eawag
aquatic research

Annual Report 2008

Eawag: Swiss Federal Institute of Aquatic Science and Technology

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
Kirsten Klappert, Caroline Baumgartner and Irene Keller – reseachers in the Aquatic Ecology department – collecting samples for analysis of the "common freshwater shrimp" *(Gammarus spp.).*
Photo: Günter Bolzern, Bülach

Content

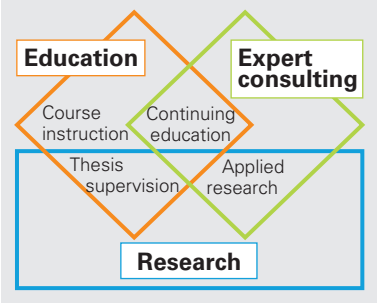
Meeting challenges – bridging theory and practice

Stewardship of the water environment – encompassing the quality and quantity of water resources, water supply and aquatic ecosystems – poses major challenges, both in itself and in relation to energy and food security issues. To meet these challenges, Eawag deploys its diverse expertise in natural and social sciences and engineering, with a multifaceted portfolio of activities in research, education and expert consulting.

In 2008, the world experienced a series of crises. The number, severity and diversity of these crises conveyed an important message: they are interrelated and global in scope. They cannot be resolved issue by issue or nation by nation. Rather, the various aspects of security – energy, food, water, public health and safety, as well as the economic and territorial dimensions – must be viewed holistically, so that a solution to one problem does not create or exacerbate another.

Holistic view

In accordance with this holistic view, Eawag brings its specific capacities and expertise to address critical problems in the domain of water, while also linking these issues with other aspects of security. The linkage between water and energy is evident in several Eawag projects, including the development of biogas generation in developing countries (p. 14), the recovery of heat from wastewater (p. 15) and the study of the ecological consequences of hydropower operations (p. 29).



The impact of water quality on human and ecosystem health is the motivation for a substantial segment of Eawag's research. In developing countries, Eawag's research is supporting methods for the rapid detection of disease-causing microorganisms (p. 16) and for mapping the risk associated with geogenic contaminants, such as arsenic and fluoride (p. 44). In industrialized countries, Eawag researchers have contributed to a comprehensive study of endocrine disruptors in the environment (p. 36) and are examining the environmental fate and effects of emerging contaminants, such as nanomaterials (p. 40). This research directly supports the activities and expertise of the new Centre for Applied Ecotoxicology at Eawag and EPF Lausanne.

Exchange between theory and practice

Eawag conducts research that explores novel and exciting science in the context of important problems facing society. The scientific basis for conserving biodiversity is developed through research that links the genetic diversity of fishes with adaptation to environmental pressures (p. 22). The goal of *bridging theory and practice* is realized through projects such as Wave21, which actively engages stakeholders and practitioners in the development and evaluation of drinking water treatment and distribution technologies (p. 10).

In the domain of water science and technology, Eawag has a mandate with three major facets – research, education and expert consulting (see Figure). In the first of these three areas, Eawag pursues high-impact research, i. e. basic research leading to fundamental advances in theory, and applied research introducing radical innovations in practice and addressing the critical needs of society. In its educational activities, Eawag supports the Federal Institutes of Technology, Cantonal Universities and Universities of Applied Sciences in formal course instruction and the supervision of student research. In its expert consulting activities, Eawag provides support and guidance for stakeholders, practitioners, industry and government through projects that address practical problems and implement solutions, as well as through continuing education for practitioners and service on expert committees and advisory boards.

Today water issues can no longer be resolved in isolation or on a national basis.

A balance of activities

Maintaining an appropriate balance among these activities is a constant challenge, calling for responsiveness to evolving external demands and opportunities. This balance will certainly not be the same for all individual researchers, or even for all of Eawag's research departments, but overall it must involve a strong portfolio of activities across Eawag as a whole. Although this complex mandate imposes certain dynamic tensions, it also offers unique opportunities to bring fundamental advances in research into practice.

Strong motivation

The water environment is subject to increasing pressures as a result of population growth, rising demands for food, water and energy, and climate change. The broad expertise of Eawag's researchers in the natural and social sciences and engineering, together with their experience and activities in research, education and expert consulting, provides a unique perspective and capacity to address the complexities of stewardship of the water environment. Bringing our expertise to bear on such vital issues is a strong motivation for all of us at Eawag.

Prof. Dr Janet Hering, Director

Swiss Ecotox Centre now operational

The new, federally mandated Ecotox Centre develops methods for identifying and assessing the risks of chemicals, so as to minimize adverse effects on the environment. It provides an interface between research and the application of ecotoxicological assessment methods in practice. Switzerland had previously lacked an independent institution of this kind. The Centre's other main responsibilities include consultancy, education and networking in the ecotoxicology field. As part of the ETH Domain, the Centre is supported by Eawag and the EPF Lausanne.

With a well-attended inaugural event including a symposium on nanoparticles in the environment, the Swiss Centre for Applied Ecotoxicology was officially opened on 30 October 2008. The occasion offered a forum for communication and discussion among representatives of industry and research, as well as policymakers and officials. Speaking at the event, National Councillor Maya Graf emphasized that the Ecotox Centre fills a gap: it should become the prime source for independent expertise, applied ecotoxicological research and professional education on ecotoxicology in Switzerland. Graf had introduced a motion on toxicology research in Switzerland in 2002, which was one of the factors leading the Federal Council and Parliament to request the ETH Domain to establish a centre of this kind in 2007.

Dialogue and expertise

Within Switzerland, the Centre acts as a hub, supporting dialogue on developments in ecotoxicology and cooperating closely with universities and government agencies. The establishment of an expert database should enable it to elaborate broad-based recommendations for action on environmental issues. Ecotox Centre staff serve on national and international expert committees, developing, for example, OECD guidelines for toxicity assays or environmental standards for the assessment of chemicals under the EU Water Framework Directive. As it is represented on the SETAC Europe Council, the Ecotox Centre maintains close contacts with the globally active Society of Environmental Toxicology and Chemistry.

Applied research

A variety of applied research projects are already under way. Three examples are given below:

Multisens: In this project, the Ecotox Centre is developing sensors for a whole series of chemical/physical and biological tests. The aim is to permit integrated evaluation of water quality in surface waters or wastewater, on levels ranging from the molecule to the ecosystem. The key organism for this modular testing platform is not, as has usually been the case to date, an algal species, but the "common freshwater shrimp" *(Gammarus spp.)*. In the "GamTox" module, the toxicity of pollutants and pollut-

Facade panels with paint containing silver nanoparticles are exposed to rainfall. The rainwater runoff is captured for ecotoxicological assessment, which involves the use of freshwater amphipods (*Gammarus*). In particular, effects on swimming activity and respiration are monitored.

ant mixtures is analysed for the amphipods themselves, their food sources and their predators (e.g. fish). Thus, for the first time, different stages of the food chain can be assessed ecotoxicologically at the same time – food quality and food choice of the freshwater amphipod are influenced by pollutants that affect the microbial colonization of leaf litter. Although Multisens is rounded off by a variety of laboratory tests, most of the modules can also be used for field-testing (e.g. in surface waters). For soil ecosystems, the testing module can also be applied with woodlice.

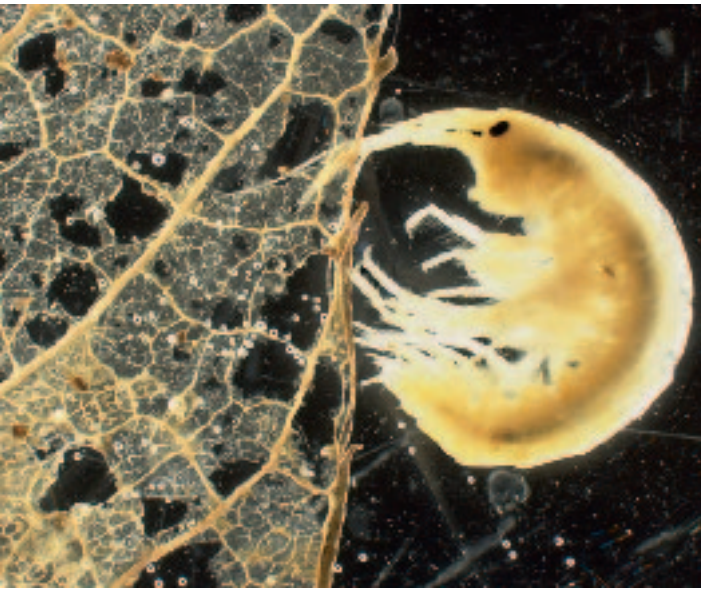
Nanosilver: Biocides with antimicrobial effects are often added to facade paints. Recently, silver nanoparticles have also been used for this purpose. It has already been shown by the Urban Water Management department at Eawag that significant amounts of substances are washed out of facades by rainwater and may enter surface waters. In cooperation with Empa and Eawag, the Ecotox Centre is currently using facade panels exposed to artificial rainfall to study the acute toxicity of runoff on aquatic organisms (see also p. 40).

Earthworms as test organisms: At the Lausanne site, the Centre is developing soil ecotoxicology tests, focusing on the use of earthworms and springtails as test organisms. Particular attention is being paid to the optimization of existing OECD assays and to the development of straightforward rapid tests suitable for *in situ* use.

Professional education

Today, information on ecotoxicology is scattered over a wide range of sources and often contained in highly specialized publications. The Centre assesses the latest findings and summarizes them for practitioners. It has already produced independent overviews of biological detection methods for endocrine disruptors in the environment, and of the relevance of the freshwater amphipod in ecotoxicology. An overview of the significance of terrestrial isopods (woodlice) in ecotoxicology is in preparation. These articles provide a starting point for the development of biotest systems.

In the "Aktuelle Stunde" seminar series, presentations on current topics are given by internationally renowned experts from a wide variety of research institutions. In November 2008, the Centre's coetox ("collaboration en écotoxicologie") basic course – sponsored by Eawag, the EPFL and the Cemagref institute in Lyon – provided an overview of terrestrial and aquatic biotests. Two workshops planned for 2009 will deal with the use of biological test methods for the detection of endocrine disruptors, and ecotoxicological methods for the assessment of pollutant mixtures. ○ ○ ○



Freshwater amphipods feed mainly on plant detritus in surface waters.

Two sites: Dübendorf and Lausanne

The headquarters of the Ecotox Centre – mainly concerned with aquatic ecotoxicology – is at Eawag in Dübendorf. The second site – focusing on terrestrial ecotoxicology – is at the EPF in Lausanne. The management team consists of the Centre Head (Dr Almut Gerhardt) and one delegate each from the Eawag Directorate and the EPFL Presidency (Professors Rik Eggen and Christof Holliger). As well as receiving federal funding of CHF 2 million per year, the centre can undertake contract research, although it is not to compete with the private sector. Operating alongside the Ecotox Centre from 2009 will be the Swiss Centre of Applied Human Toxicology, hosted by the Universities of Basel and Geneva.

National Councillor Maya Graf in conversation with Christof Holliger (EPFL), Almut Gerhardt (Centre Head) and Rik Eggen (Eawag) at the opening of the Ecotox Centre.

▸ www.oekotoxzentrum.ch

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Forum Chriesbach: reaping the rewards of sustainable construction

Eawag's new six-storey headquarters, accommodating 220 people, has performed well since it was first occupied in 2006. A review by architects, planners and clients concluded that the results for the first two years, in terms of energy use and costs, have been positive. The internationally renowned building requires only around 64 MWh of externally supplied heating energy per year – equivalent to 6400 litres of oil. Forum Chriesbach is already regarded as a model for a new generation of buildings.

In its first two years of operation, Eawag's new building at the Dübendorf site – with working areas containing no active heating or cooling systems – has been shown to function as intended. The values envisaged by the planners accord well with the data on temperature and energy use. Any deviations that have occurred are attributable to changes in general operating conditions. What has proved particularly valuable is the interaction between design and technology, cooperation on the part of the clients, and the reliance on simple principles. These include excellent thermal insulation, energy-efficient equipment, comfort ventilation and an effective control system.

Natural cooling in the summer

The building's performance has been particularly good with regard to the energy required for cooling during the summer. Worldwide, cooling energy requirements are increasing, especially for glass-fronted office buildings. Rather than using a high-tech system, Forum Chriesbach exploits the chimney effect in the atrium to cool the building overnight in the summer. This ventilation, combined with air supplied from an earth-to-air heat exchanger, means that little cooling energy is required for the server room and no air-conditioning is required for the offices. Even during the hottest summer weeks, the indoor temperatures did not exceed 26 °C, which was greatly appreciated by staff. The pleasant working climate was also confirmed by measurements of CO_2 concentrations in indoor air: with a mean value of 0.6 litres of CO_2 per m^3 air, these were very low.

External heating requirements were higher than predicted. In 2007, rather than 24 MWh, 64 MWh was supplied by the Empa/Eawag district heating network. This is still equivalent to only 6 kWh per m^2 treated floor area (11,170 m^2); expressed in different terms, energy

Forum Chriesbach, with the childcare centre in the foreground. Visible in the background are the laboratory building and the office block (refurbished in 2008).
The servers are among the biggest electricity consumers in the building, but this makes the server room an important source of heat.

consumption is the same as for two conventional single-family homes – a value clearly below the stringent "Minergie P" requirement. The higher heating requirements are partly due to lower-than-projected occupancy levels for the seminar and meeting rooms. This means that fewer internal heat sources – employees, computers and lighting – are available. In addition, following staff feedback, the temperature of the air supplied had to be increased slightly to 21 °C.

In 2007, electricity consumption was also higher: rather than the planned 121 MWh, 195 MWh was supplied from the grid (i.e. 17 kWh per m^2 treated floor area). This was due to the staff canteen aQa – producing more than 260 rather than 150 meals per day – and the more frequent and extended use of corridor lighting. On the other hand, the photovoltaic system on the flat roof generated not 60 but 71 MWh, and the thermal solar collectors supplied not 24 but 26 MWh per year.

Fine-tuning essential

A building on the scale of Forum Chriesbach is not simply "finished" once the keys have been handed over. People had to be aware that not everything is correctly adjusted so that it works properly from the outset, and that control systems have to be adapted to the individual characteristics of the building and its users. Operational optimization is far more than just remedying defects within the warranty period, and it calls for expert management. For example, the automatic system used to open the tilt windows for overnight cooling comprises more than 200 electric motors, which were – needlessly – permanently switched on. Adjustment of the control system "saved" 20 MWh per year, which is almost a third of the total power generated by the rooftop photovoltaic system. Fine-tuning was also needed for the system controlling the blue glass fins that shade the facade. The spring and autumn settings were depriving the interior of precious daylight. Even after the completion of the 2-year optimization period, there is still scope for further improvements.

Photos: Eawag/Stefan Kubli

The auditorium is occupied less often than had been assumed – one reason why supplies of external heating energy were higher than predicted.

Taking stock

Eawag's new headquarters, designed by the architectural firm Bob Gysin + Partner (BGP), has been in operation since June 2006. From the initial planning stage, Eawag and Empa aimed to make the building a model of sustainability in practice, not only environmentally, but also in social and economic terms. The need for action in the building sector is clear: households and workplaces account for more than half of our total energy consumption. The detailed energy statistics and the construction and operating costs for Forum Chriesbach were the subject of an accompanying project carried out by the two research institutes Eawag and Empa and the engineering consultancy 3-Plan Haustechnik AG. This project was also supported by the Federal Office of Energy, and the costs study prepared by Reuss Engineering AG (an independent consultancy) received additional support from the ETH Board.

Worthwhile additional investments

At CHF 30 million, the construction costs for Eawag's new headquarters were over CHF 2 million below the credit limit approved by the Federal Parliament. These costs were analysed in an additional study forming part of the detailed energy assessment project. The additional investments – compared with a similar, conventionally constructed building – amounted to just under 5 %. The somewhat higher life-cycle capital costs are however offset by the lower operating costs after only approx. 13 years. If energy prices rise as expected, the benefits will become even more marked. Thus, energy- and resource-efficient construction pays off financially. In addition, a building constructed on sustainable principles offers further advantages which are difficult to quantify in economic terms, such as high value preservation, or satisfaction and prestige for users and investors.

Need for team spirit

In a pioneering project of this kind, planning plays a particularly significant role. It is essential that the client should not only provide clear specifications when inviting architects and planners to tender, but should remain part of the team throughout the project. Room for improvement was identified both in the construction processes and in the assignment of responsibilities. The subordinate position of the architects vis-à-vis the general contractors gave rise to some friction. The recipe for success, it was concluded, is for all parties to be not only experts in their own field, but also prepared to engage with other disciplines, convinced that significant innovations can be achieved by working together. ○○○

- www.forumchriesbach.eawag.ch
- www.bfe.admin.ch/dokumentation/energieforschung/ (Energy research database)

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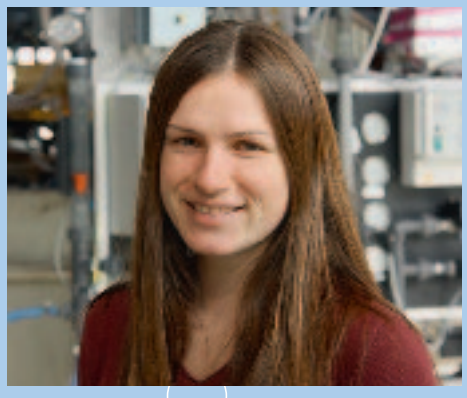
Urban water systems

At Eawag, we develop modern strategies for water provision and wastewater management to meet the needs of Switzerland and other industrialized countries. This includes not only engineering solutions for drinking water supplies, sewerage and wastewater treatment plants but also studying and preventing releases of pollutants from urban areas into surface waters. We also focus on the development of sanitation approaches specifically designed for developing countries, which can be implemented in partnership with the people concerned.

RESEARCH

Advancing towards solutions

Maryna Peter, who studied Chemical Engineering at the National Technical University of Ukraine, is currently working on her doctoral thesis at Eawag. As part of the EU project TECHNEAU (Technology Enabled Universal Access to Safe Water), she is researching a filter module in which water is purified as it passes through a membrane at low pressure. As this system does not require elaborate maintenance or control, it is particularly suitable for use by households in developing and emerging countries (see p. 10). "For me," says Maryna Peter, "what is attractive about research at Eawag is the process of following something all the way from the initial discovery of a phenomenon to the development of a technology, and advancing step by step towards solutions." Does she dream of patenting a device and reaping financial rewards for her efforts? With a smile, the young woman replies: "No. If our results help more people to gain access to safe drinking water, then that's sufficient motivation." She adds that she is particularly interested in exploring the underlying mechanisms. As she points out, the manufacturers of a similar system operating at low pressure don't know why it works. "Now that we've identified the opportunities and limitations of our filters, we can use this knowledge to set about improving them."



TEACHING

Welcoming argument

Willi Gujer, Professor of Urban Water Management at the ETH Zurich, has been a member of the Eawag Directorate since 2001. In 2006, he received the "Golden Owl" from the ETH student association for his outstanding performance as a teacher. In 2008, he also received the "Credit Suisse Award for Best Teaching". Willi Gujer is convinced that environmental engineering is an attractive field for young students: "A large proportion of humankind does not have access to safe drinking water – this represents an enormous challenge." In his view, urban water management is a broad discipline, including "not only hydraulics, but also hydrology, microbiology, chemistry and economics". He emphasizes that the multidisciplinary approach also appeals to women. And what is the secret of his exemplary teaching? "It's important that the lecturer should be highly motivated," says Gujer, "and it's all right to expect something of your students; you have to take them seriously. They have a right to learn something rather than just being required to sit through lectures. But you learn most," he concludes, "with active participation. It's a pity there's hardly ever much scope for argument with students."

Tom Kawara

CONSULTING

Saving millions

Bruno Storni is a computer systems engineer. With his company, he develops and programs electronic control systems for industrial processes and the aerospace sector. As a member of the Gordola local authority, he is responsible for the water supply system. Here, thanks to the consulting services of Eawag (supported by several dissertations), it was possible to shelve a large-scale expansion project dating from the 1990s; as a result, around CHF 10 million and a large amount of energy have been saved to date (see p. 17). Storni comments: "We could have engaged private consultants for certain parts of the work, as we do today with some success. But without Eawag's expertise, the innovative approach, considering both the consumer's and the supplier's perspective, would not have been adopted." The incentives for a genuinely sustainable infrastructure, he believes, remain ineffective – for example, because planning fees are based on the investment volume for the facilities concerned. Storni is convinced that more could be done. The ever-more apparent benefits for his municipality are increasingly turning critics into imitators. "Eawag's high level of credibility has contributed significantly to this process," he adds.

Membrane filters for safe drinking water

In close cooperation with public water utilities and the private sector, Eawag is developing more effective methods for the treatment of drinking water. Membrane filtration is playing a key role in these efforts. The versatility and relatively low costs of this approach can help to ensure safe drinking water supplies – not only in Switzerland but also in developing and emerging countries.

Until the end of 2007, the Frutigen Water Supply Association in the Bernese Oberland often had to divert springwater unused into the Leimbach for days at a time, especially after thunderstorms or during the thaw period. Although the Fuchschrummen reservoir, built in 1968, was equipped with a chlorination system for the disinfection of raw water, this classical treatment method was unable to deal with storm-related turbidity.

The karstic springs tapped above Frutigen arise on the flanks of the Niesen mountain range, where – because of the geological conditions – precipitation infiltrates rapidly and is inadequately filtered as it passes naturally through the soil. This situation is typical of a large number of karstic springs in the Swiss pre-Alps, in the Jura, and in the mountainous cantons of Valais and Graubünden. Accordingly, water suppliers in these regions are frequently confronted with the problem of highly variable raw water quality. Increased turbidity levels are often associated with excessive microbial contamination (parasites, bacteria and viruses).

Effective filtration process

Since December 2007, in spite of these unfavourable conditions, the drinking water flowing into Frutigen's (600 m^3 capacity) reservoirs has been crystal-clear and microbiologically safe. This is due to the replacement of the ageing chlorination facility by a membrane ultrafiltration system – a technology researched and refined by Eawag. Ultrafiltration, which is effective in all weathers, has made it possible for the association to increase the security of supplies without having to develop further raw water resources or create additional storage volume. After passing through a prefilter, which removes coarse particles, the karstic water enters a membrane filter system consisting of 40 modules, producing up to 108 m^3

About a fifth of Switzerland's drinking water is pumped from lakes. In a pilot project at the Lengg waterworks in Zurich, Eawag researchers aim to establish which treatment steps and process combinations ensure a high level of safety without unduly increasing operating costs. (Photos: Ruedi Keller, Andri Bryner)

drinking water per hour. In this process, the membrane pores – only a fraction of a micrometre in diameter – act as a physical barrier, permitting the passage of water and dissolved mineral salts, but effectively retaining turbid matter and microorganisms, including parasites and viruses. The mechanical cleaning thus also serves to disinfect the springwater, without requiring the use of chemicals such as chlorine or ozone.

Regular cleaning

After heavy precipitation, the turbidity of raw water in Frutigen rises to levels comparable to those found in weakly contaminated wastewater. This gave rise to concerns that the permeability of the ultrafine membrane pores might be impaired by the high particle load. In order to prevent clogging, a computer-controlled system interrupts the inflow of water to the filters up to three times a day so that the membranes can be disinfected with bleach and then rinsed with fresh water. The fully automatic treatment plant has a low external energy requirement, as the springwater – despite previously passing through a hydropower turbine – still has sufficient hydraulic pressure (1 bar) for ultrafiltration.

Method	Pore size [µm]
Microfiltration	>0.05
Ultrafiltration	0.002–0.05
Nanofiltration	0.001–0.002
Reverse osmosis	<0.001

Comparison of membrane filtration methods. A micrometre (µm) is a thousandth of a millimetre.

In view of its numerous advantages, ultrafiltration is increasingly being used by waterworks in this country to replace existing processes for the treatment of springwater. In recent years, particularly in karstic regions, a number of systems have been installed, with capacities ranging from 1 to 480 m^3 per hour. From the outset, Eawag has played a major role in the development of this technology – through basic research, support for pilot projects and specific contributions to the optimization of membrane filtration for drinking water treatment.

Elusive pollutants

For Wouter Pronk, a process engineer and head of the Membrane Technology group in the Urban Water Management department of Eawag, ultrafiltration of spring- and groundwater is a viable alternative to conventional process chains such as flocculation, sand filtration, ozonation, activated carbon filtration and chlorination for safety purposes. As he points out, the process is less technically demanding for the operators of water utilities and ensures – at relatively low cost – the reliable elimination of potentially hazardous microorganisms. "However," he adds, "if the raw water to be treated also contains pollutants, taste and odour compounds or too much assimilable organic carbon (AOC), ultrafiltration has to be supplemented with a combination of ozonation and activated carbon filtration."

Simpler treatment of lake water

To ensure that the microbiological safety requirements of Swiss food legislation are complied with at all times, 33 % of the 1000 million m^3 of water processed each year by public utilities has to undergo single-stage, and another 29 % multi-stage treatment. Process chains are absolutely essential at the 30 lake water treatment plants which together supply almost a fifth of the country's drinking water. Here, too, ultrafiltration is increasingly being applied at new or renovated facilities, generally at the end of a chain involving ozonation and activated carbon filtration.

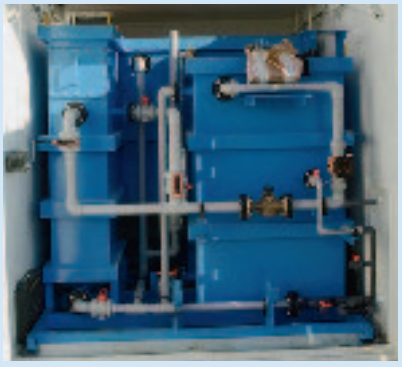
Membrane filtration requires not only a significantly smaller area than traditional sand filtration basins, but also lower chemical and energy inputs than conventional treatment processes. Consequently, it is less costly and at the same time purifies raw water more effectively, as shown for example by analyses of drinking water produced at the Männedorf (Canton Zurich) lake water plant which opened at the end of 2005. Here, up to 6000 m^3 per day of raw water pretreated with ozone and activated carbon is purified in 164 membrane modules. Suspended solids and microorganisms (e. g. bacteria and viruses) are eliminated by filters with a pore size of 0.02 µm and a

Suitable for use in developing countries

Access to sufficient quantities of safe drinking water is one of the most effective instruments for combating poverty. Today, however, more than a billion people are still denied this fundamental right. Especially in the poorer countries of Asia and Africa, water supply networks are non-existent or unreliable in many areas.

Even under adverse conditions, membrane technology can make a significant contribution to the resolution of this problem. Eawag is therefore involved in the development of simple filter systems for decentralized use which operate with gravity flow alone, so that there is no need for pumps, external power supplies or purification chemicals. Surprisingly enough, the results of research carried out so far indicate that – if certain requirements are met – systems of this type can ensure safe disinfection of microbially contaminated raw water for a period of months, even without backwashing or chemical cleaning of the membranes. If a membrane is only operated under low-pressure conditions, the biofilm that forms – after an initial drop in performance – leads to stabilization of the flux through the filter. If the filters are occasionally flushed with clean water, such systems can even operate effectively for years.

The low-cost technology is suitable for use in businesses, households and communities, as well as in emergencies or in disaster areas. For this purpose, Eawag, in partnership with Veolia (one of the world's largest environmental services companies), has developed a pilot system for low-pressure ultrafiltration in a freight container *(photo)*.



total surface area of 7380 m^2. The analytical procedures required were tested and established by Eawag scientists in cooperation with the supplier Wabag.

Optimum process combination

Eawag is also collaborating closely with Zurich Waterworks (WVZ) to further optimize the preparation of high-quality drinking water from surface waters. Using state-of-the-art analytical methods, Eawag is testing various treatment technologies and process combinations at laboratory and pilot scale for the Lengg plant – the country's largest lake water treatment facility, with a daily capacity of 250,000 m^3. The aim is to apply the treatment methods that are most appropriate given the specific raw water quality. Here, the prior analyses of water quality cover parameters that are not otherwise routinely investigated – but are crucial for the product water – such as nanoparticles, natural organic matter (NOM), taste and odour compounds and assimilable organic carbon (AOC), as well as cell count and pathogenic microorganisms.

Enhancing membrane performance

Some of these constituents of raw water, such as NOM and dissolved iron or manganese, can clog the membranes and impair their performance; this is known as membrane fouling. By carrying out basic research on this problem, Eawag is promoting a better understanding of the process. For example, it has been shown, contrary to expectations, that ultrafiltration membranes are less susceptible to clogging than the coarser pores in microfiltration. It appears that, with ultrafiltration, the finest water constituents are retained by the cake layer, whereas with larger pores – of the same order of magnitude as the particles themselves – they are readily trapped, causing a blockage. On the basis of such findings, Eawag researchers are developing models to make it possible to predict the permeability – and hence purification performance – of membranes as a function of raw water quality. Wouter Pronk explains: "With these foundations, we hope to be able to optimize the design of ultrafiltration systems and also to evaluate strategies for enhancing the performance of membrane filtration processes, which includes, for example, operating conditions such as hydraulic pressure, membrane cleaning and if necessary also additional processes for the pretreatment of raw water." ○○○

"Drinking water in the 21st century" project:
- www.wave21.eawag.ch
- Eawag News Nr. 65e: "From source to tap – good-quality drinking water for today and tomorrow"

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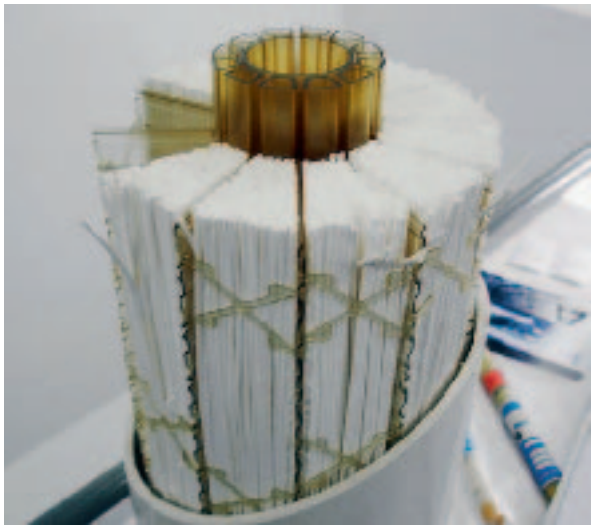
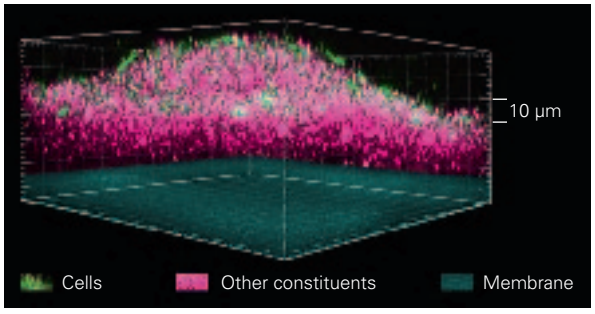


Interior of a membrane (ultra)filter. The pore size is in the range 2–50 nm. The membrane surface area per module is around 50 m^2.

AWA, Canton. Bern

The ultrafiltration system in Frutigen (Canton Bern) comprises 40 modules (cylinders containing the membranes).



3-D laser microscopic image: cavities form between the membrane and the biofilm.

Tackling waste problems with small-scale biogas plants

To combat the problem of waste in cities of developing countries, Eawag researchers are studying new options for the processing of organic household waste. A particularly promising approach is the production of biogas – even on a small scale, using simple technologies.

In developing countries, ever-increasing volumes of waste in urban areas pose major risks to human health and the environment. Soil and groundwater are polluted by the seepage of leachate from open landfills, where organic matter often accounts for up to 70 % of solid waste. In addition, the dumps are foul-smelling and attract disease-carrying rats. For Eawag researchers addressing the issue of kitchen and market waste, one point is clear: ideally, organic household waste should not be dumped in the first place.

Just because a system works in India, it can't automatically be transplanted to Africa without any modifications.

Building on past experience

In industrialized countries, organic waste has long been treated not only by traditional composting methods but also by anaerobic digestion. In this process, waste is degraded by microorganisms in the absence of oxygen, producing biogas, a mixture of carbon dioxide and methane. However, the high-tech systems used for this purpose are neither practical nor economically viable for periurban areas in developing countries. There is a need for simpler solutions – especially small-scale plants operating at the household or community level. But it is not necessary to start from scratch: Eawag has found that China, India and Nepal, in particular, have gained considerable experience with the operation of such systems. However, since anaerobic digestion is applied almost exclusively in rural areas of these countries, the input material for the several million small-scale plants is animal manure or fecal sludge.

To prevent blockage of the gas line, condensate has to be removed continuously. A proposed simple drain is shown here.

Welcome source of energy

In contrast, the processing of kitchen and market waste is a recent development, which has yet to become widespread. Pioneering projects are mainly under way in India. The plants are of varying design and quality, ranging in size from single-household systems (1–5 kg waste per day) to large-scale facilities (100 tonnes). Users are glad to have a simple way of disposing of their waste and also welcome the production of biogas, which can be used for cooking or even for power generation. Just 2 kilograms of kitchen waste per day can yield 200 litres of biogas – enough to cook with for 45 minutes, saving firewood or other types of fuel. In addition, the digestion residue serves as a nutrient-rich fertilizer for gardens.

Enhancing performance and safety

Yvonne Vögeli of the Department of Water and Sanitation in Developing Countries (Sandec) is upbeat: "Several of the pioneering projects are very promising." However, given the scarcity of sound scientific data, she is studying biogas systems in India and Lesotho. In a project carried out in Tanzania in partnership with the Ardhi University of Dar es Salaam and the Zurich University of Applied Sciences, she is testing a compact biogas plant for household use. The system's functioning and performance are being analysed, and the data on technical characteristics, environmental acceptability and safety are to be used as a basis for improving the design, operation and maintenance of a number of systems. In the long term, as Vögeli point out, such plants also need to pay off in financial terms. For this reason, Eawag is seeking to gain the support of local authorities in particular. Before long, this should enable biogas systems to make a significant contribution to the successful and sustainable management of organic household waste in the developing world. ○○○

Compact biogas system for a household in Dar es Salaam (Tanzania). Although the plant (originally developed in India) is functional, there is a lack of data, e.g. on gas yield and composition. This makes it difficult to optimize the system and adapt it to local conditions in Africa.

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Wastewater for environmentally sound heating

The higher-than-ambient temperature of wastewater makes it a valuable source of energy. In recent years, technologies for exploiting this potential in Switzerland have been continuously improved. Through its research and the involvement of experts from various disciplines, Eawag has contributed significantly to these advances – and to Switzerland's leading role in this field.

In Swiss households alone, around 1.2 million m^3 of wastewater is produced each day. Some of this has previously been heated by boilers, solar collectors, washing machines or dishwashers and retains its heat as wastewater. If all the wastewater in this country were to be continuously cooled by just 1 °C, the energy recovered would be equivalent to around 300 megawatts – close to the output of a small nuclear power plant. Setting aside the question of cost-effectiveness, our wastewater could meet the heating energy requirements of more than 300,000 households. For example, when it is completed, the country's largest wastewater energy plant – operated by the Schlieren (Canton Zurich) Energy Association, using effluent from the nearby Werdhölzli wastewater treatment plant (WWTP) – will save 5 million litres of heating oil a year, supplying the equivalent of 9000 "Minergie" homes.

With its wastewater expertise, Eawag has provided crucial support for the heating sector pioneers.

Even more heat in untreated wastewater

"In practice, however," as Oskar Wanner of the Urban Water Management department explains, "the fact that many wastewater treatment plants are located outside densely populated urban areas restricts the use of heat recovered from WWTP effluents in many places, because the distance from energy users is too great. So, depending on the area to be supplied, it may make environmental sense to recover waste heat from untreated wastewater." This can be done locally in sizeable housing developments or enterprises with high levels of hot water consumption, where energy is extracted from wastewater with a temperature of around 20 °C in a temporary storage unit. Alternatively, with adequate and reasonably constant wastewater flows, heat recovery may also be possible within the sewer network. For this purpose, heat exchangers are directly installed in sewer pipes. However, the heating sector pioneers who installed the first systems of this kind in the 1980s underestimated the impact of biofouling in nutrient-rich raw wastewater on the performance of heat exchangers.

Within just a few days, as shown by Eawag measurements, the development of biofilms can reduce the transfer of energy by up to 40 %. However, laboratory tests also indicated that a temporary increase in flow rates could – at least partly – flush away the unwanted layer of sewer slime. With weekly rinsing, most heat exchangers almost regain their original level of performance.

Opportunities and limits revealed by modelling

By transferring expertise and bringing together specialists from various areas, Eawag has helped to optimize and promote the spread of this technology. It needs to be borne in mind, for example, that the recovery of heat from raw wastewater must not impair the efficiency of microbial treatment at WWTPs. This applies in the first instance to nitrification. To ensure that the wastewater temperature does not fall below the critical level of at least 8 °C, Eawag has developed the interactive simulation program TEMPEST for engineers and planners. Using simple parameters such as temperature, discharge, distance from WWTP and sewer network topography, TEMPEST can calculate the dynamics and profile of the wastewater temperature for a planned heat recovery system upstream of a WWTP and thus determine the reliable level of heat extraction.

Kasag

Installation of a heat exchanger in a main sewer pipe.

▶ www.tempest.eawag.ch

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Tracking the growth of cholera bacteria

Cholera bacteria can survive and thrive not only in the human intestine but also in freshwater – and in competition with the indigenous bacteria found there. It was previously thought that, in the environment, the pathogen can only reproduce in brackish water. Using Greifensee lake water, an Eawag team obtained results that make it possible to assess the cholera risk more realistically.

To date, it has been assumed that while cholera bacteria can survive in freshwater – where conditions are nutrient-poor and cold compared with the human gut – they require slightly salty water for reproduction in the environment. A team of Eawag researchers collected samples from Lake Greifensee and removed the bacteria present in the freshwater by filtration. The sterilized but otherwise unchanged lake water was then reinoculated with these bacteria, and cholera bacteria were added. In the subsequent competition for nutrients, the cholera bacteria held their own against the indigenous bacteria. The pathogen is thus able to survive and even proliferate not only in the intestine but also in freshwater and in competition with the naturally occurring bacterial community.

Good sanitation remains vital in controlling the spread of cholera.

Keystone

In areas where children collect water from contaminated sources – as here in Harare (Zimbabwe) – the risk of cholera is particularly high.

Cholera

Cholera is a serious bacterial infection, affecting the small intestine. It causes diarrhoea and vomiting, rapidly leading to dehydration. Without treatment, the disease is fatal in around 50 % of cases. Cholera is mainly transmitted by contaminated drinking water. The disease is still prevalent in developing and emerging countries of the South but also occurs in Russia, China and Japan. The immediate cause of the diarrhoea is a toxin secreted by the cholera bacterium in the nutrient-rich small intestine.

Competition at higher temperatures

The researchers also investigated whether the higher temperatures expected as a result of climate change create a competitive advantage for cholera bacteria. While the reproduction of cholera bacteria was indeed increased at higher temperatures, the growth rate of lake water bacteria also rose to the same extent. In the competition for nutrients, cholera bacteria accounted for a practically identical proportion of the total bacterial cell concentration at all the temperatures tested. Environmental microbiologist Marius Vital says: "Although you can't equate the artificial laboratory situation with the much more complex natural environment, we were able to show that warmer water does not automatically give cholera bacteria an advantage, as had previously been speculated."

No risk from Lake Greifensee

The new findings indicate that for nutrient-rich, faecally contaminated rivers and lakes – such as are often found in developing countries – the cholera risk needs to be reassessed. In general, additional potential sources of infection need to be taken into consideration. However, while the experiments were successfully performed with Greifensee water, this nutrient-rich lake is not among them. This is because hygienic factors remain crucial in controlling the spread of infection. Thanks to effective wastewater treatment and safe drinking water supplies, cases of cholera occur in Europe almost exclusively as a result of travellers returning with the disease from other parts of the world, such as Africa, South America or Southeast Asia.

Newly developed method

To obtain their results, the researchers used a new method developed at Eawag. In this method, rather than culturing colonies that can be counted on nutrient plates, microorganisms are directly labelled with antibodies and fluorescent dye and then enumerated with the aid of a laser beam in a flow cytometer (a device widely used in medicine). This yields more precise results in a significantly shorter time than with conventional methods. The method is already being used, for example, by Zurich Waterworks (WVZ) to monitor drinking water quality. In cooperation with the private sector, Eawag is currently developing a version suitable for field use, which could help to prevent epidemics when deployed in disaster-stricken regions. ○○○

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Eawag consulting: millions of francs saved

Thanks to studies carried out by Eawag, the municipality of Gordola in Canton Ticino was able to shelve the planned large-scale expansion of its water supply system, saving around CHF 10 million in investments. In addition, reductions in water consumption and the streamlining of distribution led to substantial energy savings – an example that could well be followed elsewhere.

In many communes, water supply systems are ripe for renewal, and in many cases the infrastructure built in the 1960s and 1970s is now oversized. Planning at that time was based on projected growth which did not always materialize, and water consumption per capita has declined over the last few decades. Moreover, since 1992, "economical use of drinking and process water" has been required under the Water Protection Act, and – in line with the polluter-pays principle – water users rather than taxpayers have been responsible for financing water supply systems and operations. Faced with a CHF 15 million expansion project mothballed since 1993 which appeared excessively elaborate and costly, the local authority of Gordola in Canton Ticino sought expert advice from Eawag.

Saving water means saving energy, too.

Scope for research and education

The situation was analysed by the Urban Water Management department of Eawag under the leadership of Professor Markus Boller, with internal studies being complemented by a number of dissertations at the ETH and at the Zurich University of Applied Sciences School of Engineering (HSZ-T). Work began with an assessment of the current status and a systematic search for water losses from the distribution network. It soon became clear that over 500 m^3 was lost per day – almost a third of the total volume supplied – and presumably this had been the case for years. When the leaks and overflows were rectified, these losses were reduced by 80 %. In addition, a system was developed to permit continuous monitoring of the network with the aid of meters installed at strategic points.

Peak demand reduced

A user survey and an analysis of available data revealed that peak demand in Gordola was attributable solely to the sprinkling of gardens and lawns and the simultaneous filling of swimming pools. The water utility has now introduced regulations whereby private swimming pools can only be filled at nighttime and according to a schedule. With this simple solution, the local authority has been able to reduce peak demand. Further measures are currently being examined with individual major users. In the near future, for example, a vegetable farm is to be connected to the football pitch watering system, which is not fed with drinking water supplies.

Producing green power

The local councillor responsible for water supplies, Bruno Storni (see p. 9), is convinced that by saving water, energy savings can also be achieved. As a result of the rectification of leaks, which cost just CHF 20,000, around 120,000 kWh less pumping energy is now required than was specified in the original project. 2008 also saw the replacement of the main pipeline leading from the springs to the distribution network. The way is now clear for the implementation of another proposal emerging from Eawag's analysis: the 250 m slope down to the village is to be utilized for a small-scale power plant, producing 160,000 kWh of green energy per year – enough to meet the needs of at least 40 households. Experience also shows that greater awareness of drinking water use, associated with water-efficient fittings and appliances, automatically reduces hot-water consumption – with corresponding domestic energy savings.

Bruno Storni

The commune of Gordola, lying at the foot of a valley on the Magadino Plain in Canton Ticino. Visible in the foreground is the reservoir, undergoing renovation work.

Gordola has now applied other measures proposed by Eawag, including efforts to educate consumers about potential savings, the reopening of disused springs and improved integration with neighbouring communes to allow regional optimization of water supplies. These modifications naturally required investments. In addition, the water utility had to invest around CHF 3 million in quality assurance and the provision of adequate firefighting water capacity. According to Storni, however, savings of at least CHF 10 million have been achieved over the original CHF 15 million project. ○○○

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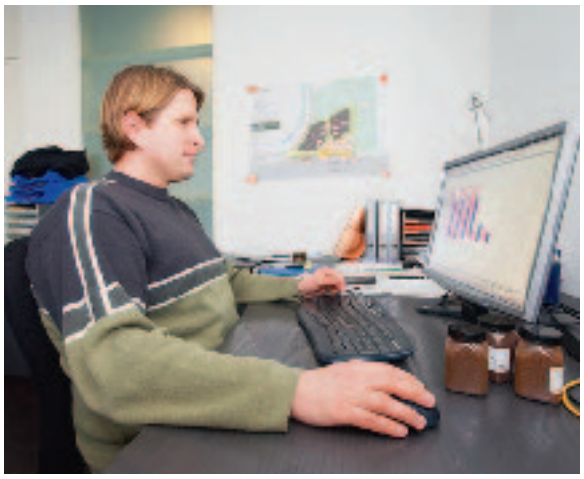
Copper – not a fish-friendly substance

Copper is a popular material for use in roofing and facades. As roof runoff either has to infiltrate the ground or be discharged into receiving waters, copper corrosion products enter the soil or surface waters. Here, the copper is toxic to aquatic organisms. This problem was recognized largely as a result of Eawag's efforts, and possible solutions have been identified by Eawag researchers.

At the Eawag testing facility, Michele Steiner studied the effectiveness of various granulates for filter systems. The most suitable combination is now being used to treat roof runoff contaminated with copper, e. g. at the Zurich University Law Faculty library building (top right), which was remodelled by Santiago Calatrava.

In this drain, roof runoff is collected from a new housing development where copper sheeting was used for roofing. Twelve individually replaceable filter cartridges filled with granulate purify the water before it is released into a stream.

Filter cartridges containing granulated ferric hydroxide and calcite are inserted at the bottom of the drain.



Patrice Goosse, an employee of the start-up based in the Zurich Technopark, reviews the measurement data. The results indicate that the efficiency of the granulate is over 98 %. Bottom: Goosse and Steiner explain the system.

From PhD student to entrepreneur

As Michele Steiner says, "The simplest solution to the copper problem is obvious – avoid the large scale use of copper and zinc for roofs and facades." At some sites, however, this is not possible, or copper is expressly specified by architects and clients. With large copper surfaces, filters are now essential to ensure compliance with quality standards for surface waters. Accordingly, Eawag sought to identify a simple method of removing copper from roof runoff. Having worked on this problem in his doctoral thesis (supervised by Professor Markus Boller), Steiner saw an opportunity to apply his expertise commercially. With his spin-off company wst21 and a partner from the construction sector, he developed the collection system with replaceable filter cartridges, for which a patent is pending.
Like Steiner, increasing numbers of PhD students and other researchers are venturing into the marketplace. Eawag supports these initiatives as far as possible. For this purpose, it is also a member of the "glaTec" association. This technology centre established by Empa in Dübendorf in 2008 serves as a business incubator, supporting innovative start-ups in the materials and environmental technology sector.

Aquatic ecosystems

At Eawag, aware of the tensions between the use and protection of water resources, we carry out research on aquatic ecosystems and develop solutions for the sustainable management of water and water resources. We investigate the effects of human interventions and climate change on the quantity and quality of water available and provide scientific foundations for successful restoration projects. As well as species and their aquatic habitats, we focus in particular on the genetic and evolutionary basis of biodiversity.

RESEARCH

Curiosity is not enough

Lukas Indermaur, who studied Biology at Bern University, worked on his thesis at Eawag from 2004 to 2008. In the wild alluvial landscape of the Tagliamento river in northern Italy, he investigated the ecology of amphibians. Their terrestrial ecology in particular has been little studied to date, as on land these animals generally remain well out of sight (cf. article on p. 27). For Indermaur, it was fascinating to observe and analyse with scientific detachment. But he also invested a lot of energy in devising and conducting experiments: "Just asking questions doesn't make you a researcher," he says. "The quality of research projects depends crucially on the operational capacity brought to bear." Although his projects often called for round-the-clock efforts on his part, he emphasizes that success was only possible thanks to numerous helpers – and the exchanges with other researchers around the world which are now part and parcel of scientific life. In this respect, Indermaur adds, Eawag is highly attractive for researchers "because here all types of water-related expertise are combined under one roof and cross-cutting projects are encouraged."

TEACHING

Tracing evolution

Ole Seehausen, Professor of Aquatic Ecology and Evolution at Bern University, is Head of the Fish Ecology and Evolution department at Eawag. His research interests include the question of how natural or anthropogenic changes in environmental conditions affect the evolution and extinction of species. In 2008, his study of speciation driven by the diversification of sense organs in cichlids was published as a leading article in Nature (cf. article on p. 22). Although the biologist is a full-blooded researcher, he devotes more than half of his time to teaching and the supervision of doctoral students – an onerous duty? "No," Seehausen insists, "I enjoy it when I'm able to infect young people with my enthusiasm for research. And I'm the one who learns most in the process." For him, teaching is the best way of better understanding what he is working on. "Students' questions, free of any preconceptions, force me to re-examine my own views all the time," he says. "Without teaching, research tends to get out of touch." And the converse, in his eyes, is just as disastrous: "Professors who just read from a textbook they wrote 25 years ago don't go down well with students."

CONSULTING

The contact point for the fishing community

Susanne Haertel-Borer, who holds a PhD in Biology, is co head, together with her francophone colleague Guy Périat, of the Swiss fishery advice centre FIBER, which is based at Eawag. The centre provides information on lakes and rivers, fish and fishery management for fishermen, fishery officials and other interested parties. FIBER also receives support from the Federal Office for the Environment and the Swiss Fisheries Association (SFV). Haertel-Borer travels a lot, addressing fishery associations, running seminars or contributing her expertise in the field. "FIBER creates opportunities for direct knowledge transfer from research to authorities and practitioners," says Haertel-Borer. "Thanks to Eawag's extensive network, we gain first-hand information about new developments in this country and abroad, and we can communicate this rapidly; at the same time, we are able to feed practitioners' questions into the research sector." And what role do members of the fishing community play? "They are key actors on surface waters," says Haertel Borer. "Their regular presence on rivers facilitates the monitoring process, and they actively support water resources in various ways. As they are well organized and also work with young people, they are themselves often required to answer queries on water-related questions."
www.fischereiberatung.ch

Species formation and disappearance influenced by humans

Female cichlids from Lake Victoria whose eyes are more sensitive to blue – an adaptation to the ambient light colour in shallow waters – will choose a metallic blue mate. Those adapted to the light conditions prevailing in deeper waters, and therefore more attuned to red, will prefer a bright red male. These mating preferences can be strong enough to drive the formation of new species – provided that habitat diversity is not reduced by human activities. A similar process has been observed by Eawag researchers in a Swiss lake: adaptation to different depths in Lake Lucerne has led to the formation of several distinct whitefish species – including one not previously identified as such.

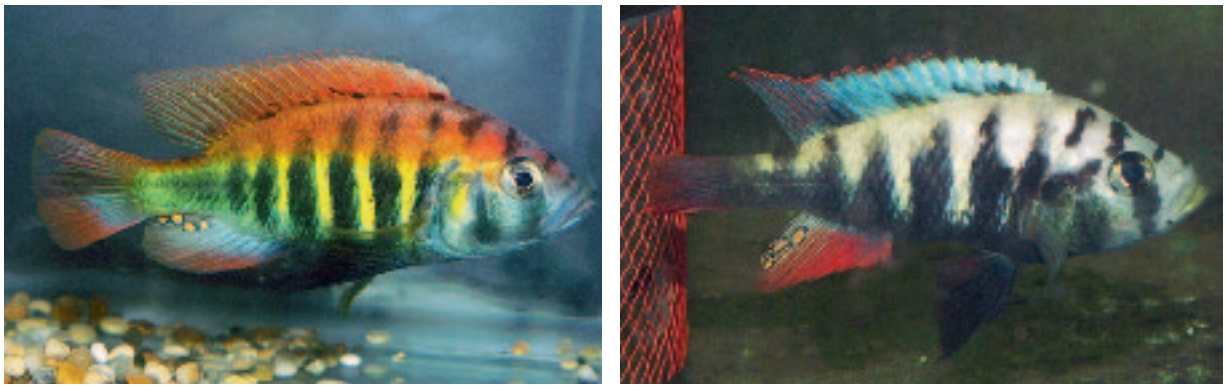
The role of natural selection in the formation of new species without geographical isolation is still much debated in evolutionary biology. The development of brightly coloured cichlid species in African lakes within only a few thousand years – a brief period on the evolutionary timescale – supports the hypothesis that sexual selection (due to mate choice) may contribute to speciation, without populations being geographically isolated from each other. In the case of African cichlids, it had been suggested that mating preferences were attributable to differences in colour perception. Compelling evidence for this theory has now been provided for the first time in a widely reported study, which has received much attention.

Seeing and being seen

In the study, evolutionary biologist Ole Seehausen (Eawag and Bern University) and his co-authors demonstrate that female cichlids from Lake Victoria whose eyes are more sensitive to blue tend to prefer blue-coloured males, while females with photoreceptors better able to detect red light choose males with red nuptial coloration. The different visual receptor pigments were distinguished by the team on the basis of DNA and protein sequences.

With the aid of special types of nets, whitefish were caught at various specific depths in Lake Lucerne, including a newly discovered species. Biologically speaking, all species of whitefish are young, as they have evolved since the last ice age. Evolution does not always require the vast timescales observed in the case of the coelacanth (bottom), which first appeared 400 million years ago. (Photos: Baenz Lundsgaard-Hansen, Andri Bryner).

Photos: Ole Seehausen, Eawag



Nuptial coloration in males of the cichlid species Pundamilia nyererei (left) and Pundamilia pundamilia is adapted to the red or blue ambient light of their respective habitats and to the corresponding visual sensitivity of the females.

The DNA sequence of the genes underlying the visual pigments also shows that specialization did not occur by chance but was in turn due to natural selection. Colour sensitivity differs according to the water depth at which the fish are found. Fish living in deeper water are more sensitive to red, and those in shallower water are more sensitive to blue. The adaptation of visual receptors to the prevailing ambient light colour confers an advantage to fish in a certain depth range. They are better able to navigate and, for example, will find more food than less well adapted fish. At the same time, the males' coloration is evidently also adapted to this situation: males with a red breeding dress predominate in deeper water, while blue-coloured males are dominant in shallower water.

An ancestral cichlid species has diverged into two wherever ambient light changes only slowly with increasing water depth, as is the case in areas of Lake Victoria with relatively clear waters. Clear water means that there is sufficient room for populations adapted to different light conditions, and at the same time, the populations are physically separated to a certain extent, which facilitates genetic differentiation.

Measurement of light conditions in a cichlid habitat in Lake Victoria.

Reasons for the dramatic decline in diversity of species

Besides demonstrating one way in which new species can be formed, the latest findings provide a mechanistic explanation for the dramatic loss of species diversity that has occurred in Lake Victoria over the past 25 years. Eutrophication of the lake due to agricultural runoff, deforestation and urbanization has substantially increased the turbidity of the water. As a result, at many sites, light conditions change rapidly within the first metres of the water column. The different ecological niches are then so narrow and so close together that the mechanism of differential genetic adaptation can no longer operate. Thus, the authors found that at sites with turbid water, rather than distinct red and blue species, only an intermediate form can occur, not specifically adapted to either of the light niches. It is very likely that merging of species, driven by environmental changes, has contributed significantly to the decline of cichlid species diversity in Lake Victoria from more than 500 to the present total of around 250 species within merely 25 cichlid generations.

New whitefish species discovered

In Lake Lucerne, a new species of whitefish has been discovered by biologist Bänz Lundsgaard-Hansen and his colleagues from Ole Seehausen's research group. Unofficially, it is called the "Schwebbalchen". Previously, four species of whitefish were known to occur in Lake Lucerne – *Coregonus suidteri* ("Balchen"), *Coregonus zugensis* ("Albeli"), *Coregonus nobilis* ("Edelfisch") and the so-called "Alpnacher-Felchen". The evolutionary biologists from Eawag chose the name "Schwebbalchen" because the species is found at a depth of 10–30 m – floating (="schweben") between the habitats of the larger "Balchen", which prefers a depth of 10 m, and the smaller "Albeli", which lives and spawns at a depth of around 40 m. Why had this species not previously been identified as such, even though it occurs in large numbers? According to Lundsgaard-Hansen, the professional fishermen may have rarely fished in these mid-depths and had presumably identified the unknown species as young and small-sized "Balchen".

It is fascinating that new species can still be discovered here in Switzerland, not just in the tropics.

Not from another lake

The "Schwebbalchen" was determined to be a distinct species on the basis of precise measurements of 14 body shape traits, as well as analyses of 14 genetic loci. Both methods indicated that, although closely related to the Lake Lucerne "Balchen" and "Albeli", it is clearly differentiated. However, comparison with whitefish from other Swiss lakes showed fewer similarities. Thus, it is not, as was originally supposed, a species introduced to Lake Lucerne from another lake.

Increase in hybridization

In response to the eutrophication of lakes, whitefish species – like the cichlids in Lake Victoria – exhibit increased hybridization, as shown by the Eawag researchers on the basis of a large, as yet unpublished data series compiled by Pascal Vonlanthen and others. From the middle of the 20th century, Lake Lucerne received increased nutrient inputs from wastewater and agricultural runoff. In the deeper waters, oxygen was depleted. As a result, the "Albeli" shifted into shallower waters, moving closer – in every sense – to the "Schwebbalchen" and "Balchen". Whether the increase in hybridization among the three species may ultimately lead to a single hybrid species cannot yet be said. As the lake water is now cleaner again and all depths are well supplied with oxygen, there is a good chance that all three species will survive in Lake Lucerne. Today, the "Albeli" can once again spawn in deeper waters. In other large Swiss lakes, however, improvements in water quality probably came too late to preserve the original species diversity. These findings not only help to improve our understanding of the formation and disappearance of species but also provide a basis for sustainable lake fishery management.

Top to bottom: "Balchen" *(Coregonus suidteri),* "Schwebbalchen" and "Albeli" *(Coregonus zugensis)* from Lake Lucerne.

What is a species?

Various concepts of a species are found in evolutionary biology. What all have in common is that populations of organisms are assigned to different species if they coexist in nature over many generations at the same site without genetically merging. Numerous species hybridize occasionally but remain differentiated as long as mechanisms exist that 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 misconception. ○○○

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Niche differentiation – room for numerous species

Different amphibian species occupy the same types of habitat, in water and on land. However, as their use of these habitats differs markedly, one species does not outcompete another, allowing for a high degree of biodiversity within a small area. The key factor is the establishment and maintenance of a wide variety of structures and environmental conditions, e. g. as a result of flooding.

When two species that share a habitat are specialized to different environmental conditions, this is known as niche differentiation. Competition with other species can be reduced by differential use of food resources, or specialization to a certain range of humidity and temperature. This – according to biological theory – is a prerequisite for a high degree of biodiversity within a small area. However, very little is known about the coexistence of organisms with complex life cycles, such as amphibians. Over a period of four years, therefore, an Eawag team investigated how amphibians use their aquatic and terrestrial habitats. The study was carried out on the unregulated Tagliamento river in the Friuli region (northeastern Italy). This wild river landscape, with riparian forests and a river corridor up to 2 km wide (depending on water levels), is among the last major pristine amphibian habitats surviving in Europe.

By demonstrating, for example, the importance of woody deposits, the study helps us directly in our amphibian conservation efforts.

Silvia Zumbach, Swiss Amphibian and Reptile Conservation Programme (KARCH).

Shallow or deep?

We studied the use of breeding waters by two toad and two frog species. At the same time, we recorded environmental factors such as prey density, water depth and temperature. All four amphibian species observed prefer essentially the same types of breeding waters, but their selection of sites differs: for example, both toad species are basically attracted to large ponds, but smaller ponds are used much more intensely by the green toad than by the common toad. Water depth preferences also differ: the green toad is highly likely to spawn in very shallow ponds (5–10 cm), and the Italian agile frog in deeper ponds (≥ 50 cm).

Risk of flooding

The selection of breeding sites influences larval growth and the number of offspring produced. Common toad larvae completed metamorphosis in riverbed ponds three weeks earlier than in riparian forest ponds. The number of juveniles (metamorphs) per square metre of spawning water averaged 489 in exposed gravel sediments, compared with 12 in the riparian forest. In addition, metamorphs in the river bed tended to be larger than in the riparian forest. Large, warm ponds in the riverbed offer the best conditions for larval growth. This is presumably mainly due to the regular scouring of sediments, which reduces the density of predators in the riverbed far more effectively than in the more sheltered riparian forest. The choice of riverbed ponds for breeding is however a risky one, since offspring can be wiped out by flooding. The number of offspring produced in riparian forest ponds is lower, but consistent; this can serve as an "insurance policy". For the growth of populations in dynamic floodplain habitats, it is therefore essential that spawning waters should be maintained both in the active riverbed and in the riparian forest.

Typical spawning pond in the riverbed.

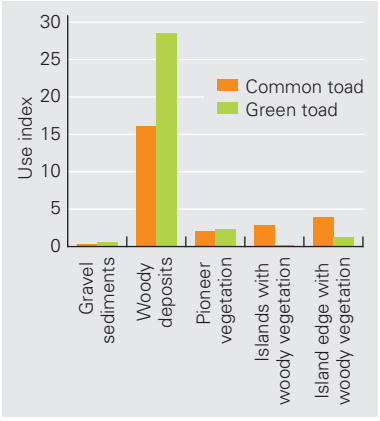
A complex life cycle

The life cycle of semi-aquatic amphibians is among the most complex in the animal kingdom. The eggs and larvae develop in the water. The larvae hatch in 2–3 weeks in the case of the common toad and in 3–6 days for the green toad. Larval development until metamorphosis takes several months. Juveniles (metamorphs) and adults of most species aestivate and overwinter in secluded terrestrial habitats, where they spend most of their time.

Woody deposits offer protection against desiccation, provide a foraging ground and promote the development of new habitat types.

No place to hide

In their summer habitat, as well as foraging, amphibians seek protection against desiccation and refuge from predators. Little is known about how their selection of terrestrial habitat patches is affected by environmental factors – temperature, habitat type, density of prey and competitors, etc. Accordingly, niche differentiation has not previously been demonstrated in terrestrial habitats, which also has to do with the retiring habits of amphibians. We wished to find out whether niche differentiation also allows two co-occurring toad species to coexist in their summer habitat. For this purpose, we fitted 56 common and 59 green toads with mini-transmitters. These were attached using waist-belts and removed at the end of the study. Accumulating this number of "research subjects" took several weeks, including often fruitless nocturnal searches. Using antennas and receivers, we were then able to keep track of the toads day and night.



Use index: ratio of habitat use intensity to availability of a given habitat type. The graph is based on 2500 fixes for the green toad and more than 3000 fixes for the common toad.

Popular woody deposits

The two toad species were found largely in the same habitat types (see graph), with piles of woody deposits being used particularly frequently relative to their availability. Woody deposits clearly play a key role in the summer habitat. This is supported by three considerations:

- According to the statistical evaluation, the number and size of woody deposits is a key factor determining the extent of the summer habitat for both toad species.
- In the exposed gravel bed – with temperatures up to 46 °C – woody deposits are often the only structure offering pioneer species such as the green toad protection against desiccation and predation.
- Woody deposits promote the development of other habitat types (pioneer vegetation, islands, temporary pools), thus contributing significantly to a richly structured floodplain.

Using the survey data and computer models, we also showed that while both toad species occupy the same habitat types, they do so for different reasons: woody deposits, for example, are used by the green toad for thermoregulation (owing to the lower temperatures), and by the common toad for foraging. The availability of woody deposits depends on an intact riparian forest and natural flood dynamics.

Natural dynamics

Our study demonstrates niche differentiation for amphibians both in the larval stage and in adults. It thus explains how species with complex life cycles can coexist. Surprisingly, the results concerning aquatic and terrestrial habitat selection both led to the same conclusion: natural flood dynamics preserve open and richly structured habitats, which are suitable for demanding pioneer species but also for non-specialists. Richly structured habitats are characterized by diverse environmental conditions, e.g. substantial variation in temperature, predation pressure and food resources. This is the key requirement for coexistence, and hence for a high degree of local biodiversity. Large-scale river restoration projects thus offer great potential for promoting amphibians in aquatic and terrestrial habitats. Top priority needs to be given to the re-establishment of natural flow regimes, including riparian forest dynamics.

Common toad (left) with a 5 g transmitter and green toad with a 2 g transmitter.

With a tracking antenna and receiver, the radio-tagged amphibians could be located day and night.

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Three-spined stickleback: successful invasion of Switzerland

Until over a century ago, the three-spined stickleback in Switzerland was only found in the Basel region. It subsequently spread rapidly throughout the country, becoming remarkably diverse. Its success appears to have been due to the combination of different genetic lineages.

The three-spined stickleback, a fish of up to 10 centimetres in length but of minimal economic significance, is found almost all over the northern hemisphere Over the past 15,000 years, the stickleback rapidly diverged into a wide variety of types. Although closely related genetically, these differ markedly from one another in appearance, preferred habitat and behaviour. For example, the species occurs in seawater and in freshwater, and while the marine type has well-developed bony lateral plates, this armour was gradually lost in the freshwater forms.

Highly adaptive species

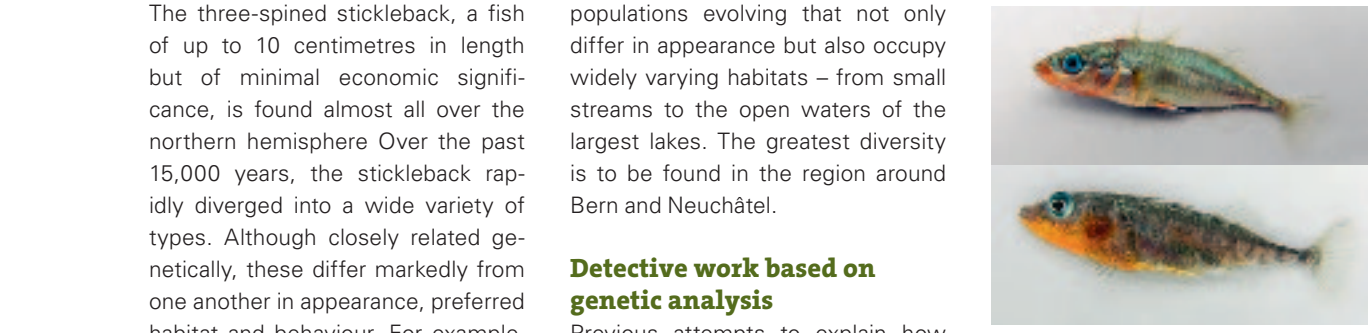
The remarkable evolutionary history of this species can also be traced in Switzerland. When the glaciers receded 10,000 years ago, making way for rivers, the stickleback's marine ancestors, originating from the Atlantic, reached Switzerland via the Rhine. Until around 1870, however, the Swiss stickleback population was confined to the Basel region. Over the next 100 years, it spread invasively right across the country, with populations evolving that not only differ in appearance but also occupy widely varying habitats – from small streams to the open waters of the largest lakes. The greatest diversity is to be found in the region around Bern and Neuchâtel.

Detective work based on genetic analysis

Previous attempts to explain how the three-spined stickleback invaded Switzerland after 1870 have been purely conjectural. It is considered likely that humans played a key role in this process: the stickleback is a fairly robust species which – unlike its natural predators – is barely affected by river engineering structures or canalization measures. Eawag researchers have now used genetic methods to investigate the evolutionary history of the stickleback. Hundreds of specimens were collected at 23 sites, and their genetic fingerprints and external traits were compared both with one another and with European reference populations, so as to construct a phylogenetic tree for the Swiss stickleback.

Historical releases

It was shown that today's stickleback population in Switzerland is derived from not one, but three evolutionary lines. The first line is represented by the population around Basel. The second is formed by individuals from the southern Rhône system released in the Geneva region around 1870. The third line goes back to fish, originally from the Baltic catchment, which were released in the Rhine near Lake Constance at about the same time. These findings accord well with historical records also reviewed by evolutionary biologist Kay Lucek – the fish released probably came from aquariums.

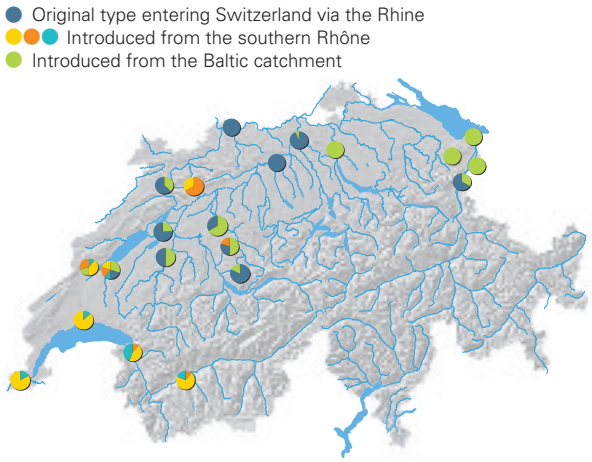


Two male three-spined sticklebacks: a typical specimen from the Rhine at Basel (left) and a hybrid from the Aare at Bern (right).

Numerous possible combinations: a recipe for success

In the region around Lake Neuchâtel and Bern, where the three lineages meet, the researchers found a particularly high degree of diversity – both genetically and in the appearance of the fish. In these "hybrid zones", the hereditary characteristics of three different evolutionary lines were available to the offspring. Kay Lucek is convinced: "That's what drove the rapid evolution and made it possible for the stickleback to successfully colonize such a large number of diverse habitats within a very short period."

In addition, the stickleback hybrid zones illustrate the fact that biodiversity can also recover after having been temporarily decimated – in this case, by the Ice Age. Comparison of hybrid zones with areas where only one lineage occurs should also further elucidate the mechanisms of invasive spread.



The various lineages of the three-spined stickleback. A hybrid zone has clearly arisen in the Bern Neuchâtel region. (Map © swisstopo)

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Hydropeaking: impacts on migrating fish

Using radio transmitters, Eawag has studied the migration of endangered lake trout in the Alpine Rhine. The fish swim more than 100 km upstream, from Lake Constance to their spawning grounds in Graubünden. But they are adversely affected by intermittent releases of water from hydropower plants.

To meet peak electricity demand, about a third of Switzerland's major hydropower plants operate in "hydropeaking" mode. This involves rapid artificial fluctuations in flow rates on a watercourse. Often, what is problematic for aquatic ecosystems is not so much the minimum or peak flows in themselves, as the frequent alternation between high peak and low base flow. The impacts are apparent in one in four of the country's medium-sized and large rivers.

The most serious effects of hydropeaking operations occur where land and water meet. In non-regulated rivers, periodically flooded zones are areas of high species density and diversity. With hydropeaking, however, the transition zone can only be used to a limited extent as a habitat for aquatic or terrestrial organisms. Macroinvertebrates and plants are repeatedly washed away, as was shown by the Eawag Rhône-Thur project (2002–2006). Eawag has now examined in more detail the impacts of hydropeaking on fish – specifically lake trout – in the Alpine Rhine.

Weekend migration

Since a fish ladder was installed at the Reichenau hydropower plant in 2000, lake resident brown trout (an endangered species) have once again migrated upstream from Lake Constance to spawning grounds in the Posterior and Anterior Rhine. This was demonstrated by an Eawag study in which fish were implanted with mini-transmitters. The longest distance covered by a lake resident brown trout migrating from Lake Constance to a spawning site was 126 km. One striking finding was that fish cover substantially longer distances at weekends – when the flow regime is not affected by hydropeaking – than during the week. The average distance covered was 3.7 km/day at weekends and only 2.5 km/day during the week (see also the photos on p. 32).

Juveniles at risk

Despite the effects of hydropeaking, natural reproduction of lake resident brown trout at their spawning sites was successful. However, a subsequent investigation of the density of fish in their first year of life revealed major differences between stretches of the river subject to and those not subject to hydropeaking. On undisturbed stretches, 60 trout were found per 100 m of shoreline, compared with only 2 on stretches subject to hydropeaking. The researchers concluded that young-of-the-year fish are adversely affected by constant fluctuations in flow rates. Rapid declines in water levels are particularly problematic, as the fish (and other aquatic organisms) can then be stranded close to the banks or in dried-up pools.

Rapid declines in water levels are particularly problematic since juvenile fish can be stranded.

The adverse impacts of hydropeaking can be partly mitigated, e.g. by the use of retention basins at hydropower plants. The federal authorities are currently working on regulations to address this problem, which are to be incorporated in the Water Protection Act. Eawag researchers are serving as consultants in this process.

Migration data for 9 lake resident brown trout (a–i): at the weekend, in the absence of hydropeaking operations, the distances covered are substantially higher than during the week.

Discharge of water below a hydropower plant on the Anterior Rhine.

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Revealing the secrets of the lake floor

Topographical surveys of the bottom of Swiss lakes have never been performed in such detail before. With the aid of a sonar system involving several transmitters and receivers, three-dimensional images can be produced, which show scars and deposits of underwater landslides, excavation pits, and other lake floor structures with an accuracy in the order of centimetres.

Flavio Anselmetti, a limnogeologist, is highly enthusiastic: topographical surveys of the bottom of Swiss lakes have never been performed in such detail before. On a 15-day excursion, a team of Eawag scientists criss-crossed Lake Lucerne aboard the research vessel *Thalassa*, using special sonar equipment to scan the lake floor. The use of several transmitters and receivers for the acoustic signal yields a large number of depth values per sweep. This means that depths can be measured accurate to a few centimetres, and the data is then processed to produce three-dimensional images. Numerous structures can thus be visualized – for example, excavation pits from underwater gravel extraction in the Reuss delta of the Urnersee.

The highly accurate lake floor images permit analyses that were formerly not possible.

Insights into the past

Particularly fascinating for the researchers are the traces of historical landslides or rockfalls. Southwest of Weggis, for example, the 4- to 7-metre high scar of a major landslide is visible over a distance of almost 6 kilometres, with slide deposits detectable at a greater depth. This landslide, which is known to have been triggered by an earthquake in 1601, generated a tsunami, with a wave 4 metres high rushing across Lake Lucerne. Between Vitznau and Weggis, the new maps show debris from an immense rockfall that plunged into the lake from the Rigi mountain some 3000 years ago. Southwest of Vitznau, the survey reveals a terminal moraine, consisting of debris and boulders left behind by the retreating Reuss glacier at the end of the last ice age about 15,000 years ago. The project has also led to the discovery of previously unknown moraines, now buried in the lake sediments: the subsurface was investigated by reflection seismic imaging after intriguing surface structures had been revealed by the new data.

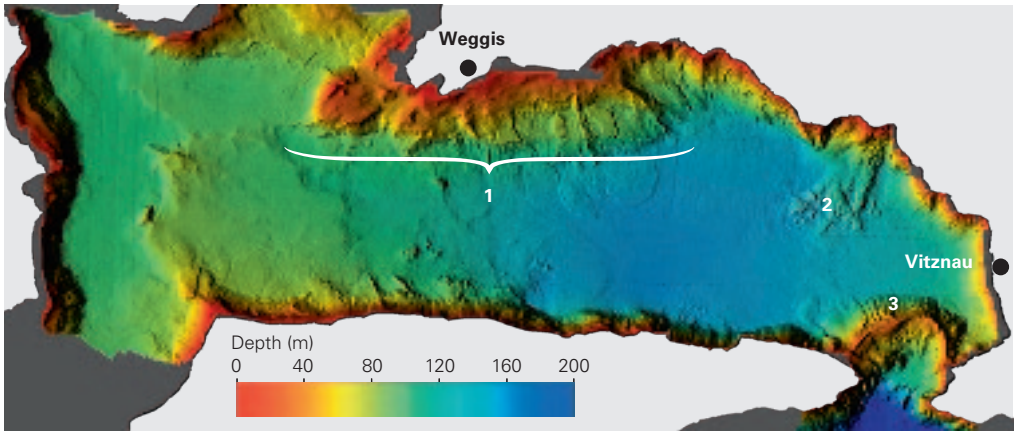
Risk management

As well as providing answers to historical questions, however, the new images are valuable to seismologists and sedimentologists seeking to predict future events: in areas where deposits are now visible on steep slopes, underwater landslides could be triggered when a future earthquake occurs.

Monitoring sediment transport

The images also make it possible to monitor sediment transport into lakes: changes in stream flows associated with climate change will lead to altered patterns of sediment transport and deposition. The excavation pits visible in the Reuss delta indicate that precise bathymetric images could also be used for monitoring gravel extraction. Archaeologists hoping to uncover evidence of settlements from earlier periods (when lake water levels were lower) have also expressed an interest in the images.

As yet, this new survey project with data from Lake Lucerne and Lake Geneva is only at the pilot stage. It was made possible in cooperation with the University of Geneva and with technical support from the Geological Survey of Norway and from the University of Ghent (Belgium). Financial support was provided by swisstopo (Federal Office of Topography), the Federal Office for the Environment, and the Federal Department of Defence, Civil Protection and Sport, among other sponsors. The reasons for swisstopo's interest are clear: the new data are far more accurate than the depth contours currently shown for lakes on official maps, which are generally based on simple soundings taken over 50 years ago.



Chrüztrichter and Vitznau basins of Lake Lucerne. (1) Scar of the major landslide of 1601 (transition from orange to yellow). (2) Debris from a Rigi rockfall that occurred around 1000 B.C. (3) Morainic ridge deposited about 15,000 years ago by the Reuss glacier.

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Optimizing river restoration efforts

Many Swiss watercourses are heavily engineered, and successful restoration projects require careful planning. Individual planning steps are defined in the Ecomorphology Level II method jointly developed by Eawag and the Federal Office for the Environment. The result is a plan in which measures are prioritized, indicating how the greatest possible improvements can be achieved with the resources available.

Channelization, flood protection, wastewater discharges, hydropower operations – most watercourses in Switzerland are seriously affected by human activities. This has been clearly demonstrated by the extensive investigations carried out using the Ecomorphology Level I method of the Modular Stepwise Procedure (see Box): a quarter of all rivers and streams have a non-natural structure or are heavily impacted or culverted. Below 600 m above sea level, the proportion is even higher – 50 %. In addition, upstream migration of fish is impeded by 88,000 artificial weirs and falls at least 50 cm high.

There is a huge potential for restoration measures, but where is the need for improvements particularly urgent? And where can most be achieved, using what measures? These questions are addressed by the Ecomorphology Level II method developed at Eawag.

From analysis of deficiencies to remedial measures

In contrast to Level I, the Level II method is not designed for regional application across a whole canton. Instead, it is suitable for detailed assessment of selected surface water systems, i. e. watercourse sections a few kilometres long, including tributaries. As a first step, significant structures and deficiencies are described: how natural is the river bed? Is the riparian zone sufficiently wide? Is the longitudinal connectivity impaired by barriers? The planning objectives are then formulated by the project managers: for example, if a river section lies in an extensively managed area, substantial widening of the riparian zone may be possible. In built-up areas, it may only be possible for the channel structure to be improved.

The importance of the river section also needs to be taken into consideration in planning. Barriers have particularly detrimental effects where one watercourse joins another, as they make colonization of the entire upstream section difficult or impossible.

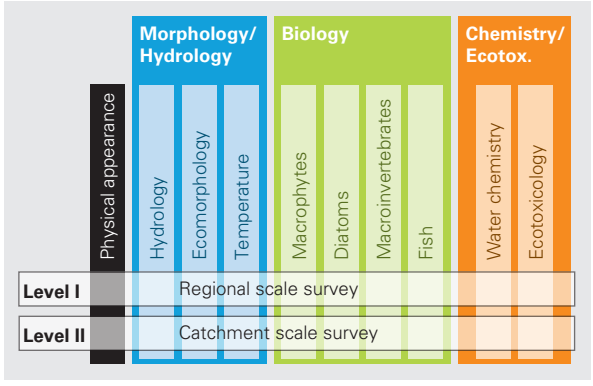
Studies of this kind make it possible to determine the ecological benefits of restoration measures. On this basis, river engineering measures are elaborated, prioritized and shown on a map. As well as a near-natural watercourse structure, particular attention needs to be paid to the provision of adequate room, without which near-natural dynamics cannot be achieved.

Promoting acceptance

Completion of the plan for remedial measures does not mean that excavation work can begin immediately. However, the results from the Ecomorphology Level II module can be fed into other planning – e. g. a regional drainage plan, a flood protection scheme or a landscape development project. The assessment method provides a clear rationale for the proposed measures and spells out the benefits for the watercourse and for stakeholders. This supports objective decision-making on the part of authorities and the public. ○ ○ ○

Hannes Scheuber

Few streams still flow as freely as the Gornerenbach in the Kiental valley. But a detailed knowledge of the current state, compared with the original natural state, makes it possible to define realistic goals for the restoration of degraded watercourses.



The modules used for assessing watercourses.

Joint project

The Modular Stepwise Procedure is a project run jointly by the Federal Office for the Environment, Eawag and cantonal water protection agencies. The aim is to develop standardized methods for investigating and assessing rivers and streams in Switzerland. Operating at different levels of intensity (survey steps), the methods (modules) cover structural and hydrological, biological, chemical and ecotoxicological aspects of watercourse quality. The methods are conceived primarily as enforcement aids for cantonal authorities. The procedure was launched in 1998 with the publication of the first method – Ecomorphology Level I – and additional methods have appeared periodically since then. The draft Ecomorphology Level II method is currently being tested in the cantons, and a revised (definitive) version is to be published by the end of the year. A method for assessment of the Flow Regime at Level I has also recently been developed.

▶ www.modul-stufen-konzept.ch

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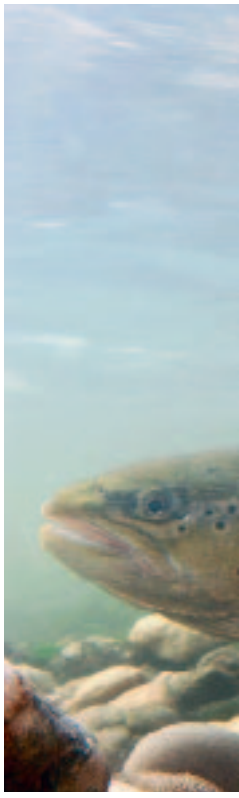
Monitoring lake trout with transmitters

With the aid of radio transmitters, Eawag monitored the migration of threatened lake trout in the Alpine Rhine. The fish migrate up to 100 kilometres or more from Lake Constance to their spawning grounds in Graubünden, negotiating artificial barriers in the process. Thanks to these studies, we now know precisely what these strong swimmers require of their spawning areas. In addition, the tracking data showed that the fish prefer to migrate at weekends, when water levels are less affected by the operation of hydropower plants (cf. also p. 29).



A male lake trout captured in the Alpine Rhine. Along with 80 other lake trout, it was implanted with a radio transmitter so that its movements could be precisely tracked – also during the spawning period in December in the Anterior Rhine gorge.

A tiny transmitter is surgically implanted in the body cavity of the lake trout.

Lake trout at a spawning site (male in the foreground). On their upstream migration, the fish swim across man-made rapids (rock ramps) and leap barriers more than a metre high – though not always on the first attempt.

To find out more about the development of eggs and the survival of newly hatched lake trout, eggs were buried in plastic boxes in gravel with good flow conditions from December to April. Almost 90 % of the eggs survived this incubation.

Observing hidden behaviour

For fish biologist Armin Peter, telemetry – the use of implanted transmitters to monitor fish – is a fascinating research method. "It reveals things that otherwise remain hidden," he says. As the radio signals can often be picked up by the receiver over long distances, it is also possible to detect fish in inaccessible reaches of rivers or in murky waters. The researchers were surprised to find, for example, that individual lake trout swam into the Posterior Rhine but then turned around after two or three days and continued along the Anterior Rhine. Peter notes: "This means that the animals' navigational instincts are not as infallible as we've always thought." It was also believed that all fish migrate as far as possible up to the mountain streams; telemetry has demonstrated that lake trout rarely enter tributaries and that they also spawn – presumably with little success – in canalized stretches of the Alpine Rhine that are subject to hydropeaking from hydropower plants. As well as providing evidence of animals' behaviour, such findings also indicate what measures could be taken to improve the natural reproduction of the species concerned.

The most difficult part of the telemetry process is tracking the free-swimming fish directly. A lake trout can cover up to 16 kilometres within 24 hours, and up to 9 kilometres in a single night. Armin Peter is therefore glad of the help provided by his assistants in the field – usually students or technical staff. Downstream migration is even more rapid: as long as enough water flows over the dam at Reichenau, the fish can reach Lake Constance within 1–3 days.

Chemicals and their impacts

Eawag is an internationally recognized centre of expertise in assessment of the risks posed by water pollutants. It provides vital scientific foundations for the definition of limits and develops cutting-edge analytical methods. The ongoing exploitation of new water resources means it is necessary to study not only man-made pollutants but also natural contaminants of biological and geological origin. A recent research focus is the impact of nanoparticles released into the environment as a result of human activities.

RESEARCH

Results are never definitive

Annette Johnson, who studied Chemistry in London, has been engaged in research at Eawag since 1991, mainly in the field of geochemistry. She is currently working on a model which can be used to estimate the risks of geogenic contaminants in drinking water (cf. article on p. 44). On the one hand, Johnson is a pure scientist: "It's fascinating when, after lengthy detective work, complex processes gradually become comprehensible or can even be represented by a formula," she says. But at the same time, she remains aware that the best formulae never provide a complete explanation. In addition it requires the interaction of various disciplines, e.g. the involvement of social scientists – an approach which is particularly encouraged at Eawag. In her view, the alleged conflict between academic and practical research does not exist. However, she acknowledges the principle that the closer a question is to practice, the more complex the answer will be. This raises the temptation to proceed by trial and error, rather than scientifically testing hypotheses and elucidating processes. This method, Johnson admits, cannot guarantee success either: "As a researcher, I know that my answers are never definitive, but at least it's a partial success if others take my findings as a basis for further work."

TEACHING

Young people keep research alive

Bernhard Wehrli, Professor of Aquatic Chemistry at the ETH Zurich, has been a member of the Eawag Directorate since 2005. His research focuses on biogeochemical processes in rivers and lakes and on the sustainable management of freshwater resources. Wehrli, who is also a member of the Research Council of the Swiss National Science Foundation, appreciates the fact that the comparatively young environmental sciences are close to practice: "It's gratifying to be able to use topical issues to present a fundamental scientific approach." He sees his work with students as bridging the gap between research and practice: "Thanks to my dual role at the ETH and Eawag, we can offer students interdisciplinary courses that wouldn't otherwise be possible." To illustrate his point, Wehrli mentions the seminars run jointly with the Political Science group on international water conflicts, and the Aquatic Systems practical, where students have to take an integrated approach – from initial sampling to final reporting. Eawag benefits in turn from the young participants, some of whom go on to write a Master's or doctoral thesis at the institute. As Wehrli says, "This has a galvanizing effect, since without new blood a research institute stagnates."

CONSULTING

Attracted by credibility and international networks

Franz Adam is Head of the Waste Management and Enterprises department at the Canton Zurich Office for Waste, Water, Energy and Air (AWEL). Originally a rural engineer, he completed a postgraduate course in Sanitary Engineering and Water Pollution Control at Eawag 25 years ago. As he recalls, this helped him to move into the environmental protection field – and to establish numerous contacts. Since then, he has frequently had recourse to these contacts and to Eawag's expertise. For Adam, Eawag is a "straightforward, open and expert" partner. In his department, Eawag is engaged whenever knowledge is required which cannot be bought in from private engineering or environmental consultants. In addition, Adam appreciates the researchers' international networks, and he rates Eawag's expert opinions as highly credible. For example, its risk assessment of tar deposits in Lake Zurich (see p. 46) "was a key factor leading us to revise our attitude to the remediation of this contaminated site," he says. Current AWEL projects in which Eawag is involved include studies of nanosilver in industrial wastewater and on the long-term behaviour of treated municipal solid waste incinerator bottom ash.


81
91
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125
137
173

Endocrine-disrupting chemicals

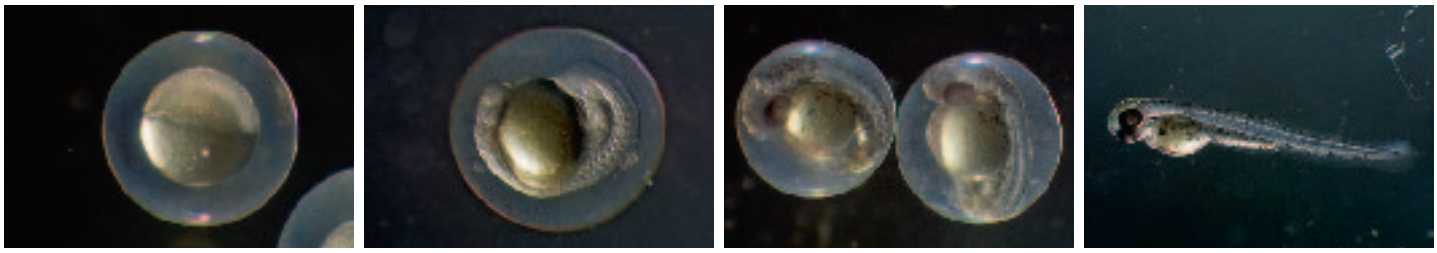
Is the deterioration of semen quality in Swiss men attributable to endocrine-disrupting compounds? This was just one of the many questions addressed by the National Research Programme "NRP50 – Endocrine Disruptors: Relevance to Humans, Animals and Ecosystems". This programme, to which Eawag made significant contributions, was completed in the summer of 2008. Our research projects focused on the contamination of lakes and rivers with endocrine disruptors, and their impacts on fish.

Wastewater contains hormonally active substances. These may be, firstly, hormones excreted by humans either naturally or after the ingestion of oral contraceptives and, secondly, substances derived from industrial chemicals, which sooner or later enter the environment and natural waters. This group of substances includes, for example, nonylphenols (see p. 40), certain UV filters used in sunscreens and antioxidants in cosmetics, or brominated flame retardants.

Elevated concentrations below WWTPs

The question of the fish with feminized impacts of endocrine disruptors on fish had already been raised by the cross-cutting Eawag project on declining fish catches ("Fischnetz"), which was completed in 2004. Under the NRP50 programme, Eawag therefore compiled existing data on contamination observed in Swiss rivers and carried out additional measurements. Because male or malformed gonads had attracted media attention, the focus was on estrogenic substances. Over a period of several months, samples collected from 19 Swiss Midland rivers were tested for estrogenic activity using a yeast assay. The values measured, expressed as estradiol equivalents (EEQ), varied widely from one site to another and also over time, between 0.2 ng/l (the detection limit) and 3 ng/l, with extremes in excess of 10 ng/l. From 1 ng/l, production of the egg-yolk protein vitellogenin – normally only occurring in females – was observed in male rainbow trout. Overall, however, the EEQ concentrations tended to be relatively low. Values were found to be higher downstream than upstream of wastewater treatment plants (see chart). Estrogenic activity was lower in effluents from WWTPs with sand filters than for plants without such filters. In the "MicroPoll" project, led by the Federal

Lake Thun whitefish (bottom) are more commonly affected by severe gonadal abnormalities than those in other lakes. Could this be due to munitions disposed of in the lake? This hypothesis was ruled out by Eawag studies, which included work on zebrafish (top). However, a satisfactory explanation has yet to be found. (Photos: Ruedi Keller, Anja Liedke)



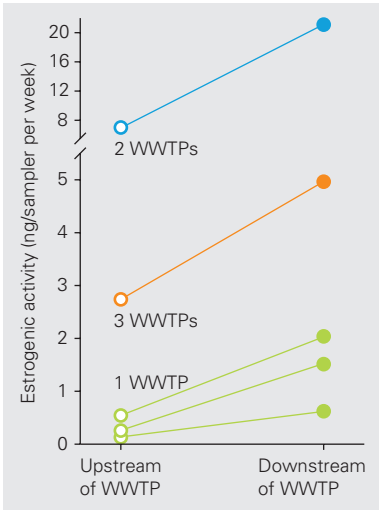
Steve Baskauf, bioimages.vanderbilt.edu

Embryonic development of the zebrafish – from the egg stage (around 5 hours after fertilization) to embryos at days 1 and 2 and a newly hatched fish at day 3.

Office for the Environment, Eawag is therefore investigating how the performance of WWTPs with respect to micropollutant removal can be improved by operational adjustments or via an additional treatment step, such as ozonation. www.environment-switzerland.ch/micropoll

Passive sampling: an alternative to grab sampling

Passive samplers, which take up substances in a similar manner to fish, have been used as an alternative to grab sampling. When these devices are deployed in a river, specific estrogenic substances are accumulated and subsequently assessed. Passive samplers are now available for numerous compounds, such as biocides or antibiotics and other pharmaceuticals. However, their deployment in natural waters can be tricky. The type of sampler used by Eawag, for example, first had to be optimized in the laboratory so as to provide comparable results for all sites, and in one case all the samplers deployed were washed away by flooding. Ultimately, the results showed excellent agreement with grab samples collected in parallel. In addition, individual trout were held captive in tubes close to the sampling points in the stream and subsequently studied. Analysis of the gall bladder – where estrogens accumulate – confirmed the values determined by passive sampling. This means that further fish bioaccumulation experiments can be avoided.



Above: The passive sampler (white disk) was optimized and calibrated in the laboratory. Left: Total estrogenic activity determined by passive sampling over a period of three weeks upstream and downstream of WWTPs. The numbers on the left indicate how many WWTPs discharge effluents into the receiving waters before the first sampling point.

One factor amongst others

The effects of estrogenic substances on trout and their reproduction were studied in the laboratory, with the aid of a computer model and in the field. The above-mentioned protein vitellogenin was used as an indicator, since its production is stimulated in males exposed to female hormones. This was found to occur downstream of WWTP discharge points. At the concentrations observed, however, contrary to what was initially assumed, endocrine disruptors appear to have limited impacts on fish reproduction and development and on fish populations overall. Any estrogenic effects are masked by other factors, such as habitat quality, other chemical pollutants, water temperature or microbial pathogens. Thus, both the model and studies carried out on the Lützelmurg (a small river in Canton Thurgau) showed that, for example, rates of juvenile survival during the first winter have a much greater influence on fish density in subsequent years than endocrine disruptors.

Zebrafish used as models

Under the NRP50 programme, as well as conducting limited numbers of studies with trout, Eawag used zebrafish to investigate endocrine disruptors. The zebrafish, a member of the carp family, is an undemanding species. Measuring only 5–6 cm, these fish are sexually mature after only 3–4 months. The females lay large numbers of eggs, and the transparent embryos develop outside the mother's body – making it easy to detect any morphological abnormalities at a very early stage. Using this model organism, it was shown that, while sexual differentiation is certainly not due to estrogen levels alone, estrogens do affect the development of other organs. If a zebrafish egg is exposed to an endocrine disruptor, this influences the development of the embryonic brain. If the formation of estrogen receptors is suppressed by toxic substances, the lateral line (a sensory organ) cannot develop properly. The fish is subsequently unable to orient itself and swims in circles. A more detailed account of Eawag's research on zebrafish is to be found in Eawag News 64.

Lake Thun mystery partly solved

Since 2000, gonadal abnormalities have been observed in whitefish from Lake Thun. More than a third of the males and about a quarter of the females are affected. As well as fusion and constrictions of testes and ovaries, there have even been cases of hermaphroditism. Alongside Canton Bern and Bern University, Eawag was involved in the efforts to identify the causes of this phenomenon – unique in its extent. Studies focused not only on water quality but also on plankton and lake sediment, i.e. on everything that whitefish come into contact with in the course of their development. Although plankton and sediment samples showed estrogenic effects in various cell tests in the laboratory, this was only partly confirmed in the zebrafish study. In addition, similar results were obtained with samples from Lake Brienz, where whitefish are scarcely affected by abnormalities of this kind. So far – to the regret of the media, which would have gladly reported the mystery solved – researchers have only been able to discount certain theories: neither the munitions formerly dumped in the lake nor wastewater from the Lötschberg base tunnel excavation works appear to play a significant role. The project has however found evidence that the sediment contains a dioxin-like substance and compounds that disrupt the development of the immune system. As the source of these compounds is unknown, the detective work will continue.

Tubes allowing the passage of river water were used to hold trout captive at measurement sites.

Consensus Platforms

An innovative feature of National Research Programme 50 (NRP50) was the establishment of Consensus Platforms. On the basis of the latest findings, practical recommendations on endocrine disruptors were to be jointly developed by researchers and representatives of the authorities and industry. The aim was that all parties should be able to subscribe to the final documents with as few reservations as possible. Three separate platforms addressed UV filters, brominated flame retardants and wastewater/the aquatic environment. Eawag was represented in the second and third of these groups. It was agreed that long-term monitoring and further research are required to find out more about the hazards posed by endocrine disruptors. It was also acknowledged that scientific uncertainty must not be used as an argument for putting off appropriate action to reduce risk. Thus, industry representatives stated that they were prepared, for example, to seek alternatives to certain UV filters or flame retardants. For their part, the federal authorities intend to include quality criteria for hormonal activity in the aquatic environment in the Water Protection Ordinance. The Platforms' findings are available online at: www.nrp50.ch/consensus-platforms

Ubiquitous flame retardants

Flame retardants are an important group of chemicals studied in NRP50; some of them are believed to be endocrine disruptors. These brominated compounds are used, for example, in computer housings, fabrics or insulation materials to prevent rapid combustion. With a sediment core collected from the Greifensee, Empa and Eawag researchers demonstrated how concentrations of brominated flame retardants have increased rapidly since 1980. The problems posed by these compounds arise not only from their widespread use but also from their distribution: they are even found in isolated mountain lakes, which means that they must also be transported by air. However, they also appear to be released into the environment via municipal and industrial wastewater: in brown trout from river stretches that carry wastewater, concentrations of flame retardants were found to be up to five times higher than in farmed rainbow trout. As yet, there is no evidence to suggest that the concentrations observed are harmful to the fish, and certain flame retardants have now been banned in the EU. Nonetheless, the researchers insist that the search for alternatives should not be neglected since degradation products of supposedly unproblematic compounds may themselves prove to be endocrine disruptors. ○○○

- www.nfp50.ch
- Special issue of the journal Chimia (5/2008)
- Eawag News 64, June 2008

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Nonylphenols: it all depends on the mixture

Nonylphenols are toxic, endocrine-disrupting contaminants, which always occur as a mixture of different isomers. Eawag has been studying these widely distributed substances for many years. New findings show that the isomers are differentially degraded by bacteria, possibly leading to an increase in the estrogenic risk posed by the mixture.

Every morning around 9 a. m., Frédéric Gabriel heads for the Eawag cafeteria, clutching a sheaf of documents under his arm. Over a quiet cup of coffee, he likes to plan the day's experiments or read an article. But today he is explaining to a visitor the findings of his latest research, carried out in Hans Peter Kohler's Environmental Biochemistry group – in the Environmental Microbiology department – as part of National Research Programme 50 (NRP50) on "Endocrine disruptors". Kohler and Gabriel are studying nonylphenols – highly toxic, endocrine-disrupting environmental contaminants which are used in the synthesis of nonylphenol polyethoxylates, an important group of non-ionic surfactants. Polyethoxylates serve to emulsify fat in water and are used in products such as detergents, pesticides, paints and plastics, but also in many industrial production processes. Worldwide, about 650,000 tonnes of nonylphenol polyethoxylates are manufactured each year.

The environmental risk of nonylphenols can be seriously underestimated if only the overall concentration is determined.

Frédéric Gabriel explaining his findings.

As Gabriel explains, the nonylphenol issue provides a perfect illustration of how toxic compounds can arise in the environment from relatively harmless anthropogenic starting materials. At wastewater treatment plants, nonylphenol polyethoxylates undergo microbial degradation, with toxic nonylphenol being released into the environment as a result. In Switzerland and the EU, the use of nonylphenol and its ethoxylates has been heavily restricted by legislation for some years. In the US and most other countries, however, no restrictions are in place as yet.

Nonylphenols: a complex mixture

On account of their structural relationship to the female sex hormone 17β-estradiol, nonylphenols can have endocrine-disrupting, estrogenic effects on many vertebrates. So-called technical nonylphenol, used in surfactant production, is known to be a complex mixture consisting of over 100 isomers, which are not only degradable to varying extents but also vary in their estrogenic activity. Gabriel emphasizes: "In our study, we were able to confirm the influence of the chemical structure on estrogenicity and thus also demonstrate how important it is, when assessing the environmental risk of nonylphenols, not to lump all the components together."

Recalcitrant isomers – more potent endocrine disruptors?

After being released from nonylphenol polyethoxylates, nonylphenol is itself further degraded, but the various isomers are broken down at different rates. In their experiments, the Eawag researchers offered technical nonylphenol to a bacterium which they had isolated from activated sludge from a wastewater treatment plant. The degradation products were then analysed by mass spectrometry. After 9 days, some nonylphenol isomers were completely, but others only partly degraded. The rate of degradation depended on the chemical structure: isomers with bulky side chains in the immediate vicinity of the phenol ring were much less readily degradable than isomers with smaller side chains at this position. Given their structure, however, as Gabriel points out, the recalcitrant nonylphenols could exhibit particularly high levels of estrogenic activity.

Microbial degradation may thus leave intact precisely that part of the nonylphenol mixture which poses a high estrogenic risk. Gabriel concludes: "This means that effective monitoring – as required by the EU for nonylphenols – is only possible if individual isomers are measured." And, as he gathers up his papers and clears away the coffee cups, Gabriel adds that the research group is now seeking to isolate the enzyme responsible for degradation. ○○○

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Silver nanoparticles: toxic to algae

Silver nanoparticles with useful antimicrobial effects are increasingly found in consumer products, but little is known about their environmental impacts. Eawag researchers have shown that these particles inhibit photosynthesis in algae. This can be explained by the known toxicity of the ionic silver present in solution as well as the metallic particles. But, strikingly, the nanoparticles are more toxic than a silver ion solution in itself.

As the production of nanomaterials opens up new possibilities for industrial and commercial applications, a growing number of consumer products are exploiting the benefits of synthetic nanoparticles. For example, nanoparticles are used in cosmetics, textiles, detergents and foods to impart dirt-resistant, water-repellent, bactericidal or even ultraviolet-absorbing properties.

Risk of environmental releases

With the strong growth in commercial applications, it is also increasingly likely that nanoparticles will enter the aquatic environment in the course of production, use or disposal. This was recently demonstrated by a joint Eawag/Empa study of synthetic titanium dioxide nanoparticles. These particles are used, for example, as a whitening pigment in facade paints and are released into the environment as a result of weathering, i. e. in rainwater runoff.

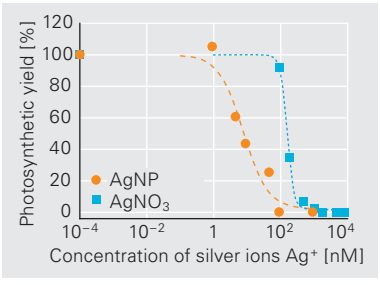
The prospect of commercially produced nanoparticles ultimately appearing in the environment raises the question of whether and to what extent they pose environmental risks. This partly depends, of course, on the quantities released. But we also need to understand how the particles behave – e. g. in surface waters – and how they affect plants and wildlife. As yet, little is known about these processes. Eawag is therefore carrying out studies on the fate and toxicity of synthetic silver nanoparticles. Owing to the well-known antimicrobial effects of silver, these are among the most widely used particles.

The nanoparticles are more toxic to the algae than the silver ions in themselves.

Interactions between algae and nanoparticles

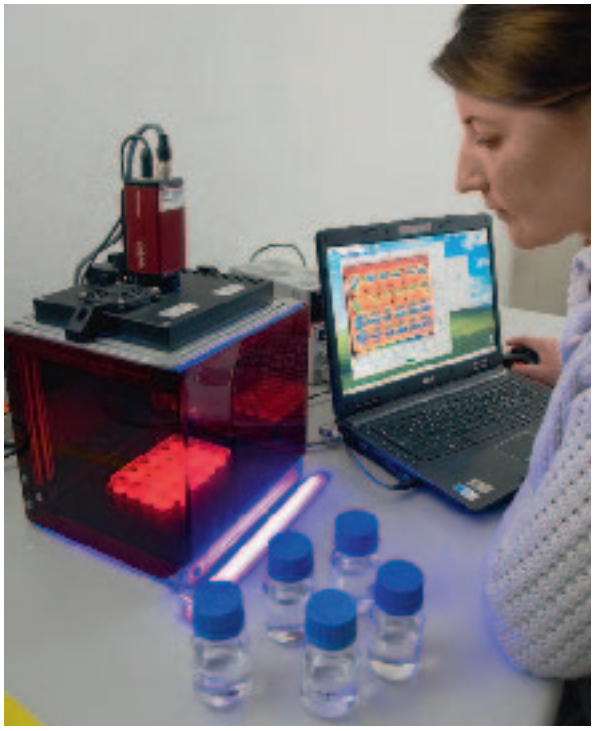
Our experiments were conducted using green algae and metallic silver nanoparticles with an average size of 25 nm (1 nanometre = a millionth of a millimetre). It was rapidly shown that the particles inhibit photosynthesis in the algae. However, it was not initially clear whether this effect is in fact attributable to the nanoparticles or merely to the presence of dissolved silver (concentration around 1 %). We therefore used the amino acid cysteine, which immediately binds free silver ions, so that they are no longer available to the algae. At once, the toxic effects were abolished.

This result clearly assigns the "blame" for toxicity to the free silver ions. However, this is not the whole truth: compared with a control experiment involving silver nitrate, algae exposed to nanoparticles show effects at far lower silver ion concentrations than in the absence of nanoparticles (see graph). This can be explained by two processes: firstly, the formation of silver ions is evidently increased when the particles are in contact with the surface of the algae – by a mechanism that has yet to be elucidated. Secondly, we found clear evidence that the minute particles are taken up by algal cells despite their protective cell walls – a significant finding, since the nanoparticles could have toxic effects inside the cells. We are therefore exploring this hypothesis in our current research.



Comparison of the toxicity of silver nanoparticles (AgNP) and a silver nitrate ($AgNO_3$) solution, as measured by the photosynthetic yield, which declines as silver ion concentrations increase. The inhibitory effects of the nanoparticles appear at far lower silver ion concentrations than for silver nitrate.

Eawag/Ruedi Keller



This set-up was used to measure the inhibitory effects of silver on algal photosynthesis.

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Reduced leaching of herbicides from bitumen sheets

Environmental researchers are occasionally accused of alarmism by representatives of the private sector – but not in the case of a joint Eawag/Empa project which investigated the leaching of herbicides from bitumen sheets. Here, close cooperation with manufacturers led to significant product improvements within a short time.

Bitumen sheets – popularly known as roofing felt – are widely used. In Switzerland, around 5 million m^2 of flat roofs are constructed each year, and more than half are sealed with bitumen membranes. They are also used in foundations and on underground garages with green roofs.

Water pollution demonstrated

Many bitumen membranes contain the herbicide mecoprop, which is designed to prevent root penetration. This substance enters the environment after being leached out by rainwater, as was shown by Eawag studies of flat roofs carried out ten years ago. Pollution of surface waters with mecoprop has been demonstrated: in the River Glatt, for example, the quality standard of 0.1 µg/l specified in the Water Protection Ordinance is often substantially exceeded. In a recent study, we investigated to what extent leaching still occurs from currently available products, how the situation in urban rainwater runoff is to be characterized, and what measures could help to reduce contamination.

Extensive testing

Sixteen products labelled as "root-resistant" were tested in the laboratory and aged under defined conditions. In addition, two gravel-covered roofs were exposed to artificial rainfall and the roof runoff was sampled. Lastly, the occurrence of mecoprop in rainwater runoff was studied at several points along a separated stormwater sewer draining a new housing development. The results are clear: among the most commonly used root protection agents with the trade names Herbitect (HE) and Preventol-B2, leaching of mecoprop is at least 10–20 times lower for HE than

Root-resistant bitumen sheets are used to seal a flat roof which is to be extensively vegetated.

for B2. Leaching of B2 is particularly marked at the beginning – after 190 days of natural weathering, concentrations were reduced by half. In the case of HE, mecoprop concentrations remained in a similar – initially already much lower – order of magnitude. The mean amounts of herbicide released per square metre were 4 mg for HE and 80 mg for B2 under our lab conditions.

The rainwater runoff samples collected from the housing development at Volketswil (Canton Zurich) showed substantial differences in herbicide concentrations. Significant contributions derived from sealing membranes in foundations and from green roofs of underground garages – not only from flat roofs, as had originally been assumed. Just before stormwater is discharged into the Chimlibach stream from the separated sewer, mecoprop concentrations of up to 10 µg/l were measured. In the stream itself, concentrations in the same order of magnitude were recorded during several rainfall events.

Successful measures

Throughout the study period, thanks to extremely open cooperation with the bitumen sheet manufacturers, we were able to discuss our findings and our proposals for measures to reduce herbicide leaching. This led, for the first time, to collaboration between the three biggest manufacturers, who have now optimized their formulations and switched either to HE or to Preventol-B5 – a product newly developed on the basis of the study. B2 is no longer being used. In addition, the producers have revised their recommendations for use and the information included on packages. They now recommend that root-resistant sheeting should only be used where it is actually needed, i.e. on genuine green roofs. As a result, the use of root-resistant bitumen sheets was reduced to 60 % in 2008, and a reduction to 40 % is expected for 2009. In the longer term, these two measures combined could prevent 96–98 % of mecoprop leaching. It will now be possible to reassess the most sustainable way of managing runoff from roofs with enhanced bitumen sheets: by drainage to wastewater treatment plants, via separated stormwater sewers to receiving waters, or through controlled decentralized infiltration.

This study is part of the URBIC project, which is investigating the leaching of additives from construction materials, and their effects on the quality of rainwater runoff. URBIC measures material flows from the source to receiving waters and assesses impacts on organisms. This work is supported by the Federal Office for the Environment (FOEN) and the Canton Zurich Office for Waste, Water, Energy and Air (AWEL). The study described above is a joint Eawag/Empa project.

▶ www.eawag.ch/urbic

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Broadening and tightening the net

The Rhine catchment is a source of drinking water for more than 20 million people. So, given the need to detect and identify problematic substances as early as possible, it is little wonder that the Rhine is among the world's most closely monitored river systems. In cooperation with the Federal Office for the Environment and the Environment and Energy Office of Canton Basel-Stadt (AUE), Eawag is investigating how the latest analytical methods can be used to detect substances in the Rhine not previously covered by monitoring programmes.

The Weil am Rhein monitoring station, lying about a kilometre below the point where Germany, France and Switzerland meet, aims to detect possibly toxic substances at an early stage, so that waterworks can be alerted and the Rhine ecosystem protected. The substances also need to be identified so that their source can be determined and pollutant discharges controlled.

Complex measurements

Unlike water levels or temperature, the measurement of potentially hazardous substances poses complex challenges for the Rhine monitoring authorities:

▶ Measurement must allow a large number of organic pollutants to be detected, within hours if possible. Traditional analytical methods – gas chromatography coupled with mass spectrometry – cannot detect all the relevant substances, and the preparation of samples is time-consuming.

▶ Concentrations down to the low nanogram (billionth of a gram) per litre range need to be detectable. While this may appear to be insignificant, even a concentration of 10 ng/l means that a kilogram of the substance in question is flowing downstream each day.

▶ Chemical analysis primarily finds what is being sought. However, monitoring of the Rhine is also supposed to identify unexpected or unknown substances that have been released accidentally. This calls for analytical methods that can detect compounds of interest without selecting the target substances in advance.

Against this background, Eawag collaborated in 2008 with the Federal Office for the Environment to investigate the potential of an analytical method which combines liquid chromatography with high-resolution mass spectrometry. This makes it possible to determine molecular masses with an accuracy that registers the mass of a single electron.

Promising tests

The study recommended the use of this type of tandem system. Using the test system (LTQ Orbitrap), 88 % of 211 selected micropollutants were detected down to low ng/l levels with a single enrichment method. Screening of the 12 Rhine water samples yielded 672 positive findings, comprising 84 different substances, including 40 pesticides and pesticide transformation products, 26 pharmaceuticals, an anticorrosive agent and several industrial chemicals. Thanks to its resolving power, the system is in principle also capable of detecting unknown pollutants that may occur at high concentrations in the Rhine following major accidents. In combination with the technologies already installed, the new analytical method should make it almost impossible for such pollutant waves to flow undetected towards the North Sea. It could also be said that the Rhine monitoring net is being both broadened and tightened.

Continuous improvements

The researchers are still faced with one problem: with liquid chromatography, the mass spectrometry fingerprints of compounds cannot be compared directly with the existing substance databases based on standard gas chromatography. Unknown compounds have to be determined via high-accurate mass measurements. This means that a compound cannot be identified definitely, but only with a high degree of probability. The likelihood of accurate identification can be increased by predictions that narrow down the expected range of substances – if not making the needle bigger, then at least reducing the size of the haystack. Eawag is therefore currently developing prediction models to facilitate the identification of transformation products of pesticides, biocides and pharmaceuticals whose concentrations and effects make them relevant to water quality.

At the monitoring station in Weil, the AUE is now operating a liquid chromatograph coupled with a high-resolution mass spectrometer. Whether this system can wholly replace traditional analytical methods remains to be seen. For the next three years, the process is being overseen and knowledge transfer assured by an Eawag postdoc. ○○○

ETH Library, Image Archive

The Rhine port in Basel. After the devastating Sandoz chemical fire in 1986, the riparian states agreed to implement a joint Rhine monitoring programme.

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Arsenic: risk identification and mitigation

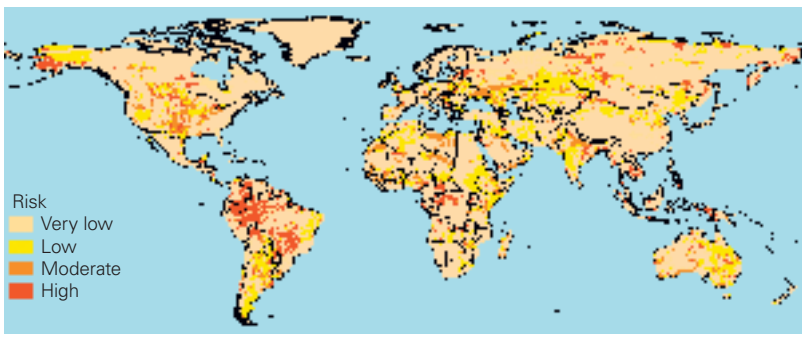
The contamination of groundwater with arsenic poses a risk to the health of millions of people, especially in the densely populated river deltas of Southeast Asia. To date, no method has been available for identifying high-risk areas without conducting costly sampling campaigns. Now, Eawag has developed a model that allows vulnerable areas to be pinpointed using existing climate and geological data. In addition, appropriate technologies are being developed so that contaminated water can be treated by the populations affected.

Human health can be threatened by naturally occurring substances. Worldwide, more than 200 million people are exposed to excessive concentrations of arsenic or fluoride in drinking water. These substances, leached from rocks into groundwater, are known as geogenic contaminants. In many areas, the problem is recognized but, because surface waters are polluted, new wells are continually installed – often without testing the pumped water for contamination.

Sampling at a drinking water well on Sumatra (Indonesia). According to the new modelling method, around 100,000 km^2 on the eastern coast of the island is considered a high-risk area for excessive arsenic concentrations in groundwater.

Making use of available data

As part of the WRQ (Water Resource Quality) project, Eawag researchers have now developed a method that allows high-risk areas to be identified relatively easily, without the need for expensive and time-consuming groundwater analysis. The team, coordinated by geochemist Annette Johnson, used digital maps to compile data on soil type, geology, climate, hydrology and topography in a geographical information system (GIS). At the same time, data on groundwater were collected from publications and from responses provided by authorities and institutions – more than 20,000 data points for arsenic and around 60,000 for fluoride. All the data were processed using a uniform classification system. The team then prepared a model combining statistical analysis and expert knowledge to produce global risk maps. These provide an indication of those regions where groundwater with high arsenic or fluoride concentrations is to be found. In the case of arsenic, the probability of



Global arsenic risk map – modelled probability of arsenic contamination in groundwater.

Arsenic

Arsenic is one of the most important inorganic contaminants found in drinking water. This metalloid occurs as a natural component of underground rocks worldwide, with small quantities being dissolved in groundwater as a result of weathering. The inorganic salts of arsenic are tasteless and odourless, but highly toxic to humans. If ingested over long periods, even low concentrations can cause damage to health, including disorders of liver and kidney function, and various types of cancer.

Problems arise from the fact that firstly, arsenic concentrations can vary widely at the local level and, secondly, in many areas people are completely unaware of the risk because their well water or groundwater has never been tested for arsenic. A concentration of 10 µg/l is recommended by the World Health Organization as a guideline value for arsenic in drinking water. In the deltas of the Red River and the Mekong, Eawag detected arsenic concentrations exceeding 100 µg/l in one in five of the samples analysed, with maximum values as high as 3000 µg/l. In the Irrawaddy delta (Myanmar), a study supported by Unicef found arsenic concentrations of more than 50 µg/l at two thirds of the sampled wells.

contamination is particularly high in the central US, Alaska, Brazil, DR Congo and in many parts of Southeast Asia.

Focusing on Southern Asia

Across Southeast Asia, arsenic-tainted drinking water is causing what has been described as "mass poisoning". In Bangladesh alone, according to Unicef estimates, 2.5 million people will ultimately be affected. Each year, thousands are already dying as a result of chronic exposure to arsenic – from skin, lung or bladder cancer. The WRQ project team therefore decided to refine the risk mapping for this region. In particular, the geology of young sedimentary deposits was incorporated into the model, and more than 4600 data points were additionally included. Deltaic deposits and organic-rich surface sediments were found to be key indicators of groundwater arsenic contamination.

Supporting governments and aid agencies

Verification of the model using available groundwater data points from the Bengal, Mekong and Red River deltas showed that the predictions accorded well with reality. However, in areas assigned a low risk by the model, the risk cannot be assumed to be zero. "There is no such thing," as Annette Johnson points out. The geochemist adds that, ultimately, even a refined model, e.g. including more data from deeper rock strata, could not serve as a substitute for analysis of water samples. "But thanks to the maps, governments, local authorities or aid agencies can tell very quickly where it might be problematic to sink a well."

New high-risk areas detected on Sumatra and in Myanmar

The new model is of particular interest for regions where no groundwater measurement data are yet available. Accordingly, the Swiss aquatic research team applied the model to the Indonesian island of Sumatra, where an area covering 100,000 km^2 on the eastern coast was found to be at high risk for arsenic contamination. The researchers subsequently used about 100 groundwater samples to verify the probabilities predicted by the model for a region on the border between a low- and a high-risk area. Once again, the results of analyses were found to agree well with the predictions: 94 % of the wells in the low-risk area showed arsenic concentrations below 10 µg/l. The maps also indicate an increased risk of elevated arsenic concentrations in groundwater in the Irrawaddy delta (Myanmar) and along the Chao Phraya river north of Bangkok (Thailand) – both areas where the risk had not previously been recognized.

Appropriate removal technologies

The goal of the WRQ project is to provide a framework enabling the relevant authorities to tackle the arsenic or fluoride issue systematically – identification of the problem, e.g. with the aid of the new risk maps, is only the first step. Eawag is therefore also researching and developing appropriate treatment methods to allow contaminants to be effectively removed from pumped groundwater. There is a need for systems applicable at the household, neighbourhood or community level, which are adapted to the local situation and do not require significant maintenance. As well as technology and costs, attention also needs to be paid to sociocultural aspects. Even the best system is worthless if it is either not accepted or not properly operated by the people concerned (see Box). ○○○

Mickey Sampson, RDI Cambodia

A groundwater well in Cambodia, where arsenic contamination is widespread along the Mekong river.

Respecting cultural norms

One option for avoiding contamination problems is to pump arsenic-free water from deep tubewells. In Bangladesh, however, it has been shown that these public wells – often centralized facilities supported by aid agencies – are underused by the public. To investigate the reasons for this, Eawag conducted a survey involving 222 households in the rural district of Sreenagar. The most important barriers were found to be social and cultural factors. Fetching water (in Bangladesh as elsewhere) is a task for women, but in many areas religious conventions prohibit women from leaving the homestead or talking to men in public places. According to the survey, women who were prepared to take the time to walk to the central well often felt harassed. The researchers now recommend that the authorities should plan decentralized wells and take cultural norms into account, e.g. by installing screens.

▶ www.wrq.eawag.ch

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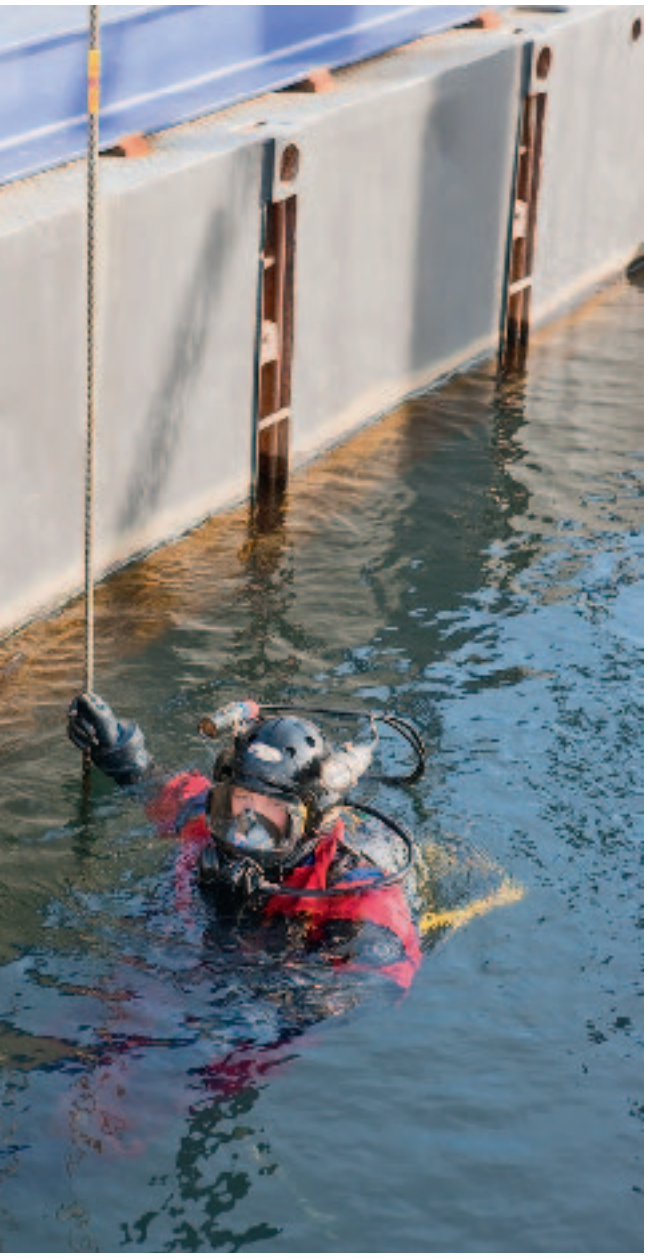
Removing toxic sludge from a reservoir

In the winter of 2008/2009, at a total cost of CHF 8.6 million, Canton Zurich is remediating a contaminated site in Lake Zurich, at Thalwil. The source of the layer of tar, covering an area of 7000 m², is a local gasworks, which was in operation until 1930. It was originally assumed that decontamination might do more harm than good. However, a risk assessment conducted by Eawag showed that recovery of the contaminants was not only advisable but urgently required: they were slowly but surely being released from the sediment into the water, posing a threat to the lake as a drinking water reservoir and also to aquatic organisms.

The entire lake bed contamination zone is enclosed by an oil boom. Work is carried out from a floating pontoon in a "clean-up box" (measuring 15 × 6 m), which is lowered to the bottom of the lake. Three divers working in shifts use pumps to suck up the tar deposits, which are up to a metre thick – each day around 100 m² of lake bed is decontaminated.

On the pontoon the sludge empties into a buffer tank and is then pumped ashore for treatment.



In a large shed on the shore (right), the sludge – containing contaminants such as the carcinogenic benzo[a]pyrene – is sieved, chemically treated and dewatered in a filter press (above). The residue is disposed of in a high-temperature incinerator in Bremen (Germany).

A diver can work on the lake bed (water temperature 5 °C) for two hours at a time. His activities and the supply of an oxygen/nitrogen mixture are monitored by colleagues on the pontoon (small photo above).

The benefits of an interdisciplinary approach

"Eawag is the right place to carry out such complex risk assessments," says Professor Bernhard Wehrli, referring to the expert report on whether the tar deposits should be removed from or left on the lake floor. "We had at our disposal extensive detailed studies from cantonal agencies and the private sector. To reach the necessary conclusions, it was helpful to be able to draw on expertise from a wide variety of environmental disciplines within a short space of time." The points to be assessed were the environmental behaviour and distribution of the contaminants in the lake, and the possibility of underwater landslides or accumulation of substances via the food chain in fish. Thanks to international cooperation at Eawag, it was relatively easy to obtain information on the best available technologies for sediment remediation.

Coal tar from former gasworks contains carcinogenic substances from the polycyclic aromatic hydrocarbon group. The tar deposits at Thalwil lay in shallow water near the lakeshore. Here, sludge was regularly stirred up and brought to the surface by gas bubbles, where oil films were sometimes visible to the naked eye. The main danger, however, lurked in the deeper waters, where the sediment could have slipped. A landslide of this kind could have spread the coal tar through the lake within a matter of hours. The expert report concluded that the contaminated site posed a major risk to Lake Zurich's ecosystem and its users. In addition, Eawag recommended removal of the contaminated sediments by suction as an appropriate remediation method.

review of 2008 Eawag

2008 was declared the International Year of Sanitation by the UN, as 2.6 billion people worldwide have no access to basic sanitary facilities. One result of poor hygienic conditions is the contamination of drinking water resources. At numerous events organized for visitors, in lectures and via a travelling exhibition, Eawag explained the significance of this dire situation and showed how our aquatic research is helping to alleviate the problem. Projects such as Novaquatis, which won the Transdisciplinary Award in 2008, show that in Switzerland, too, much work remains to be done to make problems in the water sector amenable to integrated solutions. Below, we look back over some of the year's highlights.

Bringing science to life

On 26 September, Researchers' Night attracted more than 15,000 people to the shores of Lake Zurich – and onto the steamers plying between Bellevue and Zürichhorn. With its own booths and presentations, Eawag played a major part in bringing science to life at this event. Among the exhibits, sediment cores and maps produced using a special sonar helped to reveal the secrets of the lake bed. A model house was used by Eawag and Empa to illustrate their joint research on biocides in facade paints and renders. At one of our stands, we presented a newly developed method for the analysis of drinking water, and at another, visitors measured how much energy could be recovered from wastewater. A fascinating computer simulation persuaded visitors that arguments are not in themselves enough to ensure that research findings are successfully implemented in practice.

Eawag was well represented not only at Researchers' Night, but also at a variety of other events – from the exhibition in Horw (Canton Lucerne) to the World Expo in Saragossa (northern Spain). In addition, numerous guided tours at the Kastanienbaum and Dübendorf sites provided opportunities to explain Eawag's mission and the types of water-related problems that we address. ○ ○ ○

Realignment of engineering activities

In response to personnel changes and the increasingly competitive nature of the environmental engineering field worldwide, Eawag's engineering departments underwent a strategic realignment. The Process Engineering department, led by Hansruedi Siegrist, is now concerned with the development and modelling of processes in the wastewater and drinking water sector. The latter will be addressed in partnership with the

Top: Researchers' Night exhibit, demonstrating how modern hollow fibre membranes can be used in wastewater recycling.
Bottom: Info Day on the subject of drinking water, held in Forum Chriesbach on 12 September.

Water Resources and Drinking Water department since, with the growing importance of wastewater recycling, treatment processes can no longer be so sharply distinguished. At the same time, the Urban Water Management department – headed up by Max Maurer since 1 September – is to focus on the sustainable further development of urban water systems. It will elaborate new concepts for the management of drinking water and wastewater systems and investigate pollutant flows in urban catchments.

Standard work published

The publication of "Rivers of Europe" provides, for the first time, a comprehensive overview of the state of Europe's major rivers. Under the editorship of three Eawag researchers (Klement Tockner, Christopher T. Robinson and Urs Uehlinger), authors from 20 countries helped to prepare this river science reference work. Modelled on the best-selling "Rivers of North America", the guide describes the history, hydrology, biogeochemistry and biodiversity

of 165 European catchments. Each chapter also addresses management and conservation issues. The work offers a valuable foundation for implementation of the EU Water Framework Directive. It presents striking evidence of the severe pressures affecting European rivers and freshwater fauna. Elsevier, 728 pp., December 2008.

Award winners

In 2008, various Eawag papers received national or international awards, and several Eawag researchers were honoured for their work. To mention just a few examples: the cross-cutting *Novaquatis* project on urine source separation received the Award for Transdisciplinary Research – carrying a prize of CHF 75,000 – from the Swiss Academies of Arts and Sciences (www.transdisciplinarity.ch). *Michael Berg*, as part of an international team, received a best science paper award from the renowned journal "Environmental Science & Technology" for a study on the use of chlorine isotope analysis in the assessment of chlorohydrocarbon degradation pathways. *Professor Walter Giger* and former member of the Eawag Directorate *Professor René Schwarzenbach* were named as "legends of environmental science" by the American Chemical Society. They thus belong to an illustrious group of only 15 scientists worldwide whose research over more than 40 years has, according to the ACS, "significantly influenced today's thinking and practices in environmental chemistry". *Andreas Peter* won the Otto Jaag Water Protection Award for his thesis on taste and odour compounds in drinking water. Eawag received an award from the Dübendorf conservation association for the near-natural landscaping and management of its site, while Forum Chriesbach won the Special Prize for Green Technology – part of the 2008 "Marketing+Architektur" Award.


td-net

Presentation of the 2008 Award for Transdisciplinary Research to the Novaquatis project management team. Pictured in the middle are project managers Judit Lienert and Tove Larsen.

Cooperation intensified

With a Memorandum of Agreement, Eawag has further strengthened its well-established partnership with the UNESCO-IHE Institute for Water Education in Delft (the Netherlands). Each year, as part of the Eawag Partnership Programme for Developing Countries (EPP), three students taking an MSc at the IHE are to pursue their studies at Eawag for half a year. Eawag will not only benefit from the good reputation of the Institute in Delft: since Master's dissertations often develop into doctoral theses, we will have direct access to the best, highly motivated students – who will ultimately help to disseminate Eawag's expertise around the world.

Cooperation between research institutes within the ETH Domain was also further intensified in 2008: a joint Eawag-WSL (Federal Institute for Forest, Snow and Landscape Research) Committee will now be responsible for internal review of funding applications submitted to the Swiss National Science Foundation (SNF). Representing Eawag on this body are Professor Jürg Beer (Chair), Max Maurer, Professor Hans Joachim Mosler, Christopher T. Robinson and Professor Laura Sigg.

Multi-channel knowledge transfer

As well as having staff teaching at the ETH Zurich and the EPF Lausanne, and at other universities and universities of applied sciences, Eawag uses other channels to ensure that our expertise and the results of our re-

search are disseminated as widely as possible. In 2008, 1115 newspaper articles and radio or television reports dealt with Eawag research topics. Much of this coverage is due to the fact that media professionals trust Eawag to provide expert answers to water-related queries; in other cases, it was actively encouraged by our media releases and events or the publication of *Eawag News*, the Annual Report and articles in journals. Four practice-oriented Eawag (PEAK) courses were held, on subjects ranging from ecotoxicology to an applied course on heating and cooling with wastewater. Two well-attended events were the Info Day (12 September) on drinking water and the conference on the remediation of sites contaminated with chlorinated solvents (14 May).

New staff representatives elected

In October, Eawag employees elected new representatives for the period 2009–2012: administrative staff are to be represented by Karin Ghilardi; technical staff, including apprentices, by Jacqueline Traber and Alois Zwyssig; scientific staff by Tom Gonser; and doctoral students by Simon-Lukas Rinderknecht. The outgoing representatives are Hans Peter Kohler (Chair), Claudia Bänninger-Werfeli, Philippe Bradac, Christian Dinkel and Brigitte Pfister.

Feel-good events

With copious attention to detail, creativity and musicality, the three departments responsible for organizing the 2008 Eawag Christmas party – Sandec, Cirus and Siam – once again gave the occasion a distinctive character, making it an unforgettable event for the 350 guests. The team staged an ingenious round-the-world quest ("Eawagadougou") to find the best doctoral students for Eawag. Other events such as the "Anstaltsweihnacht" and International Food Event in Kastanienbaum, or the PhD students' party, certainly contributed to the positive working atmosphere and *esprit de corps* at Eawag. These are also promoted, in a different way but no less effectively, by a range of popular sporting activities – from yoga to volleyball.

At the 2008 Christmas party, Bavaria was one of the stopping points on the "Eawagadougou" round-the-world trip.

Artist's-eye view of research

During a nine-month residency sponsored by the Swiss Artists In Labs Program, Swiss-Chinese artist Ping Qiu explored research questions and methods through dialogue with scientists at Eawag. She produced imaginative, sometimes surprising responses to water and pressing water issues. For example, sustainable water management serves as the theme of "Wasserkreislauf" (water cycle), an installation in which fountains shoot from one toilet bowl to another. The "Atmen" (breathing) installation (photo) was conceived after Qiu had studied the development of various aquatic microorganisms under the microscope. Both sides benefit from this unorthodox collaboration. River specialist Christopher T. Robinson says: "Thanks to Ping Qiu's questions, we researchers now understand much better how others see our work, so we learned something new too." Qiu is already planning a project that takes the reverse approach: scientists are to spend some time among artists in a studio and express their ideas or questions in an artistic form. www.artistsinlabs.ch

Eawag on the road

On 27 May, the Eawag excursion to Biel, Erlach and St Peter's Island focused on the historical Jura Waters Correction and the current debate concerning regulation of the three lakes. The officials responsible assured the sceptical researchers that the major floods of August 2007 on Lake Biel and along the Aar could hardly have been prevented even by lake regulation measures. The rainfall volumes during that wet summer were simply too great. Of particular interest for the aquatic ecologists were the video images of the fish ladder at the Biel/Nidau weir. Live transmission of these images to the boardroom at Bernese Power Plants Ltd (BKW) had to be stopped: instead of discussing kilowatt-hours and revenues, the directors were fascinated by the upstream progress of the chub and other species.

Personnel

New appointments

Kristin Schirmer: On 1 January 2008, biology professor Kristin Schirmer (41) became head of the Environmental Toxicology department. She had spent the previous four years as head of the Cell Toxicology department at the Helmholtz Centre for Environmental Research (UFZ) in Leipzig. She is especially interested in cellular processes triggered by toxic substances. She says: "Only if we understand what happens in cells on the protein and DNA level, can we estimate the whole-organism effects of environmental contaminants." The combination of cell biology and environmental toxicology also allows her to investigate the effects of chronic exposure to low concentrations of toxic substances or pollutant cocktails. Kristin Schirmer attaches particular importance to teaching students and to the practical relevance of research: with her team, she has patented a sampling method which permits time-integrated monitoring of biological and chemical parameters. In March 2008, her husband, Mario Schirmer, also joined Eawag to lead a research group in the Water Resources & Drinking Water department.

Almut Gerhardt: Having come to Eawag in June 2008, biologist Dr Almut Gerhardt has been head of the Swiss Centre for Applied Ecotoxicology Eawag-EPFL (p. 4) since it opened on 30 October. As well as pursuing an academic career in aquatic ecotoxicology, she has managed her own consulting and research company, LimCo International. She says that the pioneering dimension of developing the new centre particularly appeals to her. She intends to test and further develop products of ecotoxicology research, such as sensitive tests and measurement methods for the assessment of chemicals or the monitoring of water quality. Almut Gerhardt is convinced that the embedding of the centre in the ETH Domain represents a major opportunity. By being right at the heart of research, can help to develop practical products on the basis of new findings. As she points out, the independent centre has greater freedom than private companies because its work does not have to be exclusively market-oriented – a fact that will certainly enhance the centre's credibility in the eyes of the authorities and the public.

Sam Arey: Jeremy Samuel Arey (34) has an MS in environmental engineering and a PhD in Environmental Chemistry from Massachusetts Institute of Technology. He first came to the EPF Lausanne as a postdoc from MIT, and in July he was appointed by the ETH Board as tenure-track Assistant Professor of environmental chemical processes in EPFL's School of Architecture, Civil and Environmental Engineering. He is head of the Environmental Chemistry Modeling Laboratory (LMCE), which is jointly supported by the Environmental Chemistry department at Eawag and the Environmental Sciences and Technology Institute at the EPFL. The mission of the LMCE is to explain and predict the behaviour of xenobiotic organic compounds in the environment, together with their ecological and health effects. This represents a strengthening of the cooperation between Eawag and the EPFL.

Martin Ackermann: Having held the SNF-sponsored chair of Microbial Evolution at the ETH Zurich from 2006, Dr Martin Ackermann (38) was appointed by the ETH Board as Associate Professor of Molecular Microbial Ecology in July 2008. He conducts his research in the Environmental Microbiology department at Eawag. His group works on fundamental questions about the biology of bacteria, combining methods from molecular microbiology with evolutionary biology and ecology. He is particularly interested in the division of labour in simple microbial communities, and in bacterial stress responses.

Retirements

In view of the changeover from a defined-benefit to a defined-contribution scheme at Publica (the Swiss Federal Pension Fund), a number of long-standing Eawag employees retired (or took early retirement) in 2008, including Ueli Bundi, who served as Director from 2004 to 2006 (p. 54). The other retirees, apart from those mentioned below, are Erwin Grieder (Surface Waters), Heidi Gruber (Staff of Directorate), Therese Haenni (HR), Beatrice Hürlimann (Technical Services/TS), Arthur Scheiber (TS), Andreas Steffen (TS), Jutta Studer (Library), Christa Surber (Library).

Markus Boller: After working as an assistant at the ETH Rural Engineering Institute for two years, Markus Boller trained as a sanitary engineer at the IHE in Delft and joined Eawag in this capacity in 1973. Having completed his doctoral thesis on contact filtration, he became head of the Process Engineering group. For many years, he was particularly interested in advanced phosphorus removal, and he became the leading European

expert in this area. His studies on physicochemical wastewater treatment were followed by projects concerning nitrification using a wide variety of biofilm reactors. There followed, as he put it, "the drinking water and the rainwater years and finally, over the last seven years, everything combined in a NoMix [urine source separation] mixture." In the drinking water field, Markus Boller's interests included the use of activated carbon for water treatment, and he recognized at an early stage the opportunities of membrane technology, which he subsequently also applied for the treatment of urine. in addition, he worked on the treatment of karstic spring water and initiated the Wave21 project ("Drinking water in the 21st century).

His research on rainwater focused not only on treatment methods (e. g. for road or roof runoff) but also on "at source" measures, and for this purpose, he often sought the cooperation of manufacturers, professional associations and authorities. Markus Boller and his groups certainly made significant contributions to the success of the Swiss urban water management sector – and to Eawag's reputation. In addition, he was always strongly committed to teaching and was awarded the title of Professor in 1996. He was head of the Engineering department from 1994 to 2000, and head of the Urban Water Management department thereafter. As Eawag's "Samichlaus" (Santa Claus), he is regarded as the father of the traditional Christmas party, and his rhymed speeches marking the end of the year or colleagues' departures are now legendary.

Peter Bossard: Having written his dissertation at Kastanienbaum in 1972, Peter Bossard earned his doctorate with a thesis on the methane and oxygen balance in Lake Lungern and joined the Eawag Limnology department in 1979. From 1989 to 2001, he served as Managing Editor of the journal *Aquatic Sciences*, and in 1994/95 he was ad interim head of the Limnology department. In his research, Bossard was mainly concerned with algae as primary producers. He studied primary production in Lake Lucerne for over 20 years. For a time, he contributed articles to the Science & Technology section of the *NZZ*, which enhanced his reputation as a communicator. In the mid-1970s, he was among the founders of "project-oriented studies" at the ETH – at the time, a revolutionary development which initially encountered resistance from some established professors, but which can be seen in retrospect as having paved the way for case studies and other new approaches to the study of natural sciences.

Hans Rudolf Bürgi: After studying Natural Sciences at the ETH Zurich and writing a dissertation on limnology under Professor Otto Jaag, Hansruedi Bürgi came to Eawag in 1968 to work on his doctorate. As he was an excellent draughtsman, he was first called upon by Eawag Director Jaag to redesign a reference work on saprobic organisms, contributing more than 100 pen-and-ink drawings. During his 40 years at Eawag, he was particularly interested in various aspects of plankton interactions. Key projects included an assessment of plankton on behalf of the International Commission for the Protection of Lake Constance (IGKB) and the development of littoral and biological interaction modules for the MODEC (Models in Ecology) project. Bürgi was also very active as a lecturer: at the ETH, he took on up to 11 teaching assignments per year. However, he is not only well known among students: together with Heinz Bachmann, he produced micrographs and electron micrographs of algae and invertebrates which have appeared in countless reports and books. Bürgi successfully championed standardized sampling methods and was responsible for the introduction of standard zooplankton nets. As he points out, "The most sophisticated analysis is no use if inappropriate equipment was used for sampling."

Oskar Wanner: Eawag's interdisciplinary approach to research was ideal for Oskar Wanner. A mechanical engineer (ETH), he also studied Biology and wrote his doctoral thesis on the hormone oxytocin at the Institute of Molecular Biology and Biophysics. In 1979, he joined Eawag's Information Technology department – not to be confused with today's IT support unit. He was involved in many projects where systems analysis issues and mathematical problems needed to be addressed. He took a particular interest in the modelling of biofilms, a research topic to which he kept returning for more than 25 years. In recent years, as a member of the Engineering department, he was concerned with the recovery of heat from wastewater (p. 15). Here, biofilms cropped up once again – as a common source of problems on heat exchangers. ○○○

Ueli Bundi: a bridge-builder committed to sustainable water management

The end of May 2008 saw the "retirement" of Ueli Bundi. No one else at Eawag has dedicated himself for so long or so persistently to Switzerland's surface waters. Ueli Bundi championed the idea that problems should be approached holistically and solutions sought through dialogue with stakeholders – always showing a high level of personal commitment. With his wide-ranging knowledge and bridge-building skills, he was instrumental in defining Eawag's understanding of its role and building its credibility. by Professor Bernhard Wehrli, Member of the Directorate

When Ueli Bundi first came to Eawag in 1972 as a research associate, he applied what was then the new approach of life-cycle analysis to highlight the possibilities of recycling and integrated resource management. However, he soon turned his attention to water management measures.

"Gewässerschutz 2000": a milestone

The "Gewässerschutz 2000" project, which he led and energetically pursued, was among the pioneering environmental efforts, paving the way for Swiss water pollution control legislation. His early study on phosphorus pollution in the Greifensee demonstrated the need for a ban on phosphates in detergents, which was progressively implemented in the 1980s. He was a driving force in the elaboration of scientifically based quality standards for waterbodies and methods for the assessment of rivers and streams. In connection with the debate on ecological flow requirements, he was the first to emphasize the crucial importance of flow dynamics. Although these concepts were initially controversial, they are now widely accepted.

It's impossible to overestimate Ueli's contribution to integrated water protection in Switzerland.

Roland Schertenleib, a Member of the Directorate from 1999 to 2006, who shared 30 years at Eawag with Ueli Bundi.

Integrated approach

In the 1990s, Ueli Bundi initiated and led, together with colleagues from other institutions, a transdisciplinary project concerning the national nitrogen balance, in which – for the first time anywhere in the world – guidelines were developed for a comprehensive nitrogen policy in the agriculture, transport/combustion and wastewater sectors. His ability to bring together experts from various disciplines to explore possible solutions was one of his great strengths. His broad knowledge and unmistakable personal commitment to natural waters earned him wide recognition and numerous friendships. As Roger Biedermann, a long-time companion and former Cantonal Chemist for Appenzell AR, Appenzell IR, Glarus and Schaffhausen, says, "For us, Ueli was a wonderful person to deal with, as he could see the big picture and didn't get bogged down in details like many other researchers."

Influential figure

As well as shaping Eawag's public image, Ueli Bundi was in charge of internal planning processes for many years and played a key role in the development of Eawag during the directorships of Werner Stumm and Alexander Zehnder. From 1990, he was a Member of the Directorate. These years included the planning phase for Eawag's new headquarters – Forum Chriesbach. It is largely thanks to his efforts that the ideas on the sustainability of this building were so consistently pursued and put into practice.

From 2004 to 2006, Ueli Bundi served as Director on an ad interim basis. In this capacity, he led Eawag actively, together with his colleagues in the Directorate, and did not shy away from strategic decisions. In spite of his heavy workload, he was always ready to listen to staff concerns, to consult internal specialists and to express his appreciation for people's work.

Ueli Bundi will continue to serve Eawag after his retirement. In particular, he is representing the institute in the Water Agenda 21 network, which he helped to initiate – another platform for the promotion of an integrated Swiss water policy. ○○○

Equal opportunity and gender equity

In April 2008, the Equal Opportunity Officer at Eawag was replaced by a standing Committee on Gender Equity and Equal Opportunity (EOC). The goal of this committee remains the same: women and men are to have equal opportunities at Eawag, with balanced representation in all areas. This requires in particular the advancement of women in positions of responsibility within research and in managerial functions. The fact that a number of people from different departments are now concerned with gender equity creates an opportunity to raise awareness of these issues.

The measures accorded top priority by the EOC are improving career advancement, strengthening the work/life balance and providing mentoring for women, especially for postdocs. The last point is important because, while almost equal numbers of women and men complete doctorates, (too) many women abandon research careers after a stint as a postdoc. New guidelines for hiring should also help to ensure that the number of female research staff reflects the proportion of female PhD students.
Thanks to a permanent representative, the Eawag EOC maintains close contacts with the ETH Domain's Workgroup for Equal Opportunities. The joint project "Fix the leaky pipeline" was coordinated by Gabriella Meier Bürgisser, who represented the Eawag EOC until October 2008.

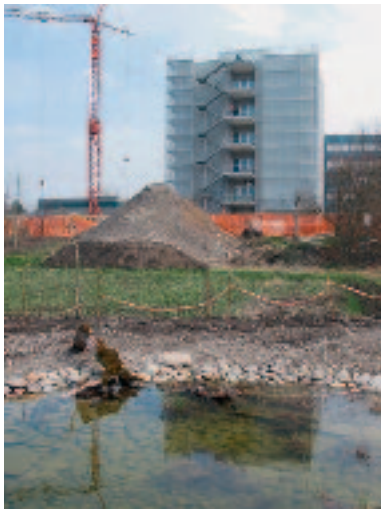
Reflecting on successes

The goals, achievements and minutes of the EOC can be viewed by all staff on the intranet. This creates transparency and should encourage further action. After all, several issues have already been resolved at Eawag in an exemplary fashion – e.g. the establishment of the on-site Eawag-Empa Childcare Centre in 2006. ○○○

by Natalija Miladinovic, EOC coordinator

Natural laboratory on our doorstep

Eawag uses its surroundings to showcase near-natural principles and new types of urban landscaping. In these projects, the institute's own research findings are taken into consideration and exemplified as far as possible. Measures of this kind are initiated and coordinated by the Eco-Team. In December 2008, for example, staff helped to establish a new pond, as an existing pond had to be removed during renovation work on the laboratory building. The new pond is the first step towards a natural laboratory on Eawag's doorstep. This is planned as part of the project to restore the Chriesbach stream – in cooperation with Canton Zurich, Flussbau AG, asp-Landschaftsarchitekten and other partners – which will be presented for public inspection in the summer of 2009. Initial construction work on the stream is scheduled for early 2010. Work will begin where the stream joins the Glatt and will include a new footpath/cycleway running along the Chriesbach to the Eawag/Empa site. The project will be accompanied by scientific studies. A programme for the monitoring of aquatic ecology and groundwater has already been launched.



The new pond in April 2009. In the background: renovation of the laboratory building.

Access for the public

From 2011, an "Arena" with seating steps is to be established in the natural laboratory area, which will be accessible to the general public and also used for teaching school classes and students. By then, another pond is to be created closer to the stream, which will be flooded during high-water conditions. Eawag is contributing to the funding of this project. The costs for the restoration of the Chriesbach are being borne by Canton Zurich. Sponsors are still being sought to finance further expansion of the natural laboratory, e.g. the installation of an aquarium.

A Banded Demoiselle – one of Heinrich Bührers beautiful photos taken in the near-natural surroundings of Eawag.

The rich diversity offered by near-natural surroundings is demonstrated by photos taken by Heinrich Bührer, a former employee. A long-time member of the Eco-Team, Bührer documented urban nature around Eawag in all four seasons, and then archived and annotated his pictures in an extensive database. In the autumn of 2008, the Eco-Team displayed a selection of these images in an exhibition at Eawag. ○○○

Thomas Lichtensteiger,
Environmental Officer at Eawag

Key data for Eawag (consumption of materials and energy) and details of Eco-Team projects: www.umwelt.eawag.ch

Organization

Directorate
Janet Hering (Director)
Rik Eggen (Deputy Director)
Willi Gujer
Peter Reichert
Bernhard Wehrli

Ecotox Centre Eawag/EPFL
Almut Gerhardt

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

Research departments

Research topic: Aquatic ecosystems

- **Surface Waters Research and Management**
  Alfred Wüest
- **Aquatic Ecology**
  Jukka Jokela
- **Fish Ecology + Evolution**
  Ole Seehausen

Research topic: Chemicals and their impacts

- **Environmental Chemistry**
  Juliane Hollender
- **Environmental Microbiology**
  Thomas Egli
- **Environmental Toxicology**
  Kristin Schirmer

Research topic: Urban water systems

- **Water Resources and Drinking Water**
  Rolf Kipfer
- **Process Engineering**
  Hansruedi Siegrist
- **Urban Water Management**
  Markus Boller (until 31.5.2008)
  Max Maurer (from 1.9.2008)
- **Water and Sanitation in Developing Countries (Sandec)**
  Chris Zurbrügg
- **Systems Analysis, Integrated Assessment and Modelling**
  Peter Reichert
- **Comprehensive Innovation Research in Utility Sectors (Cirus)**
  Bernhard Truffer

Support

- **IT Services**
  Gabriel Piepke
- **HR and Finances**
  Gabriele Mayer
- **Apprenticeship**
  Max Reutlinger
- **Technical Services**
  Max Mauz
- **Gender Activities**
  Gabriella Meier (until 30.11.2008)
  Natalija Miladinovic

Eawag / Empa

- **Library**
  Bas den Brok
- **Nursery**
  Joerg Klausen

Advisory Board

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

Ursula Brunner
Lawyer, Ettler Brunner Suter Bächtold, Zurich

Erika Forster
State Councillor, St. Gallen

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

Peter Arbenz
President Helvetas

Jürg Meyer
Director Wastewater Treatment Association Lucerne region

Willy Geiger
Vice Director, Federal Office for the Environment (FOEN), Bern

Directorate

Janet Hering
Director

Rik Eggen
Deputy Director

Willi Gujer

Peter Reichert

Bernhard Wehrli

Staff of the Directorate

Peter Häni
Leader

Herbert Güttinger
Further education

Isabel Wiedmer
Knowledge transfer

Sandra Ziegler Handschin
Communication

Ecotoxicology Centre

Almut Gerhardt
Leader

Research departments

Alfred Wüest

Jukka Jokela

Ole Seehausen

Juliane Hollender

Thomas Egli

Kristin Schirmer

Rolf Kipfer

Hansruedi Siegrist

Max Maurer

Chris Zurbrügg

Peter Reichert

Bernhard Truffer

Support

Gabriel Piepke

Gabriele Mayer

Max Reutlinger

Max Mauz

Natalija Miladinovic

Bas den Brok

Joerg Klausen

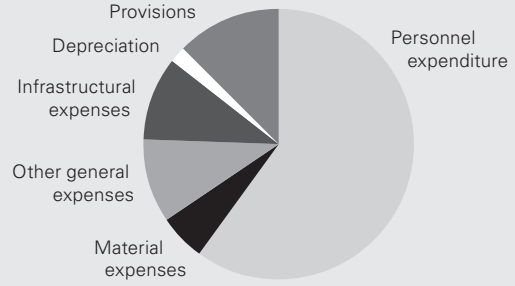
Finances

Financial statement (in CHF)	2006	2007	2008
Personnel	35 203 743	37 868 533	39 498 230
Materials	2 911 752	3 260 866	3 693 473
Other general expenses	5 556 131	6 781 444	6 582 893
Infrastructural expenses	5 160 395	6 710 435	6 466 633
Depreciation	871 718	1 082 462	1 315 815
Provisions	10 088 456	296 041	8 169 630
Expenditure	**59 792 195**	**55 999 781**	**65 726 674**
Federal government funding	49 795 822	[1] 38 491 577	54 429 850
Third-party resources	13 481 019	11 564 156	13 626 998
Miscellaneous revenue	1 010 742	1 655 624	935 584
Income	**64 287 583**	**51 711 357**	**68 992 432**
Result	**4 495 388**	**–4 288 424**	**3 265 758**

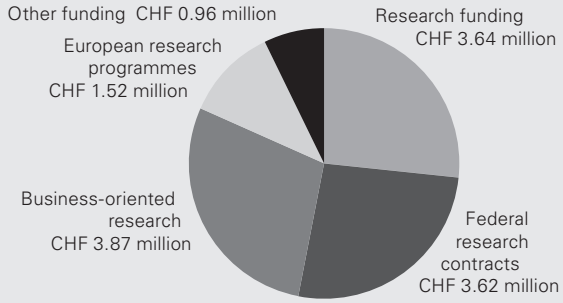
[1] Not including funding for building

Investments (in CHF)	9 370 632	15 823 645	3 849 680
Real estate	6 883 301	13 890 051	1 484 507
Movables	2 439 510	1 663 563	2 047 665
IT	47 821	270 031	317 508

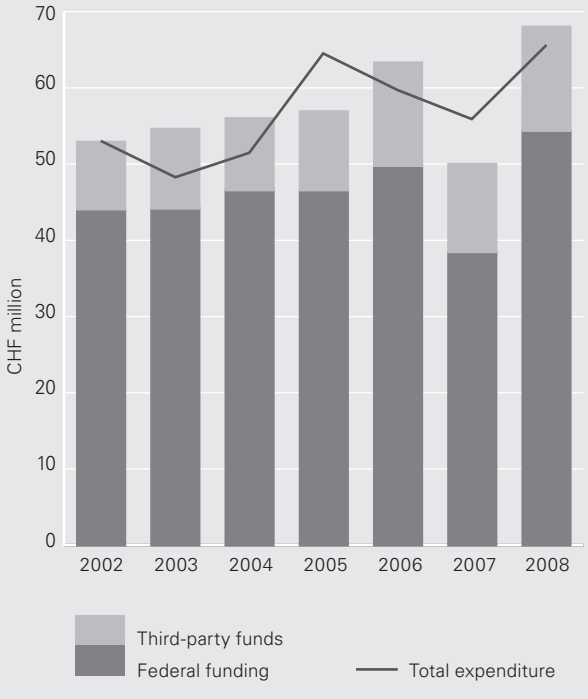
Breakdown of expenditure 2008



Third-party resources 2008



Development 2002–2008

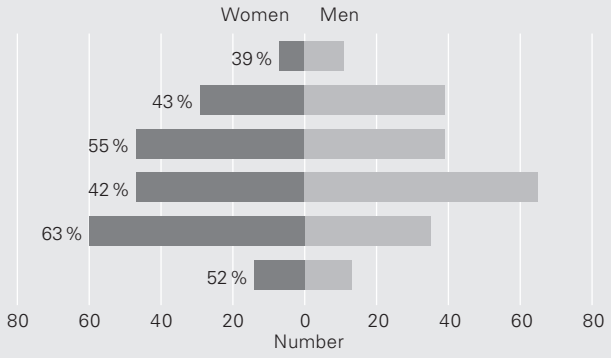


People

Personnel	People	Whereof women	Whereof non-Swiss	Full-time equivalents
Full professors [1]	7	1	4	6
Titular professors	13	2	5	13
Scientific staff (academic staff)	146	55	81	129
PhD students	72	36	40	71
Technical staff	80	39	12	68
Administrative staff	68	57	13	45
Apprentices	26	14	1	26
Total	412	204	156	358
Affiliated staff (nursery)	17	17	2	14
Trainees [2]	35	13	25	35

[1] Not or not directly employed by Eawag (incl. 1 Assistant Professor Eawag/EPFL)
[2] Variable employment periods

Age structure	Women	Men	Total
60–65	7	11	18
50–59	29	39	68
40–49	47	39	86
30–39	47	65	112
20–29	60	35	95
15–19	14	13	27
Total	**204**	**202**	**406**



Percentage employment	Women	Men	Total
1–49 %	16	11	27
50–79 %	52	8	60
80–99 %	31	19	50
100 %	105	164	269

Origin	Women	Men	Total
Switzerland	131	122	253
EU	53	66	119
Other	20	14	34

Activities

	2006	2007	2008
Supervised dissertations	107	108	119
Supervised diploma theses	104	108	97
Publications in refereed journals	194	202	253
Publications in non-refereed journals	49	55	55
Spin-offs	1	–	1
Patents, licence agreements	–	1	–
Service contracts	38	28	31
Prizes	24	19	12
Teaching programmes at ETHZ, EPFL	93	75	81
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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. A database listing all publications by Eawag staff (including article summaries) is available online at: http://library.eawag-empa.ch/eawag_publications.html Open access publications can be downloaded free of charge. The database is searchable by author, title or keyword. If you have any queries, please contact: library@eawag-empa.ch

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