eawag
aquatic research

Annual Report 2009

Eawag: Das Wasserforschungs-Institut des ETH-Bereichs

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 430 staff are employed in research, teaching and consulting at the Dübendorf (Zurich) and Kastanienbaum (Lucerne) sites.

Cover photo
Kai Udert, a process engineer at Eawag, is investigating how decentralized processes could be used for urine treatment in the future. Pictured here, a microbiological fuel cell running on urine (for more details see p. 28).
Photo: Stefan Kubli, Zurich

Content

Nothing endures but change

Heraclitus of Ephesus (ca. 535–475 BC)

Eawag has established its reputation as a world leader in aquatic science and technology. This status cannot, however, be taken for granted but must be actively maintained in an increasingly competitive arena. Eawag is well prepared to anticipate and address future challenges related to water resources, water supply and aquatic ecosystems.

In September 2009, Eawag was visited by its external peer review committee. The preparation for this visit was an opportunity to review our accomplishments since the last review in 2003 and to assess our position in research, education and service. As the committee noted, "Eawag has long had a global reputation as a leading centre – many would say *the* leading centre – for water research in the world." The committee also challenged Eawag to "devote greater attention to collectively identifying the drivers of future problems of water supply, water quality and the functioning of aquatic ecosystems in Switzerland and around the world, developing a broader shared vision of the key challenges those problems will present, [and] articulating its comparative advantages…". We will be focusing our attention on these points as we develop our strategic plan for the period 2012–2016.

Novel technologies and applications

The forefront of science is often driven by new technologies and new applications of existing technologies. A constant challenge is the need for data with high temporal resolution that can capture the complex dynamics of aquatic systems. One tool to meet this need is the Cytobuoy, an autonomous device that collects data on phytoplankton and environmental parameters along a depth transect at daily resolution (p. 16). Another example is a innovative method of rainfall monitoring using mobile phone antennas (p. 24). Eawag researchers have also developed a novel application of ultrafiltration membranes for water purification that does not require an external energy source, allowing its use in developing countries. In cooperation with Empa, several technologies have been combined to minimize the need for external water and energy supplies in the housing unit "self" (p. 21).

Emerging issues

Advances in aquatic science and technology must keep pace with new challenges. On the global scale, Eawag researchers are identifying signatures of climate change in alpine ecosystems (p. 14). On the local scale, Eawag researchers are examining the fate of new materials that are introduced into the aquatic environment through their use in consumer products. We have investigated the fate of silver nanoparticles in wastewater treatment plants (p. 25) and the occurrence of artificial sweeteners in inland waters (p. 36). In addition, investigation of the novel topic of the genetic basis for biodiversity has yielded insights into the role of sexual reproduction in combating parasites (p. 11) and suggests that the practice of fish stocking may compromise genetic diversity (p. 7).

Engaging with stakeholders

Finding and implementing solutions to real-world problems requires not only cutting-edge research but also engagement with stakeholders and practitioners. Eawag researchers are assisting the government of Rwanda in harvesting methane from Lake Kivu (p. 4). At home, Eawag researchers are investigating options for reducing the load of micropollutants from hospitals to wastewater treatment plants and thus to receiving waters (p. 38).

Research has also been conducted to assess advanced technologies for micropollutant removal at wastewater treatment plants, providing input for the FOEN's decision to introduce legal requirements for such treatment (p. 28). An important platform allowing Eawag researchers to interact with stakeholders is Water Agenda 21; here, Eawag is represented in the working groups on hydropower, integrated catchment management, and the future of water and wastewater infrastructure (p. 27). Another key forum for stakeholder engagement is the joint Eawag-EPFL Centre for Applied Ecotoxicology, which has established a strong portfolio of applied projects and continuing education and will expand its outreach activities in the coming year.

Outlook in partnership

Eawag's outstanding portfolio of activities in applied research, education and expert consulting serves as a strong base for our cooperation with partners in academia, practice, government and the public. One example is Eawag's participation in the recently initiated National Research Programme (NRP) 61 on *Sustainable Water Management.* As the lead institution in five NRP 61 projects and a participant in three others, Eawag expects to make a substantial contribution to this programme. In the educational arena, Eawag will continue its strong partnership with the two Federal Institutes of Technology (ETH and EPFL), the Cantonal Universities and international partners. In 2009, two summer schools were initiated and these will be continued in coming years. As part of our strategic planning effort for the period 2012–2016, we will be seeking opportunities to strengthen our transdisciplinary research and increase stakeholder involvement in the identification of research priorities. The overall goal is to continue to make important contributions to science and society – addressing the major global issue of meeting human needs for water, while at the same time preserving ecosystem services.

Advances in research must keep pace with emerging challenges.

Prof. Dr Janet Hering, Director

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

Passion – with a mission

Hitoshi Araki is a quiet worker who matches the popular image of a scientist – poring over data late at night, working on an article and generally betraying little emotion. But today he's beaming: What is surely his most important paper to date – on the effects of releases of captive-bred fish – has just been published in the renowned journal Biology Letters (p. 6). For the researcher, this is like an architect having his new building officially opened. "It was my father's mistake to take me fishing," he says. "Otherwise, I'd probably have opted for a 'normal' job." Now he can scarcely imagine a life without science: "It's become my passion." He began his research career investigating not fish but fruit flies and bacteria. Evolution can be studied in all forms of life. However, his childhood experiences brought him back to fish. At Oregon State University and, since 2008, as a group leader at Eawag, he has been concerned with fish ecology, population genetics and evolution. Contrary to first impressions, the thrill of probing ever more deeply into evolutionary processes is not, as he is keen to point out, an end in itself: "My aim is to improve our knowledge of how human impacts on natural ecosystems can be prevented or mitigated."

TEACHING

Sharing the capacity for discovery

Flavio Anselmetti says: "I have the privilege of being able to make discoveries." Anyone who sees the geologist giving a lecture soon realizes that Anselmetti wants to share this privilege with others. He demonstrates his capacity for discovery to his students. And they, in turn, acquire the ability to look beyond the picturesque qualities of landscapes or waterbodies. "Processes are always visible," says the professor, "if you learn how to read the signs." For example, the black layer in the sediments of Lake Zurich is not simply a pattern. It provides a record of anthropogenic environmental changes which took place over 100 years ago, when oxygen was depleted at the bottom of the lake as a result of excessive nutrient inputs. What was deposited here – rather than fully degraded matter, well mixed by organisms – was dark, partly fermented sludge from dead algae. The ability to reconstruct such changes, as well as processes which have occurred in the recent past, makes sedimentology an attractive discipline in Anselmetti's view. He has no regrets about having turned down an offer of a lucrative position as an oil company researcher after completing his PhD and working as a postdoc in Florida. And why is he so strongly committed to lecturing and excursions with students? With a smile, Anselmetti explains: "That allows me to pick out the best Master's and doctoral students for Eawag and for my field of research."

CONSULTING

Keeping an eye on vast gas deposits

Natacha Tofield Pasche, who studied environmental engineering at the Federal Institute of Technology in Lausanne (EPFL), wrote her doctoral thesis at Eawag on nutrient cycles and methane production in Lake Kivu. This lake, straddling the border between Rwanda and the Democratic Republic of the Congo in East Africa, is around one and a half times the size of Canton Zurich. Dissolved in the deep waters of the lake are almost 60 km^3 of methane and 300 km^3 of carbon dioxide. Rwanda intends to use the methane gas to produce electricity, and a pilot power plant is already in operation at Gisenyi. However, nobody knows exactly how the lake will respond to methane gas extraction. In the worst case scenario, a major gas eruption could have lethal consequences. As part of a group led by Professor Alfred Wüest, Natacha Pasche at Eawag helped to develop recommendations for methane extraction and was involved in the initial monitoring phase. Now working as a limnology expert for the Rwanda Ministry of Infrastructure, she is setting up a laboratory and training a local team which will soon be carrying out analyses independently. Also under development is a joint Congolese-Rwandan authority responsible for long-term monitoring of the lake. Pasche says: "I'm now making good use of the analytical experience I gained at Eawag and my knowledge of processes in the lake. I'm also glad that Eawag is still active on Lake Kivu, with new doctoral theses. This means my research colleagues and myself can support each other in our work."

Persistent genetic effects in descendants of hatchery fish

Young fish are released from hatcheries in efforts to maintain or restore stocks in lakes and rivers, or to promote the conservation of threatened species. A study has now shown that stocking measures of this kind may have adverse effects on the reproduction of subsequent generations of fish born in the wild.

Stocking of large and small waterbodies with fish from hatcheries is a practice with a long tradition in Switzerland and around the world. Such measures are used by cantons and fishery associations to arrest the decline of fish populations and to support threatened species, especially in waters where natural increases in stocks are hampered by a lack of the necessary structural elements (see Box on p. 10). Thanks to the large numbers released, this practice may be effective in boosting fish stocks in the short term. However, it has been known for some time that hatchery fish – generally trout in the case of rivers and streams – reproduce less successfully in natural environments than their wild counterparts. For example, in an article published in *Science*, evolutionary biologist Hitoshi Araki and his colleagues reported that reproductive fitness is reduced by almost 40 % per captive-reared generation. This decline is believed to be due to changes occurring under the artificial rearing conditions of hatcheries, but the mechanisms remain to be elucidated.

Effects also seen in wild-born descendants

In a new study, Araki has now demonstrated that these changes are heritable: They are passed on to the wild-born descendants of hatchery fish, whose reproductive fitness is thus also reduced. This downward spiral is described by Araki as a "carry-over effect".

The waterbody selected for the study was the Hood River, a tributary of the Columbia River in the Northwest of the US. For this river, long data series are available on stocking measures and on adults returning to spawn. In

Captive breeding (bottom) and the release of hatchery fish may threaten the genetic diversity of wild fish species (photo: Michel Roggo). In order to analyse genetic diversity, DNA sequences first have to be amplified with the aid of PCR systems (top); pictured in the lab is aquatic ecologist Katri Liljeroos (photo: Eawag, Stefan Kubli).

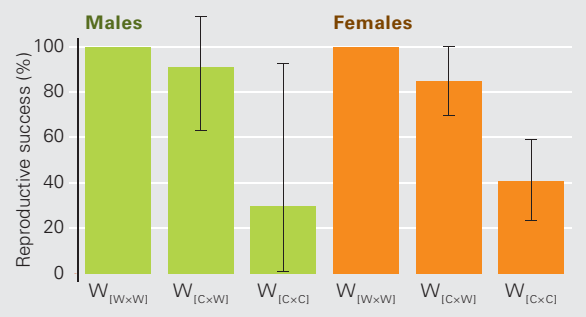


Fig. 1: Reproductive success of wild-born fish (W). This value is taken to be 100 % for fish with two wild-born parents (w × w). If either of the parents is captive-bred (c × w), the relative reproductive success (averaged over 3 years) is reduced to 84 % for females and 91 % for males. If both parents are captive-bred (c × c), the values are 30 % for males and 41 % for females. Error bars = 1 standard deviation.

particular, Araki studied steelhead trout (sea-run form of rainbow trout, *Oncorhynchus mykiss)* which returned to the river during 1999–2001 and their descendants.

Fitness of entire population reduced

Over this 3-year period, 2520 wild-born adult steelhead trout returned to the spawning grounds in the Hood River. For 779 of these fish, it was possible to determine by genetic analysis whether the parents were captive-bred or wild-born. Then, from 2001 to 2007, 1348 of the adult offspring – i. e. the third generation studied – were classified by parentage in the same way. Using statistical methods, the researchers were thus able to evaluate the reproductive fitness of the second generation. The results (Fig. 1) are unequivocal: Relative to the offspring of two wild-born parents, fish with two captive-bred parents had a reproductive fitness of only 37 % (average for both sexes over the whole period). For those with a single captive-bred parent, the relative fitness was 87 %. Relative to a hypothetical population in which all the offspring had wild-born parents, the average fitness of the Hood River population of steelhead trout was reduced by 8 %.

Interpretation hardly open to dispute

Adverse effects of captive breeding programmes are a matter of particular concern in the case of trout, since native (wild) populations of salmonids are declining sharply worldwide, and hatchery fish stocking is widely used as a countermeasure. At the same time, there is little evidence that it improves the productivity of wild populations in the long term. In addition, stocking involves a risk of introducing diseases. The fish studied by Araki were all born in the same river, were presumably exposed to the same environmental conditions and spawned in the same years. Accordingly, genetic differentiation during captive breeding in the previous generation is the most likely explanation for the substantial differences in reproductive fitness. Moreover, this effect of captive breeding appears to be carried over to subsequent generations, even though there is considerable variation from year to year (cf. error bars in Fig. 1).

What are the implications of these findings for conservation or stocking programmes? Supplementation measures involving the release of large numbers of hatchery fish may temporarily increase the size of a fish population; however, the adverse genetic effects of captive breeding appear to be so strong that they can persist and accumulate across a number of generations in the wild. The reproductive fitness of an entire population can thus be impaired. The carry-over effect is all the more striking given that the hatchery parents in this study were themselves only one generation removed from the wild.

Recovery likely to be delayed

As the reduction in reproductive fitness persists in subsequent generations, another conclusion can be drawn: Even after stocking measures have been terminated, the fish population will never be restored to its original state. And if pre-stocking conditions are gradually re-established, this will be a very slow process. The study thus also provides a possible explanation of why efforts to reintroduce endangered species through release programmes are often unsuccessful.

The precise mechanisms responsible for the observed decline in reproductive fitness have yet to be determined. Araki suspects that the artificial environment of hatcheries produces a heritable domestication effect. In a project supported by the Swiss National Science Foundation, Eawag researchers are now studying the mechanisms of rapid evolution in captive-bred brown trout.

Possibility of improvement

As well as carrying out their own studies, Araki and fellow evolutionary ecologist Corinne Schmid have evaluated the findings of other researchers. To answer the question of whether hatchery stocking is helpful or harmful for fish populations, they analysed more than 250 peer-reviewed articles published over the last 50 years. Among the 70 studies which included comparisons between captive-bred and wild stocks, 23 showed significantly negative fitness effects, while 28 showed reduced genetic variation in hatchery populations. In some studies, no positive

or negative effects were observed on the reproductive fitness of hatchery-reared fish; indeed, the abundance of fish populations was shown to be increased, as desired, in the short term. Araki and Schmid conclude that it would be worthwhile to study stocking and fishery management practices more closely in order to identify possible improvements. However, as Araki says, "Until we find a way of eliminating negative genetic effects on wild stocks, hatchery stocking should not be considered as a panacea for the recovery of endangered populations." ○○○

Swiss trout: Preserving biodiversity

The brown trout is the most common species of fish in Switzerland's waters. It is found in a wide variety of habitats, ranging from lakes and rivers in the Central Plateau to alpine streams. The environmental conditions in these habitats vary – sometimes dramatically – with regard not only to water temperature but also to factors such as flow rates, bed material, food sources, predators or parasites. For example, trout are only affected by proliferative kidney disease (PKD) in the Central Plateau. An Eawag project is investigating whether trout exhibit adaptations to local environmental conditions which can be detected by genetic analysis.

Basin of origin identifiable

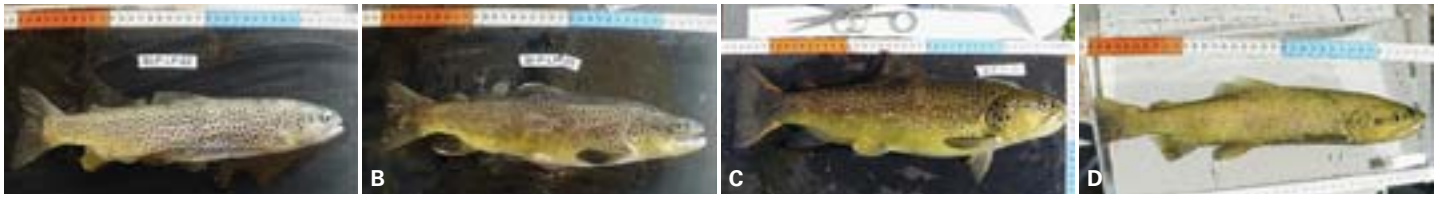
Fin-clip tissue samples were collected from 30 trout populations in tributaries of the Rhine, Doubs and Po. In the laboratory, several hundred DNA segments were then characterized as genetic markers. These data enable researchers to assess the degree of genetic similarity among fish. The analysis indicated that at least some of the historical trout diversity still exists in Switzerland. Thus, clear genetic differences can still be detected between trout from the different basins (Fig. 2). This cannot be taken for granted, since Switzerland's trout populations in particular have been heavily influenced by human factors for several decades – e.g. stocking with fish from a wide variety of origins. In many cases, it was assumed that the original diversity had already been lost.

But as well as revealing the origins of fish from different basins, the new data confirm the hypothesis that genetic differences exist between trout in the same basin. For example, some genetic variants are found much more frequently in alpine waters than in the Central Plateau and vice versa. The differences are so marked that, for evolutionary biologist Ole Seehausen, the question arises whether it would be appropriate in certain cases to speak of separate trout species.

Adaptation to environmental conditions

Seehausen's tentative conclusions – largely based on external characteristics (cf. the photographs of trout from the Poschiavino basin) – are supported by the genetic analyses carried out by two members of his team, Irene Keller and Jolanda Schuler. Many of the samples, taken at various points across the entire genome, exhibit clear spatial distributions within individual basins. Thus, even in a single basin, different trout populations appear to have different genetic adaptations to local habitats. For certain DNA segments, the same pattern is repeated in different basins. Thus, similar genetic variants have presumably become predominant in several cases, independently of each other, as a result of adaptations to comparable environmental conditions

There is little interbreeding between trout from the upper and lower reaches.



Trout specimens – with distinct appearances – from the Poschiavino basin:
A) Black spot/Lago di Poschiavo; B) Marble trout/Lago di Poschiavo; C) Brown trout/lake inlet; D) Adriatic trout/lake inlet.

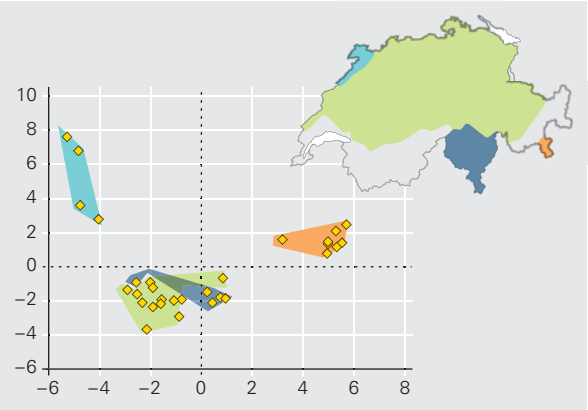


Fig. 2: Each point represents one trout population (i. e. fish from one location). The scales on the axes represent a unitless index. The greater the genetic similarity between two populations, the closer together they appear in the chart. The colours indicate the different basins studied. The Inn and Rhône were not included in this study.

(Fig. 3). In addition, it is known from other studies that two of the markers contain genes which help to determine the temperature tolerance or immune response of fish. These were analysed in detail in the case of the Allaine river in the Jura. It was shown that one genetic variant predominated in the upper reaches and another further downstream. Virtually none of the fish had mixed forms of the two variants. This finding also supports the separate-species view.

However, the data also clearly indicate the influence of stocking with trout from other basins. The high level of genetic diversity which is nonetheless still found among trout – both between major basins and within individual rivers – deserves to be protected. This diversity will be an important factor determining the ability of species to adapt to changing environmental conditions, e. g. in connection with climate change. ○ ○ ○

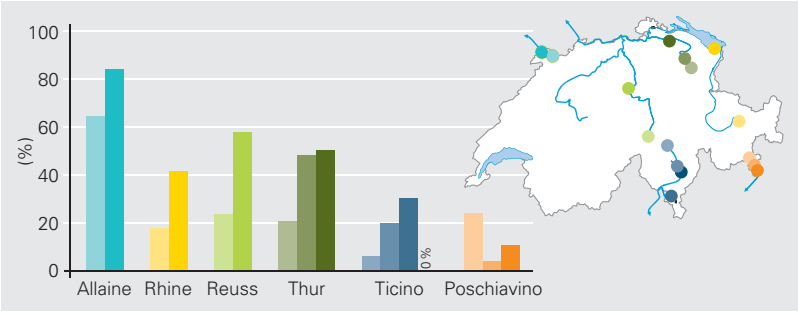


Fig. 3: Proportion of fish at the various sampling sites bearing the DNA segment designated as marker 66. Within each basin, the results are grouped by water temperature (in ascending order; close agreement with elevation). With the exception of the Poschiavino and one outlier on the Ticino, they all show the same pattern.

Trout need cover

The basic message is simple: If the structures required by fish as habitats have been lost in heavily engineered or straightened rivers and streams, the fish will soon disappear too. Two recent Eawag studies identify features which are particularly important and demonstrate the need to provide adequate structural elements for fish in river restoration projects.

▶ The first study, carried out in 2008, looked at 40 stretches of rivers and streams across Switzerland. Brown trout density and biomass were compared with various habitat characteristics. It was possible to account for 84 % of the distribution of trout biomass with only three variables – diversity of cover, total area of cover and amount of shade.

▶ For the second study, a total of 45 felled trees were introduced as structural elements in five sections along a channelized stretch of the Muehlebach stream (Liechtenstein). The following winters saw a marked increase in the abundance and biomass of trout in the "treated" compared with the control sections. The woody debris and newly created pools were sought out and used as cover by trout.

Woody debris, as here on the Luetzelmurg river (Canton Thurgau), provides cover for trout.

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Sex to keep parasites at bay

One of the most fascinating questions in biology is why large parts of the animal and plant kingdom go through the trouble of reproducing sexually. A long-term study led by Eawag has now shown for the first time in nature that – thanks to genetic recombination – sexual reproduction offers advantages in protecting populations against parasites in the long run.

Although sexual reproduction plays a central role in biology, the advantage of sex remains one of the most puzzling questions in evolution. Many plants, microbes and even some reptiles can also reproduce asexually. At first glance, this would seem to be more efficient, as it does not require the conjunction of two individuals, only one of which then produces offspring. Nonetheless, sexual reproduction is the dominant strategy. Why should this be so, when asexual reproduction permits a reproduction rate that is twice as high, as well as avoiding other complications?

Evolutionary biologist Jukka Jokela – formerly head of the Aquatic Ecology department and, since 2010, a member of the Eawag Directorate – has been studying various aquatic snails for the best part of 20 years. One freshwater species, the New Zealand mud snail, was introduced to Europe with shipments of live fish around 1880 and has subsequently spread across the entire continent. What is peculiar about this snail (which measures a mere 5 mm) is that some lineages reproduce sexually and others asexually. Together with researchers from Washington State University and Indiana University, Jokela monitored various populations of this mud snail in New Zealand.

Host-parasite arms race

The researchers found that the different snail populations do not cope equally well with parasites – and with one trematode in particular. Jokela explains: "A kind of arms race takes place between the parasites and their host." The parasites attack the host organisms, which repel the attackers – provided their genetic make-up allows them to do so. The hosts that defend themselves most effectively and persistently survive and reproduce. However, the parasites also adapt and overcome the host's defences, and the process begins anew. This arms race is known as co-evolution.

Benefits of recombination

Jokela's long-term study has now demonstrated for the first time in nature something which had previously been predicted by theorists and mathematical models. Among the sexual types, no major fluctuations were seen in the number of individuals over a period of several years. Among the asexual organisms, meanwhile, initially plentiful types were superseded by other clonal lineages within just a few years: The formerly dominant lines – sometimes almost forming "monocultures" – had become particularly vulnerable to parasites and were severely diminished or even eliminated. In other words, the parasites increasingly targeted the most abundant host and penetrated its identical defences. To use Jokela's comparison: "The best combination lock is useless if all the banks use the same code." Thus, sexual reproduction, with constant reshuffling of genes, provides evolutionary benefits – especially in the presence of parasites.

The best lock is no use if it can be opened with the same code everywhere.

Maja Schaffner

Jukka Jokela in his "snail lab" with the barely 5 mm long freshwater snails.

Parthenogenesis

The minute freshwater snail *Potamopyrgus antipodarum* can reproduce either sexually or asexually. "Normal" males and females live alongside triploid females (i. e. having three sets of chromosomes). The latter reproduce solely by parthenogenesis ("virgin birth") – cloning themselves to produce offspring. All forms of this snail are infected by a large number of parasitic trematodes. In Europe, only asexual reproduction has been observed to date. This could also provide an explanation for the mass occurrence and subsequent collapse of populations of this species. In the 1970s, densities of up to 100,000 per square metre were recorded in Lake Constance. Today, this snail occurs almost everywhere, but is not dominant anywhere.

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Jurassic Park from a Swiss lake

Ecological changes caused by humans affect natural biodiversity. For example, the eutrophication of Greifensee and Lake Constance in the 1970s and 1980s led to genetic changes in a water flea species which was ultimately displaced. Despite marked improvements in water quality, the species has not been re-established. This was demonstrated by analyses of genetic material from *Daphnia* eggs up to 100 years old.

Evolutionary biologist Nora Brede explains enthusiastically: "In the laboratory, we were able to revive resting eggs over 40 years old isolated from Greifensee sediment." For Eawag, this Jurassic Park-style science has a serious purpose: It makes it possible to determine retrospectively which *Daphnia* species was dominant in the lake around 1960, and whether the species that prevailed in the 1970s and 1980s became more tolerant of pollutants. *Daphnia*, which are crustaceans, can produce diapausing (resting) eggs – e.g. when food supplies are inadequate – which develop into a living organism when conditions subsequently become more favourable. As these eggs are deposited in datable layers of anoxic sediments, their DNA can be analysed even after the passage of 100 years or more.

The species' genome structure changed measurably in just 50 years.

Nora Brede with a Greifensee sediment core. Thanks to the readily detectable annual laminations, eggs deposited in the sediment can be precisely dated.

Irreversible effects

What makes this biological archive particularly interesting is the fact that conditions in the lake have undergone dramatic changes since 1960. In the 1970s and 1980s, inputs of phosphate detergents and fertilizer runoff led to eutrophication, with the development of algal blooms, including toxic cyanobacteria (blue-green algae). Oxygen depletion resulted in a number of major fish kills. Genetic analysis of *Daphnia* eggs has now revealed that excessive nutrient levels also affected genetic diversity. At the beginning of the 20th century, only one species of water flea *(Daphnia hyalina*) occurred abundantly in the two lakes studied. As eutrophication developed, this was displaced by another species *(Daphnia galeata)*. In the transitional periods before and after peak nutrient inputs, hybrids also developed. However, although the lakes are now once again much cleaner (thanks to significant wastewater management efforts), the original species has yet to recover.

Rapid evolution

According to Nora Brede, "This demonstrates that anthropogenic changes, such as eutrophication, can have dramatic and not fully reversible effects on animal species." In addition, the research project also showed how rapidly evolutionary processes can unfold in the animal kingdom. Brede comments: "In a mere 50 years, there have been measurable changes in the genome structure of a species, which is amazing, given that this is an extremely short period on the timescale of the Earth's history."

Better adapted to high lead concentrations

Biological archives such as the resting eggs of *Daphnia* in lake sediments are a valuable tool for investigating how organisms respond to changes in their environment and for analysing evolutionary processes. Research is focusing in particular on the question of how quickly plants and animals adapt genetically to alterations in temperature associated with global climate change. Changes in pollutant tolerance have also been observed: In one experiment, *Daphnia* raised from 30-year-old resting eggs survived considerably longer in the presence of high lead concentrations than their counterparts today. They were evidently better adapted to the conditions prevailing at that time, when larger amounts of lead entered the environment. Lead concentrations have since declined sharply as a result of the phasing-out of leaded petrol (banned in 2000).

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An alternative to dyeing river water

Restoration measures may have implications for groundwater wells close to a river. The "Record" project is investigating how water quality is affected by exchanges between surface and groundwater. Time series analysis of easy-to-measure parameters has been successfully used as an alternative to more costly tracer studies.

The widening of a channelized river can influence water quality in various ways. For example:

▶ Water exchanges between the river and riverbed are increased by the dynamics of newly formed gravel islands and bars. The filtration of river water is improved, and the self-purifying capacity of the river is enhanced.

▶ The permeability of the riverbed – and thus river-groundwater exchange – is altered.

▶ The riverbed is widened or moved closer towards groundwater wells, possibly shortening flow paths between the river and drinking water pumping station.

From the perspective of drinking water protection, the main points of interest are what proportion of the water extracted originates from the river and how long river water takes to pass through the aquifer. If the travel time is too short, the necessary purification is considered to be no longer assured. To date, these questions have been answered with the aid of tracer studies. This approach involves the introduction of dyes or other artificial tracers into river water – in considerable quantities, where large rivers are concerned. The desired information is then obtained on the basis of the time it takes for tracer-labelled water to reach the well and the degree of dilution.

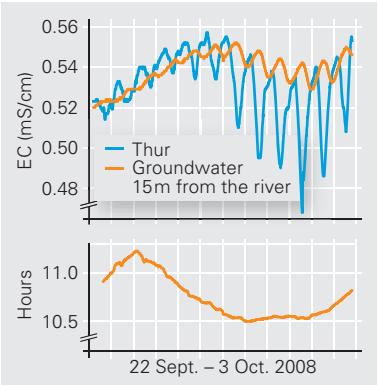
Online measurement

Eawag has now developed alternative methods of obtaining the same information, using long-term time series for water temperature and electrical conductivity. This approach is less costly and also offers the advantage that it does not require the use of artificial tracers. In addition – unlike with tracer studies – the results are not merely snapshots. As part of the Record project (see Box), the new method was applied on the Thur by installing a variety of sensors (some specially developed for this purpose) both in the river itself and in the aquifer. Data was collected at short intervals from a restored and a channelized river section and transmitted wirelessly for analysis.

Diurnal fluctuations used as a tracer

It is interesting to note that the electrical conductivity (EC) of Thur river water exhibits not only familiar seasonal variation due to snowmelt but also marked diurnal fluctuations. Maximum EC values are observed in the morning and minimum values in the late afternoon, which can be attributed to biogeochemical processes in the river. This pattern can thus be used as a natural tracer for wells close to the river. Residence times are revealed by mathematical transformations, showing that river and groundwater exchange varies not only spatially but also temporally (see Figure). The shortest residence times are observed under high-flow conditions. In addition, the EC signal is transported more rapidly in the natural bank of the restored section than in the stabilized bank of the channelized section. However, no overall trend has yet been detected which could be used to explain local clogging/declogging of the riverbed (i. e. reduced/increased water exchanges). For Record project leader Mario Schirmer, therefore, the results to date are all contributions towards an improved understanding of the complex interaction between river water and groundwater.

In the case of the pumping well studied at Niederneunforn, it was shown that around 40 % of the water extracted is freshly infiltrated Thur river water, with an average travel time of 11 days. Mario Schirmer comments: "If the residence time of river infiltrate only amounts to a few days, the restoration of sections close to wells needs to be carefully considered. But the relocation of wells shouldn't be taboo either." ○ ○ ○



The diurnal variation of electrical conductivity (EC) in the Thur and in an adjacent groundwater well (top) can be used to calculate the travel time of infiltrating river water (bottom).

The Record project

The Record (REstored CORridor Dynamics) project is designed to study coupled ecological and hydrological processes in connection with river restoration measures. The findings should facilitate more objective discussion of the outcome of restoration projects and also permit predictions based on sound models. Record, running from 2007 to 2011, is a joint project involving Eawag, the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), and the Federal Institutes of Technology in Zurich (ETH) and Lausanne (EPFL) within the framework of the Competence Center Environment and Sustainability of the ETH Domain (CCES). Record itself forms part of Swiss Experiment, an interdisciplinary environmental monitoring programme for early detection of natural hazards.

http://www.cces.ethz.ch/projects/nature/Record
http://www.swiss-experiment.ch

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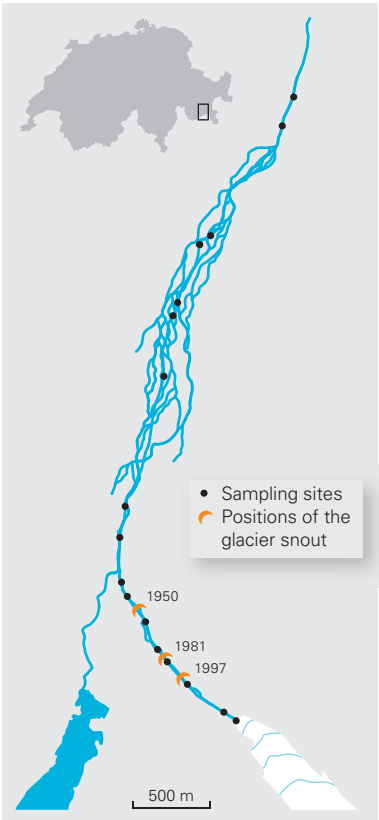
As glaciers retreat, so do Alpine specialists

When glaciers recede, they leave behind a rough, rocky landscape. However, newly formed glacial streams are rapidly colonized by cold-adapted organisms. Researchers from the Aquatic Ecology department are investigating whether Alpine specialists can adjust to the changing environmental conditions or are ultimately displaced by low elevation generalists.

The warmer the climate becomes, the more Switzerland's glaciers recede – currently by an average 10 m a year in the Swiss Alps. A retreating glacier leaves behind an apparently inhospitable area, drained by an ice-cold glacial stream. Interestingly, it only takes a few years or even less for the so-called proglacial stream reach to be colonized by alpine flora and fauna. Cold-adapted species occupy the new habitats, extending their altitudinal range. But as warm-adapted species from low elevation areas also advance upstream, entire biological communities successively shift to ever-higher altitudes along the watercourse. However, they are not exact copies of the original communities since warmer temperatures influence a variety of physical environmental factors, such as water balance and soil formation, which will continuously provide new interactions between the communities and their habitats. To find out more about these processes, a team of Eawag researchers from the Aquatic Ecology department studied a section of the glacial stream below the Tschierva Glacier. The glacial source lies at an altitude of more than 3000 m in the Val Roseg, above Pontresina (Canton Graubünden). Debra Finn, Katja Räsänen and group leader Christopher Robinson compared physical and biological data from 2007 and 2008 with data collected in the same area in 1997.

Rapid response of organisms

Over this 10-year period, the Tschierva Glacier receded by ca. 480 m. As expected, the researchers noted a marked increase in water temperature: While the highest temperature measured in 1997 was 4.7 °C, in 2007/08 it was 6.6 °C. Christopher Robinson comments: "The organisms' response to their changing environment was surprisingly rapid." As well as shifting upstream, the community changed its structure: Among 21 species of aquatic insects – the predominant local class of fauna – the researchers identified 4 species not previously recorded. These species, coming from low elevation habitats, are mostly generalists, thriving in a variety of environmental conditions. In 1997, they were presumably limited by the harsh environmental conditions in the glacier stream. Ten years later the situation has reversed: The highly specialized



The study area on the Roseg stream below the Tschierva Glacier. Sampling sites and earlier positions of the glacier snout are shown.

Temperature: A key factor

Left: Larva of the mayfly *Baetis alpinus*, a typical cold-water specialist capable of thriving at altitudes over 2000 m a.s.l. and at water temperatures below 4 °C. Right: The mayfly *Ecdyonurus* sp., a generalist species occurring in most streams and rivers, but generally found well below 2000 m a.s.l. In 2008, it was observed by Eawag researchers at altitudes up to 2200 m a.s.l. in the mainstem glacial stream of the Val Roseg. Larvae of both species feed on the same fine algal layers on the surfaces of stones (periphyton). Aquatic ecologist Chris Robinson therefore expects that *Ecdyonurus* will soon spread even further upstream. Unlike in 1997, water temperatures of 4 °C or more are now measured 1.5 km below the glacier snout in the broad Roseg floodplain between 2000 and 2100 m a.s.l. In 1997, water temperatures never exceeded this value even 5 km further downstream.

euroflyangler.com

ETH Library, Image Archive

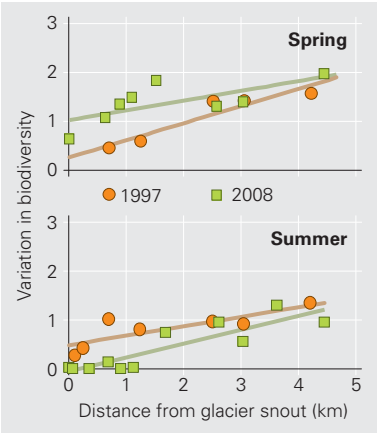
Jürg Alean

The retreating Tschierva Glacier, pictured around 1875 (left) and in 2004 (right).

species cannot adapt quickly enough to rapidly changing conditions and are increasingly losing out to species with less demanding requirements (i.e. generalists). As Robinson explains, "This development is typical of an ecosystem which is in a state of transition." As a result, the incoming species initially increase local biodiversity. Robinson says: "The highly specialized species migrate to higher altitudes – but at some point that's no longer possible." He predicts that genetic diversity and thus also biodiversity will decline in the long term.

Stream life in flux

To investigate the physical changes in the glacial stream, Robinson and his colleagues analysed hydrological data for the period 1955 – 2007. They found that, over the years, streamflow variation increased between spring/summer and autumn/winter. A shift in precipitation was observed from winter to spring and, in addition, the onset of spring runoff occurred earlier in the year. The altered hydrological regime in the glacial stream affects both the life cycles of individual species and overall species composition – depending on the various species' ability to adapt. In spring 2008, for example, biodiversity was higher than in 1997: This may be attributable to higher survival of larvae in the winter in 2008. Conversely, summer became a more stressful season in 2008, as streamflows were regularly higher and more turbulent than only a few years previously. Consequently, biodiversity was lower in summer 2008 than in summer 1997.



Variation in biodiversity (Shannon index) in the Roseg stream in spring (top) and summer (bottom) between 1997 ● and 2008 ■ as a function of downstream distance from the glacier snout.

Alpine pastures left high and dry?

The impacts of retreating glaciers extend far beyond alpine habitats: Changing precipitation patterns and decreasing winter precipitation influence all those areas that depend on water reserves in the mountains. Today, some mountain cabins and pastures already have to rethink the provision of water supplies, as the runoff that used to flow throughout the summer now dries up when the snowmelt is over. Looking ahead to the next 100 – 200 years, Christopher Robinson expects that glaciers worldwide will only persist at altitudes over 3000 m above sea level. By way of comparison, as recently as 1870 – at the time of their last maximum extent – the snout of certain Swiss glaciers lay below 1700 m.

Specialist species migrate upslope, but that can't go on forever.

The shifting of habitats to higher altitudes is not confined to the Alps. Robinson's team is therefore currently extending the scope of its research to include North America and possibly the Andes, so as to permit comparisons between the world's major mountain ranges. ○○○

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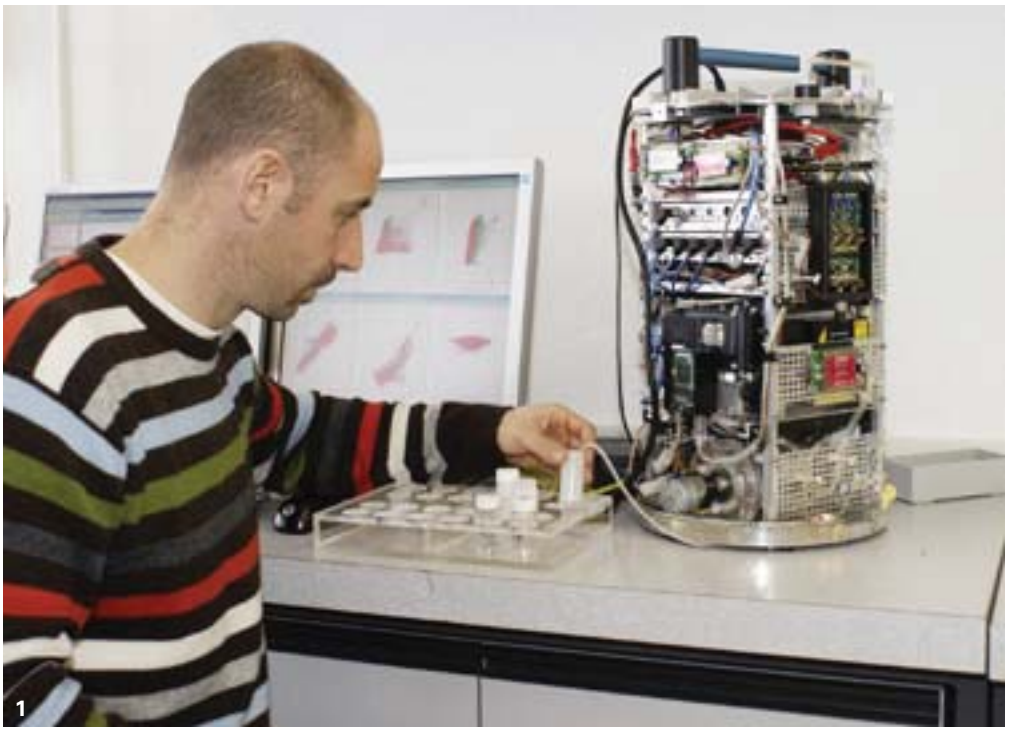
Closer monitoring of lake water

Lakes are not only valuable ecosystems but also significant sources of drinking water. Worldwide, however, they are under pressure from climate change, pollution or damming in catchments. Any monitoring data available tend to provide only snapshots of processes in lakes. Such data can neither explain the changes occurring nor allow predictions to be made. The AquaProbe project – involving a floating online monitoring platform – is designed to address this problem.



[1] In the lab, limnobiologist Francesco Pomati tests the core element of the plankton monitoring platform – the automatic flow cytometer. The initial analyses displayed on the screen indicate the assignment of the counted cells to various classes of algae.

[2] The sensitive instrument is placed in a special housing, which can then be mounted on the floating platform.

[3, 4] Apart from the floats, virtually none of the equipment could be purchased off the shelf. Pictured here are two components designed in Eawag's workshop. Top: The system used to guide the cable from the winch to the Idronaut probe, which is deployed to gather physical and chemical water data. Bottom: The sampling chamber, where lake water is stored temporarily after being pumped up from a specified depth before a small quantity is analysed in the flow cytometer.

[5] Francesco Pomati lowers the Aquaprobe (suspended on a red cable) into the lake water. Samples from predefined depths are conveyed through the blue tubing to the flow cytometer mounted on the platform.

[6] The Cytobuoy moored on Lake Lucerne during the test phase (Mount Pilatus can be seen in the background). Data is transmitted continuously to Eawag at Kastanienbaum by a radio link.

[7] Loading of the platform at Lucerne harbour for transport to Lake Lugano.

[8] Staff from Eawag and the University of Applied Sciences of Southern Switzerland (Supsi) preparing the equipment used for data collection on Lake Lugano; in 2010 the platform is moored near Caslano.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Cooperation among six Eawag departments

At a federal research institute, there is nothing unusual about cooperation between engineers and modelling experts, or between drinking water specialists and microbiologists. But the involvement of six different departments – as well as external partners – in a single project is rather special, even for Eawag. This breadth is crucial to the ambitious AquaProbe project, which aims to find out more about short- and long-term changes in plankton communities. The findings should facilitate understanding, prediction and modelling of processes in lakes and – where necessary – also be used to identify possible management measures.

Phytoplankton forms the basis of the food web in lake ecosystems. Changes in plankton affect all other lake communities. However, it remains unclear whether plankton community composition is simply a chance assembly of local species or whether the selection is controlled by particular mechanisms. New conditions can arise within a matter of hours as a result of algal blooms (e. g. toxic cyanobacteria). For this reason, the detection of detailed temporal and spatial dynamics of plankton is of fundamental importance for research. High-resolution data are lacking. Project manager Jukka Jokela explains: "Typical plankton monitoring programmes are based on monthly samples, usually only collected from one lake site and depth. Expressed in terms of forest monitoring, that would be like having a look once every few thousand years and then deducing from the comparison what has happened in the meantime."

These deficiencies are to be remedied with the aid of a floating monitoring platform. With this system, samples automatically collected from various depths are conveyed day and night through a long hose to a customized flow cytometer, which is installed in an aluminium cabin moored on the lake. Sampling is controlled by a concurrently deployed probe, which monitors physical parameters such as pressure, temperature or conductivity. As well as counting the plankton cells, the floating instrument records their shapes and fluorescence spectra and even takes individual photographs. The wirelessly transmitted data can then be analysed in detail onshore.

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

Starting with people

Hans Joachim Mosler first studied zoology and then psychology. Explaining his change of direction, the Titular Professor says: "I realized that whenever you want to change something, you have to start with people." But Mosler does not aspire to the role of a therapist – his research always relates to large groups, as his field is environmental psychology. One of the first questions he dealt with in this area was how to get as many people as possible to observe a 30 km/hour speed limit voluntarily. At Eawag, he and his team are primarily concerned with behavioural changes among people in developing countries. What measures can promote compliance with rules of hygiene or the consistent use of solar water disinfection (see the article on Sodis, p. 24)? Mosler believes that good ideas require dissemination mechanisms, and that behaviour is determined by the same factors all over the world. "For example," he says, "I've never seen a society where people were not influenced by the people around them, or where social prestige was of no importance." And what is more important for him as a scientist – helping to improve sanitation in an African community, or publishing the findings in a renowned journal? Mosler replies enthusiastically: "The great thing about our work is that we do both. We put ideas into practice, but we also carry out research and learn from our efforts so that things can be done even better somewhere else."

TEACHING

Fostering initiative

Originally, he planned to build wind turbines and devote himself to alternative sources of energy. But after studying environmental engineering, **Eberhard Morgenroth** ended up in the field of urban water management. This, of course, also gives him opportunities to do something useful for the environment and society. Having gained his Master's degree in the US and his doctorate in Germany, he worked for several years at the Technical University of Denmark (Lyngby) and the University of Illinois (Urbana-Champaign). Since August 2009, he has been head of an Eawag research group and Professor of Process Engineering in Urban Water Management at the ETH in Zurich. In his teaching, he aims to lay the foundations which will subsequently enable students to attain academic independence. Morgenroth says: "The challenge is to teach in such a way that students will think for themselves and can take the initiative." Morgenroth has been designated to step into the shoes of Willi Gujer – the recipient of a number of awards for outstanding teaching – who is due to retire at the beginning of 2011. "That certainly inspires me," he admits. "At the same time, I'll be benefiting from the fact that the students have got used to being stretched and are highly committed to the subject."

CONSULTING

Protecting water supplies against sabotage

Hans Peter Füchslin, a microbiologist who wrote his doctoral thesis at Eawag, now works at Bachema AG, a private analytical laboratory, and lectures at the ETH in Zurich. With support provided by Eawag, the Swiss army captain and other water researchers liable for compulsory service have also been able to apply their knowledge on military refresher courses. They have been focusing on possible acts of sabotage at drinking water installations. This work was prompted by an incident (as yet unresolved) which occurred at the lake water utility in Sipplingen (Germany) in 2005. Fortunately, the dumping of two canisters of pesticide did not adversely affect the quality of water supplies. However, it demonstrated to officials the acute vulnerability of such installations – the Lake Constance facility supplies water to more than 4 million people. As part of a joint project involving the army, Eawag and the Swiss Gas and Water Industry Association (SVGW), Füchslin's group has developed guidelines for sabotage prevention and preparedness. The guidelines are currently out for consultation and should be formally adopted this summer. As well as including straightforward recommendations on controlling access to water installations, the 45-point checklist deals with the detection of attacks on water supplies, communication in a crisis, and technical measures within the distribution network.


self

Efficient Recycling of a scarce resource

Lack of access to clean water is one of the main health problems in many parts of the world. With its research on decentralized water treatment, Eawag could make a significant contribution to the achievement of the Millennium Development Goals. Laboratory and pilot experiments have shown that membrane technology can make it possible to produce safe drinking water even under the most rudimentary conditions.

The "Self" module, which entered field-testing in February 2010, is designed to provide a temporary living space and workplace for two people, independent of external power and water supplies. The two research institutes Empa and Eawag contributed their technical expertise to the development of the module, while Zurich University of the Arts (ZHdK) was responsible for the design. The freight container-sized structure weighs around 5 tonnes and can thus be transported almost anywhere in the world by truck or helicopter. Although it was destroyed by fire at Easter 2010, the project managers plan to fit out a second unit, which was originally intended to serve as an add-on module. "Self" does not need to be connected to a mains power supply, as it has its own power generation system: 1280 solar cells mounted on the roof – with a maximum output of 3750 watts – will provide the electricity required all year round for a module used, for example, as a mobile research station.

Autonomous water supply

Likewise designed to ensure self-sufficiency are the technologies developed by Eawag for preparing drinking water and for recycling most of the wastewater. Rainwater is first collected on the roof, which has a surface area of 26 m^2. Maryna Peter-Varbanets of the Process Engineering department explains: "Although rainwater is relatively clean, it may, depending on the location, be contaminated, for example, by bird droppings, leaves or pollen." To remove these particles and pathogens (bacteria and viruses), "Self" is equipped with a membrane module the size of a shoebox. The pores of the plastic membrane – with a filter surface area of 0.7 m^2 – each measure only a fraction of a micrometre. While water and dissolved

The self-sufficient living module "Self" – here, pitched near Lake Sihl – is a research and demonstration project. As regards water, it is designed to demonstrate the feasibility of obtaining drinking water from treated rainwater and recycling grey water. Decentralized systems could thus represent an alternative to more costly centralized infrastructure – which is not even a realistic option in many parts of the world. Bottom: Sewer repair work. (Photos: Empa, Beat Guyer; Waste Disposal + Recycling Zurich/ERZ)

minerals pass through this mechanical treatment step, turbid matter, bacteria, parasites and even viruses are retained. Ultrafiltration thus also functions as a disinfection process, without any need for chemical agents such as chlorine or ozone.

Gravity-driven system

When ultrafiltration is used for large-scale drinking water treatment, as is increasingly the case at centralized waterworks, the process generally involves pumps. These allow raw water to be forced through membrane pores at regular design fluxes of 20 – 100 l per m^2 membrane and hour, so that the system can provide sufficient quantities of treated water within a reasonable time.

In the interests of low-energy and low-maintenance operation, "Self" functions without a pump, relying on gravity alone. The pressure of 100 mbar arising from the roughly 1 m height difference between roof and membrane is enough to permit the preparation of at least 30 l of safe drinking water for daily consumption. In the living area, a display reminds the occupants of how much fresh water they are using. This relatively modest amount (compared to normal domestic drinking water consumption) is sufficient because, in addition, treated grey water is available for applications such as personal hygiene, dish-washing and toilet-flushing.

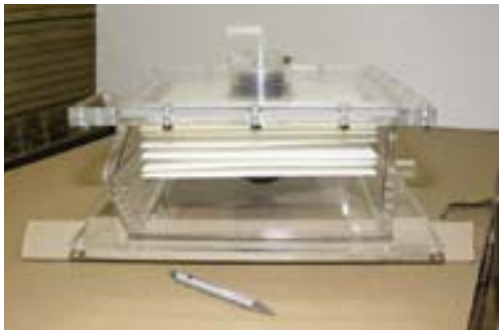
How does the low-pressure process work?

With an expected flux rate of around 5 – 10 l per m^2 membrane and hour, the capacity of the low-pressure filtration system developed by Eawag is considerably lower than that of conventional membrane systems. This, however, is a deliberate design feature, since the operational advantages of the system easily outweigh the higher membrane area required. As laboratory and pilot tests have shown, the permeability of the membrane is preserved for a long period even without the use of chemical cleaning agents. During the initial days of operation, the flux rate declines markedly, as filtration gradually leads to the development of a biofilm on the membrane. However, despite the increased resistance, this process does not result in the formation of an impermeable fouling layer. Instead, the flux rate stabilizes after several days and then remains at a constant level. According to Wouter Pronk, head of the Drinking Water Technology group, laser microscopy confirms that the biological activity leads to the formation of cavities in the biofilm, which combine into channels. As a result, the cake layer becomes porous, and a state of equilibrium is established between the deposition and degradation of organic matter on the membrane, which also stabilizes the flux rate. By contrast, if raw water is disinfected with chemicals such as sodium azide prior to ultrafiltration, membrane permeability declines steadily throughout the period of operation, as the disinfectant also inhibits desired microbiological activity in the layer covering the membrane.

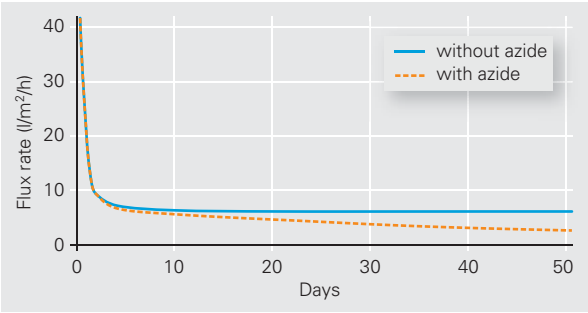
The performance of low-pressure membrane filtration depends in particular on the contaminant load of the raw water to be filtered and on the composition of the natural organic matter: the cleaner the starting product, the greater the flux rate. For example, with a membrane surface area of 1 m^2, approx. 14 l of drinking water per hour can be obtained from river water which has previously passed through a sand filter. However, if diluted wastewater is used, the long-term flux rate is reduced to 3 l/hour.

Variety of advantages for developing countries

Given its simplicity, low-pressure ultrafiltration is especially suitable for decentralized water treatment in developing countries. More than 900 million people currently lack access to safe drinking water – a public health



Left: A compact treatment system is installed above the grey water tank in the equipment compartment of "Self". Centre: Membrane module for preparation of drinking water from roof rainwater. Right: Membrane module for recycling of grey water.



Flux rate for membrane filtration of river water with and without prior disinfection with sodium azide.

problem which also severely impairs productivity. As the costs of membranes have fallen substantially, point-of-use water treatment systems could now be provided for individual homes or small communities for around EUR 1 per person and year, given the economies associated with large-scale production. Another advantage of the low-pressure process is that it does not require an external power supply or chemicals, needs very little maintenance and is both easy to operate and relatively safe. As Wouter Pronk points out, "Faults such as possible clogging of the membrane after prolonged use do not lead to the breakthrough of pathogens, but merely a decline in performance."

As a participant in the European "Techneau" project, launched in 2006, Eawag has not only carried out basic research but also designed a pilot system, which was constructed in cooperation with industrial partners KWB and Opalium (a Veolia Water Systems company). The low-pressure ultrafiltration unit installed in a space half the size of a freight container uses a biosand filter for pretreatment and can supply approx. 5000 l of treated drinking water per day. Following a successful test phase in France, using river water from the Marne, the unit is now (since the end of 2009) being tested in the South African village of Ogunjini near Durban. Maryna Peter-Varbanets explains: "Here, we're particularly interested in how membrane filtration is affected by the sometimes highly turbid raw water."

Decentralized wastewater treatment

In dry regions, where water is a scarce resource, or in remote (e.g. mountainous) areas not connected to supply or disposal systems, decentralized wastewater treatment may also be a viable option. For this reason, the "Self" living module is equipped with a compact wastewater treatment unit in the form of a membrane bioreactor, which is also gravity-driven. The washing machine-sized unit treats the daily kitchen and shower wastewater (grey water) but not the heavily soiled wastewater from the water-saving toilet (black water). The latter is stored in a separate tank and periodically removed from the cycle. Taking into account the recycled grey water, which can be reused for showering, dish-washing and toilet-flushing, Eawag calculates that the occupants of "Self" have at least 100 l of water available per day. This means that – even without rain – two people will have sufficient fresh water to live in the module without any loss of comfort for about 2 weeks. To prevent microbial recontamination during storage, the treated drinking and grey water in the two 200 l tanks is irradiated with a UV lamp at regular intervals.

As costs have come down, point-of-use water treatment with membrane technology has become an attractive option.

The field tests will show how effective the grey water treatment process is. Microbiologist Adriano Joss says: "At conventional plants, wastewater treatment via membrane filtration is now running relatively smoothly. The question is whether biological degradation of carbon in the 'Self' project will also work well enough with a lower supply of nutrients. The grey water lacks the abundant nutrients present in urine and faeces, which are used by microbes." At worst, a viscous substance could form, gradually clogging the pores of the membrane.

However, the idea of repeated use of treated wastewater remains promising. The international "Reclaim Water" project, for example, has investigated technologies for treating wastewater in such a way that it can be used for groundwater recharge. The main objectives are to monitor and reduce the content of pathogens, micropollutants and other contaminants in reclaimed wastewater. In this context, Eawag has studied the effectiveness of a membrane bioreactor combined with nanofiltration on a pilot scale. ○ ○ ○

EU project "Technology Enabled Universal Access to Safe Water": www.techneau.org

EU project: "Water Reclamation Technologies for Safe Artificial Groundwater Recharge": www.reclaim-water.org

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Measuring rainfall with mobile phone antennas

As rain interferes with radio signals, Eawag researchers have been able to measure rainfall using data supplied by the mobile telecommunications company Orange. The new method offers greater spatial resolution than traditional point measurements provided by rain gauges. In the future, this could be combined with intelligent control systems for sewer networks so as to reduce water pollution in urban areas.

Especially in built-up areas, sewer systems are frequently overwhelmed by unexpected rainfall: Stormwater is mixed with sewage in pipes, and the murky mixture overflows from retention basins into local surface waters. Diluted but untreated wastewater – containing chemicals such as cleaning agents and pesticides – is thus discharged into streams, rivers and lakes. Across the year as a whole, the inputs are relatively low, with only about 2–5 % of the total load (depending on the individual substance) entering surface waters via combined sewer overflows. However, short-term peak pollutant levels can be harmful to algae or fish. Accurate detection or even prediction of rainfall at the local level would allow sewer systems to be controlled more effectively.

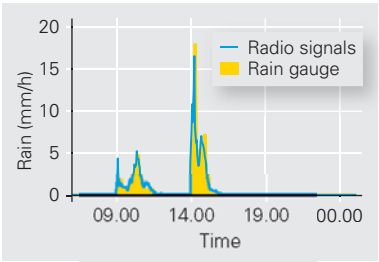
Greater accuracy

How does the method work? Project leader Jörg Rieckermann and his research team are taking advantage of what is essentially a nuisance for mobile network operators – the fact that raindrops interfere with microwave radio links between base stations, thereby disrupting signal transmission. Data on the attenuation of signal strength is used to calculate the intensity of rainfall along the path between two antennas. Thanks to the density of the mobile phone network, the spatial and temporal resolution of the Eawag rainfall data is superior to that provided by rain gauges or weather radar. In contrast to point measurements, the mobile signal data is based on a network of overlapping microwave radio links. However intense a small-scale storm may be, it will not be captured by a rain gauge located even 100 metres away. And while weather radar can cover a wide area, misleading echoes are generated by the terrain, and radar signals are heavily attenuated by intense rainfall.

Directional antennas transmit mobile phone signals over the rooftops of Zurich.

First-ever data from Switzerland

Although rainfall measurements have been derived from radio signals before, they have not so far been applied in practice. Using the copious data made available to Eawag by Orange, it is now possible for the first time to employ this system for purposes of water pollution control. In order to apply the method to an area of around 150 km^2 – with an extensive sewer network – in the Zurich region, the researchers analysed data from 23 microwave radio links in this part of Switzerland (in principle, almost 100 could be used). They compared the data with measurements from 13 rain gauges, 2 disdrometers and the Albis weather radar station operated by MeteoSwiss. The model was thus calibrated, and precipitation can now be reconstructed from radio signal data. Rieckermann hopes that accuracy can be further improved in future by also including drop size distribution in the calculations: While a few large drops scatter and attenuate the radio signal in a similar way to numerous small drops, they generally mean less rain. Accordingly, a method taking these patterns into account is currently being developed by project partners at the Federal Institute of Technology in Lausanne (EPFL).



The attenuation of a microwave radio signal is in close agreement with the rainfall intensity measured by a rain gauge (rain rate in mm/h); however, this is only the case if a rain gauge happens to be located at the centre of a rain cell.

Municipal trials under way

The model is now being field-tested in two municipalities. In at-risk areas, local forecasts of precipitation intensity and movement are being used to regulate retention basins before and during rain events, so as to free up capacity to cope with the expected water volumes. The aim is to keep wastewater overflows to a minimum. As Rieckermann points out, "This means that existing reserves can be activated without having to rebuild the drainage system." ○○○

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Silver nanoparticles removed from wastewater

A growing number of products contain silver nanoparticles, and washed-out silver enters treatment plants in wastewater. Do its antimicrobial effects inhibit biological treatment? Not at the concentrations to be expected in real life, according to a recent Eawag study. The experiments also indicate that nanosilver is effectively eliminated by wastewater treatment.

Nanosilver is increasingly being used in cosmetics, paints, plastics, disinfectants and textiles. These tiny silver particles have antimicrobial effects when silver ions are released in the presence of moisture. But washed-out silver particles can also enter wastewater treatment plants (WWTPs) via discharges from households and industry. As it was not clear whether the effectiveness of biological treatment is reduced as a result, Eawag – in collaboration with the Federal Office for the Environment and the Canton Zurich Office for Waste, Water, Energy and Air (AWEL) – investigated the behaviour and effects of silver at a WWTP.

No reaction with realistic concentrations

Michael Burkhardt and Steffen Zuleeg (both environmental engineers) examined how silver affects nitrification in activated sludge, given that ammonia-oxidizing microbes are considered to be the most sensitive in the biological treatment step. Since numerous types of silver are currently on the market, various products were tested in addition to silver nitrate – ranging from "pure" nanosilver to nanosilver bound in larger (micro-sized) carrier particles.

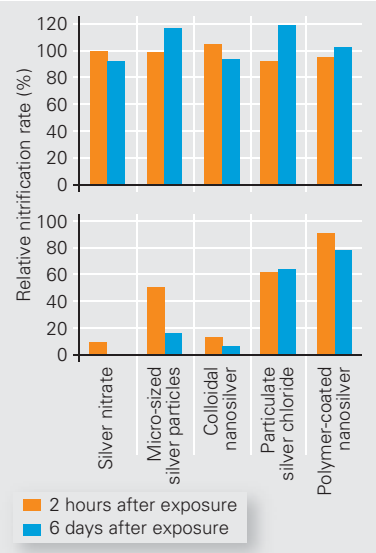
Silver concentrations of 2 – 6 µg/l were detected in wastewater influents. At the WWTP studied (Kloten/Opfikon), concentrations of up to 20 µg/l were measured in one influent stream, as silver particles are used at a plant operating in this area. Accordingly, experiments were carried out using quantities of silver corresponding to a concentration of 50 µg/l – i.e. roughly an order of magnitude greater than is to be expected in influent under real-life conditions. For comparison, activated sludge was also exposed to a silver concentration 100 times higher.

While in the relatively realistic case no effects on ammonia oxidation were observed either after 2 hours or after 6 days, ammonia oxidation was significantly reduced with the highly elevated concentration. The high levels of chloride and sulphides in wastewater bind the free silver, making it harmless for the nitrifying bacteria. In contrast, the system appears to be unable to cope with extremely high silver concentrations.

Over 90 % found in sewage sludge

The researchers studied the fate of the silver particles both at the Eawag pilot plant and at the Kloten/Opfikon WWTP. The results showed close agreement: of the silver reaching the WWTP via the sewer system, 93 – 99 % ends up in sewage sludge, with only 1 – 7 % entering receiving waters in treated effluent. As sewage sludge is incinerated in Switzerland, this means that the bulk of the nanosilver is not released into the environment. If necessary, even the small remaining proportion could be retained relatively simply, since the nanosilver is bound to sludge flocs.

Thus, at the concentrations occurring in wastewater today, nanosilver does not have any inhibitory effects on nitrifiers, and the elimination rates at WWTPs are very high. Furthermore, the concentrations of the ecotoxicologically relevant form – free ionic silver – found at treatment plants and in treated wastewater are barely measurable. This is suggested by the results of inhibition tests and initial analyses of silver particles in effluent. Free silver ions react to form silver chloride or combine with sulphur, presumably forming insoluble silver sulphide.



Effects of various forms of silver on nitrification in activated sludge. Top: Silver concentration under relatively realistic conditions (50 µg/l). Bottom: 100-fold higher concentration. Deviations of up to around 20 % are attributable to normal fluctuations in the stability of process conditions.

The "Nanolyzer"

Analysis of nanoparticles in liquids is a tricky business. But it may be important to have detailed information on these minute particles when monitoring production processes – e.g. the preparation of drinking water from lake water. For this reason, a detection method which uses laser pulses to break down nanoparticles has been further developed at the Eawag Particle Lab. With the laser-induced breakdown detection (LIBD) method, the signals produced allow nanoparticles to be described in quantitative and qualitative terms. While Eawag, together with the ETH Zurich, continues to carry out basic research to refine the LIBD method, a chemist and a materials scientist in 2009 set up a spin-off called Nanolytix and now plan to turn their prototype "Nanolyzer" into a marketable product.

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Promoting Sodis effectively

It's not always true that good ideas don't need to be promoted. Accordingly, environmental psychologists are trying to find out what strategies are most successful in promoting consistent use of solar water disinfection (Sodis). Three field studies carried out in Bolivia and Zimbabwe indicate how efforts to disseminate this method can be optimized.

Sodis – solar water disinfection in plastic bottles – is an effective treatment method. As Eawag has demonstrated, waterborne pathogens are destroyed by ultraviolet radiation (UV-A) in sunlight. Various studies show positive effects on users' health: In Kenya diarrhoeal diseases were reduced by around 25 % among Sodis users, and during a cholera epidemic, rates of infection were almost 90 % lower among people who applied this method.

Voluntary work, yes – but with due recognition for volunteers' efforts.

Not consistently applied

However, these favourable results do not mean that Sodis will become established automatically – even in areas where promotional campaigns have taken place. In 2009, for example, a study performed in Bolivia by the Basel-based Swiss Tropical Institute revealed that, in many cases, the method is applied incorrectly or inconsistently. Thus, while families did use Sodis to prepare drinking water, they would also drink untreated water, e. g. while working. Eawag has therefore carried out field studies in Bolivia and Zimbabwe so as to identify the most effective strategies for disseminating Sodis and promoting regular, long-term use of the method.

Voluntary promoters – here in a suburb of Harare (Zimbabwe) – are rooted in the community and know instinctively how to get the message across.

Volunteers: Significant potential

Two months after the implementation of measures, the outcomes were assessed with the aid of surveys. The intervention found to be most effective was home visits by professional instructors. Between 73 % and 90 % of those visited subsequently became regular Sodis users. A high success rate – 67 % – was also observed when Sodis was disseminated by unpaid but well-trained volunteers. In addition, as the volunteers came from the study area themselves, Sodis was discussed more widely within the community. The somewhat higher effectiveness of paid instructors is thus offset by the fact that volunteers are less expensive and more closely integrated into the community.

In one study, tokens for PET bottles were distributed in addition to the activities of professional instructors. However, this strategy – by itself – only persuaded 26 % of interviewees to use Sodis to prepare their drinking water. For the environmental psychologists at Eawag, therefore, this approach is more suitable as a maintenance measure and less as a way of gaining new Sodis users. Finally, the effectiveness of information events (10 % persuaded) and stands at health fairs would appear to be limited. Although fairs of this kind – generally organized by NGOs – are attractive for those who attend them, Sodis is only one topic among many. After one such event, only 20 % of interviewees had heard of Sodis and only 14 % said they now intended to use the method.

Sustained use

Once a family has started using Sodis to prepare safe drinking water, there is no guarantee that it will still do so a few months later. The behavioural researchers therefore investigated how habit formation could be supported and lapses avoided. To encourage sustained use, they asked people to sign simple self-commitments and handed out decorative reminders which could be placed in users' homes. They also distributed posters and stickers which – e. g. displayed in doorways – draw the attention of other residents to the use of Sodis. All these methods increased by a factor of 2 to 3 the likelihood that Sodis would continue to be used for a prolonged period, even without further campaigns.

The authors of the studies recommend a strategy combining professional instructors and voluntary disseminators, but focusing in the long term on the potential of volunteers, who should periodically receive supervision and recognition. ○○○

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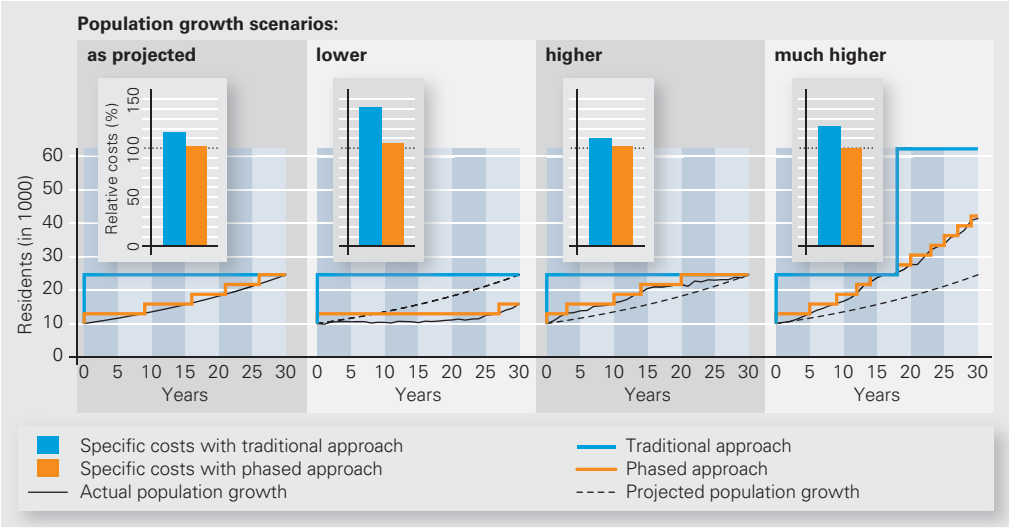
Calculating the costs of an uncertain future

Much of Switzerland's wastewater infrastructure was built in the 1960s and 1970s. Today, significant damage is found in around a quarter of these facilities, and repairs are expensive. Against this background, Eawag researchers are investigating sustainable ways of securing an efficient wastewater system.

Switzerland's wastewater system operates effectively. But the country's 759 centralized wastewater treatment plants (WWTP > 500 population equivalent) and 47,400 km of public sewers are showing signs of age. Recently, an Eawag study commissioned by the Federal Office for the Environment estimated the total replacement value of Switzerland's wastewater infrastructure to be CHF 108 billion. Given this figure, should the traditional system of wastewater disposal at centralized treatment plants be preserved in Switzerland?



Costs can be controlled by adapting the expansion of WWTPs to population growth (orange line).

Seeking optimal solutions

"Certainly, we could continue to rely on the same system," says Max Maurer, head of the Urban Water Management department. "But we don't know whether it's the best possible solution." For this reason, there is a need to define criteria which indicate under what conditions a particular approach to wastewater management is optimal for a particular area. In Maurer's view, it is also necessary to find out more about the existing system and, in planning for future wastewater management, to take account of uncertainties such as population growth and climate change using not just rough estimates but explicit projections. This indicates the complexity of the task which Max Maurer and his team have set themselves. As a first step, the researchers are currently developing models which represent the behaviour of infrastructure. These include system models which can calculate the value of a sewer network for any given settlement. A degradation model is used to describe changes in the condition of a sewer network over time. With both types of model, the results are derived from available data, without any need for costly field studies.

Focusing on costs

The analyses are initially focusing on the appropriate characterization of costs. This is especially challenging in the case of long-term capital investment projects or when assessing the potential of new technologies. Initial results indicate, for example, that the per capita costs of purchasing decentralized (home) treatment systems are already comparable to those for centralized plants. However, the costs of operation and maintenance are still several times higher, and questions of monitoring remain unresolved. Research and development efforts should therefore concentrate on optimizing the operation of such systems.

Price of uncertainty

Other studies are concerned with the influence of demographic changes – and uncertainties – on the costs of wastewater treatment. Modelling indicates that traditional calculations significantly underestimate the costs of a system, because they are based on the possible rather than the actual level of services provided. Uncertainty, as well as growth, has its price. Over the long term, therefore, the greater flexibility offered by smaller, decentralized wastewater treatment systems could conceivably make them less costly than large-scale centralized plants.

Expansion as needed

Max Maurer says: "In the past, plants have tended to be built with excess capacity, just to be on the safe side. But our calculations suggest that this strategy is actually more expensive than installing a plant of optimal size and then expanding it in line with requirements." A quarter of Switzerland's wastewater infrastructure is already due for repair or renewal. Eawag is therefore committed to developing new methods and models which will generate the knowledge required to support decision-making on a sustainable basis in the wastewater sector. ○○○

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Research on urine as a natural resource

While urine accounts for barely 1 % of the total volume of wastewater, it contributes 50 – 80 % of the nutrient content. Nutrients are removed by elaborate processes at wastewater treatment plants. Separate collection and treatment of urine could offer benefits in terms of both water protection and nutrient recycling. For this reason, the Process Engineering department at Eawag is studying various ways of managing urine – some of which are almost ready to be applied in practice, while others are still at the visionary stage.


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[1] In the "NoMix" toilet, urine is collected separately from faeces ("source separation").

[2] In the basement of Eawag's main building, environmental engineer Steffen Zuleeg draws off urine from the collection tank for use in research.

[3] Chemist Michael Wächter delivers fresh urine to the lab, where various processes are being investigated and optimized.

[4] In an aerated cylindrical reactor (right), ammonium is oxidized to nitrate by bacteria. Nitrogen is stabilized in urine to prevent the loss of gaseous ammonia during further processing or transport.

[5] The powder remaining after stabilization and evaporation contains all the essential nutrients.

[6] In another method, phosphorus is precipitated by the addition of magnesium. The product (struvite) can be used as a fertilizer.

[7] Struvite precipitation has already proved its value in the field. In a SANDEC pilot project, a hand-powered reactor was used by the Nepalese environmental engineer Raju Khadka.

[8] A third method studied by environmental engineer Mieke Teunissen involves a nitritation/anammox reactor, where ammonium is oxidized to harmless molecular nitrogen by specialist bacteria in a highly energy-efficient process.

[9] A microbiological fuel cell could represent the most exciting potential option for urine management. Depending on the configuration, the cell would produce electricity or hydrogen.

[10] Stabilized urine is stored for subsequent use.


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Combining water protection with recycling of natural resources

Urine is not exactly known as the stuff that dreams are made of, but process engineer Kai Udert has been carrying out research on the yellowish fluid for many years. And this commitment has paid off, as considerable progress has been made.

Various processes for the treatment of source-separated urine have been developed at Eawag. The goals are two-fold: The removal of the nutrients nitrogen and phosphorus, as well as micropollutants, should help to protect the environment and natural waters in particular. At the same time, urine can be used to produce fertilizers, which – depending on the process employed – contain the nutrients phosphorus, nitrogen, potassium and sulphur.

Struvite precipitation, developed as part of the cross-cutting "Novaquatis" project, is already being used in pilot projects. In combination with the anammox process, as Udert explains, this allows phosphorus and nitrogen to be removed from urine, and phosphorus – supplies of which are limited worldwide – to be recovered as a fertilizer.

Another research group at Eawag is using the anammox process at wastewater treatment plants for energy-efficient removal of nitrogen from sludge digester effluent. With the combination of nitrification and evaporation, all the nutrients contained in urine can be recovered. This process is currently being successfully operated in the laboratory.

One option about which Udert is particularly enthusiastic sounds rather utopian: In a microbiological fuel cell – more precisely an electrolytic cell – bacteria break down the organic compounds in urine, thus supplying electrons to the cathode. When voltage is applied, hydrogen can be produced which in turn – in a conventional fuel cell – could provide electricity for the first process. The goal is not to generate power from urine, but to develop a highly efficient reactor for decentralized urine treatment – ideally to be installed directly in a toilet. "But that's still a long way off," Udert admits.

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

Detective work

"What attracted me to this topic for my thesis," says **Irene Wittmer**, "was the mixture of practice and theory, fieldwork and modelling." For almost 4 years, the environmental scientist has been investigating where the pesticides found in surface waters actually come from. Agriculture was long assumed to be the main source but, to her surprise, Wittmer discovered that a proportion of the pollutants ending up in surface waters come from urban areas, e.g. as a result of pesticide use in gardens. Just as surprising as her scientific findings, however, was the discovery of a severed power cable at one of her monitoring stations. "It definitely wasn't a mouse," she says. Rather, it looked as if someone had deliberately cut through the cable with a knife or scissors. Matters became even more mysterious when, on the same day and the same river, the researcher recorded one of the largest pollutant waves at another monitoring station further upstream. She was not able to establish whether this had been a coincidence or whether someone really did have something to cover up. But to return from criminal to scientific investigations: On completing her doctorate in June 2010, Wittmer will be participating in a joint Eawag/FOEN project designed to develop a monitoring concept which will enable the cantons to assess surface water pollution.

TEACHING

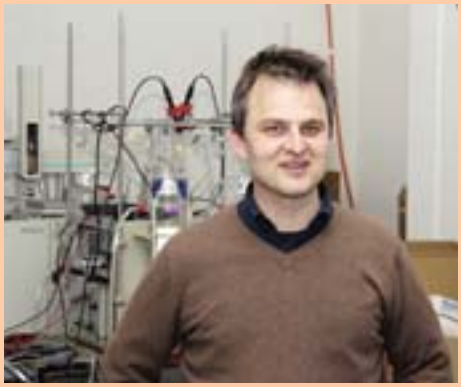
Questions welcome!

Ecotoxicologist **Kristin Schirmer** still recalls with a shudder the occasion when, early in her studies, she asked a professor a question, only to receive the reply: "But I explained that to you in my last lecture!" In her own teaching, she is anxious to avoid giving the impression that questions will be dismissed as stupid. On the contrary, Schirmer, who has been head of the Environmental Toxicology department since 2008, sees it as a challenge to create an atmosphere of openness which allows students to engage in discussion without any inhibitions. As a lecturer at the ETH in Zurich, she teaches foundational and Master's courses in ecotoxicology; in addition, together with her department, she offers a 6 day practical in the Eawag labs. When asked why she invests so much time in teaching, alongside her research work, she replies: "I'd like to pass on as much knowledge as I can, because only well-trained scientists will address the tricky issues and help to advance the discipline." She is particularly pleased about the growing number of women who, after graduating and doing a PhD, pursue a scientific career – without making sacrifices in their family lives. These young women are successfully combining professional and family responsibilities. Kristin Schirmer herself – married with two children – serves as an example. For her, being a stay-at-home mother was never an option: "You put a lot of energy into your studies, so I always knew I wanted to make use of what I'd learned. And fortunately," she adds, "I have a supportive husband."

CONSULTING

Benefiting from discussions

Michael Schärer is a scientific officer in the Surface Water Quality Section of the Federal Office for the Environment (FOEN). Among other responsibilities, he leads the "MicroPoll Strategy" project on the reduction of micropollutants from urban drainage, in which Eawag has played a major role. But Schärer's association with Eawag goes back much further: Studying under Professor Heinz Ambühl, he not only learned the rudiments of limnology but also – when collecting lake water samples – improved his rowing technique. It was also at Eawag that he wrote his diploma thesis on inputs of agricultural pesticides to surface waters. The combination of fieldwork, laboratory analysis and modelling, he recalls, gave him a feeling for the system as a whole. Now, says Schärer, this understanding of systems and the early detection of problems are precisely the abilities which make Eawag a sought-after partner for the authorities. Another asset, he believes, is the network of contacts maintained by various Eawag scientists with professional bodies and interest groups: "These people enable Eawag to bridge the gap between research and politics or society; from my perspective, their involvement should be actively encouraged." And what if disagreements arise between researchers and representatives of an authority responsible for enforcement? "Differences of opinion are always valuable," says Schärer, "They're reassuring – if something goes through too smoothly, it's usually no good."



Biocides

from homes and gardens in surface waters

According to a new Eawag study, herbicides and pesticides find their way into surface waters not only from agricultural areas but also – to a similar extent – from urban areas. In fact, relative to the amounts used, towns and villages make a larger contribution to water pollution than farmland. Most of the substances are washed out from the original site of application by rainwater, but others enter the environment via wastewater.

Biocides are used in agriculture and in urban settings to control pests and other unwanted organisms. The spectrum of products ranges from insecticides and herbicides, through antialgal additives in paints and renders, to antifungal agents in cosmetics. At some point, a proportion of these chemicals – containing potent active ingredients – will inevitably end up in water and in natural waters, where they may be harmful to individual organisms or the entire ecosystem.

Until recently, it was assumed that most of the pollutants observed in surface waters originate from agricultural applications. The use of pesticides in agriculture is therefore strictly regulated, and the annual volumes of pesticides sold in Switzerland can be quantified fairly accurately (around 2000 tonnes). In 1998, an Eawag study had already shown that urban areas also contribute to the contamination of surface waters with biocides, e. g. through leaching of the root protection agent mecoprop from bitumen sheets. And in 2007, non-agricultural use of biocides in Switzerland as a whole was estimated at 2000 tonnes a year. However, more precise data have been lacking to date. Now, as part of the interdepartmental "Rexpo" (realistic exposure scenarios) project, for the first time Eawag has investigated what substances and quantities are contributed by urban and agricultural areas respectively for an entire catchment.

For this purpose, a 25 km^2 catchment in the Zurich Oberland region was divided into four subcatchments with different types of land use, ranging from an almost exclusively agricultural to a predominantly urban area. Sampling stations were installed at a number of points in the

Top: Irene Wittmer, Carina Carlsson and Alfredo Alder of the Environmental Chemistry department set up an automatic sampling station on the stream in the study area.
Bottom: Pollutants enter surface waters particularly during wet weather – from urban as well as agricultural sources.
Photos: Ruth Scheidegger, Andri Bryner

Not just the dose makes the poison

Whenever small streams are exposed to pollutants, the question immediately arises whether these compounds are toxic to algae, fish or other aquatic organisms. In most cases, the concentrations of individual substances measured in the Rexpo project were below the limit of 100 ng/l specified for organic pesticides in the Swiss Water Protection Ordinance. However, this standard requirement merely indicates that no effects are generally to be expected at this level; it does not address the possible effects of combinations of substances or peak concentrations of individual substances. While research has previously focused on the effects of individual substances under controlled laboratory conditions, it is now becoming clear that the situation in natural waters is considerably more complex: Mixtures of substances can produce additive effects, and new stressors – such as increased water temperatures or higher levels of ultraviolet radiation associated with climate change – can create additional pressures for organisms exposed to pollutants. In particular, the classical doctrine that effects are determined by the dose alone has now been called into question. For example, exposure to pesticides typically fluctuates sharply, and Eawag researchers have shown that the interval between two peak concentrations is a crucial factor determining whether organisms are permanently damaged or are able to recover. If this period is too short – e.g. less than 28 days in the case of the freshwater amphipod *Gammarus pulex* exposed to the pesticide diazinon – a second wave of contamination will be significantly more toxic, as the organisms have been damaged by the previous exposure.

Eawag has developed a model which takes these findings into account and can thus improve risk assessment for chemicals. In addition, Eawag researchers have shown that it is essential for transformation products to be taken into consideration in chemicals assessment and water quality monitoring: In a study involving 37 pesticides, 30 % of the transformation products were found to be as toxic as or even more toxic than the parent compound. The transformation products are also frequently more persistent and mobile, so that they can even be detected in groundwater.

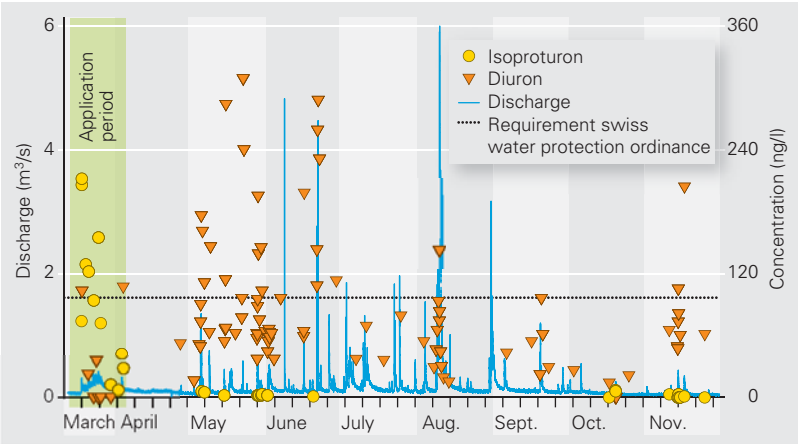


Fig. 1: Concentrations of isoproturon (cereal herbicide) from a largely agricultural subcatchment and diuron (preservative) from an urban subcatchment. Agricultural pesticide concentrations are increased seasonally, especially after rain events during the application period. Increased concentrations of urban biocides may occur throughout the year. Study period: 13 March to 31 November 2007.

surface water network and also at the outlet of the sole wastewater treatment plant (WWTP), in a storm sewer and downstream of a combined sewer overflow. Samples collected automatically were analysed for 12 frequently used biocides, 8 of which were regularly detected.

Equally large inputs from urban areas

The researchers determined or estimated the amounts of substances used by conducting surveys involving farmers and 60 households, and performing calculations based on models. They then compared the loads observed in surface waters with these usage figures. Interestingly, although larger quantities are applied in agriculture, the relative inputs from urban areas clearly exceeded those from agricultural areas. For example, about 110 kg of the cereal herbicide isoproturon was applied in the study area, but the total load observed was only 470 g (0.4 %). By contrast, of the roughly 10 kg of the biocide diuron applied in urban areas (e.g. to control algal growth on facades), 210 g (2.1 %) was detected in surface waters. Even though it is far more difficult to determine the quantities of substances used in urban areas, statistical analysis clearly indicated that loss rates for urban biocides may be 5–10 times higher than for agricultural pesticides.

Pesticides used in spite of bans

In the case of both agricultural and urban compounds, loads are strongly dependent on the duration and intensity of rainfall. In addition, agricultural pesticide loads show marked seasonal patterns, as these substances are only applied during certain periods (Fig. 1). However, some of the urban biocides were constantly found in surface waters, especially in WWTP effluent. As well as being applied outdoors (e.g. for pest control in gardens), substances such as diazinon or carbendazim must therefore also be used in households, from where they enter the environment in wastewater, independently of rainfall. The products in question could be antifungal agents used in bathrooms or biocides in textiles. The ubiquitous nature of "hidden" biocides is illustrated by the example of flea collars for pets. These products contain diazinon, although in

this case it is labelled as a veterinary medicine. Generally, however, the use of these substances is more deliberate: Pesticides are applied in 80 % of the households surveyed, usually to protect roses from insects. In addition, 20 % of respondents reported that they also spray pesticides on driveways or garden paths – despite the ban on such uses (of which they were not aware).

Peak concentrations due to overflows

Thanks to the distribution of the sampling sites, the Rexpo project researchers were also able to determine which substances mainly enter surface waters as a result of diffuse losses and which find their way via the urban drainage system (i. e. sewers, WWTP, combined sewer overflows or storm sewers). Depending on the individual substance, the proportion of the load passing through the WWTP varied between 8 % and 71 %, and – for urban areas only – between 41 % and 71 %. The fact that, in the case of agricultural pesticides, the proportion is not zero (as would have been expected) can be attributed to improper cleaning of spraying equipment and to a single proven disposal incident. Another non-negligible factor – particularly for small watercourses – is the proportion of substances released from combined sewer overflows. For example, it was observed in one subcatchment that, over a period of several hours, an overflow accounted for up to 50 % of the discharge in a small stream, with a corresponding rise in the concentrations measured (Fig. 2).

Measures to be taken

Applications of biocides in urban areas represent a significant source of water pollution. Certain substances now scarcely applied in agriculture appear to be widely used in households and gardens. From here, they are released into the environment all year round, either by diffuse losses or via the urban drainage system. While the study did not demonstrate any direct damage to the ecosystem, biocides of urban origin contribute to chronic background contamination which – in the long term or in combination with other stress factors – may adversely affect aquatic organisms. It is therefore worthwhile to promote consumer awareness of sound handling of biocides, to evaluate and improve the biocide leaching behaviour of materials, and to pay greater attention to this problem in urban water management. These measures should go hand in hand with continuing efforts to further reduce inputs of agricultural pesticides to surface waters. ○ ○ ○

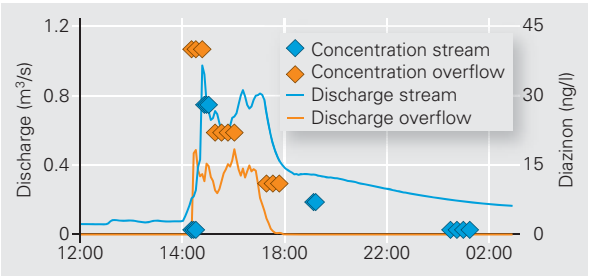


Fig. 2: For a short time, the stormwater overflow influences stream discharge and concentrations of pollutants (here, diazinon, frequently used in gardens). Rain event: 14 June 2007.

Sampling in the spillway of the stormwater tank.

Urban and agricultural compounds may be chemically identical.

"Anthropogenic micropollutants in water" was the subject of the Eawag Info Day held at the ETH Zurich on 23 June 2009, which was attended by over 300 people; for more information on this event, including a link to the relevant issue of *Eawag News* (no. 67), see: http://www.eawag.ch/lehre/infotag/2009

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Sweet or sour?

Though it has only been available in Switzerland for 4 years, sucralose – a new artificial sweetener – is already contaminating lakes, rivers and groundwater. Eawag is using sophisticated analytical methods to keep track of this substance, which is not amenable to conventional wastewater treatment or ozonation.

The artificial sweetener sucralose, which began its meteoric rise in the US, has also been available on the European market since 2004. Its advantages are obvious: Sucralose is about 600 times sweeter than sugar and calorie-free. What's more, unlike other artificial sweeteners, it does not leave a bitter aftertaste and is heat-resistant. Sucralose is already used in more than 4000 products, ranging from iced tea and low-calorie yogurt to toothpaste. The substance is considered to be safe for human consumption since most of it is excreted unchanged.

Sucralose passes straight through the human body – and wastewater treatment plants.

Not eliminated by wastewater treatment

But this is precisely where the problem starts: Sucralose is a small, chlorine-containing molecule which is therefore extremely stable – i.e. it persists in the environment for years. In addition, initial investigations in Sweden and more recent studies carried out at Eawag as part of the Swiss "Micropoll" project have shown that sucralose is just as poorly "digested" by wastewater treatment plants as it is by the human body: according to Heinz Singer of the Environmental Chemistry department, "What goes in one end, comes out the other end." Even an additional ozonation step, capable of breaking down many chemical compounds, has little effect in the case of sucralose. Singer says: "It eliminates a third at most, which is not nearly enough."

As the substance is not just persistent but highly mobile, spreading rapidly and widely, direct conclusions can be drawn about the consumption of products containing sucralose. However, it is difficult to detect sucralose reliably at low concentrations because the molecule forms addition products during ionization in the mass spectrometer. Still, a number of research institutes, including Eawag, have now managed to develop an analytical method which can detect sucralose in the low nanogram-per-litre range (1 ng = a billionth of a gram), even in automated routine measurements. The method – liquid chromatography combined with high-resolution mass spectrometry – is being used, for example, at the Rhine monitoring station near Basel.

Also found in groundwater

In 2007, barely 2 years after sucralose had also been approved for the Swiss market (in November 2005), the substance was already detected by Eawag in the Rhine and in Lake Constance. The concentration of 10 ng/l measured in the Rhine corresponds to a load of 1 kg per day. Meanwhile, consumption of sucralose in Switzerland continues to increase sharply, now totalling around 4 tonnes a year. "That is reflected by rising concentrations in lakes and rivers," says Juliane Hollender, head of the Environmental Chemistry department. "In fact, the most recent measurement of sucralose at the Regensdorf wastewater treatment plant found several micrograms per litre." Particular cause for reflection is given by the concentrations of around 25 ng/l observed by Eawag in Thur groundwater in the course of the "Record" project.

Effects on aquatic organisms?

As a result of these developments, the artificial sweetener has become a target of criticism in Scandinavia. The industry is now voluntarily withdrawing consumer goods which contain sucralose, as it fears that the substance may otherwise be banned. Little research has yet been carried out on possible hazards. While ecotoxicology invokes mortality rates for other substances, it is much more difficult to assess the effects of "non-toxic" sucralose on aquatic organisms, since sweetening could possibly affect their eating habits or sense of direction. Juliane Hollender comments: "Such a persistent sweetener will always place a burden on the environment – is it really needed?" ○○○

Markus Bertschi

In the Eawag laboratory, environmental chemist Heinz Singer inspects water samples from Lake Constance. "It doesn't taste sweet yet," he admits.

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Toxic arsenic removed from fields by monsoon floodwaters

As a result of irrigation with arsenic-rich groundwater, this toxic substance can accumulate in paddy soils and – at high concentrations – ultimately finds its way into rice plants. Researchers from Eawag and the ETH Zurich, collaborating with scientists from Bangladesh, have shown that a certain amount of arsenic is released from soils into floodwaters during the monsoon season.

Worldwide, millions of people drink water with arsenic concentrations far above the WHO guideline value of 10 µg/l. The situation is particularly dire in Bangladesh. Here, between 1980 and 1990, tube wells were sunk (with support from the WHO and Unicef) to provide supplies of clean groundwater from a depth of 5 – 50 m. The aim was to reduce the incidence of diarrhoeal diseases and cholera outbreaks caused by the consumption of polluted surface water. In many places, however, water from these depths is contaminated – not with dangerous pathogens, but with arsenic. Concentrations of 0.5 to 2500 µg/l have been measured by Eawag, with contamination levels typically around 400 µg/l. But risks are not only posed by contaminated drinking water – arsenic-rich groundwater is increasingly also being used for irrigation purposes.

Over 1000 tonnes per year

As paddy fields in Bangladesh are irrigated with arsenic-rich water, an estimated 1360 tonnes of arsenic is added to arable soils per year. There is thus a risk of long-term accumulation of arsenic in paddy soils. In fields that are flooded, arsenic concentrations in soils decrease over the monsoon season. To date, the reasons for this decline have not been clear: Arsenic could migrate to deeper soil layers or be released into the atmosphere as a result of microbial activity.

Across the fields by boat

With analyses of soil porewater and overlying floodwater, it has now been possible to demonstrate the pathway for arsenic removal. For this study, Linda Roberts (a doctoral student at Eawag and the ETH Zurich) used a boat to collect samples from two flooded rice paddies in Bangladesh. The analyses showed that arsenic is predominantly mobilized into the soil solution in the uppermost 10 cm of soil, where the greatest accumulation occurs during irrigation; it then enters the overlying floodwater by diffusion. The patterns of arsenic distribution in water on the fields and in canals indicate that arsenic is transported to rivers by the receding floodwaters. Thus, 50 –250 mg/m^2 arsenic is washed out of paddy soils into floodwater and ultimately into the ocean. Each year, via this process, 13 – 62 % of the arsenic added to soils through irrigation is released again.

Risk of reduced yields

In an earlier project, the researchers studied how arsenic is distributed across fields as a result of irrigation. They demonstrated that concentrations are particularly high near the irrigation inlet. However, concentrations also rise gradually in more distant parts of the fields, increasing the risk of arsenic accumulating in rice plants and grains. As well as entering the food chain in trace amounts, the toxic effects of arsenic could lead to reduced yields. Roberts comments: "We conclude from our findings that arsenic accumulates more rapidly in areas which are not regularly flooded, and that there is a greater risk of future yield reductions in these areas." Non-flooded fields should therefore be sparingly irrigated, so that the amount of arsenic added to soils is kept to a minimum.

In a flooded paddy, a boy from Bashailbhog village (Bangladesh) helps researchers to collect porewater samples from various sediment depths.

The risk of reduced yields is higher in fields not flooded during the monsoon season.

A global problem

Contamination of drinking water with arsenic is a global problem. Regions affected include West Bengal, Vietnam, Thailand, Taiwan, Inner Mongolia, several South American countries, the US, Canada and parts of Europe. Slightly elevated concentrations of arsenic in groundwater are also found in certain areas of Switzerland. As a result of the weathering of rocks, arsenic is released into sediments and transported to the fertile deltas of major rivers. If the sediments are adequately supplied with oxygen, arsenic remains bound to them. Generally, however, organic matter is also deposited in these sediments, and oxygen is consumed as this matter is degraded. Under anoxic conditions, microorganisms resort to the reduction of iron oxides and iron hydroxides. Arsenic bound to these compounds is then released, contaminating groundwater.

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Tracking cadmium accumulation

Heavy metals in surface waters are absorbed by microalgae which form biofilms on stones and sediments. To date, little has been known about how precisely and under what conditions such uptake occurs. The process has now been studied in detail by a research group from the Environmental Toxicology department, taking cadmium as an example.

Algae are extremely sensitive to environmental influences – including pollutants in surface waters. For this reason, they are frequently used as bioindicators in the assessment of water quality. To gain a better understanding of the mechanisms involved, chemist Laura Sigg and her team are analysing the interactions between freshwater algae (periphyton) and various metals. In particular, they have focused on cadmium (Cd), a toxic heavy metal which very rarely occurs naturally. In Swiss surface waters, cadmium concentrations are slightly elevated over natural background levels, mainly as a result of wastewater inputs. During heavy rainfall, concentrations of cadmium – like those of other metals – rise sharply in many waters, as metal-rich particles are stirred up from the sediments by increased flows. In addition, wastewater discharges to receiving waters are generally higher in the event of rain.

Uptake is determined by the available, not the total, concentration.

Ruedi Keller

Flow-through channels are used to study the effects of various risk factors on algae.

Biofilm sensitivity

In certain algal species, intracellular concentrations of cadmium are known to increase rapidly and sharply as soon as cadmium concentrations in freshwater rise. But little was known about the responses of complex algal communities in natural biofilms. Now, for the first time, findings obtained in the laboratory have also been validated in natural waters: Philippe Bradac (a member of the research group led by Laura Sigg and Renata Behra) measured the metal content in samples of algae and water collected from the Altbach – a small stream (maximum depth 30 cm) near Zurich – before, during and after rain events.

Bioavailability: A key determinant

The results confirm that microalgae respond rapidly and sensitively to rising cadmium concentrations. In addition, Bradac showed that uptake is determined not by the total concentration but solely by the concentration of those cadmium compounds which are present in a form that is readily available to algae. This is much more difficult to determine, as it depends on other molecules which bind to cadmium as ligands.

If the metal is freely dissolved in water or only weakly bound to smaller molecules such as organic acids, it is readily taken up by the algal cell. However, if the ligands are strongly bound larger molecules such as humic acids, the metal cannot be absorbed by the algae. Bioavailability was determined *in situ* by Bradac with the aid of passive samplers.

Why cadmium is toxic

Algae absorb cadmium not because they require it, but because they cannot distinguish it from the essential metal zinc. Ilona Szivák of the Environmental Toxicology department recently demonstrated that, compared with other metals studied, cadmium is highly cytotoxic. It increases levels of free oxygen radicals, which damage the cell. Algae, often consisting of only a single cell, have developed various strategies for detoxification: The metal is generally bound by a protein and thereby inactivated. In this form, it is either stored temporarily or excreted.

Sample collection: algae on glass slides and two passive samplers used to monitor metals in the stream.

In these devices, smaller, weakly bound metal complexes diffuse through a membrane, while larger complexes are retained, in a manner similar to algal uptake.

In the Altbach experiment, cadmium was present almost exclusively in readily available forms. This means that even a small rise in cadmium concentrations can have a significant impact on the biofilm. However, the precise effects on algae and the algal community remain to be elucidated. Another question requiring further study is whether cadmium also accumulates in higher organisms via the food chain. ○○○

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From degradation studies to a new production process

Recently identified bacteria are able to degrade β-peptides which are otherwise highly stable in vivo and in the environment. Eawag scientists have now shown that the enzyme used by these bacteria can also be employed for the reverse reaction – synthesis of β-peptides. The method involves the use of whole cells which produce the enzyme in large quantities. It therefore has considerable potential as a greentech alternative to the purely chemical synthesis of β-peptides.

β-peptides are peptides (small proteins) which consist of β-amino acids. Pure β-peptides do not occur in nature. As they have similar properties to naturally occurring peptides but are highly resistant to enzymatic degradation *in vivo,* β-peptides are increasingly attractive for pharmaceutical companies wishing to develop so-called peptidomimetics – drugs which mimic the action of endogenous peptides.

However, as stable bioactive substances, β-peptides also present a risk of accumulation in the environment, with effects being exerted where they are not desired, e.g. in surface waters. This led Eawag to investigate how β-peptides are degraded. The environmental microbiologists Birgit Geueke, Tobias Heck and Hans-Peter Kohler found that bacteria of the genus *Sphingosinicella* can hydrolyse β-peptides in a process catalysed by a novel enzyme class – β-aminopeptidases (BapA).

E. coli as a bio-factory

It has now been shown that the same enzymes can also serve as a catalyst for the reverse reaction, i.e. for the synthesis of β-peptides. In industrial applications, the vitamin-like substance carnosine, for example, a dipeptide with an *N*-terminal β-amino acid, is synthesized by purely chemical means. Together with colleagues from other institutions, Eawag researchers wished to determine whether such compounds could be produced using whole-cell biocatalysts. They therefore analysed the relevant amino acid sequence and identified the gene responsible for its production. This was then optimized, amplified and transferred to bacterial *(E. coli)* and yeast production strains. Functioning as biological factories, these cells can produce large quantities of the enzyme catalyst, thereby synthesizing β-peptides from the starting substances added. For this test, carnosine was synthesized from β-alanine and L-histidine.

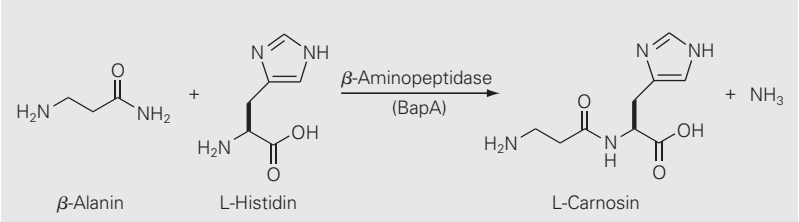
The three-dimensional structure of the BapA enzyme helps to explain the mechanisms of its catalytic action. X-ray analysis of the crystallized enzyme was performed at the PSI in collaboration with Professor Markus Grütter of Zurich University.

Commercial potential

In subsequent experiments, the researchers optimized the process so as to maximize the yield of carnosine. For this purpose, they varied the temperature, pH, substrate concentrations and other reaction parameters. They achieved yields of up to 71 % product per β-alanine-amide building block. In addition, the long-time stability of the cells in the reaction buffer was tested, as well as losses on repeated centrifugation. The cells "passed" both of these tests. The final test, for the time being, involved synthesis of the β-peptide carnosine in a semi-continuous process. Only a process of this type would permit a continuous harvest and recycling of unused starting products, paving the way for commercial application of the new biosynthesis. While the yields obtained were somewhat lower than with the batch process (65 % vs 71 % incorporation of alanine), this reduction would be rapidly offset in continuous processing.

Whole-cell biocatalysts offer the prospect of greener processes.

E. coli bacteria which produce β-aminopeptidases can thus be used directly as whole-cell biocatalysts for the production of β-peptides such as L-carnosine. This biotech method offers considerable potential for avoiding the solvent-intensive process of chemical synthesis – making it not only a greener but also an economically attractive option. ○○○



Enzyme-catalysed formation of the β-peptide carnosine from two amino acids.

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Local treatment of hospital wastewater?

Hospitals are point sources for pharmaceuticals and disinfectants in wastewater. Local treatment of hospital wastewater has been proposed as a possible strategy for preventing these substances from entering the environment. In a pilot plant at the Cantonal Hospital in Baden, Eawag is therefore testing various treatment processes. In addition, elaborate sampling and analytical methods are being used to analyse material flows, providing a basis for deciding whether it would be advisable to implement decentralized treatment measures.


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[1] Two members of the project team, Anita Wittmer and Martina Hagenbuch, get ready for the descent into a drain at the Cantonal Hospital in Baden where wastewater is collected for the pilot plant.

[2] Anita Wittmer at work in the drain, where murky effluent flows at a depth of 8 m. Although wastewater is delivered continuously, the suction tube of the pump and the monitoring camera need to be cleaned every 2 months.

[3] The membrane bioreactor – a small-scale biological treatment plant using membrane filtration.

[4] Researcher Lubomira Kovalova inspecting samples.

[5] This automatic system collects composite samples for a specified period.

[6] The ozone dosing and supply are checked. A valve needs to be replaced.

[7–9] Ozone (7) or powdered activated carbon (PAC) (8) is added to the biologically treated wastewater, and photocatalytic treatment with UV-irradiated titanium dioxide is tested (9). The ozonation and PAC processes are quite effective: The elimination rate for most pharmaceuticals is over 50 %.

[10] In the laboratory at Eawag, the samples are analysed by Lubomira Kovalova and the results are discussed with project manager Christa McArdell.


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Providing decision-making aids

Eawag's hospital wastewater project has attracted a great deal of interest, with the involvement not only of the Federal Office for the Environment and eleven cantons, but also the State Secretariat for Education and Research and the Federal Office for Spatial Development. These bodies are providing support within the framework of the European cooperation in the field of scientific and technical research (COST), the EU Neptune project and the Interreg PILLS (Pharmaceutical Input and Elimination from Local Sources) project. Numerous other partners are participating: specialized agencies, other research institutions, the Cantonal Hospital in Baden, and the engineering consultancies Holinger and Hunziker Betatech.

Not surprisingly, project manager Christa McArdell has a heavy workload, with her responsibilities ranging from negotiating with sponsors to discussing details with postdoc Lubomira Kovalova, who is overseeing operation of the plant, sampling and chemical analysis. Kovalova is also "on call" whenever the sampling pump fails and action is required to avoid gaps in the data.

Sound data on hospital wastewater, after all, is in short supply. So McArdell and her team – together with Hansruedi Siegrist, head of the Process Engineering department – first had to install a continuous, flow-proportional sampling system and develop an automated analytical method. This has made it possible for 69 different substances – including antibiotics, pain killers and X-ray contrast media– to be identified and quantified. Such an elaborate strategy is necessary to permit the detection of peak loads, which occur regularly, for example, in the case of contrast media. For the mass flow analysis, account also has to be taken of the proportion of medicines dispensed at the hospital but excreted by outpatients at home. The analysis of mass flows and the assessment of results from the pilot plant are to be completed by the end of 2010. Research will also address the costs and acceptance of measures, so as to provide decision-making aids for the authorities.

review of Eawag 2009

At Eawag, 2009 will be remembered in particular as the year in which the laboratory building at the Dübendorf site was extensively refurbished (p. 46) – while research operations continued – and in which the Institute was evaluated by an external peer review committee. The annual Info Day event, which focused on anthropogenic micropollutants in water resources, once again proved highly popular, attracting 330 attendees. Below, we look back over some of the year's highlights.

In-depth evaluation of Eawag

From 7 to 10 September, Eawag was visited by an 11-member peer review committee, comprising 5 experts from the US and 6 from Europe. Two of the members had already participated in the first peer review, which was conducted in 2003. The committee's work was facilitated by a critical self-assessment undertaken in advance by Eawag. The preparation of this assessment was itself a valuable exercise, as it required all departments to reflect on their own performance and goals.

The committee's evaluation report was highly favourable, emphasizing Eawag's reputation as a leading centre for water research and the high quality of its developments in the aquatic technology field. The reviewers recommended that Eawag should develop a broader shared vision of the key challenges arising for the water sector both in Switzerland and around the world. Research priorities defined in accordance with strategic considerations should allow Eawag to fully exploit its excellent infrastructure and breadth of expertise in tacking water-related issues. This in turn, the committee concluded, would continue to require a combination of problem-oriented, practical research and fundamental research activities.

Several of the committee's recommendations are already being put into effect: For example, with internal cooperation among chemists, ecologists and ecotoxicologists, and through the Eawag-EPFL Ecotox Centre, Eawag is strengthening its leading position in the area of chemical risk management.

It is also currently developing a Drinking Water Competence Centre. In a number of other areas, such as the expansion of social scientific re-

The 2009 peer review committee

Prof. Hubert van den Bergh	EPFL
Prof. Richard Luthy (Chair)	Stanford University
Prof. Granger Morgan	Carnegie Mellon University
Dr Stephan Müller	FOEN
Prof. Nelson Hairston	Cornell University
Prof. André F. Lotter	Utrecht University
Prof. Jennifer Field	Oregon State University
Prof. Valery Forbes	Roskilde University
Dr Michael Kavanaugh	Malcolm Pirnie Inc.
Prof. Mark van Loosdrecht	Delft University of Technology
Prof. Ortwin Renn	Stuttgart University

Top: The Chinese Science and Technology Minister Wan Gang is welcomed by Eawag Director Janet Hering.
Bottom: Fish expert Rudolf Müller and students attending the PhD Summer School at Kastanienbaum on Lake Lucerne.
Photos: Yvonne Lehnhardt, Hitoshi Araki

The 2009 Peer Review Committee (Stephan Müller is not pictured).

search, the Directorate is pursuing a middle course between establishing resources of its own and collaborating with other higher education institutions. The 2009 peer review will be discussed in the Directorate-departmental reporting process and will be taken into account, for example, in the selection of new cross-cutting projects or in strategic planning for the period 2012 – 2016.

25,000 visitors at Researchers' Night

What role can small terrestrial or freshwater organisms play in the early detection of pollutants and in risk assessment? At Researchers' Night in Zurich on 25 September, scientists demonstrated how they monitor, for example, the effects of toxic substances on organisms' respiration or swimming activity. Altogether, almost 25,000 visitors explored the stands at the "research fair" – five of which were run by Eawag. In addition to the use of small organisms at the Ecotox Centre (p. 47), the Eawag presentations focused on global freshwater reserves,

A budding scientist at Researchers' Night.

the measurement of rainfall with mobile phone antennas (p. 24), the influence of solar activity on the climate, and stress factors for algae.

Keeping active at Eawag

In June, 154 Eawag staff in 39 teams took part in the nationwide "bike to work" campaign – this time in partnership with Empa. During the programme, participants were required to get to work under their own steam on at least half of all working days. It didn't matter whether they cycled, walked or rollerbladed, as long as they left their car at home. The campaign also involved a photo competition.

A welcome change from brainwork for Eawag researchers – building a beach volleyball court at the Dübendorf site involved shovelling 90 tonnes of sand.

In May, for the second time, Eawag received a "Prix Velo". This award – previously won in 2004 – recognizes cycle-friendly workplaces. Also in May, the Eawag/Empa soccer team beat Empa St. Gallen and, at the end of June, 12 teams took part in an Eawag soccer tournament, which was won by the Kastanienbaum Fish Ecology team. In the autumn, Eawag and Empa staff used some of their leisure time to build a beach volleyball court at the Dübendorf site, which involved shifting over 90 tonnes of sand.

Public interest undiminished

Eawag research facilities and the sustainable Forum Chriesbach building continue to attract visitors – almost 1,700 in the course of 2009. Among the visitors were prominent international delegations, including the Association of Managing Directors of Water Boards in the Netherlands (VDW) and China's Minister of Science and Technology, Wan Gang. Guided tours open to the public took place at Kastanienbaum and Dübendorf. Public interest in water issues is also evident from the extent of media coverage in 2009, with a total of 934 newspaper articles and radio or TV reports. Particularly widely reported were the Info Day on anthropogenic micropollutants in water (held in June) and the media releases on the development of Daphnia species in Greifensee and Lake Constance (p. 12), the surveys of the floor of Lake Maggiore, and the joint Empa-Eawag project on pollutants in glaciers. The new Eawag website – relaunched in June with an attractive and user-friendly layout – is proving popular, attracting around 30,000 unique visitors per month. In addition, as part of cooperation at the ETH Domain level, factsheets on topical issues were published at regular intervals for the attention of parliamentarians in particular. The topics covered in 2009 included endocrine disruptors in water and river restoration projects.

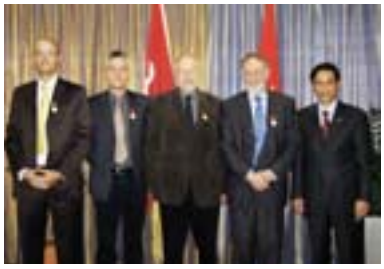
Numerous courses and conferences

2009 saw the launching of two Summer Schools. These events were well attended, with each attracting about 30 PhD students. The course at Dübendorf focused on environmental systems analysis and statistical methods, while the course at Kastanienbaum dealt with interactions between ecological and evolutionary processes in aquatic systems. (Three Summer Schools are planned for 2010.) Five practice-oriented Eawag (PEAK) courses were held in 2009, with a total of 107 participants. These included an introductory course on fish in Swiss waters and in-depth courses on the development of sustainable wastewater management strategies or the use of environmental psychology measures

to promote behavioural change. On 23 January, a meeting to review initial experience at Forum Chriesbach was attended by 140 construction and energy experts. On 3 April, a large number of people attended a symposium entitled "Water policy of the future – what can we learn from 30 years of experience?" which was held in honour of two long-standing members of the Directorate (Ueli Bundi and Roland Schertenleib). And on 16 November, 175 delegates attended a conference on the use of membrane technology in drinking water treatment and wastewater management. This gathering was jointly organized by Eawag and the Swiss Gas and Water Industry Association (SVGW) as a farewell event for Professor Markus Boller, who has now retired. ○○○

Award winners

In 2009, Eawag staff once again earned numerous honours and awards for outstanding research and teaching efforts. To mention just a few examples: *Professor Sam Arey* was named Best Teacher by students in the School of Architecture, Civil and Environmental Engineering (ENAC) at the Federal Institute of Technology Lausanne (EPFL). For his doctoral thesis on gonad malformations in whitefish from Lake Thun, *David Bittner* received the Bern Prize for Environmental Research, which is only awarded every 2 years. *Michael Dodd's* dissertation on the elimination of biologically active micropollutants from wastewater by ozonation earned him several prizes, including the ETH Zurich Silver Medal and the Young Scientist Award of the German Chemical Society's Division for Environmental Chemistry and Ecotoxicology. *Lubomira Kovalova* won first prize in Cyprus University's Young Scientist Competition for her work on the analysis of cytostatics and metabolites in wastewater.



Antoine Morel, Michael Berg, Walter Giger and Roland Schertenleib (left to right) with the medals awarded by the Vietnamese ambassador Hoang Van Nha.

Four Eawag scientists *Roland Schertenleib, Antoine Morel, Michael Berg and Walter Giger* received official medals from the Vietnamese government. The award – a distinction rarely bestowed on foreign nationals – recognized in particular their efforts to develop two research centres in Northern Vietnam, building local capacity for applied research in the areas of drinking water quality and wastewater management. At the beginning of 2010, Eawag and the commune of Gordola in Canton Ticino were joint winners of the Federal Office of Energy's Watt d'Or award for the exemplary implementation of a sustainable water supply system.

Also worthy of mention are the appointment of Eawag Director *Janet Hering* as a member of the Board of Reviewing Editors of *Science,* of *Piet Spaak* as an associate editor of the *Journal of Plankton Research,* and of *Flavio Anselmetti* as Titular Professor at the ETH Zurich. ○○○

Research collaboration with Romania

The publication of the final report and a special issue of Environmental Science and Pollution Research (Springer; Vol. 16/August 2009) marked the completion of the ESTROM programme. This Swiss-Romanian research programme was funded by the Swiss National Science Foundation (SNSF), the Swiss Agency for Development and Cooperation, and the Romanian Ministry for Education and Research. The focus was on the growing contamination of Romanian surface waters with heavy metals and persistent organic pollutants. The Danube, groundwater and selected lakes were also investigated. As well as coordinating five of the nine projects, Eawag was also represented on the ESTROM Steering Committee – by Professor Walter Giger, who served as President. ○○○

New appointments

Professor Christoph Vorburger joined Eawag in 2009, having been awarded an SNSF Professorship in Evolutionary Ecology. The 38-year-old zoologist will be dividing his time between the Institute of Integrative Biology at the ETH Zurich and the Aquatic Ecology department at Eawag. After working as a postdoc in Melbourne (Australia), Vorburger returned to Zurich in 2004 to take up an appointment as a Senior Research Associate at the University Institute of Zoology. His research is concerned with the evolution of alternative reproductive modes and with biological interactions that maintain genetic diversity (e.g. in host-parasite coevolution).

Professor Eberhardt Morgenroth, previously Associate Professor at the University of Illinois, has been Professor of Process Engineering in Urban Water Management at the ETH Zurich since August 2009. Designated as Professor Willi Gujer's successor, he has his research group at Eawag. His research areas include biological drinking water treatment and biological wastewater treatment. At Eawag – at the interface between theory and practice – the environmental engineer aims to develop integrated solutions for obtaining clean water for urban use and also returning clean water to the natural cycle. ○○○

New lease of life for 40-year-old building

2009 saw a complete overhaul of the Eawag laboratory building which came into service in 1970. As the labs remained in operation throughout the refurbishment, the project was technically challenging and called for considerable patience on the part of staff plagued by noise and dust. However, the CHF 20 million investment was urgently required – and the results are impressive.

Maintaining lab operations posed challenges for all concerned.

Draughty windows, poor insulation, leaky pipes and antiquated electrical installations – Eawag's 40-year-old laboratory building near the Chriesbach stream was showing unmistakable signs of age. In addition, new needs had arisen, e. g. for more refrigerated and climate-controlled spaces. But rather than tearing the laboratory building down and starting anew, it was decided to extend its lifespan by another 30 years. The overhaul was carried out between January 2009 and April 2010.

Empa building, Stephan Mäusli

Top: Laying the foundations for the concrete stabilization elements designed to ensure earthquake resistance. Bottom: A modernized lab, now including a service column and local extraction units.

Heat recovery

New windows were installed, fume hoods were adapted to meet the latest standards, the sanitary facilities were renewed and the lighting, fire-alarm system and telephone and data lines were all replaced. Above all, the building's energy efficiency was optimized as far as possible, with the installation of parapet insulation and a lab cooling system with heat recovery.

Few changes were made to the exterior of the six-storey building. However, the western facade was reinforced by two concrete columns to provide earthquake resistance, which necessitated major excavation work. To avoid unnecessary transport, some of the material excavated was used for site landscaping purposes. New features added include a biotope, a beach volleyball court and bicycle racks. Unfortunately, the planned rehabilitation of the Chriesbach stream had to be postponed as a result of budgetary cuts imposed by Zurich's Cantonal Parliament on the agency responsible (the Office for Waste, Water, Energy and Air/AWEL).

Keeping disruption to a minimum

Max Mauz, the head of technical operations, is relieved that the overhaul has now been completed. Because laboratory work could not simply be stopped for a year or fully relocated, the refurbishment was carried out in two stages, with lab operations being disrupted as little as possible. This posed challenges for everyone concerned, as temporary facilities had to be set up and moved, and many areas also had to be jointly used. In spite of the precautionary measures taken, researchers and technicians working in the building were inevitably exposed to noise, vibrations and sometimes also dust. Equally unavoidable was the occasional haggling over the allocation of space and equipment and, in particular, belated requests for modifications, not all of which could be accommodated. Naturally enough, this sometimes led to frayed nerves. But Deputy Director Rik Eggen paid tribute to all concerned for their patience – and for the fact that Eawag's scientific activities had demonstrably not been adversely affected during the year in question.

Refurbishment to continue at Kastanienbaum

With the construction of the new Forum Chriesbach building and the Eawag-Empa daycare centre (opened in summer 2006), as well as the refurbishment of and addition of two new storeys to the office block (opened in January 2008), redevelopment of the Dübendorf site is now complete. However, refurbishment work has still to be carried out at the Kastanienbaum site. Here, in 2009, an asbestos removal project was carried out earlier than originally planned, a new lift was installed, and a building automation and locking system was introduced. ○ ○ ○

126 kilometres of cabling laid

The extent of the refurbishment project is indicated by the following numbers: 57 meetings were held with user representatives; 250 tonnes of concrete was torn down, 126 km of electric cabling was laid, 2500 m of piping was dismantled and 4500 m newly installed, 2423 holes were drilled in walls, and 126 m^3 of waste was disposed of.

The Ecotox Centre: A strong partner

After only two years in operation, the Ecotox Centre – jointly run by Eawag and the Federal Institute of Technology Lausanne (EPFL) – has already established itself as a strong partner in the training sector. Courses attended by practitioners, officials and researchers provided opportunities for sharing experience. The topics covered were risk assessment using computer models, detection of endocrine disruptors in natural waters and evaluation of ecotoxicity tests.

Since autumn 2008, the Swiss Centre for Applied Ecotoxicology has been helping to ensure that recent research findings can be applied in practice. The Ecotox Centre informs professionals about international developments in ecotoxicology, offering a platform for interaction between various stakeholders who are brought together in applied research projects and courses. In 2009, the training programme comprised three courses and a conference on the use of the freshwater amphipod *Gammarus pulex*. Over 90 experts were brought up to speed on the latest findings and discussed possible approaches to current problems.

Testing the tests

Ecotoxicity tests are required to assess the effects of the complex mixtures of pollutants found in waters and soils, sometimes at very low concentrations. But which of the numerous tests are suitable for which specific questions? What exactly do they tell us? And how can they be combined? To answer these questions, the Ecotox Centre provided an introduction to the available biological test methods in the first of its courses. In a practical session, participants were then able to familiarize themselves with and evaluate selected test methods in the lab. Working in small groups, they particularly appreciated the opportunity to discuss specific problems in depth.

Bioassays to complement modern analytical methods

Posing a special challenge among pollutants are those substances which exert hormone-like effects on organisms. Because endocrine disruptors have variable structures and occur in waters in widely varying combinations, they are very difficult to detect by chemical analysis. Likewise, the effects of a cocktail of substances are difficult to assess analytically. Here, biological methods may be useful. At an Ecotox Centre workshop on bioassays for endocrine disruptors, test developers and users from Switzerland and abroad spent several days describing their activities, sharing their experiences and discussing their needs. No recommended methods for the detection of endocrine disruptors currently exist in this country – nor have any limits been specified to date. The Ecotox Centre therefore recommends the application of a number of test methods covering various modes of action, which can be combined as required.

Risk assessment at the computer

The toxicity of environmental pollutants can also be predicted with the aid of computer models. The third of last year's courses focused on risk assessment methods based on quantitative structure-activity relationships. QSAR methods are useful for filling gaps in existing toxicology data. The course gave an overview of various models, which could then be applied by the participants. The Ecotox Centre's standard training programme consists of introductory courses on ecotoxicology, practical courses for users and courses on the degradation of natural systems. In addition, topical issues are addressed in workshops on an ad hoc basis. Selected courses are organized in cooperation with the new Swiss Centre for Applied Human Toxicology.

Group work in a course on ecotoxicity tests.

Our core activities are making knowledge applicable and providing a platform for exchanges.

Professor Rik Eggen, Eawag Deputy Director, Ecotox Centre Board member

Applied research projects

In addition to training activities, the dozen Ecotox Centre staff at Eawag in Dübendorf and at the EPFL were of course also involved in a wide variety of research in 2009. Mainly commissioned by the federal government and cantons, the projects were concerned with, for example:

- leaching of pollutants from facade paints containing nanosilver,
- ecotoxicological assessment of nanosilver in laundry wastewater,
- ecotoxicological assessment of landfill leachate,
- effects of epoxy linings in drinking water pipes,
- assessing the effects of an additional treatment step to remove micropollutants at WWTPs, and
- development of ecotoxicologically based environmental quality standards for potential water pollutants.

Contact:
info@oekotoxzentrum.ch
www.oekotoxzentrum.ch

Equal opportunity and gender equity

In 2009, at the request of the Committee on Gender Equity and Equal Opportunity (EOC), a mentoring programme for young female researchers was approved by the Directorate. An internal project involving a group of around 10 postdocs is to be launched in spring 2010. The aim is to provide support in career planning and obtaining higher research and management positions for women who48 have completed doctoral and postdoctoral studies. At Eawag, women are still underrepresented in senior positions. Last year, as a result of cooperation with Empa, the "Gender in research" workshop hosted by the EU Commission was held at Eawag. Cooperation with other EO groups at ETH Domain level also resulted in a successful application for continuation of the "Fix the leaky pipeline" programme. The main goal of this initiative is to increase the number of female professors in the ETH Domain.

Family support

Since it is challenging for men as well as women to achieve a reasonable work/life balance, the EOC joined an ETH initiative in which fathers meet regularly to try and improve working conditions for male researchers who would like to be more involved in family life. Efforts in this area included participation in the national Daughter Day event (offering daughters – and sons – the opportunity to visit their parents' workplace) and an increase in the capacity of the Eawag/Empa nursery. Now that additional space has been rented, nursery places are available for all interested parents from Eawag/Empa, with no waiting lists.

Language sensitivity

Eawag's international and multicultural environment sometimes poses language-choice problems. While there is no dispute about the predominance of English in scientific publications, this is not always true for less formal settings such as meetings. For this reason, an EOC Language group has been formed to develop recommendations on tackling the issue of language barriers. ○○○

Dr Natalija Miladinovic, EOC Coordinator

Eco Team: Participation in CO_2 monitor programme

In recent years, Eawag has reduced its consumption of energy and other resources. The institution is close to meeting all internal energy requirements from renewable sources and making employee travel carbon-neutral. But the success of these efforts also depends on individual behaviour in everyday working life.

Individual reduction targets

Since October 2009, on the initiative of the Eco Team, Eawag has been offering staff an incentive to record their personal CO_2 emissions on a voluntary basis and set individual reduction targets. This is being done under the CO_2 monitor programme, which is to run initially for 3 years. Major savings are made possible, for example, by changes in mobility behaviour and the use of energy-efficient equipment at the workplace. Personal energy-saving measures have therefore also been adopted by the Directorate as an institutional annual objective, to be discussed in performance reviews.

Off to a flying start

CO_2 monitor was developed for institutions with ambitious environmental goals. The launch of the programme at Eawag set a new record: After only a month, 25% of staff had signed up for a personal account. The project is accompanied by themed events and competitions. At the launch event, a balloon was used to illustrate the generation and removal of CO_2: a car travelling for 2 minutes at 120 km/hour generates 1 kg, the production of a T-shirt 4 kg of CO_2; a tree with a circumference of 2 m takes 55 days to remove 1 kg of CO_2.

Dr Thomas Lichtensteiger, Environment Officer

Project information: www.co2-monitor.ch

Eawag key data (materials and energy use) and Eco Team projects: www.umwelt.eawag.ch

The CO_2 monitor launch event, featuring electric and folding bikes.

Water Agenda 21: Tackling problems together

In 2009, the Water Agenda 21 network focused on two issues – "watershed management" and "dialogue on hydropower". Ideas were developed for integrated watershed management and for dealing with conflicting objectives in the hydropower sector. Communication was strengthened, with a conference and a newsletter.

The principle underlying Water Agenda 21 is that viable solutions require broad-based support. Individual topics are considered by working groups, whose findings are then discussed by the Board and by members. Eawag is represented on the Board and in the working groups.

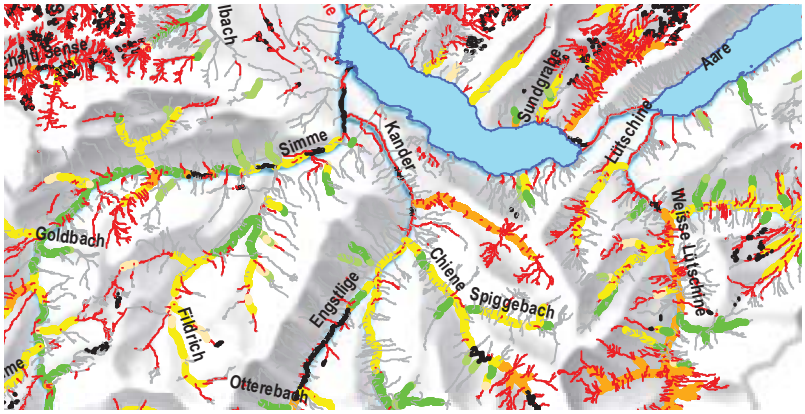
Pursuing watershed management

According to a 2007 study commissioned by the Federal Office for the Environment and Water Agenda 21, it would be advisable for water resources to be managed primarily on a watershed basis, rather than merely on the basis of cantonal or communal boundaries. However, scientific foundations and a nationally valid legal framework are lacking for the broad implementation of an approach of this kind. A Water Agenda 21 working group has been appointed to remedy these deficiencies and to give new momentum to the watershed management process.

The group is currently developing guidelines which, by the end of 2010, should establish a common frame of reference and formulate a clear rationale for the adoption of watershed management in Switzerland. The guidelines are addressed, firstly, to the cantons responsible for enforcement – which also have legal control over the use of their water resources – and, secondly, to federal and communal authorities and all other actors with water management responsibilities.

Hydropower: Setting priorities

Another concern is how to deal with conflicts associated with hydropower use and water protection interests. Conflicts are increasingly arising in this area, as shown by various analyses and – following the introduction of cost-covering remuneration for feed-in to the grid – more than 600 proposals for small-scale hydropower plant projects. Water Agenda 21 is seeking to promote a more objective dialogue and improve the exchange of information among stakeholders, with integrated solutions being developed and supported. In 2009, a method was developed for assigning priorities to the protection and use of river stretches. The method enables transparent evaluation of suitability for use across extensive geographical areas, thus providing guidance for policy-makers and helping to define political objectives within a planning framework. Overall, it aims to facilitate the development of projects optimized in terms of both hydropower use and surface water protection. This method was applied in Canton Bern, and the results were incorporated in the cantonal water strategy.



A method of assessing the suitability of surface waters for hydropower use according to transparent criteria, developed by Water Agenda 21, was adopted by Canton Bern.

Information platform

As well as tackling specific issues, Water Agenda 21 is increasingly promoting communication among representatives of the various interested parties, e.g. via a newsletter. On 9 March 2009, a conference was held on the subject of hydropeaking. Here, 12 experts from Switzerland and abroad described the impacts of hydropeaking operations on aquatic ecosystems and the current status of legal regulation, as well as presenting examples of surge-mitigating measures and other solutions. The conference showed that the problem is being taken seriously, and that intense efforts to find solutions are already under way in Switzerland.

Broad support is key to viable solutions.

Water Agenda 21

The Water Agenda 21 network was established in 2008 to support the development of Switzerland's water management sector. The network brings together major players representing a variety of interests within the sector, such as the Federal Office of Energy, the Federal Office for the Environment, cantonal authorities, the Swiss Association for Water Resources Management (SWV) and environmental groups. Offering a platform for dialogue among the various actors concerned, it helps to facilitate an integrated approach to cross-sectoral water-related issues. A key role in the launching of Water Agenda 21 was played by Eawag. Maintaining close contacts with water professionals, Eawag includes Water Agenda 21 themes in its aquatic research and contributes its findings and strategies to ongoing debates. The Water Agenda 21 office is currently based at Eawag.

Further information and details of the above-mentioned studies are available at: www.wa21.ch

Contact:
Wasser-Agenda 21 c/o Forum Chriesbach, Überlandstrasse 133, CH-8600 Dübendorf, Stefan Vollenweider, Director;
stefan.vollenweider@wa21.ch

Organisation

Directorate
Janet Hering (Director)
Rik Eggen (Deputy Director)
Willi Gujer
Peter Reichert
Bernhard Wehrli
Jukka Jokela (from1.1.2010)

Ecotox Centre Eawag/EPFL

Standing Commitees

Research departments

Research topic: Aquatic ecosystems

- **Surface Waters Research and Management** – Alfred Wüest
- **Aquatic Ecology** – Jukka Jokela, Piet Spaak (from 1.1.2010)
- **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** – Max Maurer
- **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

- **Corporate Services** – Thomas Lichtensteiger
- **Communication** – Anke Poiger
- **IT Services** – Gabriel Piepke
- **HR and Finances** – Gabriele Mayer
- **Technical Services** – Max Mauz
- **Apprenticeship** – Max Reutlinger

Eawag / Empa

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

Advisory Board

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

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Ursula Brunner
Lawyer, Ettler Brunner Suter Bächtold, Zurich

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

Jürg Meyer
Head Infrastructure Services, ISS Switzerland

Directorate

Janet Hering
Director

Rik Eggen
Deputy Director

Willi Gujer

Peter Reichert

Bernhard Wehrli

Jukka Jokela
(from 1.1.2010)

Research departments

Alfred Wüest

Jukka Jokela

Piet Spaak
(from 1.1.2010)

Ole Seehausen

Juliane Hollender

Thomas Egli

Kristin Schirmer

Rolf Kipfer

Hansruedi Siegrist

Max Maurer

Chris Zurbrügg

Peter Reichert

Bernhard Truffer

Support

Thomas Lichtensteiger

Anke Poiger

Gabriel Piepke

Gabriele Mayer

Max Mauz

Max Reutlinger

Bas den Brok

Joerg Klausen

Ecotoxicology Centre

Rik Eggen (Eawag) and **Christof Holliger** (EPFL),
ad interim heads

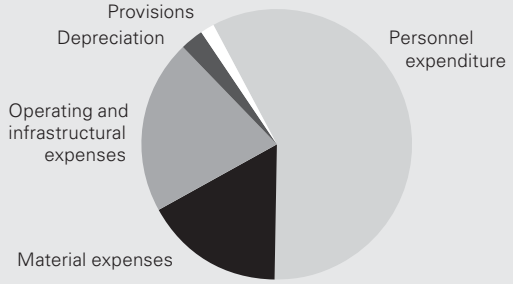
Finances

Financial statement	2007	2008	2009
Personnel	37 868 533	39 498 230	39 278 708
Materials	3 260 866	3 693 473	11 426 136
Operating and infrastructural expenses	13 491 879	13 049 526	14 011 009
Depreciation	1 082 462	1 315 815	1 896 647
Provisions	296 041	5 780 247	1 001 944
Expenditure	**55 999 781**	**63 337 291**	**67 614 444**
Federal government funding	38 491 577	54 429 850	47 596 574
Third-party resources	11 564 156	11 237 615	11 068 789
Miscellaneous revenue	1 655 624	935 584	1 238 918
Income	**51 711 357**	**66 603 049**	**59 904 281**
Result	**–4 288 424**	**3 265 758**	**–7 710 163**

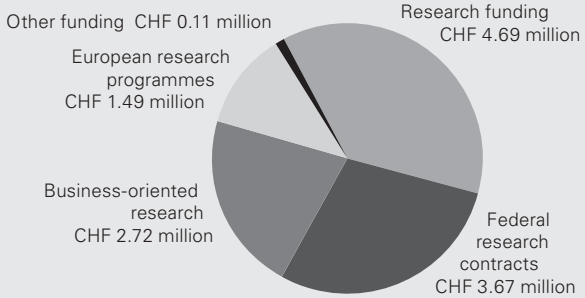
all figures in CHF

Investments	15 823 645	3 849 680	10 786 584
Real estate	13 890 051	1 484 507	8 462 580
Movables	1 663 563	2 047 665	1 953 614
IT	270 031	317 508	370 390

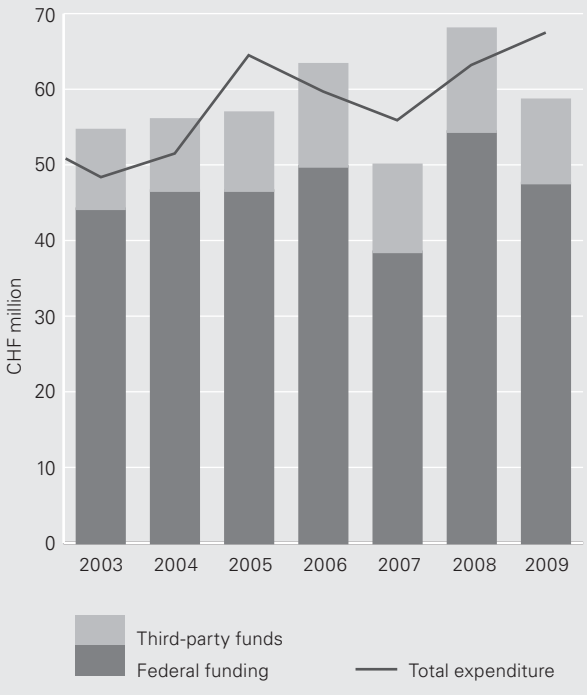
Breakdown of expenditure 2009



Third-party resources 2009



Development 2003–2009

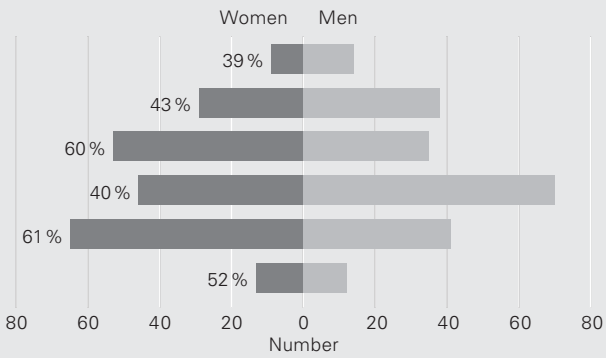


People

Personnel	People	Whereof women	Whereof non-Swiss	Full-time equivalents
Full professors[1]	9	1	3	9
Titular professors	14	2	4	14
Scientific staff (academic staff)	152	57	77	137
PhD students	87	46	49	86
Technical staff	80	41	12	67
Administrative staff	65	57	12	45
Apprentices	26	12	3	26
Total	433	216	160	384
Affiliated staff (nursery)	19	17	1	17
Trainees[2]	47	19	34	46

[1] 8 of them are not or not directly employed by Eawag
[2] Variable employment periods

Age structure	Women	Men	Total
60–65	9	14	23
50–59	29	38	67
40–49	53	35	88
30–39	46	70	116
20–29	65	41	106
15–19	13	12	25
Total	**215**	**210**	**425**
	(50,6 %)		



Percentage employment	Women	Men	Total
1–49 %	14	10	24
50–79 %	47	7	54
80–99 %	35	16	51
100 %	119	177	296

Origin	Women	Men	Total
Switzerland	137	130	267
EU	53	69	122
Other	25	11	36

Activities

	2007	2008	2009
Supervised dissertations	108	119	111
Supervised diploma theses	108	97	109
Publications in refereed journals	202	253	232
Publications in non-refereed journals	55	55	114
Spin-offs	–	1	–
Patents, licence agreements	1	–	–
Service contracts	28	31	24
Prizes	19	12	19
Teaching programmes at ETHZ, EPFL	75	81	82
Teaching programmes at other universities	39	52	41
Teaching programmes at universities of applied sciences	4	2	6
PEAK courses (further education)	5	4	5
Conferences	54	39	53
Committee memberships	216	178	184

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

The e-mail addresses of all staff are available via the search function on the website: www.eawag.ch

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