbed.

In addition, underwater acoustic signals were continuously recorded along three stretches of river 8–23 km in length (Thur, Tagliamento in Italy, and North Fork in Montana, US). These recordings make it possible to determine the spatial

arrangement of habitats and areas of increased sediment transport.

Habitat-specific sound patterns are clearly identifiable: riffles exhibit a bimodal frequency distribution, while steps display a peak in the 160 Hz – 2 kHz frequency range. Laboratory experiments indicate that riverbed roughness and water velocity are key factors in sound generation.

Attractiveness enhanced by sound

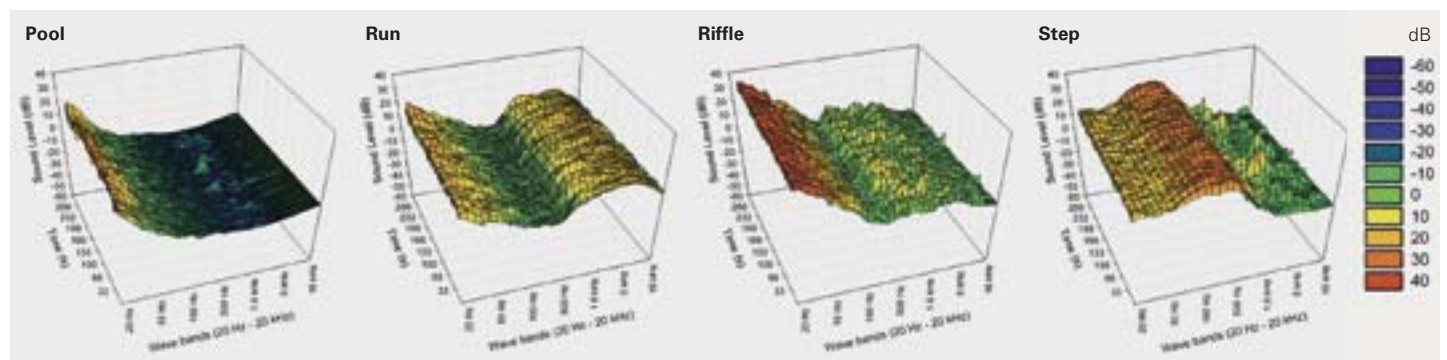
To investigate the association between visual and acoustic aesthetic evaluation of rivers, we played back various video sequences to a total of 1079 people. The representative survey in German-speaking Switzerland shows that the appearance and sound of restored river sections are rated as clearly more attractive than non-restored stretches. The association is somewhat less marked when only the soundtrack of the video sequence is played back to respondents. The perception of river sound is thus influenced by visual impressions. However, the way we perceive the sound of a river is not only influenced by whether or not it has been restored. Discharge also plays an important role, with stretches of river characterized by low flow



Sound recording on the River Inn near Strada.

rates – below the legally specified residual water volume – being rated as less attractive than stretches with medium flow rates. Rates of flow in the latter stretches are frequently reduced as a result of hydropower generation.

Our project generated a lot of media interest. We now intend to develop a simple tool for assessing the ecological integrity of surface waters. The aesthetic value of landscape – hitherto appreciated purely in visual terms – is to be augmented with the acoustic component. ○○○



Underwater sonograms for different habitats. Plane: time (seconds; 5-minute recording) and wave bands (20 Hz – 20 kHz); perpendicular axis: sound level (relative decibels).

How natural is the rehabilitated River Thur?

Does river rehabilitation actually lead to the development of more natural species communities? Fish surveys in widened reaches of the River Thur have shown that, while habitat diversity is greater in large widenings than in canalized reaches, the fish assemblage structure cannot yet be described as near-natural. Christine Weber, Armin Peter

According to the contemporary “Wild Map”, the Thur at Niederneunforn about 150 years ago was a braided river with a broad gravel bed. Around 1892, Wehrli counted a total of 22 fish species in the diverse river habitats. Dominating the community were the rheophilic barbel, nase, spirlin and vairone. Also abundant at that time were the brown trout and sculpin – both cold-water species. Each year, the Atlantic salmon and European river lamprey would migrate up the Rhine from the North Sea to spawn.

Shoreline length more than halved

At the end of the nineteenth century, long sections of the Thur were canalized for purposes of flood control and land reclamation. At Niederneunforn, the shoreline length was reduced

River widenings offer refugia that canalized reaches lack.

from 4.5 km per kilometre of river to just 2 km. This measure has led to a dramatic reduction in exchanges with the adjoining land, which are important for river ecology. There is a lack of flooded areas, and inputs of woody debris decline. Despite the extensive modification, flooding continued to cause significant damage (events of 1965, 1977 and 1978). The 1990s saw a paradigm shift in river engineering, and 15 increasingly

large-scale widening projects were implemented.

In the winter and summer of 2005, we collected samples by means of electrofishing from the three largest widenings (Gütighausen, Niederneunforn, Pfyn) and five canalized reaches. We also produced accurate maps of fish habitats with the aid of GPS. Monotonous flow conditions (moderate depth, moderate flow velocity) predominate in the canalized reaches and the shortest widening (<300 m), while shallow areas and fast-flowing waters occur frequently in the two longer widened reaches. In addition, the shoreline length is much greater along these reaches, even though all the current shoreline lengths are markedly lower than those seen in 1850.

Flood refugia

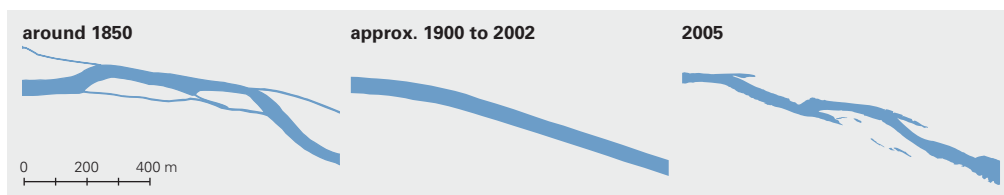
We observed a rich fish community, with a total of 20 species; however, there were no differences in community composition or individual density between the canalized and widened reaches. Fish abundance is generally low, although more fish are found in well-structured habitats – regardless of whether these are situated in canalized or rehabilitated reaches. The highest fish densities occur in deep backwaters, which are found only in the rehabilitated reaches. These serve as refugia during floods or in the winter. Compared with the

historical community composition, specialist species are now markedly underrepresented, while the European chub – a tolerant species – is dominant. Only individual specimens of brown trout and sculpin were found in the catch (0.5 %).

Habitat diversity can be increased by large-scale river-widening projects. However, the weak response of the fish fauna reflects persisting deficiencies, such as low thermal heterogeneity. In addition, the habitat condition of the Thur as a whole needs to be considered: 65 % of the lower 90 km of the river is still morphologically degraded, fragmented by weirs, or impaired by residual flows. Moreover, the rehabilitated habitats may not yet be fully recolonized. Monitoring of the outcome should therefore be continued for several years ○○○

This study was part of the *Rhône-Thur project*, an interdisciplinary research programme funded by Eawag; the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL); the Laboratory of Hydraulics, Hydrology and Glaciology (VAW) of the ETH Zurich; the Federal Office for the Environment (FOEN); and the Federal Institute of Technology, Lausanne (EPFL). The original project was completed at the end of 2005 (see Eawag Annual Report 2006), and an EPFL river engineering module in 2007. The topic of rehabilitation is being pursued in a follow up project involving the same partners – “Integrated river basin management”. (www.rivermanagement.ch).

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Weber C., Schager E., Peter A.: Habitat diversity and fish assemblage structure in local river widenings: a case study on a Swiss river; accepted in River Research and Applications.



The changing face of the Thur at Niederneunforn. Historical topographical maps of the river have been digitized, and GPS field mapping was carried out in 2005.

European rivers under pressure

The Danube alone drains parts of 18 different countries and thus is the world's most "international" river. For the implementation of the EU Water Framework Directive, Europe's hydrogeographical, ecological and cultural diversity represents a major challenge. The development of river basin management plans required by the Directive should be facilitated by the Rivers of Europe project.

Klement Tockner¹, Urs Uehlinger, Christopher Robinson, Diego Tonolla, Rosi Siber, Fabian Peter

In the Rivers of Europe project, under the direction of Eawag, the ecological status of 165 European river basins is being described for the first time. These basins drain almost 8 million km² – more than 70 % of the total area of Europe. Seven of the 10 largest catchments are in Eastern Europe, including, for example, the Pechora and the Dnieper – two rivers that are still widely unknown. With this database, it will be possible for the first time to compare the status of and risks to biological diversity across the whole of Europe. This information provides an essential basis for the planning of protection and management strategies, as required under the EU Water Framework Directive.

Few remaining reference ecosystems

Across Europe, only a small number of rivers are still in a relatively natural state. Besides rivers in the far north,

these include the Frome in the UK, the Tagliamento in Italy, and the Ural in the border regions of Russia and Kazakhstan. Accordingly, these rivers are reference ecosystems of continental importance. Most of Europe's river basins are heavily affected by human activities. Natural flows in Europe's waterways are disrupted by over 6000 major dams. Pressures on surface waters will intensify as a result of the predicted increase in extreme flow events and the growing demand for water by agriculture. By 2070, the area of river basins with a massive water deficit is expected to double, from 1.3 million km² today (18 % of the total area under consideration) to more than 2.5 million km².

Growing homogenization

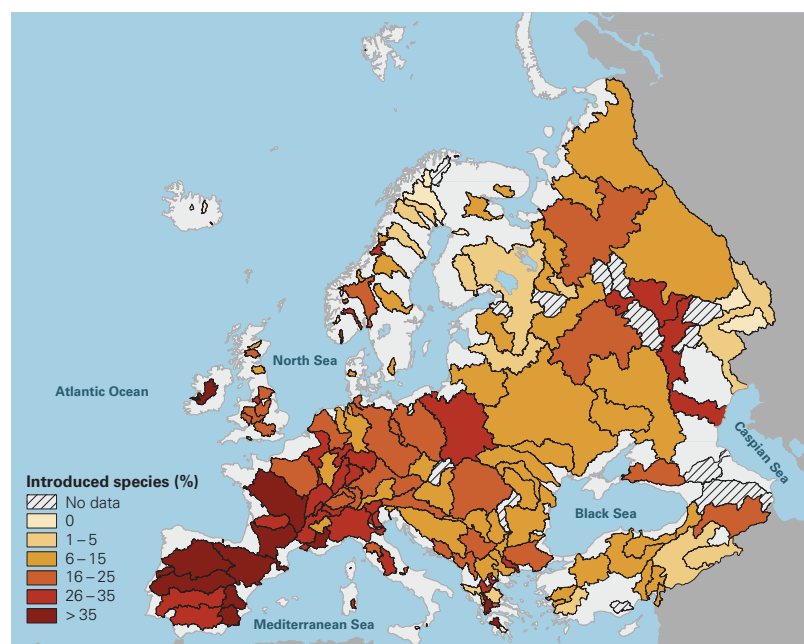
In some cases, the proportion of non-native species is already very high. For example, up to 50 % of the fish species found in the Ebro (Spain), the Seine (France) and the Shannon (Ire-

land) are not indigenous (see map). At the same time, up to 40 % of the original native fishes, e.g., in the rivers of the Iberian Peninsula, are now extinct. Particularly affected are fishes that migrate over long distances, such as the sturgeon and Atlantic salmon. In the case of crayfish, the situation is even more dramatic. As well as six native species, seven alien species are now found in Europe.

40% of native fish species have disappeared from the rivers of the Iberian Peninsula.

Many river basins that were naturally free of crayfish are now dominated by introduced species. Overall, Europe's natural freshwater fauna has become increasingly homogenized.

The pressures facing European freshwater habitats are indicated by the sharp decline in the biological diversity of Mediterranean river basins (Iberian Peninsula, Italy, the Balkans and Turkey), which originally harboured a particularly rich fauna and flora, meriting protection. For example, 45 % of the fish and almost 30 % of the amphibian species of the Iberian Peninsula are endemic to – i. e., found exclusively in – this region. At the same time, these areas are particularly exposed to the impacts of climate change, such as reduced streamflows, land-use changes and the spread of alien species. For this reason, these rivers should have top priority in the development of pan-European conservation and restoration projects.



Mapping: F. Peter, D. Tonolla

Proportions of introduced fish species in Europe's river basins.

¹ Eawag and Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB), Berlin

Tockner K., Robinson C.T., Uehlinger U. (2008): Rivers of Europe. Elsevier.

Species boundaries set by the environment

At least 24 whitefish species are known to occur in Swiss lakes. Studies in Lake Neuchâtel have now demonstrated the presence of intermediate forms, which coexist with the known species but are not commercially fished or actively managed. The development and merging of species can be significantly influenced by natural or human-induced changes in the environment. Pascal Vonlanthen, Denis Roy, Alan Hudson, David Bittner, Carlo Largiadèr, Ole Seehausen

Since the recolonization of the Alpine region after the last ice age, whitefish have differentiated into a large number of distinct species in Swiss lakes. As they have become specialized to different niches, the populations have no longer interbred freely, even though in some cases they are not geographically isolated from each other.

Palées and bondelles

In Lake Neuchâtel, only two whitefish species have been distinguished to date – a fast-growing species known as “palée” (*Coregonus palaea*)

and a slow-growing species called “bondelle” (*Coregonus candidus*). These two species differ in several ecologically relevant morphological characteristics, such as the number of gill rakers, but also in their selection of spawning habitat. Palées tend to spawn in shallows early in December,

while bondelles tend to spawn in deeper waters (below 50 m) and later, in January. However, a few publications and the experience of local fishermen suggested that intermediate forms could also occur.

Intermediate forms rarely fished for

For the first time ever for whitefish, we used genetic and morphological methods to study depth distribution. The results show that Lake Neuchâtel actually harbours not two whitefish species, but an ecological, morphological and genetic continuum of populations adapted to different water depths and in which the two species originally described form just the extremes. To date, ecological isolation mechanisms have prevented the various forms from fully merging into a single, homogeneous species. The most important mechanisms at work here are probably specialization to different feeding niches and adaptation to different spawning depths. However, the selection pressures do not currently appear to be strong enough to lead to complete genetic isolation of the whitefish species.

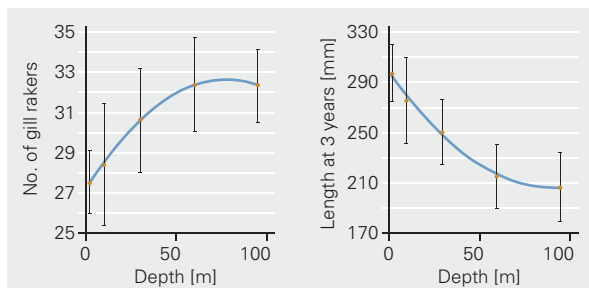
Our data suggest that the functional diversity of whitefish responds directly to changes in lake ecology. If the niche structure collapses, species diversity can be lost within a few generations through increased genetic mixing. We suspect that the lack of oxygen in deeper waters during the decades of lake eutrophication brought the species ecologically closer together and led to genetic assimilation. It is conceivable that the recovery of Lake Neuchâtel in recent times has re-established some of the original niche structure, and that the whitefish are now beginning to differentiate once again. Selection by fishing may also play a role: for economic reasons, the fishermen fish specifically for either the larger palées or the smaller bondelles; the intermediate forms are thus inadvertently spared. In order to improve

What is a species?

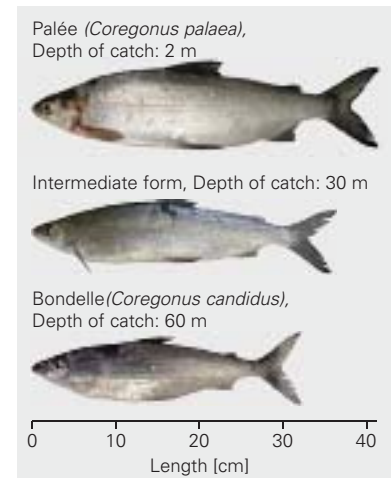
Various concepts of a species are found in evolutionary biology. What they all have in common is that populations of organisms are assigned to different species if they coexist in nature over many generations in the same habitat without genetically merging. Numerous species hybridize occasionally but remain differentiated if mechanisms exist to restrict gene flow. The definition of a species as a group of individuals not capable of interbreeding with members of other species is a popular misunderstanding of species concepts.

our understanding of how environmental changes affect the origin and loss of whitefish species, we have started to evaluate historical data series. ○ ○ ○

Knowledge of how whitefish species emerge or disappear is essential to optimize fishing and conservation regulations.



Two morphological characteristics of Lake Neuchâtel whitefish plotted against depth of catch: number of gill rakers (left) and size (right)



Examples of whitefish caught in Lake Neuchâtel (Photos: P. Vonlanthen and A. Hudson).

www.fishecology.ch
Seehausen O., Takimoto, G., Roy, D.,
Jokela J. (2008): Speciation reversal
and biodiversity dynamics with hybridization in changing environments;
Molecular Ecology 17, 30–44.

Hard workers and cheaters in microecosystems

Interactions between species have long been a central issue in ecology. However, little research has been devoted to the consequences arising for ecosystem processes. These processes could be dramatically altered by the loss of indigenous species or the invasion of alien species – a previously neglected aspect of the current biodiversity crisis. Sonja Raub, Christian Dang, Françoise Lucas, Eric Chauvet, Mark Gessner

It is only possible to assess the significance of biodiversity for ecosystem processes if the interactions of various species within a biological community are understood. In our experiments, we used a model system to observe the decomposition of leaf litter by bacteria and fungi – a process that is just as vital in many rivers as it is in forests. Our aim was to investigate the interactions occurring between bacteria and fungi: are there any synergies, is the relationship neutral, or does antagonism prevail? And what are the consequences for the rate of litter decomposition?

Decomposition simulated in microcosms

We first isolated from a river six bacterial and six fungal species that had colonized natural leaf litter. In the laboratory, these species were then combined to form new communities and allowed to grow on sterile alder litter in microcosms for 10 weeks. We studied pure bacterial and fungal communities, each consisting of three or six species, and also mixed communities, each comprising three bacterial and three fungal species. In addition, we used non-inoculated microcosms as controls.

Asymmetric interactions and unaffected decay rate

In the mixed microcosms, the bacteria had negative effects on the fungi, with fungal biomass production being on average 29% lower than in pure fungal microcosms. The strength of this inhibition did not depend on which bacteria and fungi had been combined (Fig. 1a). Conversely, the fungi stimulated the bacteria in one of the two mixed communities (Fig. 1b). Presence of the bacteria did not affect the rate of litter decomposition (Fig. 2). Rather, the bacteria are cheaters that take advantage of the industrious fungi, whose degradation activity makes leaf litter available as a resource to their bacterial competitors.

Comprehensive assessment needed

It thus appears that even in a highly simplified system, interactions in microbial communities can simultaneously give rise to synergistic, antagonistic or neutral effects, depending on which ecosystem process (in this case, litter decomposition or biomass production by bacteria and fungi) and which community is observed. It would therefore seem

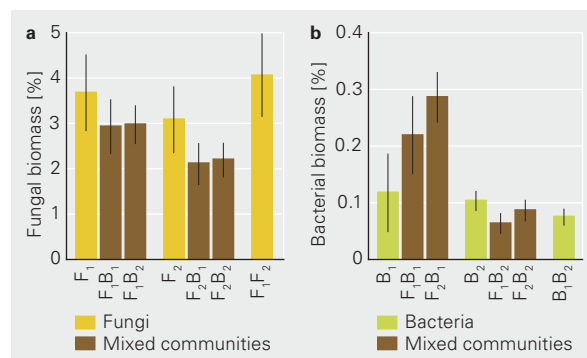


Fig. 1: Biomass production of fungi and bacteria in microcosms, expressed as a percentage of the amount of litter initially present. Bacteria inhibit fungal growth in mixed assemblages (a) and, conversely, can be stimulated by fungi (b).

necessary to take all key ecosystem processes into account in assessing the ecosystem-level impacts of community changes resulting from biodiversity loss or the invasion of alien species. ●●●

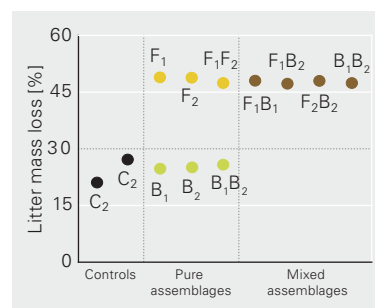
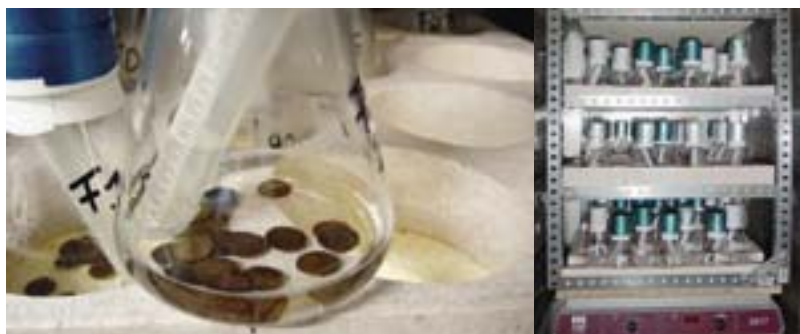


Fig. 2: Microbial litter decomposition in microcosms: despite their effects on litter-degrading fungi, bacteria make neither a positive nor a negative contribution to litter decomposition.



Precisely defined quantities of alder litter were inoculated with fungal and bacterial communities in simple microcosms (left). Growth of the cultures was then observed in a climate chamber (right).

Raub S. (2007): Effects of fungal and bacterial interactions on leaf decomposition in stream microcosms. Master's Thesis, UNESCO-IHE/Delft University of Technology, Netherlands.

Wohlensee: lake flatulence and global warming

As a greenhouse gas, methane is 25 times more potent than carbon dioxide. Accordingly, methane emissions from reservoirs are more significant than was previously assumed. On the Wohlensee, Eawag has studied how – and how much – methane from the bottom of the reservoir reaches the atmosphere. The emissions are roughly equal to those produced by 7000 Swiss cattle. Tonya Del Sontro, Torsten Diem, Carsten Schubert

From a water depth of 10 m, about half of the methane reaches the atmosphere via the lake surface.

The construction of dams and the flooding of vegetated areas can lead to increased emissions not only of carbon dioxide but also of methane – a greenhouse gas with a global warming potential about 25 times greater than that of CO₂. While little is known about the parameters controlling methane emissions from reservoirs, ebullition (bubbling up) appears to be the most effective pathway for methane transport from the sediment to the surface. Bubbles protect the gas inside from being oxidized, as generally occurs to dissolved methane. As bubbles rise in the water column, gas exchange is known to occur, and in deep lakes bubbles may dissolve completely before reaching

the surface. However, in shallow waters – characteristic of most of the world's lakes – methane in bubbles typically reaches the atmosphere, and from a depth of 10 metres the proportion is around 50%, depending on bubble size.

High organic matter load

The Wohlensee is a hydropower reservoir, built in 1920 by the impoundment of 15 km of the River Aare downstream from Bern. It has a maximum depth of 18 m and an area of about 2.7 km². The plant is a run-of-the-river system: all of the water flowing into the reservoir flows out without restriction. The short residence time (around 2 days) enables the water to remain oxic and mixed throughout the year. However, also during most of the year, methane bubbles can be seen reaching the surface in many parts of the reservoir. This is largely due to the large amounts of organic matter carried by the Aare.

Equivalent to 6780 cattle

A year-long study revealed that, despite its small size, this reservoir is a large methane emitter. Dissolved methane concentrations increase by an order of magnitude from the beginning of the reservoir to the dam, indicating intense methanogenesis. Using specially designed gas traps – essentially inverted funnels – we carried out ebullition surveys across the reservoir. Average methane emissions from the Wohlensee to the atmosphere via bubbles were found to be 792 mg/m² per day. This is an order of magnitude higher than the average for other reservoirs in temperate regions (20 mg/m² per day) and is even higher than the average

for tropical reservoirs (300 mg/m² per day). Annual methane emissions from the reservoir as a whole were estimated to be approx. 780 tonnes. For comparison, one cow produces 115 kg of methane per year, and the total Swiss cattle population about 80,000 tonnes.

Tracking methane bubbles with a microphone

Emissions from the reservoir via dissolved methane at the outflow and diffusion at the surface are one or two orders of magnitude smaller than releases via ebullition. Therefore, to quantify bubble fluxes more precisely, we are using a hydroacoustic method. In addition, we are measuring atmospheric methane concentrations above the Wohlensee. ○○○



Retrieving methane traps – inverted funnels which capture the gas as it rises through the lake.

This study was funded by the SNF and is now part of the MAIOLICA project, sponsored by the Competence Center Environment and Sustainability (CCES): <http://www.cces.ethz.ch/projects/clench/MAIOLICA>

Ostrovsky I., McGinnis D.F., Lapidus L., Eckert W. (2008): Quantifying gas ebullition with echosounder: the role of methane transport by bubbles in a medium-sized lake. *Limnol. Oceanogr.* 6, 115–118.

Lake Kivu: time bomb or energy resource?

For some years, Eawag has been keeping a watchful eye on Lake Kivu in East Africa, where danger lurks in the form of billions of cubic metres of dissolved gases in the deep waters. Controlled exploitation of methane could now offer a dual benefit – ensuring secure power supplies in the region and reducing the risk of a deadly gas eruption. Martin Schmid, Natacha Pasche, Lukas Jarc, Alfred Wüest

Lake Kivu, which straddles the border between Rwanda and the Democratic Republic of the Congo, is in many ways one of the world's most fascinating waterbodies. Attention has focused largely on the vast quantities of gas stored in the depths of the lake – around 300 km³ of carbon dioxide and 60 km³ of methane. If these gases were distributed over the surface of the lake, they would form a layer more than 100 m thick.

Gas concentrations rising

The dissolved gases pose a hazard, as they could erupt from the lake, causing a catastrophe. In 1986, an eruption of gas from Lake Nyos in Cameroon claimed 1800 lives. Although the probability of such an event occurring on Lake Kivu is very low at present, it is likely to increase since our measurements show that gas concentrations are rising. But methane is also an important resource: because Rwanda in particular lacks other sources of energy, the government has granted licenses for pilot power plants, which are to begin operating towards the end of 2008.



Sediment traps collect sinking algae – one of the factors in the lake's nutrient cycles.

In the long term, power generation is planned to reach 100–300 MW – a huge increase over the country's current total installed capacity of around 30 MW.

Stability of stratification

The exploitation of methane could, however, also have undesirable consequences, if the stable stratification of the lake were disturbed or an increase in the flow of nutrients from the deep to the surface waters led to marked eutrophication. Eawag has now developed a numerical simulation model making it possible to predict such effects under various methane recovery scenarios. The results of these modelling calculations are being used by the Rwandan and Congolese governments to specify guidelines for licensees involved in methane extraction. In addition, Eawag is participating in the development of a programme for monitoring whether the effects of methane exploitation on the lake are in line with projections.

Methane production in Lake Kivu is directly dependent on internal nutrient cycles. In cooperation with the Institut Supérieur Pédagogique de Bukavu (DRC) and the National University of Rwanda, Eawag is studying and quantifying nutrient inputs from external sources and nutrient fluxes within the lake.

Adventurous research

Initial analysis of sediment cores indicates that sedimenting material has undergone massive changes over the past 40 years. This could be partly attributable to strong population growth in the region; at the same time, we suspect that biological food chains in the lake have been significantly affected by the introduction of a sardine species from Lake Tanganyika in the 1950s. Our



Studies of tributaries are also required in order to assess nutrient cycles in the lake.

research on the ground is sometimes attended by unexpected difficulties – for example, having spent a few days in Bukavu, you may encounter a customs official who is unwilling to let you back into Rwanda because the rules have changed again and your documents are incomplete. You may also be caught in a storm when you are out on the lake in a pirogue. However, these problems pale into insignificance beside the idyllic landscape, richly varied experience and fascinating scientific results. ○ ○ ○

Schmid M. et al. (2005): Weak mixing in Lake Kivu: new insights indicate increasing risk of uncontrolled gas eruption. *Geochemistry, Geophysics, and Geosystems* 6/7, Q07009, doi:10.1029/2004GC000892.

Schmid M. et al. (2004): How hazardous is the gas accumulation in Lake Kivu? Arguments for a risk assessment in light of the Nyiragongo Volcano eruption of 2002. *Acta volcanologica* 14/15 (2002–2003), 115–121.

Wat

Urban water management

In the countries of the North, the problem of disposing of human wastes is generally solved simply by flushing the toilet. But in many countries of the South, the situation is quite different: inappropriate management of wastewater and faecal sludge poses acute risks to human health and the environment. As 2008 has been declared International Year of Sanitation (IYS) by the United Nations, this year's account of our activities in this sector focuses on projects that aim to provide sustainable sanitation solutions. Below, we spotlight just a few of the numerous scientists who have been involved in our research efforts.

"I have an affinity for water," says geographer **Monika Schaffner** (32). When she was studying hydrology at Bern University, she chose the River Aare and water supply systems in Nepalese villages as the topics for her dissertation. Her interest in Nepal goes back to her childhood, when she spent some time there, as her parents were involved in development assistance. It was natural for her to choose a water-related subject for her doctoral thesis, too. Collaboration with Eawag – which had begun during her earlier studies – was also a logical step:

"Anyone in Switzerland who does aquatic research ends up working with Eawag," says Schaffner with a smile. As part of the North-South programme of the National

Centre of Competence in Research (NCCR), she participated in a study of nutrient flows on the Tha Chin River in Thailand. Rather than considering only individual sources, a model was developed to analyse flows throughout the river basin (*page 46*).



"This kind of integrated approach appeals to me," she says. "I like the fact that Eawag is committed to solution-oriented projects as well as fundamental research." So will her thesis provide concrete benefits for Thailand? Schaffner warns against inflated expectations. Thanks to this study, she says, it is now known that aquaculture, not pig farming, is mainly responsible for (excessive) inputs of nutrients in the Tha Chin basin. Possible ways of tackling the problem have been identified in a dissertation, but the question of how rapidly any measures can be implemented is completely open. Accordingly, the researcher will be spending the next few months at Eawag preparing a number of publications and will also be travelling to Thailand again to present her findings to the authorities.



Having completed her Master's in Civil Engineering at the University of British Columbia, **Elizabeth Tilley** (28) came to Eawag for a six-month internship. As she had already worked on the recovery of nutrients from wastewater during her studies and in her dissertation, her input was particularly welcome for the research group

that had been concerned with urine source separation in the cross-cutting Novaquatis project from 2000 to 2006. Previously, Tilley had only been familiar with Nomix toilets and related technologies from scientific publications. "Then suddenly," she says,

"it all came to life, at Eawag and especially in the new Forum Chriesbach building, where these facilities have been installed. For me, working with these pioneers of urine source separation was a great opportunity." Now that Novaquatis has been completed, she is working on another project: in the Department of Water and Sanitation in Developing Countries (Sandec), she is involved in pilot studies and further development of the Household-Centred Environmental Sanitation (HCES) approach. This planning tool is used, in consultation with stakeholders, to seek sustainable water supply and sanitation solutions at the household and neighbourhood level, especially in the rapidly expanding cities and slums of developing countries (*page 39*). Tilley is no newcomer to this type of work: she had already managed a project sponsored by the Canadian International Development Agency, which was designed to improve sanitation in Mexico. As an engineer, she finds it very rewarding to be part of the highly international team at Eawag, with a wide variety of individual backgrounds: "Although everyone speaks good English I sometimes miss the Canadian accent from back home, but I've never regretted joining Eawag."



Ticino-born microbiologist **Adriano Joss** (42) financed his studies largely by working as a white-water kayaking instructor with the Zurich Academic Sports Association. Now, however – as a father of two daughters – he has little time to indulge his passion for being on (and occasionally under) water. Joss chose to study biology because he has always been fascinated by insects and the sometimes sophisticated strategies they use for locomotion and defence. In addition, with their short life cycles, insects can adapt evolutionarily – more rapidly than, say, tortoises – to new (environmental) conditions. Joss finds this problem-oriented behaviour attractive: "I'm

motivated to carry out research where I can see knowledge feeding into practice." He originally came to Eawag as a doctoral student in 1999, working on the fermentation of organic wastes, and has retained his interest in biotechnological processes ever since – although he is now mainly concerned with wastewater rather than solid wastes. As part of the team led by Hansruedi Siegrist, he is investigating, for example, how combined nitrogen can be converted to gaseous nitrogen without the addition of a carbon source (*page 48*). This process, involving so-called anammox bacteria, plays an important role in nature within the global nitrogen cycle. However, it has not previously been implemented successfully in a reactor. "Now," Joss is convinced, "we have found a robust solution, in collaboration with wastewater treatment plant operators and a manufacturer of special sensors." The process is intended to make treatment plants more efficient – and the results of initial full-scale tests have increased Joss's confidence. Nitrogen emissions are also problematic in many other settings – for example, on livestock farms where slurry cannot be directly utilized. "Could the anammox process be used there, too?" he wonders.





Turning stakeholders into participants

People who are involved in decisions on how sanitation is to be improved in a neighbourhood or community will help to ensure the long-term success of the measures adopted. Eawag has therefore developed a planning approach that gives a key role to the households concerned. Pilot projects designed to test this approach have been successfully launched at six sites. Christoph Lüthi, Elizabeth Tilley

2008 has been declared International Year of Sanitation (IYS) by the United Nations, since clean drinking water and hygienic disposal of wastewater and excreta are essential to human health, dignity and development. Without improvements in basic sanitation, none of the Millennium Development Goals can be achieved. In-sanitary conditions have a direct impact on child mortality, poverty and school attendance.

Rapid urbanization

This year, for the first time, the majority of the world's population will be urban. African and Asian cities, in particular, are growing at breakneck rates. Most of the new city dwellers live in unplanned settlements – favelas, bidonvilles or bustees. Here, “on-site sanitation” is the norm – if any facilities exist at all. Yet despite pit toilets being the reality for the vast majority of the developing world's urban population, policymakers still focus almost exclusively on sewerage networks and centralized systems designed without the participation of stakeholders. This conventional thinking needs to be challenged, for the following reasons:

- ▶ Experience has shown that importing industrialized-world models of sanitation is neither appropriate nor sustainable, e.g. in regions where water is too scarce for waterborne sewage systems to be implemented.
- ▶ Stakeholder involvement is vital to enable ownership and achieve cost recovery.
- ▶ There is a lack of integration between the various components of environmental sanitation: excreta, wastewater, solid waste and storm water are managed by means of separate systems, often run by different people. Better use of synergies can lead to more sustainable and cost-effective solutions.
- ▶ Growing pressures on the environment and on water resources make it essential that wastewater and nutrients in wastes should be recycled.
- ▶ “Business as usual” is often not sustainable even in industrialized countries: the use of water of drinking quality to transport human excreta is extravagant and wasteful with regard to valuable nutrients.



Maji na Ufanisi (Nairobi)

Communal sanitation block with toilet and shower facilities and a water kiosk in the Kiambu informal settlement of Nairobi (Kenya). The Waruku community has opted to build a similar block, and construction was completed in March 2008.

Progress in sanitation has been hindered by a number of factors:

- ▶ Responsibilities for sanitation are fragmented at the national and local level. In some African countries, for example, as many as four different ministries share responsibilities for water and environmental sanitation.
- ▶ In the public sector, low budgetary priority is accorded to sanitation and hygiene.
- ▶ There are major human resource and capacity gaps at the local level.

Developing alternative approaches

In response to these problems, a new approach was developed – under the guidance of Eawag – by the Environmental Sanitation Working Group of the UN Water Supply & Sanitation Collaborative Council (WSSCC). The Household-Centred Environmental Sanitation (HCES) approach places the household and neighbourhood at the core of the planning and implementation process. Decisions on determining the type of environmental sanitation meas-

ures to be implemented are closely based on the actual needs and means of users – especially women, who often make basic decisions on personal hygiene and environmental sanitation. The approach also focuses on sustainability: environmental sanitation problems are to be addressed as close to the source as possible, resources are to be conserved and waste is to be reduced.

Testing the HCES approach

In 2007, Eawag began testing the HCES planning approach in pilot projects at six sites – in Costa Rica, Burkina Faso, Kenya, Tanzania, Laos and Nepal. In each case, cooperation was initiated with local partners, such as the Latin American Faculty of Social Sciences (FLACSO) in Costa Rica, the CREPA research institution in West Africa, the Public Works and Transportation Institute in Laos and “Maji na Ufanisi” (Water and Development, an NGO) in Kenya. In contrast to local administrations, which often lack expertise, capacity and resources, research institutes or NGOs tend to offer more flexibility and have better-trained personnel, with strong connections to the communities in which they work.

All the HCES launching workshops held to date have proved successful, generating lively debate and producing concrete results. The success of these events was largely due to the following factors:

- ▶ A good mix of stakeholders (including community groups, senior administrators and religious leaders, etc.).
- ▶ Gender balance in community representation.
- ▶ An appropriate space for the community to voice its concerns.
- ▶ Careful preparation.
- ▶ Avoidance of bureaucratic and technical jargon in all materials and presentations.

Assembling components into systems

Those responsible for improving environmental services require detailed information. Municipal officials, urban planners and other decision makers can only fulfil their new roles if they are trained to implement household-centred approaches and if they receive the necessary technical and organizational support. Currently, therefore, we are developing a “Compendium of Sanitation Systems and Technologies” to facilitate a key step in the HCES process – the identification of different sanitation options.

The Sanitation Compendium is divided into five sections: User Interface, Collection and Storage, Conveyance,

Appropriate communal sanitation blocks

In the densely populated slums of Waruku in Nairobi, one unhygienic “toilet” is currently shared by an average of 60 people. Faced with this situation, as Eawag project manager Christoph Lüthi recalls, “We thought every family would want their own toilet as soon as possible.” But in line with the key requirement of the HCES approach – not to define a single solution as optimal in advance – things turned out quite differently. Lüthi says: “People saw that they lacked not only the money but also the space and affordable water for a large number of private toilets.” Accordingly, a delegation from the community visited a communal facility in another part of the city, and were impressed by what they saw. Maji na Ufanisi (local NGO) has now completed a sanitation block including not only toilets but also showers, and a kiosk selling affordable drinking water. The block has created jobs, and its maintenance and continued operation are assured by the low rates charged for users. Around 1000 residents now have access to basic – but hygienic and sustainable – sanitation, with a corresponding increase in quality of life.

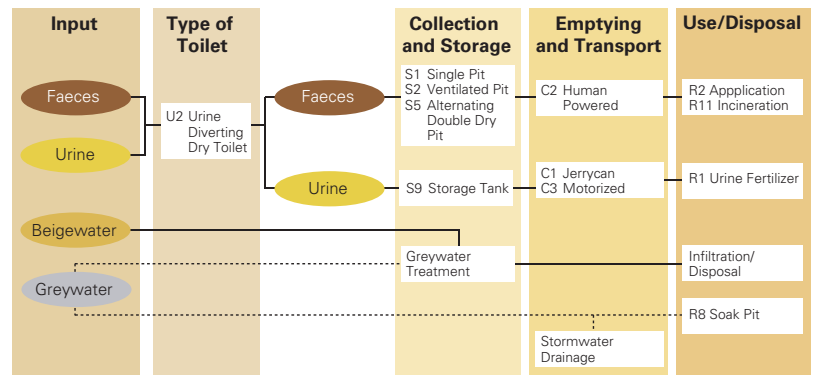
Treatment, and Use and/or Disposal. Rather than being offered ready-made “packages”, users can select one or more options from the various sections to build an entire system that is optimally adapted to local conditions and ensures sustainable management of wastes and wastewater. By way of example, a system being considered in Dodoma (Tanzania) is shown in the Figure. The technologies listed in the Compendium range from a simple dry toilet to a complex biogas reactor. The sole criteria for inclusion of options were the promotion of health and sustainability. Thus, options such as hanging toilets (erected over surface waters) or bucket latrines were not included, given the potential for disease transmission.

Community decision-making

The task of changing deeply ingrained ideas among engineers and policymakers is not an easy one. For this reason, the Compendium is first used in target groups where the participants can ask questions freely. When the groups subsequently come together to discuss possible options, all the stakeholders are already familiar with the same concepts and terminology. After the focus group workshops, the professionals design various systems, which are then presented to the community. In this first phase, it is essential that trained professionals are involved, so that time and money are not wasted on technically inappropriate options. Ultimately, however, the system and its components are chosen by the community. If the community is unwilling or unable to select a complete system initially – for example, because some of the technologies may still seem foreign to the majority of people concerned – pilot projects may be a useful first step.

Different solutions for Tanzania and Costa Rica

In Dodoma, the capital of Tanzania, the HCES launching workshop was held in October 2007. Seventy participants from various backgrounds (e.g. primary school teachers, clerics, unemployed) formed working groups to discuss topics such as social and economic aspects, hygiene and sanitation infrastructure. Among the ideas now being pursued are improvements to sanitation through the use of urine-diverting latrines with twin pits used alternately. Another option under consideration for this dry region is the “Arborloo” – a portable latrine that is moved from one shallow pit to the next when the first is full. The old pit is then closed and planted with a tree. In San Martin (Costa Rica), by contrast, where more water is available, small-scale sewerage systems can be implemented. These networks connect up to 200 households, with pipes laid just below ground level. Instead of using expensive manholes, seal chambers are installed at each connection point to facilitate maintenance, to avoid blockage of the low-gradient pipes and at the same time to prevent overflowing at peak times. A community sewer of this type discharges into a settling pond or a simple treatment plant.



From 6 types of toilet (U), 11 options for collection and storage (S), 6 for conveyance (C) and 12 for use/disposal (R), these components were deemed feasible in the Chang’ombe district of Dodoma. The Compendium describes the suitability of each module (rectangles), listing advantages and disadvantages and giving details of maintenance requirements and the costs of construction and operation. Special attention is paid to impacts on health and questions of acceptance. In the present case, grey water management had to be designed in such a way that anal cleansing water (beige water) could also be processed, since the use of toilet paper is unacceptable for many Muslims. This system does not include a “treatment” stage; other systems incorporate, for example, a constructed wetland between transport and use/disposal (see p. 12).

Infrastructure projects based on the HCES approach may take more time to implement and involve greater planning and coordination efforts than capital-intensive projects planned in a “top-down” fashion. However, the investment in this type of project development is justified because the HCES approach offers the one result that previous approaches have been unable to achieve – sustainability. ○ ○ ○

The Eawag pilot projects testing the HCES approach and the development of the Compendium are supported by the Swiss Agency for Development and Cooperation (SDC), the National Centre of Competence in Research North-South (NCCR North-South) and the Swiss State Secretariat for Economic Affairs (seco).

Household-Centred Environmental Sanitation: Provisional Guideline for Decision Makers (English/French/Spanish), Eawag, 2005.

Compendium of Sanitation Systems and Technologies, Eawag, 2008 (available from August 2008).

International Year of Sanitation 2008: <http://esa.un.org/iys/> and www.siedlungshygiene2008.ch

Millennium Development Goals: www.un.org/millenniumgoals/
HCES approach: www.eawag.ch/hces

Faecal sludge: health risk or natural resource?

In vegetated drying beds, faecal sludge can be dewatered and mineralized by bacterial degradation of organic matter. This permits hygienic recycling of nutrients and recovery of humified sludge. However, these facilities need to be adapted to local conditions and operated with indigenous plants. Ives M. Kengne, Doulaye Koné

More than 1.1 billion urban inhabitants of developing countries – about 40 % of the urban global population with access to sanitation facilities – use onsite installations such as latrines, septic tanks, or aquaprivies for urine, faeces and wastewater storage/disposal at household level. These facilities are not connected to sewers and are designed to be regularly emptied manually or mechanically when full. Most often, faecal sludge collected from onsite sanitation installations is spread untreated on farmland, disposed of with household waste, on streets, or simply discharged into rivers and lakes.

Separating liquids and solids

A key requirement for sustainable management of faecal sludge is the development of efficient and low-



Vertical flow constructed wetland pilot bed for faecal sludge dewatering and mineralization in sub-Saharan countries.

cost methods for the separation of solid and liquid fractions. This step is essential in order to avoid hygienic problems and to permit the recovery of resources or energy.

In cooperation with the Asian Institute of Technology (AIT, Bangkok), Eawag has previously demonstrated, especially in Thailand, that constructed wetlands represent a viable solution for the treatment of faecal sludge. However, the characteristics of sludge vary widely from one region to another, and appropriate indigenous plants need to be identified so as to ensure successful operation of these facilities.

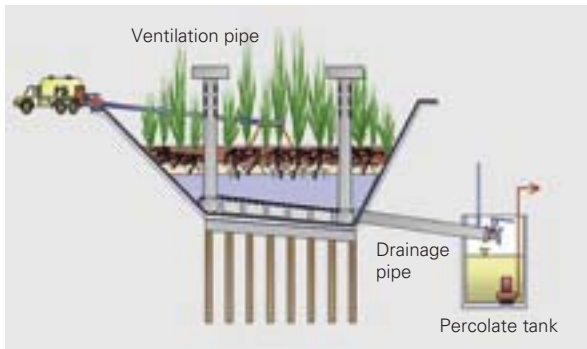
Antelope grass and papyrus

In studies carried out in Cameroon, antelope grass (*Echinochloa pyramidalis*) and papyrus sedge (*Cyperus papyrus*) were shown to be suitable plants. In the case of antelope grass, which is used as a forage plant worldwide, biomass production tripled, compared with growth in natural habitats, to 100–150 tonnes of dry matter per hectare per year. We are now investigating whether the quality of the grass would allow it to be sold as animal fodder.

The biosolids accumulating on the top of the beds are well suited for

use as a humus-forming material (organic fraction 40 %) and fertilizer (N: 2%, P₂O₅: 2.3%). However, after the facility had been in operation for 6 months, the biosolids still contained high concentrations of parasites, particularly helminth eggs (79 eggs per gram of total solids). For this reason, the dewatered sludge needs to be co-composted – e.g. with organic solid waste – or stored for a longer period before it can be spread on farmland. No significant differences were observed when different sludge loading rates (100–300 kg of total solids per m² per year) were used.

The results obtained in this project will be reviewed in a scale-up currently under way in Dakar (Senegal) (see the article opposite). ○ ○ ○



Structure of a vegetated drying bed with sand and gravel filter layers. In this example, the sludge water (percolate) is drained into a tank.

Wetland flowers and vanishing sludge

Two examples involving vegetated drying beds illustrate just how quickly an effective system can find acceptance among the local population. On Koh Phi Phi (Thailand), a constructed wetland was planted with ornamentals as well as reeds and cattail. The flowers are now sold at a profit to local hotels by the operators of the facility. And in Dakar (Senegal), under cover of darkness, farmers have already helped themselves on several occasions to treated sludge that was being stored, rather than waiting for parasite testing to be completed. The product's advantages as a humus-forming material and fertilizer are obviously appreciated.

Kengne I.M. (2008): Design optimization of dryings beds vegetated with *Echinochloa pyramidalis* (Lam.) Hitch & Chase and *Cyperus papyrus* L. for faecal sludge treatment in Sub-Saharan countries. PhD thesis, University of Yaounde, Cameroon.

Kone D., Cofie O., Zurbrugg C., Gallizzi K., Moser D., Drescher S., Strauss M. (2007): Helminth eggs inactivation efficiency by faecal sludge dewatering and co-composting in tropical climates. *Water Research* 41 (19), 4397–4402.

Developing local expertise

In Senegal, Eawag is supporting the development of an education and research centre for sustainable faecal sludge management. While the focus is on building local capacity, Eawag research is also benefiting from the opportunity to scale up approaches and treatment methods at the new facility. Doulaye Koné, Mbaye Mbéguéré

In the Dakar region, an estimated 170 000 m³ of faecal sludge from latrines and septic tanks arises per year – sludge that has to be treated and then appropriately disposed of to prevent public health risks in a city with a population of over 2 million. With financial support from the World Bank and the European Union, Senegal's National Sanitation Agency (ONAS) has already built two treatment plants in Dakar and is planning to extend the faecal sludge management (FSM) programme to other cities. Since 2005, at the request of the Senegalese government, this programme has been supported by Eawag. In July 2007, a new education and research centre was inaugurated in Dakar.

Implementing large-scale processes

At the pilot facility, ONAS and Eawag can scale up treatment processes developed in the laboratory and in smaller pilot studies – for example, faecal sludge humification in constructed wetlands (see the article opposite). However, this collaboration also provides an opportunity to test sustainable FSM planning concepts,

such as that developed by a former Eawag PhD student in Burkina Faso, or, together with the authorities, to develop business models designed to make sludge management attractive for small businesses.

These joint efforts, including the work carried out at the education and research centre, have already produced encouraging results:

► The *expertise* of ONAS staff in FSM has been strengthened. Experience from other countries (e.g. Benin and Mali) indicates that treatment facilities often encounter difficulties within the first year of operation. The two ONAS facilities have already been operating smoothly for 18 months. This has not escaped the notice of the emptiers: the two plants are each receiving 50 truck loads a day, rather than the 10 deliveries originally planned, which means that they are already operating close to capacity. Training modules are enhancing dialogue between the private sector and other stakeholders.

► In Dakar, FSM is no longer seen merely as a technical problem. A comprehensive *strategy* has been developed to facilitate improvements. This covers, for example, rules for



Sludge is delivered to one of the two ONAS facilities.

the economic viability of private emptiers, the management of public infrastructure and the definition of responsibilities.

► *National experts* are playing a greater role: before the collaboration with Eawag, ONAS – like many other authorities in the region – relied on experts from abroad for FSM projects. Support of this kind is costly and of limited duration, and it is often not possible to respond to new problems as they arise. Now the country has experts of its own. In Touba, Senegal's second-largest city, a contract to build a new FSM plant was recently awarded to a local engineering company – which had hired staff previously involved in our project.

► In partnership with the *University of Dakar (UCAD)*, we are currently developing a training programme on water for doctoral students and an MSc course in sanitary engineering for developing countries, which is due to start in the autumn of 2008. ○ ○ ○



The Dakar research facility was officially opened by Senegal's Deputy Minister of Infrastructure, Urban Hydraulics and Sanitation in July 2007.

The Eawag/ONAS pilot facility in Dakar is supported by the Velux Foundation.

www.sandec.ch > Main Topics > Excreta and Wastewater Management

Rapid detection of pathogens

A new screening method based on flow cytometry allows pathogens to be detected in drinking water and other types of samples within two hours. With existing detection methods, it is necessary to wait two days for visible colonies of microorganisms to develop on culture media. The new technique has great potential. Hans-Anton Keserue, Hans Peter Fuechslin, Stefan Köttsch, Thomas Egli

The method's strength is apparent when pathogens have to be isolated from complex matrices to permit detection.

For centuries, water was considered to be of good quality if it was clear, with a pleasant taste and no bad odours. Since the mid-nineteenth century, bacteria have been cultivated on solid media (agar plates). Bacteriologists showed that bacteria can cause diseases, including many which are waterborne. Today, despite major advances in microbiology, the official detection method for the majority of pathogenic microorganisms still involves cultivation on agar plates and enumeration of the colonies formed. However, such assays take a long

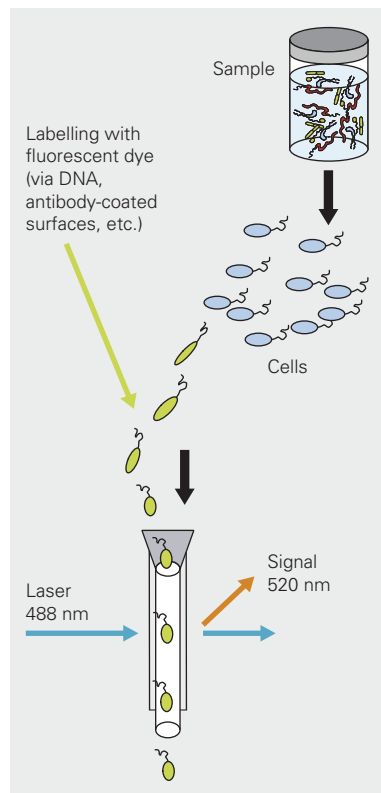
time and only permit the detection of culturable cells.

Drawbacks of recent methods

Efforts have been made to develop faster detection methods. The most frequently used approach is the polymerase chain reaction (PCR), in which multiple copies of a DNA sequence are synthesized. However, the PCR method can be compromised by the presence of inhibitory compounds, and it is not capable of differentiating between living and dead cells. Other methods in use involve the labelling of microbes and viruses with dyes and enumeration via fluorescence microscopy. But even with increasing instrument automation and digital image analysis, this method of quantification is still time-consuming and laborious.

per litre. For comparison, the limit specified by the Federal Office of Public Health for *Legionella pneumophila* in drinking water is 1000 colony-forming units per litre.

The resting stages of protozoan parasites, such as *Giardia* and *Cryptosporidium*, can also be enumerated – with a detection limit of approx. 40 cysts per litre. Although this is not yet sufficiently sensitive for tap water, it is adequate for more complex matrices such as wastewater, milk or stool samples, where pathogen concentrations are far higher. Our method could therefore be of interest not only for the analysis of drinking water but also in the food industry, in clinical microbiology and for rapid assessment of microbiological risks in disaster areas – wherever the target cells have to be isolated from complex matrices before they can be reliably detected. ○ ○ ○



Rapid detection of microbial pathogens using immunomagnetic separation followed by flow cytometric analysis.

Alternative approach

At Eawag, we have developed flow cytometric (FCM) techniques which can be used for screening drinking water – e.g. for determining the total bacterial count or the bacterial regrowth potential in the distribution network. Our new method for rapid detection of pathogens begins with an enrichment step, in which cells present in a water sample are collected by filtration and resuspended in phosphate buffered saline (PBS). They are then labelled using antibody-coated microscopic magnetic beads and isolated from other cells (immunomagnetic separation) so that they can subsequently be directly identified and enumerated by flow cytometry.

Preventing epidemics

Initial results indicate that the method allows detection of bacterial pathogens such as legionella or *Escherichia coli* O157 within two hours, with a detection limit of around 500 cells

Hammes F., Berney M., Wang Y., Vital M., Köster O., Egli T. (2008): Flow-cytometric total bacterial cell counts as a descriptive microbiological parameter for drinking water treatment processes. *Water Res.* 42,269–77.
Hammes F. A., Egli, T. (2005): New method for assimilable organic carbon determination using flow-cytometric enumeration and a natural microbial consortium as inoculum. *Environ. Sci. Technol.* 39, 3289–3294.

Helping the helpers – a handbook for relief missions

After natural disasters or in a crisis situation, survival may depend on an intact water supply system and hygienic disposal of excreta, wastewater and waste. In cooperation with a team of experts, Eawag has developed a manual for emergency assignments involving Switzerland's humanitarian aid workers. Christian Zurbrügg¹

Natural disasters and humanitarian crises arising from armed conflicts are all too common – the devastating Indian Ocean tsunami, hurricanes in Central America, an earthquake in northern Pakistan, conflicts in western Sudan or Lebanon. The health of the victims of such crises is severely threatened by inadequate supplies of drinking water and poor wastewater and waste disposal. Contaminated water and insanitary conditions cause diarrhoea and infections – diseases that may ultimately claim more lives than the original event.

Hygiene often overlooked

After the tsunami, Switzerland's Humanitarian Aid responded with relief measures, providing shelter and care for the homeless and injured. A team of specialists in the areas of medicine, logistics and water assessed local needs on the ground and initiated emergency assistance. In retrospect, this aid can be described as efficient. In certain cases, however, an emphasis on the restoration of drinking water supplies meant that too little attention was paid to questions of sanitation and, in particular, wastewater disposal.

Experts deployed within a matter of days or even hours are subject to high expectations. Firstly, they need to ensure drinking water supplies and wastewater/solid waste disposal for the assignment team. At the same time, they need to assess the situation in the disaster area as rapidly as possible and decide where and how Switzerland can contribute to emer-

gency relief efforts. To facilitate this task, Eawag – as part of a team of experts – was requested by the SHA (see Box) to develop an instrument in the form of a handbook, including checklists and decision tools. Lists of questions are designed to support preparations and analysis of the situation: for example, what other organizations have already been deployed and for what purpose? Are water and soap for personal hygiene available at sanitary facilities? In addition, procedures are suggested for systematic priority-setting. Decisions have to be taken in close consultation with the people concerned, local authorities and relief agencies. Who is to take what action where and when, and who is to coordinate the efforts?

Guidance and documentation

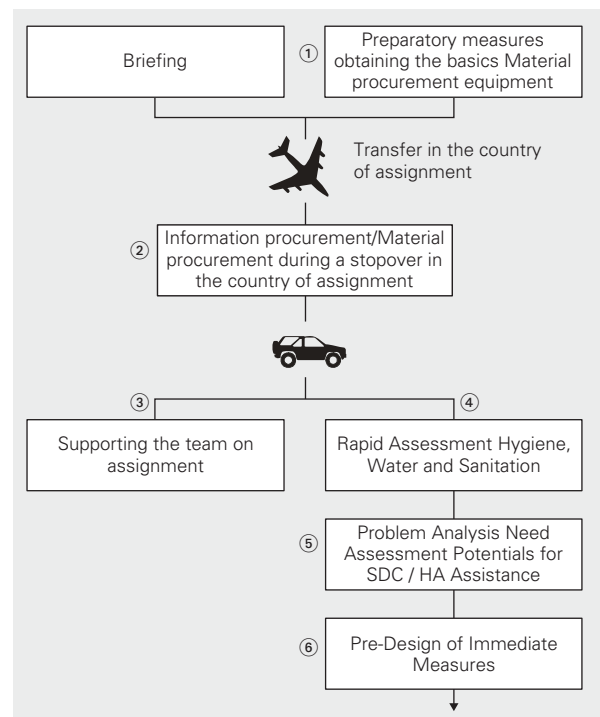
The Handbook should help to ensure that all key areas are taken into consideration. It can also serve as a notebook for aid workers in the field, documenting their experience and assuring knowledge transfer to other experts on subsequent assignments. ○ ○ ○

Humanitarian Aid Unit

The Swiss Humanitarian Aid Unit (SHA) is the operational arm of the government's international Humanitarian Aid programme. The SHA is a "militia corps", with a pool of about 700 people ready for deployment at short notice. Civil engineers, hydrogeologists and chemists from the Water and Sanitation group construct or repair facilities for water treatment, storage and distribution, and are responsible for excreta and wastewater management and for training local personnel. Employment with the SHA is assignment- and project-based.



Should this damaged drinking water well in Aceh (Indonesia) be repaired? The well is continuously contaminated by a pit latrine situated behind the black plastic sheet.



Overview of the procedure for a relief mission, with the relevant checklists (1–6) from the handbook.

¹ Co-authors of the handbook are Peter Kaufmann, Aquawet; Karl Wehrle, Skat; Ueli Graf, Construction, Transport and Energy Directorate of Canton Bern; Chris Zurbrügg, Sandec/Eawag.

Nutrient overload in the Tha Chin River

According to a material flow analysis carried out by Eawag, the main source of nutrient pollution in Thailand's Tha Chin River basin is not pig farming, but fish farming. In the light of this finding and other results from the study, possible mitigation measures can now be discussed by all stakeholders. Monika Schaffner, Ruth Scheidegger, Hans Peter Bader, Irene Wittmer

In developing and emerging countries, river water quality improvement is of vital importance for both people and ecosystems. Conventional water quality models study pollution on the basis of inputs to receiving waters, but they give no indication of how and where these inputs arise.

Analysis leading to remedial measures

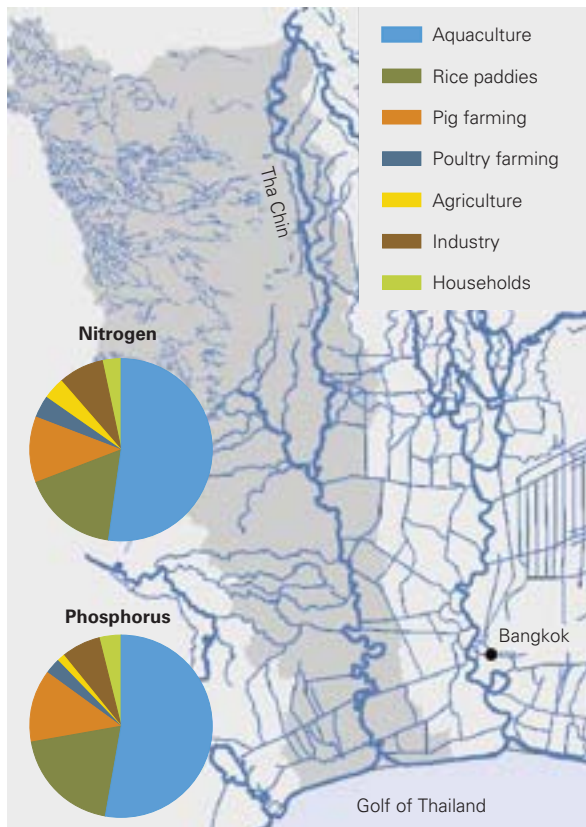
A material flow analysis (MFA) represents a valuable complement to water quality models, making it possible to analyse where pollutants originate and how they spread within a river system. Options for avoiding or preventing pollution at source can thus

be identified. An Eawag case study on nutrient pollution in the Tha Chin River basin in Thailand aimed at tracing and quantifying the sources and flows of phosphorus and nitrogen in the river system.

The Tha Chin River, a branch of the Chao Phraya River, flows through the intensively used Central Plains of Thailand. This flat region is characterized by a heavily regulated network of waterways, with low flow rates and changing flow directions. In 2000, a basin-wide fish death raised awareness of the water quality issue among policymakers and the public. Studies showed that high nutrient loads (eutrophication) and the resulting oxygen depletion are of particular concern.

are well above the regional recommendations. Nutrient pollution from aquaculture is due to overfeeding and the discharge of pond sediments into canals.

With these insights from the MFA model, it is now possible to discuss with all stakeholders how pollution could be most effectively reduced through locally adapted measures. Such measures could include appropriate fertilizer application in rice production, feeding practices better suited to the specific requirements of fish, a more balanced feed nutrient content, or the reuse of sediments from fish farms. However, such recycling would only make sense if the sediments are not contaminated with antibiotics or other chemical additives used in aquaculture. ○ ○ ○



Main sources of nitrogen and phosphorus pollution in the Tha Chin River basin.

Aquaculture: main source of nutrients

The aim of our study was to identify the main sources of nutrient inputs to the river system and to explore possible remediation measures. A simple MFA model was developed on the basis of field observations, combined with existing data, expert surveys and estimates. The results indicate that:

- ▶ More than 50 % of all nutrients derive from aquaculture.
- ▶ Intensive rice production in the region accounts for more than 15 % of the nutrient inputs.
- ▶ Pig farming is among the major contributors mainly in the middle reaches of the basin.
- ▶ Nutrient inputs from industry and households, as well as from poultry farming and agriculture, are orders of lower magnitude.

The study reveals not only the main contributions, but also the underlying causes. In the rice paddies for example, fertilizer application rates

This project was carried out under the National Centre of Competence in Research (NCCR) North-South programme, co-funded by the Swiss National Science Foundation and the Swiss Agency for Development and Cooperation.

Wittmer I.: Modeling the Water and Nutrient Flows of Freshwater Aquaculture in Thailand. A Material Flow Analysis, in Department of Environmental Science. 2005, ETH Zürich: Zürich.

Schaffner M., Wittmer I. (2006): Alarm – zu viele Nährstoffe im Tha Chin; Eawag News 62d.

Schaffner M. (2007): Applying a Material Flow Analysis Model to Assess River Water Pollution and Mitigation Potentials – A Case-Study in the Thachin River Basin, Central Thailand. Dissertation Universität Bern. NCCR North-South/Eawag.

When tap water smells musty

Whenever tap water smells peculiar, water utilities receive calls from worried consumers. At Eawag, methods have been developed for identifying – and if necessary eliminating – odour compounds in drinking water. Advanced oxidation with ozone and hydrogen peroxide has proved to be a successful approach. Holger Lutze, Andreas Peter, Urs von Gunten

Taste and odour problems are the most frequent causes of complaints to drinking water suppliers. Although the substances that cause these problems do not pose a health risk, many consumers are concerned when their tap water has an unpleasant smell. Apart from residues of chlorine (which is added to water supplies as a disinfectant), odour compounds from natural sources give rise to most complaints. Microorganisms in surface waters (especially algae) or on biofilms in water distribution networks can produce a wide variety of odour compounds.

Advanced oxidation

Since most odour compounds originate in surface waters, many odour problems can be dealt with by appropriate water treatment. This calls for a method that can respond flexibly to peak concentrations, which often

occur seasonally. Here, ozonation is a promising option, as the breakdown of trace compounds is supported by not one, but two reactive substances (ozone and hydroxyl radicals), and the process can be relatively easily controlled. Thus, the formation of hydroxyl radicals can be promoted by the addition of hydrogen peroxide (H_2O_2), and this advanced oxidation process can enhance the removal of ozone-resistant compounds.

Avoiding unwanted by-products

As well as optimizing the elimination of contaminants, however, it is necessary to preserve the disinfectant capacity of ozone and to prevent the formation of undesirable by-products as far as possible. The compound of most concern in this connection is bromate, a potentially carcinogenic oxidation product, which arises

when untreated water containing bromide undergoes ozonation. We investigated to what extent odour compounds can be eliminated using ozone-based processes while at the same time keeping bromate formation to a minimum. In our study, conventional ozonation was compared with advanced oxidation. The experiments were performed both at laboratory scale and in a pilot plant. This plant was operated in cooperation with the Zurich water utility as part of the cross-cutting Wave21 project.

Advanced oxidation with O_3/H_2O_2 was shown to be a valuable tool for controlling odour episodes associated with lake water. Not only does this process eliminate odour compounds significantly more effectively than conventional ozonation, but the formation of bromate is also minimized. Pilot-scale research has shown that existing ozone treatment facilities can be upgraded, if necessary, so as to remove odour compounds and other contaminants. ○ ○ ○

With some substances, we can smell a single drop in a swimming pool.



ETH-Rat, A. Poi

Collecting samples from the ozone reactor in the Wave21 pilot plant at the Lengg lake water treatment facility operated by Zurich's water utility.

A nose (and an instrument) for odours

Before taste and odour compounds can be dealt with, they first have to be detected and identified. For this purpose, a method previously applied mainly in the perfume industry was further developed at Eawag. It involves a combination of technology and the human nose: while a water sample is analysed in a mass spectrometer, odours are simultaneously "sniffed out". Any irregularities detected by the researcher's sensitive nose are recorded. By analysing the peaks in the mass spectra, it is then possible to identify the substance responsible for a given odour component.

Energy self-sufficiency for wastewater treatment plants

Today, despite the production of biogas, conventional wastewater treatment plants (WWTPs) are net consumers of energy. At Eawag, a process for the removal of ammonium nitrogen which includes anaerobic oxidation has been further developed. Because less energy for aeration is required, the addition of a carbon source is not needed and biogas production can be increased, this anammox process could bring WWTPs a step closer to energy self-sufficiency. David Salzgeber, Jack Eugster, Karin Rottermann, Adriano Joss, Hansruedi Siegrist

Ammonium-rich sludge digester liquid can undergo nitrogen removal in a separate treatment step at WWTPs. This can prevent the nitrogen load from being unnecessarily increased when sludge liquid is recirculated to the primary settling tank. In the conventional process involving nitrification and denitrification, a carbon source (e.g. methanol) has to be added to reduce nitrate to molecular nitrogen. In addition, this process requires a lot of energy for aeration.

To avoid these drawbacks, we have now further developed a method involving anaerobic ammonium oxidation: in PNAA (Partial Nitritation and Anaerobic Ammonium oxidation), part of the ammonium is oxidized with oxygen to nitrite, while the remainder is oxidized anaerobically to molecular nitrogen using the nitrite produced in the process (Figure). The addition of a carbon source is thus no longer needed, and the aeration energy required is reduced by up to 60 %.

From laboratory to full-scale operation

The intermittently fed sequencing batch reactor (SBR) has a capacity of 400 litres. The sludge liquid was



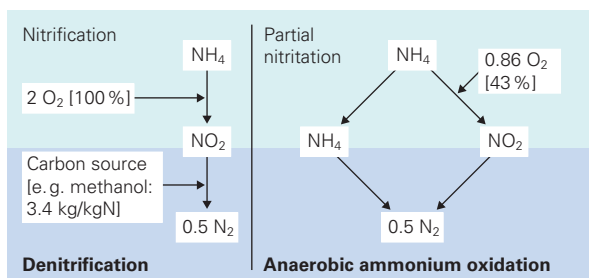
The 400-litre SBR reactor at the Eawag testing facility.

regularly delivered from the Zurich-Werdhölzli WWTP. Although anammox bacteria grow slowly and we used a small amount of inoculum for this experiment, we achieved excellent N removal performance after only 4 months, with a hydraulic retention time of 1 day.

Given the good results obtained with the 400-litre reactor and the savings to be expected from lower energy and methanol consumption, we were able to find two plants – Zurich-Werdhölzli and St. Gallen-Au – that were prepared to implement the process at full scale. Both reactors – with a volume of 300 m³ at the St. Gallen and 1400 m³ at the Zurich plant – began to operate in the late summer/autumn of 2007, inoculated with sludge specially produced in an 8 m³ reactor at the Eawag testing facility. While the initial results of full-scale operation are encouraging, they also show that smooth running of the process depends on well-equipped facilities and continuous supervision, especially during the start-up phase.

More sludge for biogas production

A further advantage of the PNAA process is that it allows better use to be made of anaerobic energy recovery. If nitrogen is removed from the digester liquid before it is recirculated to the primary settling tank, the nitrogen load is reduced at this stage. Accordingly, less substrate is required for denitrification in the biological treatment step. The hydraulic retention time in primary settlement can be extended. Thus, more substrate is available for digestion, and the production of biogas is increased. Combined with the savings in aeration energy, the PNAA process can bring WWTPs a step closer to energy self-sufficiency in their operations. In order to promote understanding of PNAA and to improve control of the process, we are currently elaborating a dynamic model of the performance observed in the reactors. ○○○



Conventional nitrification/denitrification (left) and partial nitritation with anaerobic ammonium oxidation (PNAA).

Salzgeber D., Joss A., Siegrist H. (2007): Autotrophe Schlammwasserentstickung (Nitritation/Anammox) in einem SBR. Gas Wasser Abwasser 3, 205–209.

Siegrist H., Salzgeber D., Eugster J., Joss A. (2007): Anammox brings WWTP closer to energy autarky due to increased biogas production and reduced aeration energy for N-removal. 11th World Congress on Anaerobic Digestion, 2007, Brisbane.

Wett B. (2007): Development and implementation of a robust deammonification process. 4th IWA Leading Edge Conference and Exhibition on Water and Wastewater Technologies, 3–6 June 2007, Singapore.

Catching polluted road runoff in a filter bag

When rain falls on roads after a lengthy dry period, the runoff is black, contaminated with, for example, heavy metals from tyre and brake pad abrasion. Filter bags installed in drains can prevent these substances from entering receiving waters – but not all fleeces are equally suitable for this purpose. Markus Boller, Martin Wyttenbach

Filter fleeces can be used for the treatment of road runoff. As shown by earlier Eawag studies, they retain a substantial proportion of the pollutant content since heavy metals (cadmium, lead, zinc, copper) and polycyclic aromatic hydrocarbons (PAH) are bound to dust emissions from road vehicles.

In cooperation with the University of Applied Sciences Burgdorf and the Canton Bern Water Protection Office, Eawag tested both fleece filter bags and rotating filter drums with automatic backwash. Filter bags tend to be more suitable as a decentralized measure for treatment of less contaminated runoff in roadside drains, while filter drums are suitable as centralized processing units for more heavily contaminated road runoff, e.g. from sewer sections of motorways.

Pilot plant

Scale-up and operational aspects of the installation and cleaning of textile filters were studied by the experts responsible in Canton Bern. The treatment performance and colmation (clogging) of various filter fleeces were investigated by Eawag. The results provide an indication

of which parameters are crucial for evaluating fleeces with regard to retention capacity, pressure losses and run times. In a pilot plant specially set up for these tests, road sludge was diluted to specified solids concentrations with water from the rainwater harvesting facility at Eawag's new "Forum Chriesbach" building. This "standardized" road runoff was then used to test various textile filters for pressure loss and solids/heavy metal retention with different filter velocities and loads.

The tests showed that there are considerable differences between the fleeces (see Figure). For example, fleece 3 has unfavourable properties, with poor retention performance and a rapid increase in pressure loss.

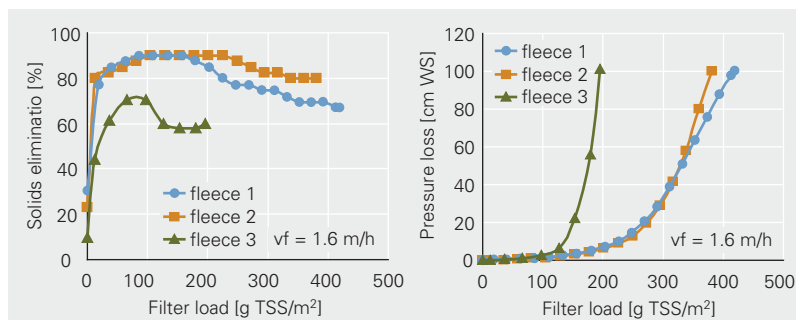
Sediment in filter bags

The filter performance determined in the tests cannot be directly applied to real-life conditions. It has been shown that fleeces used as filter bags in drains also function as sedimentation containers, exhibiting a solids retention capacity of up to 20,000 mg TSS/m² – many times higher than was found in the filter experiments. In bags of this type, road sludge is deposited at the bot-



Changing a textile filter bag filled with road sludge.

tom, making the filter impermeable. Depending on the amount of rainfall, filtration proceeds via larger or smaller areas of the sidewalls. This allows filters to be used for substantially longer periods before cleaning, considerably increasing the potential for application of fleece filters in practice. ○ ○ ○



Performance of fleece filters as a function of total suspended solids (TSS) load (grams per square metre). Elimination of solids is initially poor in new fleeces, but subsequently improves rapidly. As the filter load increases, performance declines again somewhat (left). Increasing pressure loss (right) means that the filter gradually becomes clogged and is able to treat less and less wastewater. Filter velocity in both experiments: 1.6 m/hour. Solids content of wastewater: 70 mg TSS/l.

Broad-based cooperation

A variety of research projects investigating pollutant loads in roof and road runoff are combined under the heading of "Rain analysis" (www.regenanalyse.ch). In addition to Eawag, the following partners are involved: the Federal Offices for Roads and the Environment, the Federal Institute of Technology Lausanne, Canton Bern, the University of Applied Sciences Burgdorf and the Association of Swiss Road and Traffic Engineers.

Forward-looking strategic planning for the sanitation sector

In designing sanitation infrastructure, planners are confronted with a variety of uncertainties associated with the long operational life of the facilities. Few approaches are available for handling these uncertainties. But if tomorrow's sewerage systems and wastewater treatment plants are misconceived, costly adaptations will be required. Eawag has therefore developed a forward-looking planning approach that makes it possible to assess the sustainability of technical and organizational options. Eckhard Störmer, Annette Ruef, Damian Dominguez, Max Maurer, Bernhard Truffer

As Switzerland's sanitation infrastructure largely dates from the 1960s and 1970s, local authorities and municipal associations are increasingly facing decisions on major investments in the renovation of wastewater treatment plants and sewers. Planning generally focuses on remedying existing shortcomings. However, few people are aware of the implications of 30- to 50-year planning horizons. Decisions made today will affect the next 1–2 generations.

The future of sanitation in a given region depends on developments in numerous areas and thus involves substantial uncertainties. For this reason, a research group at Eawag sought to develop a planning methodology – Regional Infrastructure

Foresight (RIF) – that allows uncertainties to be taken into account more systematically. This methodology was tested and refined in three case studies – in the Klettgau region (Canton Schaffhausen), in the Kiesen/Aare Valley (Canton Bern) and in the Dübendorf/Wangen-Brüttisellen/Dietlikon region (Canton Zurich).

Taking uncertainties into account

Uncertainties for the sanitation sector are driven by economic development and population growth in the catchment area. These factors determine not only wastewater volumes and the quantities of problematic substances, but also the capacity to pay for infrastructure. Additional unknowns include the future development of environmental and water protection requirements, which are shaped by regulations, but also by the demands of the public and businesses at local level. A current example is the question of how micropollutants are to be

dealt with. Also subject to change is the sanitation sector's conception of itself as a public service provider, given the pressures of liberalization and privatization. Lastly, the regional consequences of climate change – with heavy rainfall events and droughts – are difficult to assess. Overall, it is apparent that in order to meet future challenges, it is not enough merely to extrapolate from past experience.

Sanitation sector planning: a demanding exercise

In view of the diversity of tasks performed by the sanitation sector, careful planning is a highly complex process. As well as controlling water pollution, there is a need to ensure acceptable charges for society and business, allocation of costs according to the polluter-pays principle, political controllability and much else besides. The importance of these tasks will be rated differently by the various stakeholder groups, depend-

Klettgau case study

In the wine-growing region of Klettgau (Canton Schaffhausen), on the border with Germany, the wastewater treatment plant has reached the end of its lifespan after over 30 years. The members of the Sanitation Association's Construction and Operation Committee were not convinced by proposals for rebuilding or renewal of the plant. They were not sure whether continuation of the existing system represents an appropriate solution for the next 30 years. By taking part in the RIF pilot project, they aimed to identify future challenges for the sanitation sector and to assess a wide range of alternative solutions in a strategic planning process. Comprehensive consideration of the sanitation tasks of the Sanitation Association and the local and cantonal authorities allowed the potential for further optimization – beyond WWTP operations – to be investigated. As a future strategy, regional stakeholders participating in the RIF process recommended options that had previously been scarcely discussed: firstly, the establishment of a multi-utility service provider that could largely relieve local authorities of their sanitation-related responsibilities and subsequently take on additional functions, e.g. provision of drinking water. Alternatively, the possibility of collaboration with a neighbouring WWTP in Germany is to be explored. Prior to the process, the latter option had been regarded as not politically feasible. The open, unfettered discussion and transparent analysis of the pros and cons of various proposed solutions led the participants in the RIF process to make clear recommendations on the future orientation of the sanitation sector.



The RIF planning approach promotes long-term strategies rather than quick fixes.

ing on the future context. All these aspects have to be taken into consideration in a forward-looking assessment of strategic options.

The RIF approach

The Regional Infrastructure Foresight planning approach involves the following four elements:

► Development of scenarios for the region and the sanitation sector context in 25 years' time. This allows systematic identification of uncertainties in the development of context conditions.

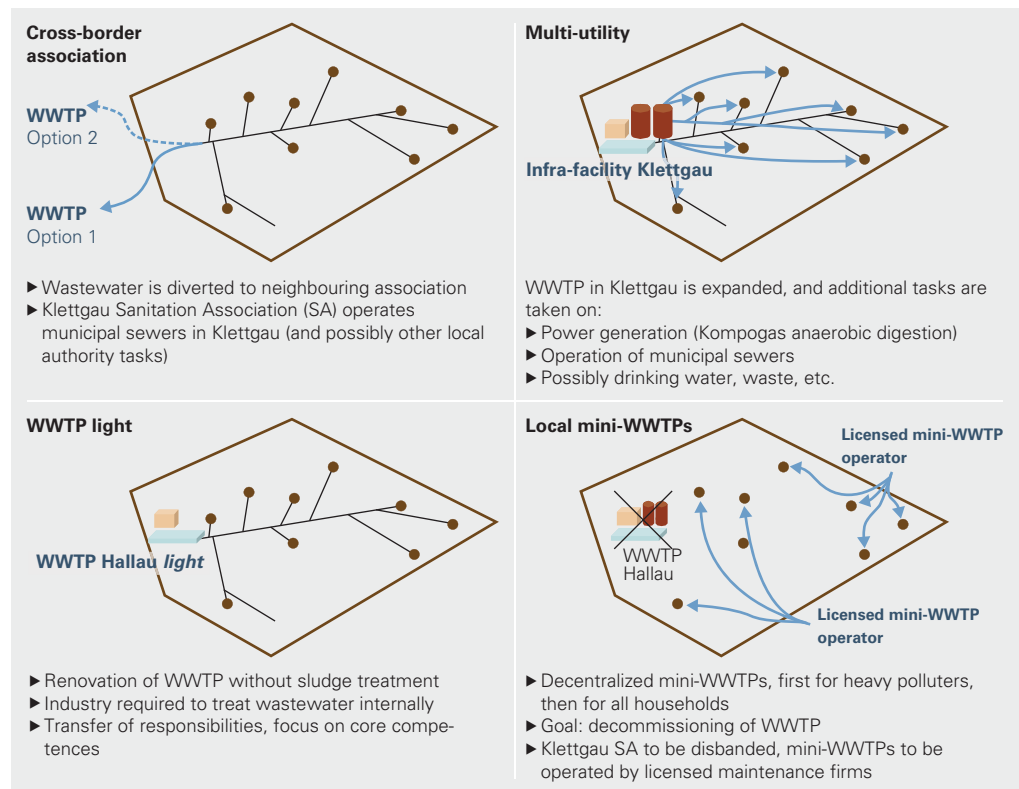
► Elaboration of options for the sanitation sector in the region. The solutions considered comprise technical and organizational elements (see Figure): is the catchment area to be enlarged or reduced in size? Are the organization's responsibilities to be expanded or cut back? Are contemporary approaches or innovative emerging technologies to be preferred? Should wastewater treatment be centralized or decentralized?

► In-depth analysis of the target dimensions of sustainable sanitation in the region. This creates transparency with regard to the particular challenges in the individual scenarios.

► Finally, evaluation of options. Based on the future demands placed on the sanitation sector by citizens and businesses, the various options can be ranked for each context scenario. The assessments are then compared and those options are selected which have been shown to exhibit a high level of desirability and a low conflict potential.

Exploiting regional knowledge

In conventional planning procedures, far-reaching strategic definition of the future development of the sanitation sector is often delegated to planning/engineering consultants. In contrast, the RIF process is based on the idea that local decision makers should be involved in shaping the fundamental strategy. At two workshops, these parties are brought together with representatives of regional stakeholder groups so that their future expecta-



Options considered in the Klettgau case study. Two options are being pursued – a cross-border association and a multi-utility.

tions and interests can also be taken into consideration in the assessment of options.

Result: strategic action plan

The result of the RIF process is a strategic recommendation for the long-term orientation of wastewater management in the region, combined with an action plan for the next steps in the planning process.

In the case studies, a variety of conclusions were reached. In the Klettgau region (see Box), the process resulted in the recommendation of two options that had previously appeared unacceptable or had barely been discussed. In the Kiesen/Aare Valley, possibilities for increasing cooperation were explored, and the merger of several associations was formulated as a vision for the medium term. In the economically dynamic region of Dübendorf/Wangen-Brüttsellen/Dietlikon, it was proposed that a multi-utility should be established, offering additional wastewater-related services to local authorities.

Sustainable solutions

The sanitation sector is having to meet growing demands with diminishing resources. Regional Infrastructure Foresight enables decision makers to take a global view of the sector – from household connection to receiving waters – and to identify synergies with local authorities and other wastewater management agencies in the region. With RIF, strategic options for sustainable sanitation can be comprehensively assessed. ○ ○ ○

The RIF project was sponsored by the Swiss National Science Foundation (SNSF) as part of the National Research Programme NRP 54 "Sustainable Development of the Built Environment" (www.nfp54.ch). Eawag's partners in the project are the ETH Zurich, Bern University, Empa and the Fraunhofer Institute for Systems and Innovation Research/ISI (Germany).

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2007 Eawag

review of

Under its new Director, Eawag had an exceptionally busy year in 2007. Thanks to Janet Hering's membership of the ETH Board (as a representative of the four research institutes Empa, WSL, PSI and Eawag) and her international contacts, new partnerships were initiated and existing ones strengthened. In 2007, 117 groups visited Eawag, while two members of the Federal Council – Pascal Couchepin and Moritz Leuenberger – also demonstrated their interest in water research and the new building Forum Chriesbach. Below, we look back over some of the highlights of the year. Andri Bryner

Accolades for Eawag

In 2007, once again, several Eawag projects and a number of researchers received awards or distinctions. For reasons of space, only a few examples can be mentioned: Directorate member Willi Gujer was granted an honorary doctorate by the Technical University of Denmark, while Urs von Gunten (Water Resources and Drinking Water Department) was made an Honorary Professor at the Harbin Institute of Technology (China). Roland Schertenleib (Directorate), together with Markus Eggenberger of the Swiss Agency for Development and Cooperation, received the Campaign Medal for works in the water sector in Vietnam. The project involving the installation of a compact, closed system treatment plant for wastewater

recycling at the Hohtaelli (Zermatt) cableway station (3286 m a.s.l.) won the Muelheim Water Award. Environmental toxicologist Roman Ashauer was the winner of the generously funded Innovative Science Award, presented by the European Chemical Industry Council (cefic), for his work on improving the definition of water quality criteria. ○ ○ ○

Overall water management strategy

To permit an integrated approach to the management of water resources, key stakeholders from the Swiss water and wastewater sectors, including Eawag, have launched the "Water Agenda 21" project. The aim of this initiative is to analyse – and

find ways of dealing with – future challenges in this area. The studies carried out to date have shown that the existing sectoral orientation makes it difficult to meet emerging water management challenges and deploy resources in an economically optimal manner. There is a lack of overall strategies and mechanisms for cross-sectoral coordination. In 2008, Water Agenda 21 will develop into a network of Swiss water professionals. The deficiencies identified are to be addressed, and stakeholders are to be supported in developing sustainable water management solutions, with Eawag making a vital contribution to this process. ○ ○ ○

Potential of urine source separation

Urine source separation is a promising wastewater management option, especially for rapidly expanding cities



The search continues for new methods of separate urine treatment, ideally for use in decentralized systems.

in coastal areas. This was the message taken home by the 250 people – researchers, officials, industry representatives and policymakers – who attended Eawag's Info Day on 7 March 2007. The event was widely covered on television and radio and in the press, reflecting the high level of public interest in this topic, both nationally and internationally. The completion of the cross-cutting Novaquatis project does not mark the end of Eawag's research in the area of separate urine collection and treatment. New methods are currently being sought to allow the nutrients nitrogen and phosphorus to be removed and recovered from urine at the earliest possible stage, using decentralized technologies. The opportunities and potential applications of such decentralized systems are also being explored in a wide-ranging analysis.

www.novaquatis.eawag.ch



Eawag's stand at the special exhibition on water at the muba fair in Basel.

The ABCs of water

At a number of events – including the 20th anniversary of the Department of Environmental Sciences at the ETH Zurich, a summer camp for children of Eawag staff, a "Research Night" and the Basel trade fair – Eawag researchers presented water-related topics to the general public. The centrepieces of the special exhibition on water at the muba fair were the "Sound of Rivers" project (page 29) and information on global water consumption in the food sector. Recordings of the Basel rivers Birs, Wiese and Rhine were used to explain to visitors the connection between the sound spectrum and diversity, and a huge bratwurst illustrated the immense amounts of water that are required to produce meat – around 15,000 litres for a kilogram of beef.

Ecotoxicology Centre taking shape

In the autumn of 2007, Parliament followed the Federal Council in approving the establishment of a Centre for Applied Ecotoxicology at Eawag. This Centre is to be developed in cooperation with the Federal Institute of Technology Lausanne (EPFL) in 2008, filling the gap created by the closure (in 2001) of the Institute for Toxicology in Schwerzenbach. A business plan has already been drawn up, and facilities for the Centre are currently being prepared in the Eawag office building at Dübendorf where renovation work was completed at the end of 2007. The Centre's essential functions are:

► Clearing house: monitoring developments in applied ecotoxicology and discussing current and emerging issues and potential solutions with representatives of practice and academia.

► R&D: developing, for example, cost- and time-saving test methods

for the detection of ecotoxic effects, or new analytical methods.

► Information platform: publishing new findings in specialist journals and other media, organizing continuous education events for professionals and students, and answering queries as a public service contact point.

Public funding totalling CHF 2 million per year will be available for the period 2008–2011. ○ ○ ○

Partying hard

In an internal survey, Eawag staff reported above-average levels of satisfaction with their jobs and working environment. One of the reasons, no doubt, is the strength of the bonds existing within departments and throughout the institute. These in turn are promoted by the annual "works outing" and the now-traditional celebrations. The biggest date in the 2007 social calendar was the



Members of the Directorate in "The Wizard of Schweiz".

Forum Chriesbach Christmas party, attended by almost 400 people. The theme chosen by the organizers for this highly successful evening was ups and downs ("Stägeli uf, Stägeli ab"). Among the most memorable contributions was a specially devised musical performed by the Directorate. ○ ○ ○

Upgrade successfully completed

In 2007, the 1970-vintage office block at the Dübendorf site was completely refurbished and extended by two storeys. Eawag will no longer need to rent additional office space, but these savings are not the only advantage: thanks to various improvements, energy consumption is now significantly lower despite the increase in floor space, and the proportion of self-generated power is to be further increased by the in-



The completely refurbished Eawag office building at Dübendorf – now two storeys higher – will also house the new Ecotoxicity Centre.

stallation of a photovoltaic system. In addition, the allocation of space between Forum Chriesbach and the laboratory and office buildings has been optimized. All workstations are now located close together. In Forum Chriesbach, operations are currently being streamlined, and a detailed energy accounting project is being carried out with support from the Swiss Federal Office of Energy. Plans for 2009 include the modernization of the laboratory building and the rehabilitation of the Chriesbach river, which flows through the Eawag site. At the Kastanienbaum site, the boathouse, which dates back to 1938 and is now a listed building, was gently renovated: this involved, for example, improving the insulation, extending the photovoltaic system, and installing a new kitchen and workstations for doctoral students. Also restored was the large mural on the facade, which depicts the “legend of Kastanienbaum”. ○○○

Water professionals learning from each other

In September 2007, Eawag convened 45 leading experts from the research, administration, NGO and



IWMF participants on a restored section of the River Thur.

river engineering sectors for the International Water Management Forum. This event, sponsored by the reinsurer Swiss Re, is not a conference in the conventional sense. Instead, it brings together decision-makers in a workshop setting to share their experience – in this case on the topic of river restoration. With its long tradition of river engineering and a well-established water protection regime, Switzerland serves as a model for other countries in the management of rivers and streams. However, many restoration projects do not get beyond the planning stage, and even those which are implemented are not always as successful as hoped. Accordingly, one of the conclusions of the IWMF 2007 was that greater attention needs to be paid to decision-making processes, the definition of goals and the evaluation of outcomes. ○○○

Expanding partnerships

In 2007, Eawag's collaboration with the Federal Institute of Technology Lausanne (EPFL) was further intensified. Apart from the development of the Ecotoxicity Centre and joint research efforts in the field of ecotoxicology, this involved in particular the participation of Eawag researchers in teaching at the EPFL and the establishment of joint professorships. Eawag also strengthened partnerships with other institutions, for example:

- ▶ with the European Commission's Joint Research Centre (JRC), especially the Institute for Environment and Sustainability at Ispra (Italy). On 16 March 2007, a JRC Information Day was held at Eawag. Charles Kleiber, State Secretary for Education and Research, described the event

as “a kick-off meeting to intensify research collaborations between Switzerland and the European Union”.

- ▶ with the Swiss Gas and Water Industry Association (SVGW), particularly in the water supply sector;
- ▶ with the Electron Microscopy Center of the ETH Zurich (EMEZ), focusing on biological research methods;
- ▶ with the California Institute of Technology (Caltech), for a Summer Undergraduate Research Fellowship (SURF) programme.



10-point plan for fish

At the end of August, the interdisciplinary “Fischnetz+” project issued a 10-point plan designed to restore fish stocks and improve fish habitats. In Swiss rivers, yields have declined dramatically – e.g. brown trout catches have decreased by two thirds since 1980. The measures proposed are based on the results of the “Fischnetz” project (1998–2003), in which Eawag, the Federal Office for the Environment and all the cantons sought to identify the causes of declining fish yields. The plan includes measures to make hydropower operations more fish-friendly, control fish diseases and reduce chemical pollution through alterations to wastewater treatment plants. It also indicates how fish habitats can be improved through rehabilitation efforts. www.fischnetz.ch



Among the measures recommended in the 10-point plan is the fish-friendly design of hydropower facilities, including fish ladders at dams.

Personnel

New appointment

Gabriele Mayer: At the beginning of September, Gabriele Mayer was appointed head of HR & Finances at Eawag. She gained her first degree in business administration, majoring in tourism. She then took a Master's in European Tourism Management at Bournemouth University – a course which included semesters in Breda (Netherlands) and Madrid. Gabriele Mayer worked at Kuoni, serving as head of Finances & Administration Switzerland and a member of the Executive Committee. She subsequently managed the newly established company TRX Central Europe, developing a market in the travel sector for automated online booking systems. She joined Eawag from Xerox AG, where she was CFO Switzerland.

Retirements

Roland Schertenleib: Water has been the theme of Roland Schertenleib's career ever since he obtained his Master's in Civil Engineering from the ETH Zurich. After working as a consultant for municipal wastewater treatment plants and sewer networks, and taking a Masters in Sanitary Engineering at Stanford University, he joined the Engineering Department at Eawag in 1976. From 1980 to 2003, he was head of, first, the Dübendorf based WHO International Reference Center for Waste Disposal and then the Department of Water and Sanitation in Developing Countries (Sandec). From 2000, he was a member of the Directorate. Early on, Roland Schertenleib recognized that Eawag's responsibilities should include helping to tackle the growing problems of the Third World through practice oriented research. He always attached great impor-

tance to developing and carrying out research projects in collaboration with local partners, thereby promoting local expertise and research skills. He contributed his knowledge and networked approach to a wide variety of international bodies. As Chair of the Environmental Sanitation Working Group of the Water Supply and Sanitation Collaborative Council (WSSCC), he played a decisive role in the formulation of the Bellagio Principles for Sustainable Sanitation. He also initiated the household-centred environmental sanitation (HCES) approach (page 39), a new model for the planning and implementation of sanitation measures in urban areas of developing and transition countries. In the Directorate of Eawag, Roland Schertenleib was responsible for property, among other matters. His main challenges in this capacity were the completion of the pioneering Forum Chriesbach building and the planning and realization of the renovated office facility in Dübendorf. Eawag will still be able to benefit from his expertise in various activities, such as the National Centre of Competence in Research (NCCR) North-South, or a project concerned with decentralized sanitation options – Capacity Building in Environmental Science & Technology in Northern Vietnam (ESTNV).

Barbara Sulzberger: At Bern University, where she received her doctorate in 1983, and then as a postdoc at the renowned Royal Institution of Great Britain in London, Barbara Sulzberger was already interested in physical chemistry – in particular, the photochemical conversion of solar energy. Until 1986, she worked as a research chemist at Ciba-Geigy. She then established an environmental photochemistry research group at Eawag. Using modern methods, she studied photochemical processes on mineral surfaces in aquatic systems, the formation of reactive oxygen species and their role in transforming natural and synthetic compounds. She qualified as a lecturer at Bern University in 1998 and taught mainly at the ETH Zurich. At Eawag, she was

head of the Chemistry Department for a time, but after the reorganization in 2000 she moved to the Limnology Department. Here, she established a new group to investigate the effects of sunlight on the availability of organic carbon, iron and copper in rivers, lakes and oceans. In collaboration with doctoral students, postdocs, and research associates, Barbara Sulzberger produced a large number of outstanding publications and was regularly invited to participate at international conferences and on expert committees. From 2002, she also served as Editor-in-Chief of the journal *Aquatic Sciences*. She remains a member of the UN Environmental Effects Assessment Panel.

Rudolf Müller: Anyone wishing to enquire about practical aspects of fisheries management – associations, fishermen or authorities – was well advised to contact the biologist Ruedi Müller. He always understood the concerns of practitioners, including the Romans, thanks to his proficiency in French. His career at Eawag began with his PhD thesis on body temperature in freshwater fish, which he completed in 1974. A year later, after working as a research associate in Toronto, he became a researcher at Eawag. From 1986 to 1999, he was head of the Department of Fisheries Sciences (until the reorganization in 2000). From 1986 to 1989, he served as the first president of the newly founded Swiss Society of Limnology (SGL), and from 2000 to 2006, he was Chairperson of the European Inland Fisheries Advisory Commission (EIFAC) of the FAO. Ruedi Müller was an active member of numerous bodies, ranging from the federal cormorant-fish working group (AG K+F) to the expert committee on

changes in the ecosystem of Lake Brienz. After the Sandoz warehouse fire at Schweizerhalle, he played a key role in analysing the effects of the release of toxic chemicals into the Rhine. In his research, Ruedi Müller focused on how individual fish species are affected by lake eutrophication, and on how management can be adapted to respond to such changes. More recently, he concentrated on questions of population genetics and developmental biology, e.g. how genetic diversity in fish is altered by breeding and stocking measures. Internationally, he has been a leading light in whitefish research.

Urs Uehlinger: As an expert in stream ecology, Urs Uehlinger has earned an international reputation. In 1977, having completed his thesis on cyanobacteria at the Federal Institute of Technology (ETH) Zurich, he joined Eawag to work on biological and physical processes in lakes. In the 1980s, the focus of his research shifted to rivers and streams, where he was particularly interested in nutrient and organic matter dynamics. In 1986, as a visiting scientist at Idaho State University, he was impressed by the untouched wild rivers. Accordingly, when Professor James Ward became head of the Limnology Department in 1995, Urs Uehlinger began to concentrate on alpine streams. Following extensive studies in Val Roseg (Upper Engadine), Ward and Uehlinger jointly edited a book entitled "Ecology of a Glacial Flood Plain". Urs Uehlinger supervised numerous PhD students and undergraduates and lectured on stream ecology at the ETH Zurich. After leaving the Department of Aquatic Ecology, he intends to pursue his research on lotic ecosystems.

Martin Wegelin: ETH-trained civil engineer Martin Wegelin took a Master's degree at the IHE in Delft and taught at the University of Dar es Salaam (Tanzania) before joining Eawag in 1982. His initial research was

concerned with the optimization of gravel filters for drinking water preparation and wastewater treatment. His manuals are still consulted today. He then became fascinated with the idea proposed by a Lebanese professor, Aftim Acra, that it should be possible to use sunlight to disinfect drinking water. Although the notion was not taken seriously by some scientific colleagues, he refined the method and, together with Silvio Canonica and Klaus Mechsner, demonstrated that it was indeed effective and could represent an opportunity for countries with inadequate drinking water supplies. Thanks to his commitment and persistence, the Sodis (Solar Water Disinfection) project has been supported by a variety of donors and has now gained international recognition among experts. As Martin Wegelin was always open even to unconventional ideas, he managed to establish the PET bottle as a universal container for Sodis. This system is now used in more than 28 countries, with the support of the WHO and in many cases also government agencies. "Mister Sodis" was never discouraged by setbacks: his visits to Coca-Cola Headquarters in Atlanta have become legendary at Eawag, even though they failed to secure the incorporation of instructions for Sodis on the labels of all Coca-Cola PET bottles. Martin Wegelin will continue to serve Eawag as a senior adviser and contact for Latin American programmes at the Sodis Reference Center.

Death

Heinz Ambühl: On 14 May 2007, Heinz Ambühl died in his 79th year. As a hydrobiologist, he set new standards, starting with his thesis on "The importance of flow velocity as an ecological factor", for which he was awarded the Silver Medal of the ETH in 1959. In 1960, having previously worked as a water chemist in Canton Aargau, he was appointed head of the Hydrobiology/Limnology Department at Eawag and took on numerous teaching responsibilities. In 1972, he was elected Extraordinarius of Hydrobiology. Many of the research areas which he promoted – e.g. fish biology, fish management, ecotoxicology and multidisciplinary studies involving mathematical modelling – have since become established as independent departments at Eawag. Long before the advent of computer based literature searches, he compiled for Eawag a catalogue of almost 20,000 original publications on register cards, with an index comprising hundreds of keywords. In a voluntary capacity, he edited the Schweizerische Zeitschrift für Hydrologie and developed it into the renowned journal Aquatic Sciences. Whenever he started a new scientific project, a careful approach and an appropriate sampling technique were top priorities for him. If no analytical methods or procedures were available, he would devise an ingenious method of his own. More than thirty PhD students and numerous undergraduates benefited from his selfless support. His long-term studies of ecosystems laid the foundations and remain a limnological gold mine for many contemporary models and new projects. With the death of Heinz Ambühl, the limnology community has lost an internationally recognized champion of Swiss water protection. ○ ○ ○

Books – and total immersion

Eawag-Empa Library. Standing at the counter in the new library, the water researcher is apologetic: during his field work, the books he had borrowed had got “a bit wet”, he confesses. Strictly speaking, they had fallen overboard. At any rate,



Bas den Brok, Head of the Eawag-Empa Library, talking to librarian Stephanie Hofmann.

they will have to be replaced. “But that’s the exception,” says librarian Jutta Studer. “The vast majority of our clients are exemplary,” library head Bas den Brok agrees, “and if something does happen to a book, they hang their heads in shame and get out their wallets.” Of course, it is the exceptions that make library life interesting, and sometimes there are pleasant surprises, too – for instance, when books are returned that had never officially been borrowed. But Brok is sympathetic in cases like this: “If a researcher is so engrossed in his work that he forgets to check out a book when he leaves the library, then it’s not premeditated.” He has less sympathy for the individual who regularly walks off with a specific journal: “That’s unfair to everyone else. We’re not a kiosk!” Brok is determined not to close the library outside working hours: the open-door principle meets the needs of

researchers who – in spite of increasing digitization – may still want to read an article in the small hours of the morning or at the weekend. Since the summer of 2006, the Empa and Eawag libraries at the Dübendorf site have been combined in the new Forum Chriesbach building. Accordingly, 2007 saw a sharp rise in the number of items borrowed – from around 3200 to 4900 (+53%). In fact, the increase in the number of registered users – from 1290 to 1590 – was so large that the operators of the NEBIS library network enquired whether everything was in order. Bas den Brok is pleased: “It shows we’re on the right track.” But numbers are not everything: if all the books from the various departments were to be held centrally, as originally planned, the library would soon run into problems of space. And librarians are always reluctant to throw out books. ○ ○ ○

An elegant sufficiency

Staff canteen aQa. The weekly menu for the staff canteen aQa is one of the most popular links on the Eawag Intranet. When it became temporarily inaccessible for Empa staff following a system migration, complaints were received immediately. Each day, between 220 and 280 meals are prepared at the kitchen operated by



Peter Czerwinski, aQa’s chief cook: “Even environmental scientists don’t always choose the organic option.”

the catering company DSR – aQa is frequented not only by Eawag and Empa staff, but also by employees of nearby companies. The kitchen and dining facilities were originally designed for 150 guests. This means that the catering team led by Peter Czerwinski sometimes needs to draw on all its improvisation skills and stamina – for example, if 50 extra visitors need to be fed at short notice, or on the occasion when a box containing 20 kg of frozen peas ripped, spilling its contents over the kitchen floor. The 5-strong aQa team (with a total of 4.1 full-time positions) was also hard pressed at the 2007 Christmas party: more than 360 guests queued up at the catering stands in the atrium of the Forum Chriesbach building. But, as Peter Czerwinski recalls, the event itself went off smoothly: “The shock came the next day, when I had to plough through

around 1000 unwashed glasses and piles of other dishes in the kitchen.” Overall, however, chief cook Czerwinski is very satisfied: “Ninety-nine per cent of the feedback from our customers is excellent.” There were some complaints when an external bakery stopped supplying dark fruit rolls – Czerwinski now bakes these himself. ○ ○ ○

40 kilos of salad a day

The rush starts at 11:30. Each day, aQa offers three set menus and a salad bar. One of the set meals is vegetarian and one – possibly the same dish – carries the organic “Goût Mieux” label. Czerwinski is no longer surprised by the fact that environmentally aware Eawag staff don’t necessarily choose the organic option: “You eat whatever you fancy.” His team prepares almost 40 kg of salad per day. Every month, he purchases 200 kg of potatoes, 80 kg of coffee beans and 750 litres of milk. www.dsr.ch, www.goutmieux.ch

A home from home

Childcare centre. Eveline Vonlanthen, the manager of the joint Eawag-Empa childcare facility, arrives a little later than planned: a four-year-old has taken a tumble and bumped his head. “Nothing serious,” she says,

“but it must be sore – so I couldn’t just run off.” Happily, the boisterous band of children at the “KiPa” have so far been spared any more dramatic accidents. In 2007, one broken finger was the only serious case requiring the attentions of voluntary in-house first-aiders. The children clearly feel comfortable at the centre. Particularly popular are the activities in which all three groups participate, as these events make new interactions possible or bring together siblings who, as a matter of policy, are not assigned to the same group. The shared activities include singing, weekly forest days and, of course, the various parties which parents are also invited to attend.

There is plenty of space for the children to let off steam, not only in the woods or in the new garden around the centre, but in the building itself. Having got used to the wide play corridor, none of the carers would now like to go back to the nooks



At the Eawag-Empa childcare centre, it is often the fathers who drop off or pick up their children

Childcare centre

At the childcare centre, a total of 33 preschoolers aged between 4 months and 5 years are looked after in three groups from 07:30 to 17.30. The centre is run by the “IG Kinderpavillon” association. Empa and Eawag make the new building opened in August 2006 available to the IG and also take on administrative responsibilities. In the allocation of places, priority is given to children of Eawag and Empa staff; their parents pay reduced rates. Two places are supported by the neighbouring company Givaudan for its employees. The children are looked after by 9 qualified carers, 4 trainees and 3 interns. The members of the IG serve on a voluntary basis. The centre is currently fully subscribed, with waiting times of 6–12 months for new enrolments. www.kinderpavillon.eawag-empa.ch

and crannies of the old building. So does the team have everything it could wish for? Eveline Vonlanthen replies: “A few male carers would be good for the children.” But the prospects of that are still fairly dim. “Oh yes,” she adds, “and we’ve wanted a teepee for the garden for quite a while.” ○ ○ ○

Green mobility

Eco-Team. In December 2006, Eawag set itself new energy goals, paying greater attention to transport. In 2007, we began the process of implementation:

► Eawag is taking all necessary measures to ensure that its electricity and heating requirements are progressively – and by 2010 fully – met by renewables and in a sustainable manner.

► All travel undertaken by Eawag staff is to be carbon-neutral.

CO₂ reductions and transport measures. The Kastanienbaum site recently celebrated the 10,000th kilowatt-hour of self-generated solar power. The new photovoltaic system – twice as large as its predecessor and with an annual capacity of 10 MWh – came on stream in the autumn of 2007. It was financed by CO₂ charges levied internally on air travel. These charges are also

used by Eawag to subsidize passes for staff using public transport. Compared with bonuses for non car users, this type of support offers the advantages of saving administrative costs and being tied to a specific purpose. As a result, many staff also use public transport for personal travel. In 2007, Ecodrive courses for Eawag staff who are still dependent on cars demonstrated how fuel consumption can be reduced by appropriate driving techniques.

Cycling: as attractive as ever. The pool of 50 Eawag bikes available for loan is heavily used. At Dübendorf, it was agreed with officials that bicycle stands will remain in place at Stettbach station until the construction of the Glattalbahn railway line starts; arrangements for the subsequent period are being worked out. The plans for a cycle path free of intersections and traffic lights are completed. In

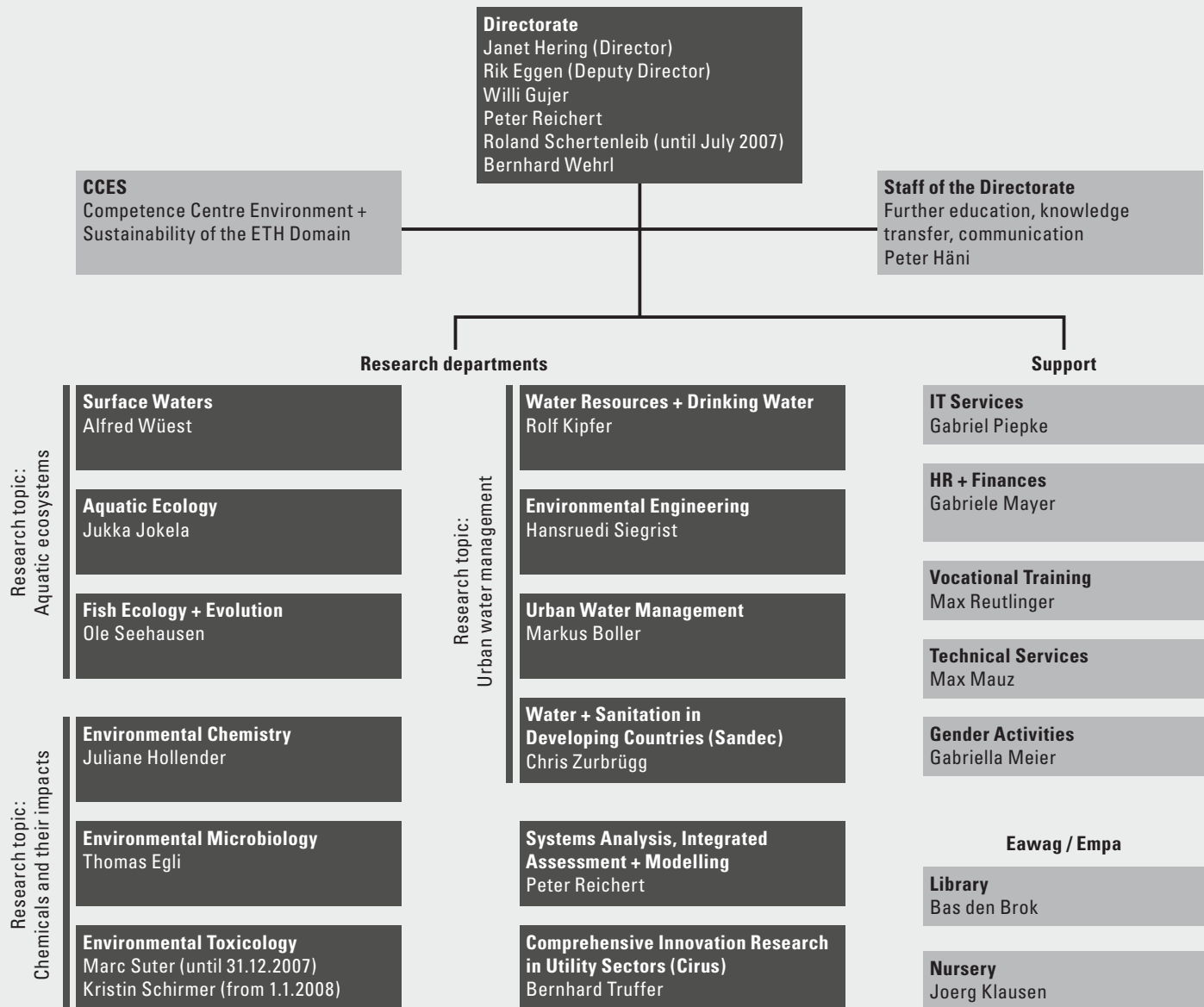
this year’s “bike to work” initiative, the Eawag teams – actively supported by members of the Directorate – once again improved on the previous year’s results. ○ ○ ○

Thomas Lichtensteiger, with the Eco-Team
www.umwelt.eawag.ch



The photovoltaic system on the renovated boathouse in Kastanienbaum has already generated more than 10,000 kWh of power. It was financed by internal CO₂ levies on air travel.

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Office for the
Environment (FOEN),
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(Director)



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(Deputy Director)



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Peter Reichert



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Leader



Herbert Güttinger
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Knowledge transfer



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Bernhard Truffer

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Gabriel Piepke



Gabriele Mayer



Max Reutlinger



Max Mauz



Gabriella Meier



Bas den Brok



Joerg Klausen

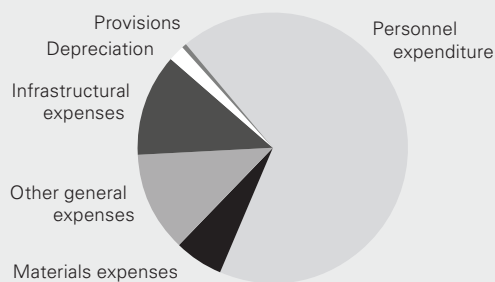
Finances

Financial statement (in CHF)	2005	2006	2007
Personnel	33 136 459	35 203 743	37 868 533
Materials	2 310 907	2 911 752	3 260 866
Other general expenses	5 051 942	5 556 131	6 781 444
Infrastructural expenses	3 399 665	5 160 395	6 710 435
Depreciation	1 029 614	871 718	1 082 462
Provisions	19 660 190	10 088 456	296 041
Expenditure	64 588 777	59 792 195	55 999 781
Federal government funding	46 624 468	49 795 822	¹ 38 491 577
Third-party resources	10 293 942	13 481 019	11 564 156
Miscellaneous revenue	1 110 280	1 010 742	1 655 624
Income	58 028 690	64 287 583	51 711 357
Result	-6 560 087	4 495 388	-4 288 424

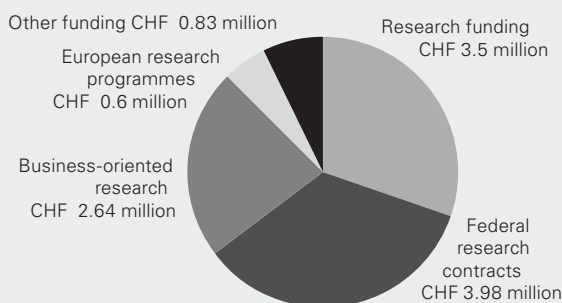
¹ Not including funding for building

Investments (in CHF)	2005	2006	2007
Real estate	18 463 636	6 883 301	12 780 799
Movables	2 259 269	2 439 510	1 663 563
IT	206 740	47 821	270 031

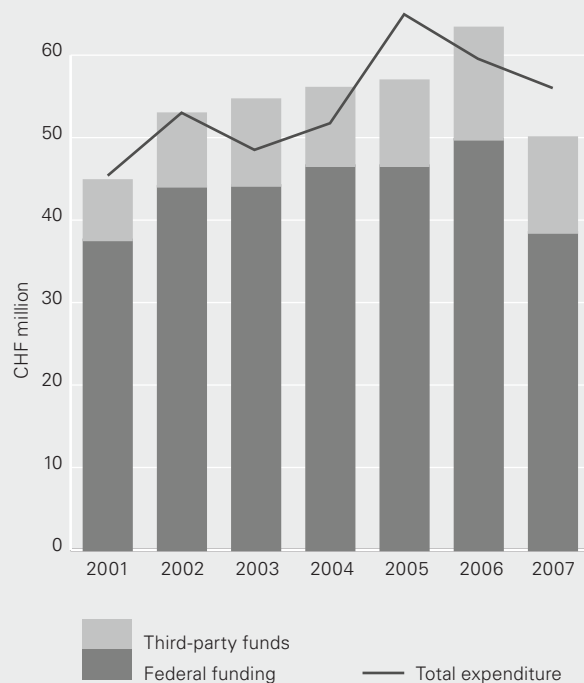
Breakdown of expenditure 2007



Third-party resources 2007



Development 2001–2007



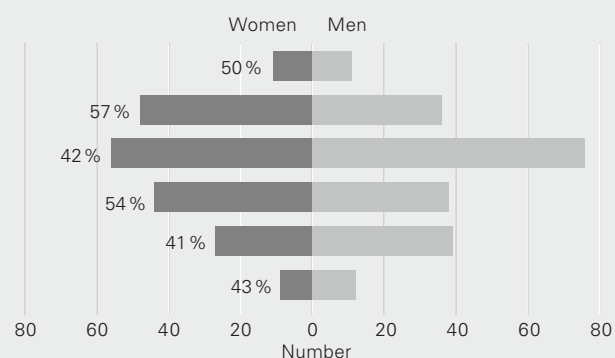
People

Personnel	People	Whereof women	Whereof non-Swiss	Full-time equivalents
Full professors ¹	5	1	3	5
Titular professors	13	2	5	13
Scientific staff (academic staff)	152	50	81	134
PhD students	76	37	40	71
Technical staff	78	37	8	64
Administrative staff	63	55	8	43
Apprentices	24	13	1	24
Trainees ^{1,2}	12	6	7	12
Affiliated staff (nursery) ¹	16	16	1	14
Total	439	217	15	380

¹ Not or not directly employed by Eawag.

² Only traineeships funded by Eawag at 31.12.2007, total for 2007: 63.

Age structure	Women	Men	Total
15–19	11	11	22
20–29	48	36	84
30–39	56	76	132
40–49	44	38	82
50–59	27	39	66
60–65	9	12	21
Total	195	212	407



Percentage employment	Women	Men	Total
1–49 %	22	9	31
50–79 %	47	11	58
80–99 %	35	14	49
100 %	91	178	269

Origin	Women	Men	Total
Switzerland	133	130	263
EU	48	66	114
Other	14	16	30

Activities

	2005	2006	2007
Supervised dissertations	105	107	108
Supervised diploma theses	97	104	108
Publications in refereed journals	186	194	202
Publications in non-refereed journals	47	49	55
Spin-offs	–	1	–
Patents, licence agreements	–	–	1
Service contracts	39	38	28
Prizes	8	24	19
Teaching programmes at ETHZ, EPFL	85	93	75
Teaching programmes at other universities	31	37	39
Teaching programmes at universities of applied sciences	10	10	4
PEAK courses (further education)	9	6	5
Conferences	39	45	54
Committee memberships	180	201	216

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.

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