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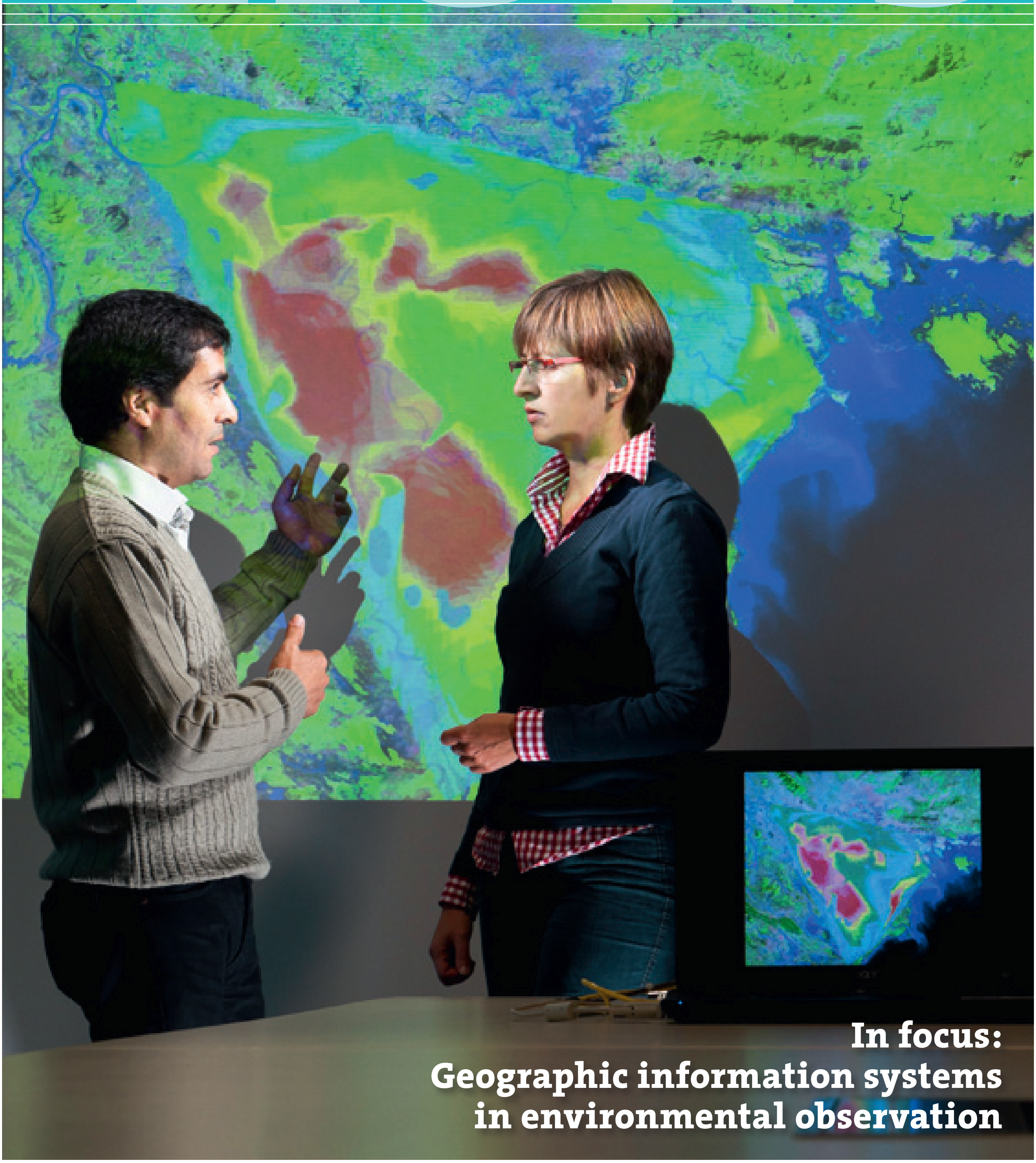

In focus:
Geographic information systems in environmental observation

Editorial

Peter Reichert is Head of the Systems Analysis, Integrated Assessment and Modelling department and a member of the Directorate of Eawag.

The importance of the spatial dimension

The spatial dimension is of major importance for the behaviour of environmental systems – and for the impacts of human activities on these systems. For example, crucial factors influencing water pollution from diffuse agricultural sources are how close farmland lies to surface waters, whether rainwater can run off directly and whether pollutants from other subcatchments are present. Morphologically or hydrologically improved stretches of rivers can only be successfully recolonized if displaced or locally extinct species are able to migrate from more near-natural river reaches. On the other hand, good longitudinal connectivity can also facilitate the spread of invasive species. These few examples illustrate how important the spatial dimension is in understanding ecosystems and in assessing restoration or enhancement measures.

Today, geospatial data is stored, processed and visualized in geographic information systems (GIS) and associated databases. These systems can also be used to produce interactive maps, to analyse data using statistical or mechanistic models which are either directly embedded in or externally linked to a GIS, to investigate environmental systems, or to manipulate input data and display the output.

This issue of Eawag News explores various aspects of geospatial data and analysis across a wide range of scales. In the interview with Rosi Siber (see page 4), for example, the potential of GIS as a means of communication is emphasized. In her own article (see page 14), she also demonstrates the benefits offered by GIS in developing relatively simple quantitative models for herbicide run-off from agricultural areas. Another application – described by Manouchehr Amini (see the article on page 6) – involves the integration of more complex models of groundwater contamination with arsenic and fluoride into GIS so as to identify areas where the use of groundwater resources for drinking water could pose health risks. Lastly, Christian Folberth (see the article on page 10) shows that the incorporation of complex models of agricultural production in a GIS can generate a large-scale overview of food production and its dependence on the climate.

As well as focusing on geospatial data, this issue of Eawag News also considers the topic of hydropower exploitation (see page 18), the expansion of which is subject to strong political pressures following Switzerland's decision to phase out the use of nuclear power. Here again, the spatial component is extremely important in numerous respects – in the protection of intact landscapes and in assessing the effects of habitat fragmentation, the consequences of hydropeaking operations or the residual flow regime associated with discharges from hydropower plants.

Finally, to mark the retirement of Willi Gujer, this issue includes a brief review of his career (see page 30). He has been instrumental in shaping Eawag's philosophy of not only making significant contributions to scientific research, but also being open to the concerns of practitioners; with his knowledge, he has actively helped to resolve practical problems in the water supply and wastewater management sector.

Cover photo: Geospatial modeller Manouchehr Amini of the Systems Analysis, Integrated Assessment and Modelling department discussing with a colleague a risk map for geogenic groundwater contamination. (Photo: Peter Schönenberger, Winterthur)

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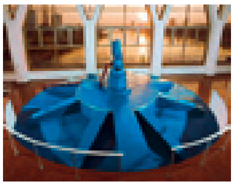
As nuclear power is phased out, the Swiss government intends to expand the use of hydropower. However, the assumption that the potential exists for a net increase in capacity of four billion kilowatt-hours is questioned by various experts.

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eawag aquatic research

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"GIS is an excellent means of communication"

A geographic information system, according to Rosi Siber (a GIS specialist at Eawag), is an effective tool for visualizing abstract phenomena graphically in a readily comprehensible way. This can facilitate exchanges between disciplines and communication with the public. But to create a good map, cartographical expertise is indispensable.

Interview: Andres Jordi

Rosi Siber, what exactly is the difference between a conventional map which you can buy in bookshops and what is displayed by a geographic information system? As print products, there's no difference between the two kinds of map. They're both static and cannot be altered as regards scale or information content. But the advantage of GIS is that computerized maps can easily be adjusted at any time. So you can display a section at different scales and show or hide different thematic layers, such as land use or surface elevation. That makes a GIS map – even one with a greater information content – much clearer than a conventional map. Also, the latter is a snapshot taken at a particular point in time, which may go out of date very quickly, whereas a GIS map can be continuously updated.

GIS links a geographical area to information about that area.

Is this kind of map just as accurate as its conventional counterpart? The first GIS maps were created by scanning conventional maps. So the basis of the geographical data is the same. Now, of course, the data exists in a purely digital form.

A map produced by a GIS may be quite clear, but the concept itself is still a bit vague. What is a geographic information system? A GIS provides a link between a geographical area and information relating to that area – herbicide run-off to surface water *x* is high, run-off to surface water *y* is low – and this is presented graphically. A GIS always comprises the software which can process this kind of information, the spatial data with the specific information content and the user. In a GIS program, data is input, processed, analysed and output in a graphical format, and that also applies to organization and management in a database. Data can be imported as a simple table consisting of the specific information – for example, concrete measurement values or landscape categories (arable land, surface water, forest) and the associated coordinates. As well as using point objects, you can also process lines, areas and graphical data such as aerial or satellite images.

Apart from the points you've already mentioned, what are the advantages of a GIS? A map can explain more than a thousand words. A GIS is an effective tool for visualizing abstract phenomena and spatial correlations graphically and very clearly. This can facilitate exchanges between experts across different disciplines. That makes it an excellent means of communication, especially when dealing with the public. But a map always makes some kind of statement, too, and this can be appropriately supported by the form of graphical presentation you choose. So you can persuade, but also influence people. And there may be something manipulative about that. If you show a region's pesticide use in bright red, that will convey a different message than if the same map employs delicate shades of green. Which makes it all the more important that this kind of visualization should be expertly handled.

Can a GIS do more than visualize data? The core function of a GIS is spatial analysis. This means you can generate intersections, or "overlays", from different measurement data, or integrate data spatially. Distances can be determined using network calculations, and catchment areas with hydrological calculations. In addition, integrated viewing and analysis of data from different disciplines enables you to identify new connections. Certain types of statistical analysis and modelling are also possible. Of course, specific programs are often used for more in-depth analyses, but some modelling tools are based directly on a GIS. Applications of this kind are also being developed by Eawag (see page 10).

With a GIS, abstract data and spatial correlations can be clearly visualized.

Is it worthwhile for scientists to acquire these skills themselves, or should they leave GIS to the specialists? The basic skills can be acquired relatively easily. A longer training period is necessary if you want to carry out analyses in more depth. Because the effort involved in producing maps is not that great, a GIS can pay off fairly quickly. As soon as data are to be used in the longer term, it becomes worthwhile. There are also open-source applications available online, which can be downloaded free of charge. They are certainly usable for simpler visualizations.

What about the compatibility of the various programs and formats? The standard here is set by the US software company Environmental Systems Research Institute (Esri), which has its own data format. Programs produced by other companies offer interfaces for this format. But data can also be saved in a generic format, as a simple text file. That ensures it will still be possible to read it in twenty years' time, in spite of continuing technological developments.

Where is GIS used within Eawag? It's mainly used by researchers whose work has a direct relation to space. They frequently use GIS maps to gain an overview of a study area and its geological, hydrological and biological characteristics. With the aid of digital elevation models, surface water catchments and their characteristics are calculated for a given region. Another important area is GIS-based modelling. For example, we've modelled herbicide run-off processes on arable land (see page 14).

What are the sources of the data used in your GIS applications? Firstly, of course, the researchers collect project-specific data. Basic – particularly spatial – data is obtained primarily from the Federal Office of Topography (swisstopo) and, if necessary, adapted to our requirements. Other suppliers include the Federal Statistical and Environment Offices and the cantonal GIS agencies.

With swisstopo we have a data contract, so we can use their geodata freely within Eawag. Many cantons make data available free of charge, or we conclude project-level agreements so that we can also use data free of charge for research purposes.

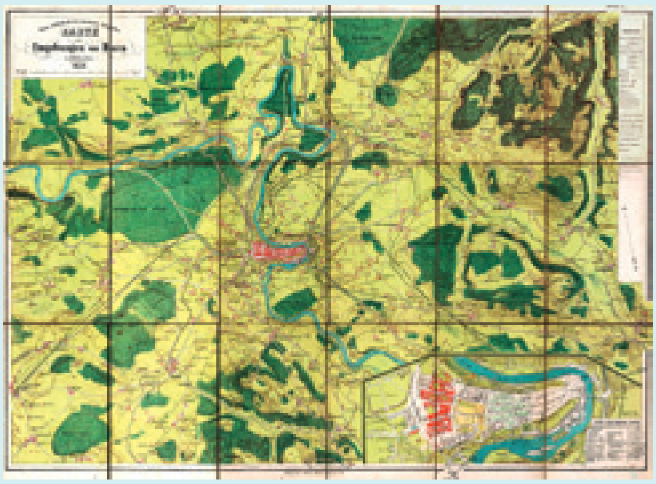
At Eawag, you're responsible for the coordination of geoinformation systems and geodata. What does that involve in practice? Firstly, I offer researchers conceptual advice – for example, on the GIS options available for the questions they're studying – and provide support with data acquisition, processing and management. I coordinate the GIS projects running at Eawag, know who's doing what and can bring people together internally. Secondly, I'm the point of contact for external partners and keep in touch with the people responsible for GIS at other research institutions. In addition, I follow technological developments and am familiar with the latest software versions or tools.

What are the latest trends? At the moment, there's a strong focus on the Internet and on mobile applications for general use – for example, how maps can be displayed on smartphones. Of particular interest for Eawag in this connection are Web-based solutions. We've already developed a few applications of this kind. For example, we've recently made the residual flow maps for Switzerland available online at www.eawag.ch/webkarte-restwasser. A Web-based application for groundwater contamination with arsenic and fluoride will be completed soon (see page 6). ○ ○ ○

Swiss map search portal

Kartenportal.CH, launched at the beginning of 2011, allows users to search online for printed/digital geographical maps or geodata held by map collections, archives and geodata providers in Switzerland. Bringing together all the relevant information, the portal offers an efficient, newly developed map search tool. Based on the Google Maps API, the geosearch system enables all the cartographic materials available for a given area to be found, including details of library locations. Kartenportal.CH was developed and continues to be operated by Lib4RI – the joint Eawag/Empa/PSI/WSL library – in collaboration with other Swiss higher education institution libraries.

www.kartenportal.ch



On this map dating from 1858, the city of Bern and its environs are shown at a scale of 1:24,742.

Manouchehr Amini, geospatial modeller in the Systems Analysis, Integrated Assessment and Modelling department, is responsible for developing Web-based GIS applications.

Putting geogenic contamination on the map

Arsenic and fluoride occurring as natural (geogenic) contaminants in groundwater threaten the health of millions of people. A Web-based GIS application will not only raise awareness of this issue but also help policymakers to identify areas at risk of contamination.

Providing safe drinking water and improving water quality are global challenges requiring huge efforts. According to the World Health Organization's latest estimates, more people die each year from the consequences of unsafe or inadequate water supplies than from all forms of violence [1]. Poor water supplies and sanitation also have an impact on economic growth in much of the developing world, costing countries of the Middle East and North Africa between 0.5 and 2.5 per cent of GDP every year [2]. Accordingly, one of the UN Millennium Development Goals is to halve, by 2015, the proportion of the population without sustainable access to safe water and basic sanitation.

Geogenic contaminants: a health risk. In many parts of the world, groundwater is an indispensable source of drinking water, as it is free of the pathogens which are widely found in surface waters. However, groundwater quality may be affected by natural substances leached from the aquifer's rocks and sediments. These geogenic contaminants pose a risk to human health. It is estimated that around 200 million people are affected by arsenic and fluoride contamination alone – roughly 5 per cent of all those who use groundwater for drinking worldwide.

Chronic exposure to excessive levels of arsenic in drinking water can cause a variety of health problems, ranging from skin

Drinking water from groundwater wells in many parts of Cambodia contains elevated concentrations of arsenic.

Mickey Sampson, Resource Development International, Cambodia discoloration and keratosis to cardiovascular disorders and cancer. High fluoride concentrations in drinking water can cause growth disorders, dental fluorosis and bone deformities. According to the World Health Organization, arsenic concentrations of less than 10 micrograms per litre are acceptable, while the WHO guideline value for fluoride is 1.5 milligrams per litre.

Arsenic-enriched groundwater resources are found worldwide. The first cases of chronic arsenic poisoning were reported in Taiwan, Chile, Argentina and Mexico. Critical concentrations of arsenic in groundwater occur in numerous regions across China, Nepal, Cambodia, Vietnam, Myanmar and the Indonesian island of Sumatra. However, the region with the highest population suffering from groundwater-derived arsenic poisoning is the Bengal delta (comprising Bangladesh and part of India) [3].

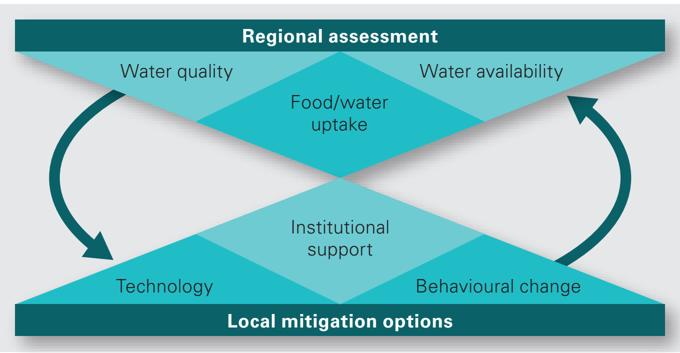
The East African Rift Valley, extending from Eritrea to Malawi, is one of the well-documented regions with severe fluoride contamination. High concentrations of fluoride in groundwater have also been reported from India, China, Pakistan, Senegal, South Africa, Argentina and Mexico [4].

With the rapid growth of the use of groundwater for drinking and irrigation, the ability to reliably identify safe groundwater resources is essential. This is one of the motivations for Eawag's interdisciplinary research project "Water Resource Quality". The aim is to develop a framework – applicable at the regional and local level – for the mitigation of arsenic and fluoride contamination (Fig. 1).

Firstly, we wish to enable government agencies and international NGOs to gain regional overviews of the spatial distribution of geogenic contamination in the countries concerned, and subsequently to develop large-scale strategic approaches for the mitigation of risks. Secondly, through direct collaboration with local authorities and NGOs, we are seeking solutions for specific local problems, such as how to deal with contaminated water supplies in a town or village. Here, we provide information and expertise to support local stakeholders in developing affordable and broadly applicable measures.

Arsenic poisoning leads to overgrowth of horny tissue (keratosis) and can even cause cancer.

Fig. 1: The Water Resource Quality project involves both a regional and a local approach. One component focuses on the assessment of groundwater resources, while the other is concerned with specific mitigation options for arsenic and fluoride contamination.
Further information is available at: www.wrq.eawag.ch



Using models to fill gaps in data. One component of the project involves the development of a Web-based GIS application for global and regional risk maps. To date, affected groundwater bodies have largely been identified by large water-quality monitoring programmes, such as the US National Water-Quality Assessment Program (NAWQA, http://water.usgs.gov/nawqa/), the European Geochemical Baseline Mapping Programme in Europe (FOREGS, http://www.gsf.fi/foregs/geochem/) or the International Groundwater Resources Assessment Centre (IGRAC; www.igrac.nl/). However, in developing countries – where knowledge of high-risk areas would be particularly beneficial – systematic monitoring activities are frequently limited by a lack of institutional and financial support.

In recent years, the increasing availability of geospatial information (e. g. on geology, climate, soil properties and land use) and the computing power to process this information has revolutionized the environmental sciences. Though it can never replace local monitoring, geospatial information can be used as a proxy for geochemical conditions to identify aquifers that are highly likely to be affected by geogenic contamination. For example, the solubility and release of arsenic into groundwater is controlled

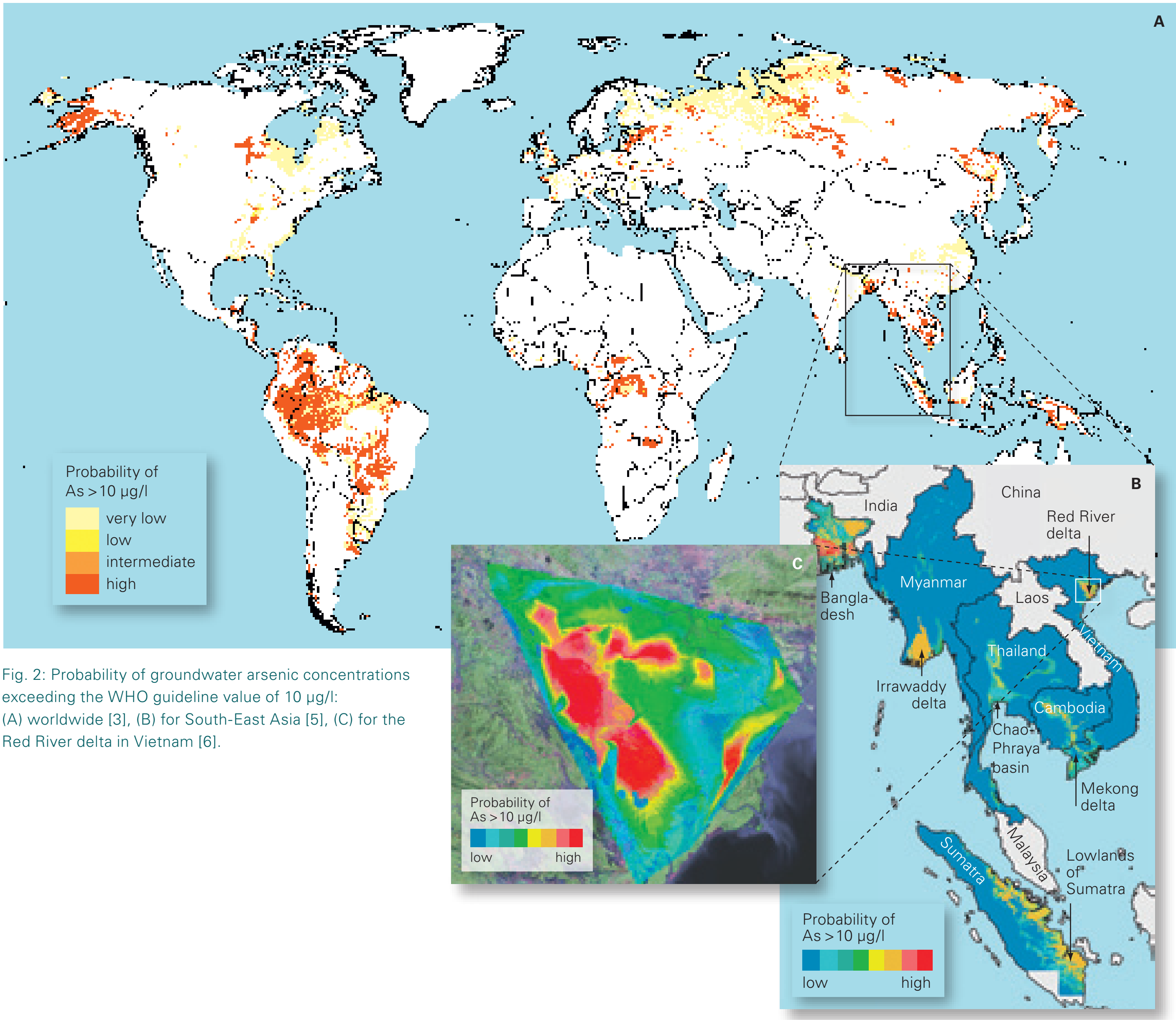


Fig. 2: Probability of groundwater arsenic concentrations exceeding the WHO guideline value of 10 µg/l: (A) worldwide [3], (B) for South-East Asia [5], (C) for the Red River delta in Vietnam [6].

by chemically reducing conditions, which in turn are governed by geology, climate, drainage and topography. Equally, fluoride concentrations in groundwater are determined by the fluoride content of rocks (e.g. granite, basalt, syenite and shale) or their constituents (e.g. apatite, fluorite, biotites or topaz).

With the aid of modelling, we have used such information to make global predictions of elevated levels of arsenic and fluoride in groundwater [3, 4]. In addition, based on measured groundwater concentrations and digitally available geospatial information (e.g. on surface geology, soil, elevation, land use and agricultural management), we have produced arsenic risk maps on various scales – global, continental for South-East Asia, and regional for the Red River delta in Vietnam (Fig. 2).

Making data accessible to the public. Geographic information systems (GIS) are now widely accepted as powerful tools for storing, managing, manipulating, analysing and visualizing geospatial data. Recently, GIS technologies have been integrated with the Internet in the form of Web-based or online GIS applications (see the interview on page 4). These developments have created new opportunities for researchers working with geospatial information. Web-based GIS applications also facilitate the accessibility and dissemination of geospatial information to the public. The attractiveness of these applications has been enhanced by the development of open-source software for hosting, processing and visualizing geodata.

One such development is GeoServer (http://geoserver.org), an open-source server which can be used to host, edit and share geospatial data from any major data source using open standards. It provides different services, allowing users to interact with data-

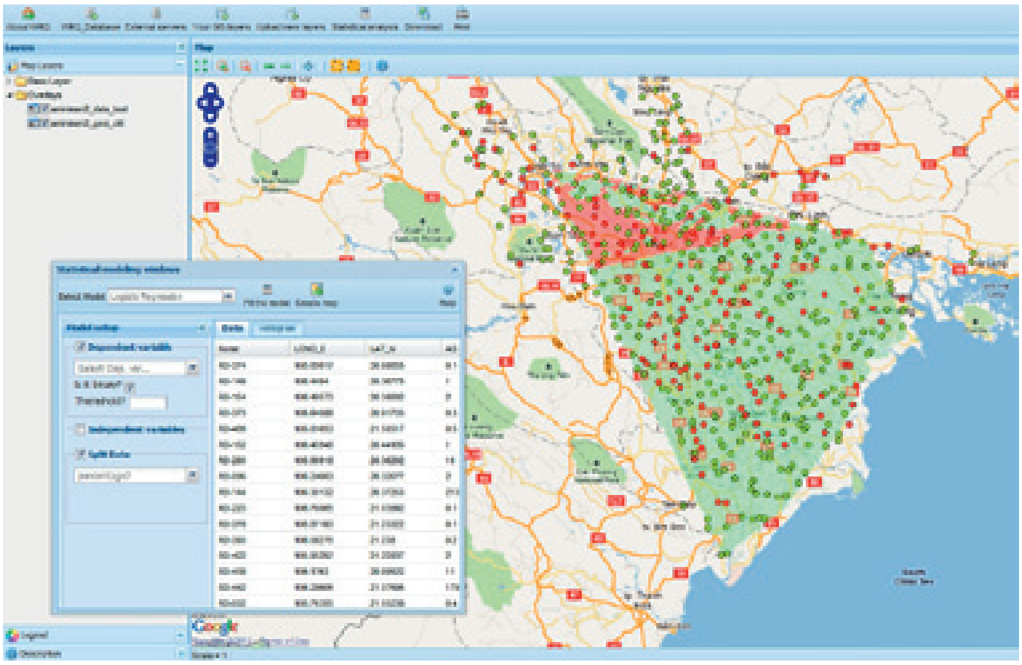


Fig. 3: The user interface of the Web-based GIS application (pre-release version).

bases and explore geospatial information. Another example of open-source GIS libraries is OpenLayers (http://openlayers.org).

In order to share our data on geogenic contaminants in groundwater and our modelling expertise, we have used these freely available tools to develop a Web-based GIS application (Fig. 3). We have established a local open-source server which hosts our global geospatial database and probability maps. With this application, users can overlay and manipulate the available geospatial information, as well as obtaining data from other spatial data infrastructure services such as the UN GEO Data Portal (http://geodata.grid.unep.ch/webservices).

With our Web-based GIS application, we aim to put geogenic contamination on the map in an attractive and informative manner. The online tools should also provide information for regions where groundwater monitoring is not routinely carried out, thus helping policymakers, global organizations, local governments and NGOs to identify high-risk areas and locate safe groundwater resources.

Continuous improvements. The GIS application will become available at http://webgis.wrq.eawag.ch in 2012. It should be noted that the global maps are not yet suitable for detailed regional assessments, since their accuracy is limited by two factors – the spatial resolution of globally available information and the availability of measurement data. However, on the regional scale, the quality of such models can be improved – as shown by our regional models [5, 6]. Users will be able to upload their own data and develop regional probability maps, using the statistical library and support provided.

As more information becomes available, we are likely to see numerous and rapid developments in the years ahead. Improvements in our understanding of hydrogeochemical processes and optimized modelling procedures should enable us to identify affected aquifers more precisely in the future. ○○○

[1] World Health Organization (2002): World health report – Reducing risks, promoting healthy life. Geneva, Switzerland.

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Climate change and sub-Saharan agriculture

Changes in the global climate are expected to have major impacts on agriculture. Sub-Saharan Africa, in particular, will experience declining yields. Using GIS models, Eawag is studying how climate change will affect agricultural output in this region, and how farmers can increase crop production – both in general terms and under changing climatic conditions.

Christian Folberth, who has an MSc in environmental planning and ecological engineering, is a doctoral student in the Systems Analysis, Integrated Assessment and Modelling department.

In sub-Saharan Africa, agricultural productivity rates for the cultivation of staple crops such as maize, wheat, millet and rice are among the lowest worldwide. Along with extreme events – droughts, torrential rains or insect infestations – one of the main problems is the depletion of soil nutrients. Often, the plant varieties grown are not ideally adapted to the environmental conditions. In addition, many smallholders harvest not only the corn but the entire plant, for use as fodder, fuel or building material, thereby depriving the soil of nutrients. In most cases, they cannot afford to buy mineral fertilizers. On average, fertilizer consumption in this region is less than 5 per cent of that in industrialized countries. Less than 4 per cent of the area under cultivation is irrigated.

Seeking regionally adapted solutions. In recent years, several studies have sought to estimate the impacts of climate change on agricultural productivity in sub-Saharan Africa with the aid of statistical analyses or crop growth models; the picture they paint is generally bleak. In some areas, according to these studies, yield reductions of more than 50 per cent are to be expected by the end of the century. At the same time, local actors are successfully developing methods of increasing agricultural production and mitigating the adverse effects of a changing climate. Potential solutions are also being explored by scientists in a large number of field studies.

Labouring in the barren fields of Eritrea: in agricultural areas of sub-Saharan Africa soil degradation is widespread. Very few smallholders can afford to use mineral fertilizers.

Stefan Boness/Ipon

In our ongoing project, we are using a regional crop growth model to estimate the impacts of climate change on sub-Saharan agriculture and to assess and compare the effectiveness of various methods of increasing productivity. The aim is not to identify a solution applicable for the entire subcontinent, but to investigate which methods are most promising for specific areas.

For our simulations, we use the Environmental Policy Integrated Climate (EPIC) model, which is one of the most well-established programs for the modelling of agricultural systems [1]. To make EPIC suitable for grid-based output maps, it was coupled with a geographic information system (GIS-based EPIC = GEPIC) in an earlier Eawag project. To obtain appropriate (raster format) input data, we divided the study area into grid cells. Each cell represents an agricultural unit with an individual dataset, comprising e. g. climate, soil type, slope, irrigated area and fertilizer input. The range of input data can be extended as required. The resolution can also be adapted, according to the granularity of the data; at present, it is set at 50 × 50 kilometres. In addition, management measures for the crops in question are fed into the model [2].

From this data, the model calculates the biomass and crop yield, evapotranspiration, nutrient cycling, erosion, soil water balance and numerous other variables. These can be directly evaluated in the GIS or combined with other raster datasets such as population statistics (e. g. for food availability per capita).

Influence of socio-economic factors. In estimations of this kind, socio-economic factors – especially the health status of the population – play an important role. Thus, quite apart from the human tragedy, HIV prevalence rates of up to 30 per cent (Botswana) and the persistence of widespread cholera and malaria epidemics are associated with massive losses of experienced farmers and agricultural workers. Smallholders affected by diseases frequently have to sell their meagre resources (equipment or livestock) so that they can afford medical treatment. Moreover, the rural population may be forced to flee as a result of recurrent armed conflicts.

As many of these diverse factors are locally variable and little data is available, they cannot readily be integrated into models. It is, however, important to bear them in mind, as they restrict the extent to which the results of modelling are comparable to official statistics. It is not unusual for simulated yields to be 20–40 per cent higher than those reported by official sources. Our model is likewise confined to physical environmental conditions (soil, climate and topography) and agricultural practices (varieties, management, fertilizer and irrigation intensity).

Estimation of soil degradation. The soil and climate data used in our model is taken from global datasets compiled by other institutions. The crop growth parameters are based on studies by colleagues who calibrated EPIC in the field [3, 4]. For planting dates, we developed a method allowing us to determine – on a regional basis – the optimal date for each year of the study period.

In estimating yields, one important factor usually neglected in earlier studies is soil degradation. The available soil data generally relates to natural ecosystems, rather than to (often degraded) croplands. To obtain more realistic information, therefore, we simulated the yields which would result for various crops after 20 years of continuous cultivation, assuming that 85 per cent of the biomass is removed from the field after each harvest (Fig. 1).

Although this scenario only represents real-world conditions to a limited extent, the simulated yields are in relatively good agreement with the official statistics. However, proper validation can only take place when spatially explicit data on soil degradation is available. Efforts to collect such data are currently being pursued in various international projects, such as the Africa Soil Information Service.

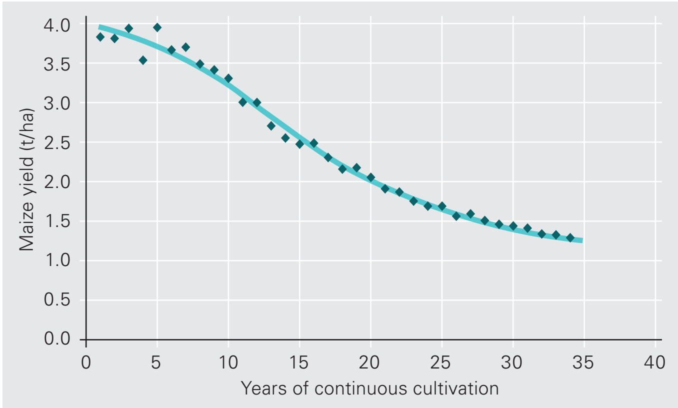


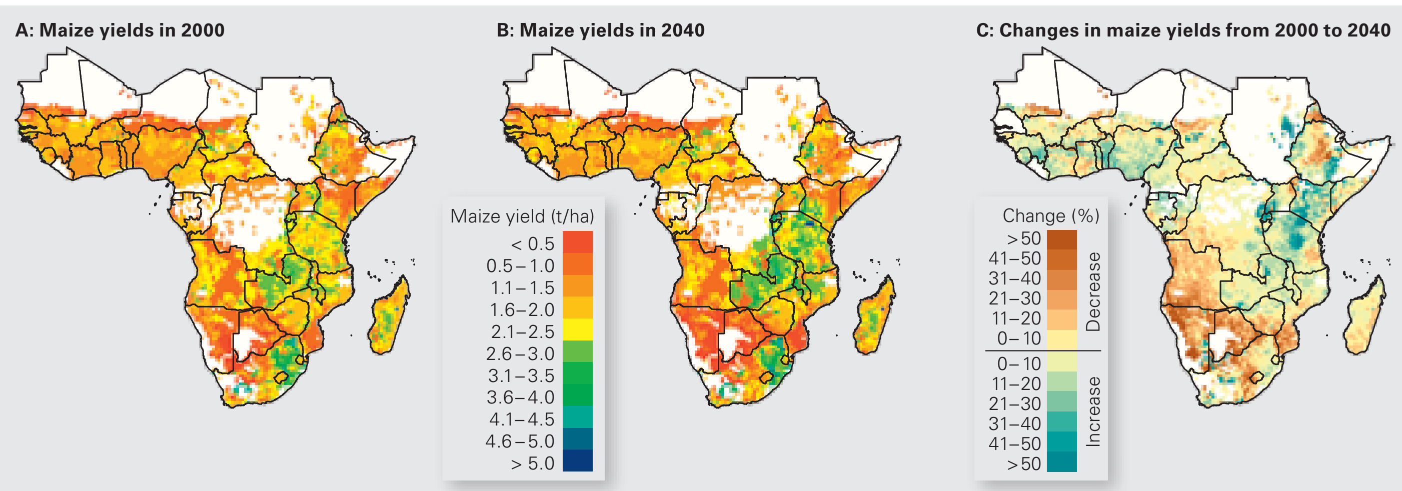
Fig. 1: As the example of maize shows, yields decline over a number of years of continuous cultivation if plant residues are removed and no nutrients are added. In our model, yields after 20 years are used [5].

Increasingly adverse impacts of climate change. On the basis of all this data, together with climate models, the expected impacts of climate change on crop yields can be estimated using GEPIC. In the case of maize, we have already done this for the period 2000–2040 (Fig. 2).

According to this simulation, reduced yields are to be expected over the next few decades particularly in the south of the continent (in Botswana, Namibia and South Africa) and in Ethiopia and the Sahel region. However, there are also regions where yields can be expected to increase, including large parts of West Africa (Nigeria, Niger and Guinea) and East Africa (Mozambique, Kenya and Somalia). This is primarily attributable to higher atmospheric CO_2 concentrations (the CO_2 fertilization effect) and predicted local increases in rainfall. In addition, the expected temperature rises could well be beneficial for crop growth at higher altitudes.

If we consider the period up to 2080, higher yields are to be expected particularly around the middle of the century, when temperature rises will still be modest and, at the same time,

Fig. 2: Simulated maize yields for 2000 (A) and 2040 (B), and changes in yields over this period (C).



Increased yields thanks to low-cost measures: in a field trial in South Africa, maize with more reliable supplies of water (left and right), from in situ rainwater harvesting and the application of greywater (mainly wash water), grows better than control plants (middle).

somewhat higher CO_2 concentrations will allow more biomass to be produced. But thereafter, the adverse effects of elevated temperatures will predominate in many regions and, on average, yields will decline again [6].

A need for innovative farming methods. How can smallholders in sub-Saharan Africa adapt their cultivation practices to changing climatic conditions so as to achieve stable or even increased yields?

One approach frequently advocated is that of a "green revolution", as pursued by industrialized countries in the 1960s. This would involve in particular the use of mineral fertilizers, irrigation systems and higher-yielding varieties. But the price of fertilizers in sub-Saharan Africa is 4 to 6 times the global market price – mainly as a result of high transport costs. Local fertilizer production is marginal and has only limited potential for development in the medium term, owing to the high energy requirements.

As well as these cost-intensive options, however, various low-cost methods exist. For example, several studies have found in situ rainwater harvesting to be highly promising. This involves soil management measures which promote infiltration of water into the soil. In areas with heavy but irregular rainfall, this means that, rather than running off the surface, water is stored in the ground and is thus available to plants during the growing period. With this method, yields can be increased locally by a factor of 2 to 4. Above all, rainwater harvesting makes it possible to compensate for fluctuations in precipitation.

As regards the addition of nutrients, low-cost alternatives also exist. Nitrogen-fixing legumes – including local varieties such as *Sesbania sp.* or *Vicia faba* (broad bean) – can be grown in rotation or in combination with nutrient-intensive crops such as maize. Another option which has proved successful in field trials is agroforestry, where for example a nitrogen-fixing acacia *(Faidherbia albida)* is grown alongside crops as a source of shade and nutrients.

Higher yields with nitrogen fertilizers. Most of these management measures can be assessed with GEPIC. So far, however, we have mainly simulated the effects of high-input methods (nitrogen fertilizers and irrigation), as these permit an estimation of the yield limit and serve as a reference.

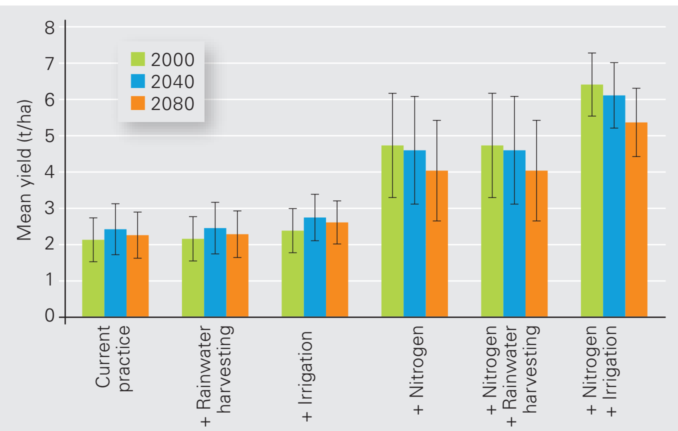
In a preliminary study, we have already evaluated a selection of agronomic measures for maize cultivation (Fig. 3). If one looks at the differences between the simulated effects under the current climate, no significant improvement is apparent with rainwater harvesting. Conventional irrigation likewise only leads to a yield increase of approximately 10 per cent. With the application of sufficient nitrogen, however, a dramatic increase of more than 100 per cent is seen. Here, too, the addition of rainwater harvesting has a limited effect, but additional irrigation leads to a further marked increase. Thus, with adequate nitrogen and water supplies, yields could be increased on average more than twofold, although in relation to the region as a whole the priority must be to tackle nutrient depletion.

The fact that rainwater harvesting, which has proved effective in practice, shows marginal effects in the simulations may be due to various factors. The method is particularly effective on steeply sloping fields, where – in the absence of special management measures – surface run-off is especially high, limiting the water available to crops. With our relatively coarse resolution (50 × 50 kilometre grid cells), however, slopes are frequently cancelled out across the whole area. In addition, the timing of soil tillage measures is of major importance. In the model, therefore, local adjustments may still be required.

If one looks at the effects of climate change in the "business as usual" scenario, yields can be expected to increase slightly by 2040, but by 2080 they will decline again to just over the levels seen in 2000. This also applies to the scenarios involving rainwater harvesting or irrigation without additional nitrogen. In contrast, for all three scenarios with adequate nitrogen supplies, a continuous decline in yields is to be expected. Nonetheless, the lower yields in 2040 and 2080 are still considerably higher than current levels.

It may thus be concluded that, both today and in the future, high-input agriculture can help to increase yields. However, the return on investment is likely to decrease in the future. At the same time, with adequate irrigation, water requirements can be expected to rise, sometimes substantially. This applies in particular to Madagascar, the West African coast around Liberia, the Gulf of Guinea and parts of Central Africa [7].

Fig. 3: Mean maize yields in sub-Saharan Africa with various management measures under current and future climate regimes. Error bars indicate the standard deviation.



More comprehensive and precise models. This preliminary study permits only a rough estimation of the impacts which climate change can be expected to have on sub-Saharan agriculture. We therefore intend to incorporate a larger number of climate models and emission scenarios, so as to cover the broadest possible range of potential developments and to limit the uncertainty of our estimates. In addition, we are increasing the number of staple crops studied, including not only wheat, millet and rice (as mentioned above) but also cassava and sorghum. As well as allowing us to assess the impacts of climate change, this should also indicate whether certain crops could play a particularly important role in assuring future food security.

First and foremost, there is a need to analyse the low-cost management measures in more depth. In cooperation with local organizations and research institutions, we shall be focusing on studies of legumes, soil conservation and agroforestry. Since the choice of methods is usually largely determined by economic factors, these will also be included in our future analyses. ○ ○ ○

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Rosi Siber, GIS specialist in the Systems Analysis, Integrated Assessment and Modelling department, is responsible for GIS and geodata coordination at Eawag.

Where is herbicide use particularly critical?

Although herbicides can be detected in surface waters throughout Switzerland, herbicide-intensive crops are mainly cultivated in low-risk areas. This was shown by an assessment involving GIS-based modelling of discharge processes on the Central Plateau. With this approach, critical areas can also be identified.

Is chemical pollution of surface waters responsible for declining fish stocks in various parts of Switzerland? Can adequate supplies of safe water be assured for the growing population in an age of climate change? In addressing these and many other issues, monitoring of water quality remains a priority concern, particularly in regions as densely populated as the Swiss Central Plateau, where a wide variety of interests confront each other in a relatively small area – hydropower generation, agriculture, flood control and protection of natural habitats. Assessment of water quality calls for a knowledge both of the sources of water pollution and of the processes whereby pollutants enter surface waters. Among the most important diffuse (i. e. non-point) sources of water pollution are herbicides used in agriculture.

Lack of soil data for Switzerland. Scientists seeking to understand and quantify herbicide losses to surface waters have car-

On the Central Plateau, agricultural herbicides are mainly applied in areas where their use is appropriate from a water protection viewpoint.

agenda/Michael Kottmeier

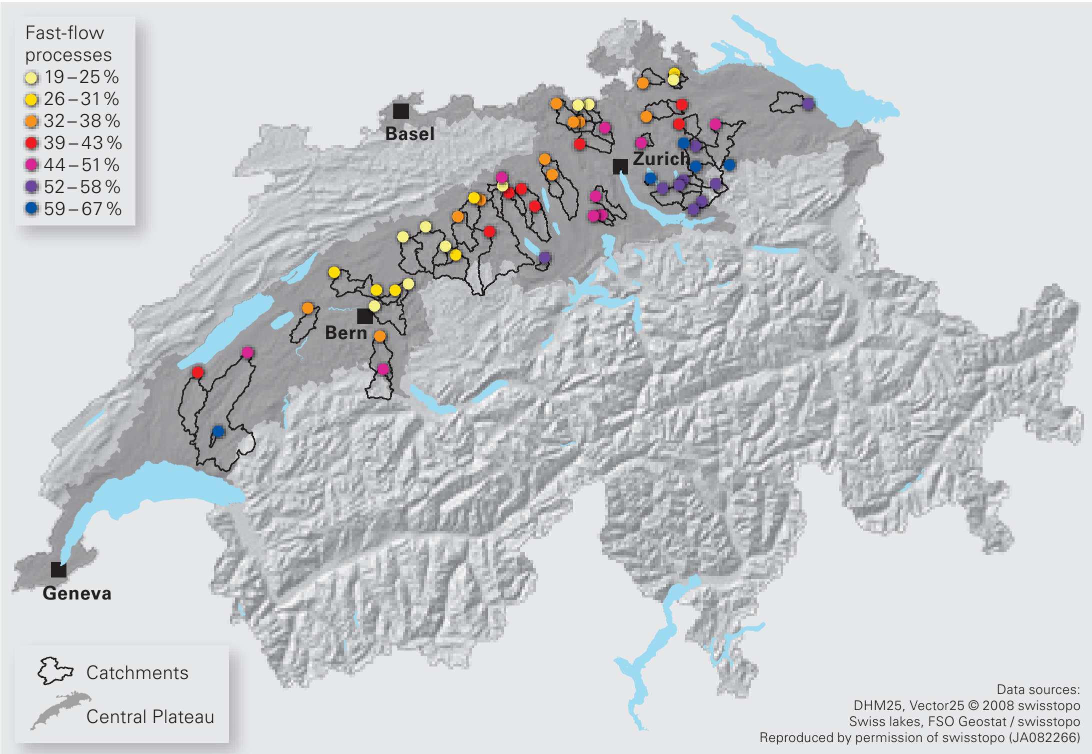

Fig. 1: National discharge stations in the Central Plateau and their catchments. The colours represent the relative contribution of fast-flow processes to total flow. The higher this percentage is, the higher herbicide losses are expected to be.

ried out field studies [1, 2]. However, such studies are costly and require considerable effort. Mathematical models can therefore be useful in assessing diffuse losses for extensive areas. Over the last 20 years, numerous complex models have already been developed for inputs of pesticides to surface waters [3]. But the applicability of these models in Switzerland is limited, mainly due to a lack of adequate soil and drainage data.

Christian Stamm of the Environmental Chemistry department and Peter Reichert and Rosi Siber of the Systems Analysis, Integrated Assessment and Modelling department of Eawag have therefore developed a simpler model which, while capturing the main processes underlying herbicide losses, is still applicable in practice with the data available [4]. The aim of this modelling was not to predict possible concentrations in surface waters, but to assess the risk of herbicide losses for agricultural areas – in other words, to identify areas that are particularly susceptible to such losses, e.g. on account of soil properties. Inputs to surface waters can then be estimated by combining the results of modelling with the spatial distribution of estimated herbicide use. We confined our study to the Central Plateau because intensive agriculture – associated with high levels of pesticide use – is primarily concentrated in this region.

Although the processes determining herbicide losses are highly complex, the temporal dynamics of herbicide concentrations in surface waters follow a simple pattern: these substances are mainly transported to waterbodies during and shortly after application, if they are simultaneously washed out of the soil by rain or as a result of irrigation. Herbicide transport from fields to surface waters mainly involves what are known as "fast-flow" processes, such as surface run-off or tile drain flows [5]. Accordingly, the extent of losses to surface waters is largely determined by the level of fast-flow processes in a catchment.

Higher risks in the east and in the pre-Alps. For our modelling, we therefore used the predicted level of fast-flow processes [6] as a good proxy for herbicide transport [7]. Information on flow processes was provided by long-term measurement data from the national discharge stations operated by the Federal Office for the Environment (Fig. 1). In addition, using a GIS, we delineated individual catchments on the basis of a digital elevation model and Swiss river network data, and for each catchment we calculated the parameters relevant for discharge patterns. These included data on topography, climate, soil and land use (Table).

To eliminate gaps in coverage, a prediction model including climate and soil data as well as topographical parameters was used for areas where discharge measurements were not available. In order to find out which factors have a major influence on the level of fast-flow processes, we subjected the discharge data and catchment parameters to statistical (regression) analysis. The results indicated that fast-flow processes are influenced by three factors in particular – soil permeability, river density (ratio of the total length of all watercourses to the area of the catchment) and precipitation frequency. With a discharge model, we were able to account for the level of fast-flow processes to a high degree (62 per cent) using the combination of soil permeability and river density alone.

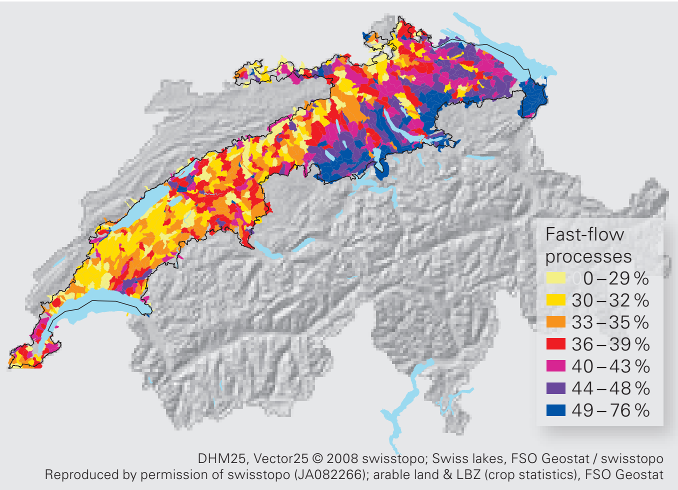

Fig. 2: The risk of herbicide losses, indicated by the relative contribution of fast-flow processes to total flow. A higher percentage corresponds to a higher risk.

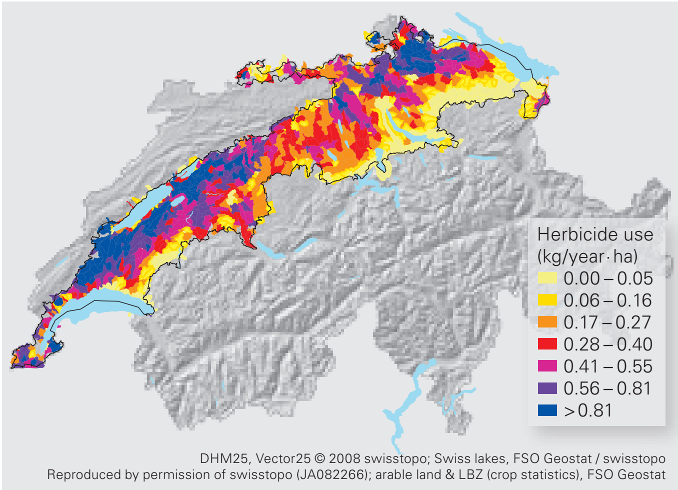

Fig. 3: Estimated herbicide use: the amount used in a particular catchment depends on the crops cultivated there.

With the aid of this model, discharge patterns for the catchments with no data could now also be predicted and visualized in the GIS together with the catchments for which data were available. This complete picture of the Central Plateau shows, for all areas, the relative contribution of fast-flow processes to total flow and hence the risk of herbicide losses. This risk can be seen to increase from the west to the east, and also towards the pre-Alps and Alps (Fig. 2).

Table: Parameters relevant for discharge patterns in individual catchments.

		Data sources
Topography	Slope	swisstopo: DHM 25 © 2004-8, reproduced with the permission of swisstopo (JA 082266)
	Minimum elevation	
	Maximum elevation	
	Mean elevation	
	River density	swisstopo: Vector25 © 2004-8, reproduced with the permission of swisstopo (JA 082266)
Climate	Mean annual precipitation	Hydrological Atlas of Switzerland (2008): www.hades.unibe.ch
	Precipitation frequency	Wüest M., Frei C., Altenhoff A., Hagen M., Litschi M., Schär C. (2008): A gridded hourly precipitation dataset for Switzerland using rain-gauge analysis and radar-based disaggregation. Intern. J. of Climatology
Soil	Permeability	Soil suitability map (BEK 200, FSO Geostat)
	Waterlogging	
Land use	Herbicides used per crop	Keller L., Amaundruz M. (2004): Pflanzenschutzmittelverbrauchserhebung der Jahre 1997–2003 in den Einzugsgebieten Greifensee, Murtensee, Baldeggersee. LBL, Lindau, SRVA, Lausanne
	Arable land	FSO (2004): Ackerland, ackerfähige Böden, Dokumentation. FSO Geostat, Neuchâtel
	Crop types	FSO (2002): LBZ (annual crop statistics). FSO Geostat, Neuchâtel

Herbicide use higher in the north-east. The amounts of herbicides used in agriculture vary according to the type of crop cultivated [8]. Although field-scale crop data are lacking in Switzerland, a raster dataset on land use categories (including arable land) was available. By combining this with current crop statistics from the Federal Statistical Office, we were able to estimate the total amount of herbicide used for each catchment of the Central Plateau; again, this was visualized in the GIS.

The spatial distribution of individual crops across the Central Plateau varies considerably. For example, cereals and maize are distributed more or less evenly throughout this region – they are grown wherever arable farming is possible. In contrast, the cultivation of potatoes, sugar beet and vegetables is concentrated in certain areas. The fact that these crops require higher quantities of chemicals is reflected in the spatial distribution of herbicide use, which is particularly high, for example, in the north-east (Zurich Weinland and Thurtal region) and in the Seeland (Three Lakes) region (Fig. 3).

If one compares herbicide use with the risk of losses, it is striking that in many areas – such as the west and the north-east – high use is associated with a low risk. In other words, on the Central Plateau, intensive agriculture is mainly practised in areas where high levels of herbicide application are acceptable from a water protection perspective.

Floodplains: critical areas. However, the comparison also reveals certain exceptions – areas where high herbicide use coincides with a high risk of losses. These are the critical areas where the possible need for mitigation should be investigated. The deviations from the general trend are mainly demonstrated by analysis at a higher spatial resolution. The sites concerned frequently lie in former floodplains.

Even though in this case further studies are needed, modelling based on fast-flow processes can help to identify particularly vulnerable areas where, if necessary, intensive agricultural use could even be prohibited. Such models are therefore suitable for targeted monitoring efforts and can make a significant contribution to the improvement of water quality and the quality of surface waters as habitats for animals and plants.

Nonetheless, for a more precise evaluation, better data availability would be desirable. Studies of input pathways of herbicides to surface waters clearly indicate that soil properties are an important factor [9], but detailed soil data are not available for the whole of Switzerland. In addition, owing to the lack of long-term herbicide measurements, it was fairly difficult to test the model with real data. For example, only three atrazine monitoring datasets were available. However, these agreed closely with the results of the model – which again underlines the essential suitability of fast-flow processes as a proxy for vulnerability to diffuse herbicide losses. Although our modelling method cannot be transferred directly, it does point the way towards the construction of relatively simple and practical models for regions other than the Central Plateau. ○○○

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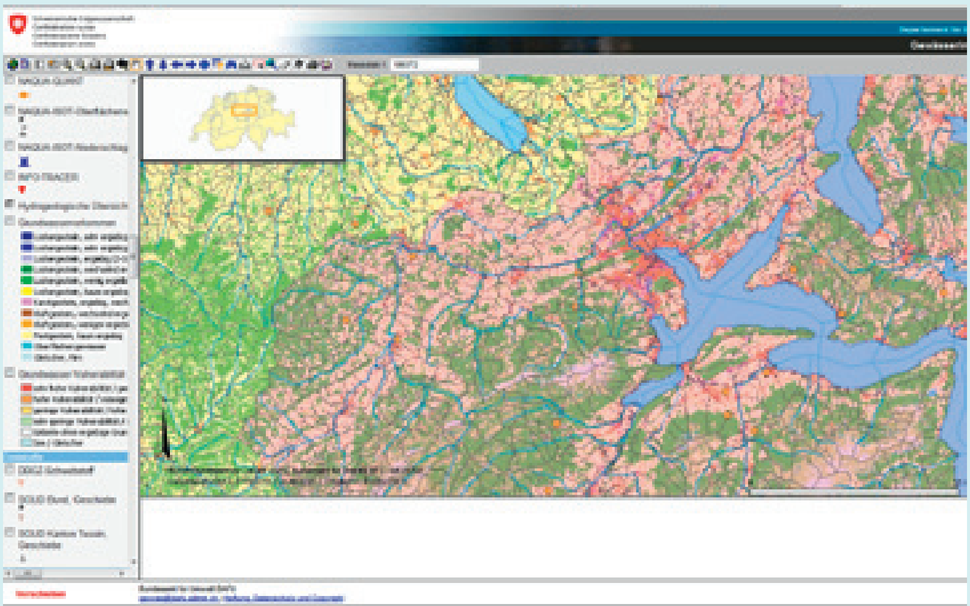
Swiss waterbodies information system

The Swiss waterbodies information system (GEWISS) is an online GIS portal, hosted by the Federal Office for the Environment, which presents interdisciplinary data and overviews covering all aspects of the country's waterbodies. The portal is designed to facilitate integrated analysis and delivery of data to national or international organizations and agencies, to support the enforcement of legislation at the federal level, and to inform the general public. Based on consolidated (published) national statistical datasets, it offers a variety of simple viewing and data search/retrieval functions. (aj)

www.gewiss.ch



Hydropower – striking the right balance

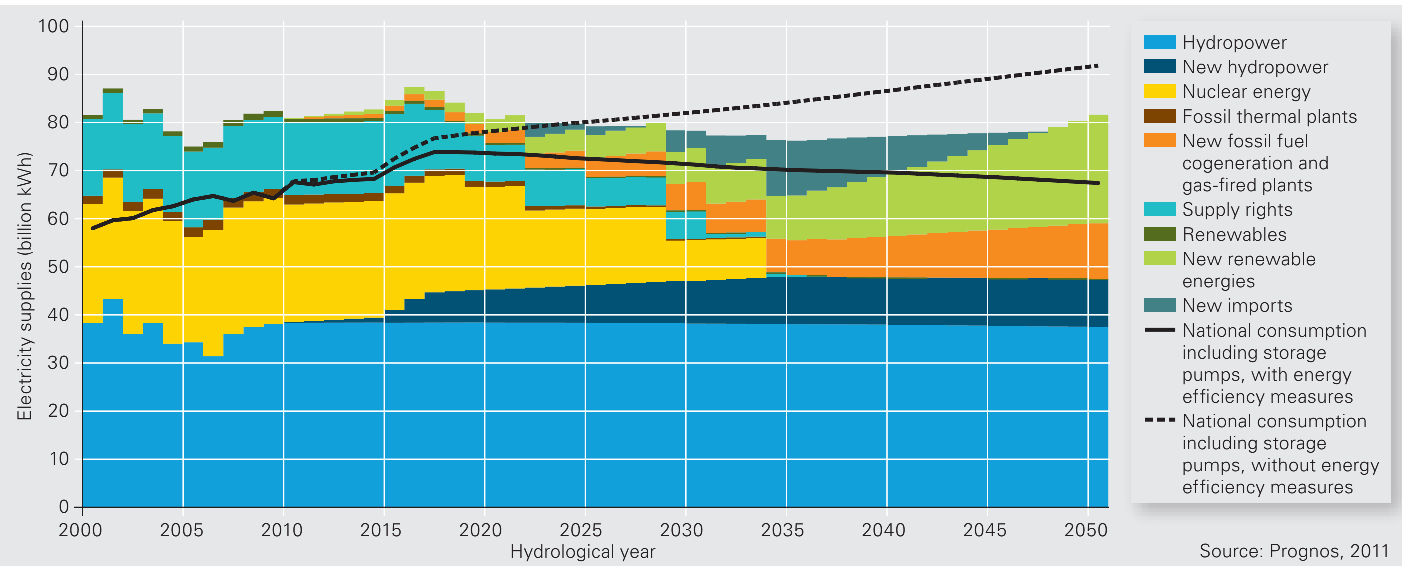
Switzerland has decided to phase out nuclear energy. As well as renewable sources, such as photovoltaics, the federal government intends to expand the use of hydropower. According to numerous experts, however, its assumptions regarding the potential for hydropower development are unrealistic. The benefits of additional small plants, they argue, are limited compared to the ecological damage; at the same time, there is a need for new pumped-storage plants. Text: Andres Jordi

By the standards of Swiss policymaking, it was a remarkably quick decision on a matter of such far-reaching importance: just a few weeks after the Fukushima nuclear disaster, the Federal Council decided that nuclear energy was to be phased out in the medium term. This decision was approved by both chambers of the Swiss Parliament. On the basis of a safe operational lifespan of 50 years, the existing plants are to be successively decommissioned – Beznau I in 2019, Beznau II and Mühleberg in 2022, Gösgen in 2029 and lastly Leibstadt in 2034.

At present, Switzerland's nuclear power plants account for roughly 40 per cent, or 25 billion kilowatt-hours (kWh), of annual electricity production [1]. In the future, this share is to be progressively replaced by other sources of energy. An outline of how this could be achieved is provided by the Swiss Federal Office of Energy's "Energy Perspectives 2050", which are based on updated models and scenarios from an earlier version ("Energy Perspectives 2035"). Assumptions concerning population growth, transport trends and energy policy instruments have been adjusted, as well as climate projections. Philipp Schwander of the SFOE explains: "The perspectives for 2050 are currently being revised by the federal authorities in preparation for the consultation procedure on the future energy strategy, so as to obtain more precise scenarios." The new version should appear in mid-2012.

Expansion of hydropower. According to the Energy Perspectives 2050, the loss of nuclear power is to be compensated for primarily by renewables (notably photovoltaics, geothermal energy and wind) and the expansion of hydropower exploitation. Any remaining shortfall is to be covered by fossil fuel (cogeneration, gas-fired) power plants and electricity imports (Fig. 1). In addition, the Federal Council is relying on energy efficiency measures, which are to limit electricity consumption to less than 70 billion kWh by 2050 (for comparison, Switzerland's consumption in 2010 was around 60 billion kWh). If current energy policy

Fig. 1: Future electricity production is to come largely from hydropower and other renewable sources. Under the federal scenario, measures to improve energy efficiency will also be needed to stabilize electricity consumption. In the chart, pumped-storage plants are included in the expansion of hydropower, although they do not lead to a net increase in the amount of power generated over a year.



Hydropower in Switzerland is already highly developed – pictured here is the Birsfelden plant on the High Rhine in Canton Baselland.

were to be continued, the SFOE projects that consumption would exceed 90 billion kWh in 2050 [2].

Conclusions similar to those of Energy Perspectives 2050 were reached by researchers at the ETH Zurich Energy Science Center. In their study, however, a more important role is assigned to biomass in electricity production [3].

In 2050, in the absence of nuclear power, a capacity shortfall of around 30 billion kWh will need to be met. Here, hydropower will continue to play a key role. At present, hydropower plants produce 56 per cent of Switzerland's electricity (an average of 36 billion kWh per year) (Fig. 2). Looking to the future, the federal energy strategy calls for capacity to be increased by 4 billion kWh, which is equivalent to about half the annual production of the Gösgen nuclear plant.

Potential for increased capacity is believed to lie in the renovation or expansion of existing facilities and in the construction of new hydropower plants (see Table). In the large hydropower sector (> 10 megawatt capacity), the federal estimates are based on projects planned but not implemented over the past 30 years. "In principle," says Alfred Wüest of the Surface Waters department at Eawag, "one additional large plant – or possibly two – would appear to me to be acceptable." But it would be important, in his view, to select sites involving minimal disruption to the environment, and to optimize construction projects as far as possible within the framework of mandatory environmental impact assessments.

Potential for expansion of hydropower, according to federal estimates.

	billion kWh
Renovation/conversion	+ 2.4
New large plants (>10 megawatt capacity)	+ 2.0
New small plants (<10 megawatt capacity)	+ 1.9
Use of VAEW* areas	+ 0.4
Gross increase in production	*+ 6.7*
Loss of production due to residual flow regulations	− 0.7
Loss of production due to climate change	− 2.0
Net increase in production	**+ 4.0**

* Landscape areas deserving special protection which are exempted from electricity production, in accordance with the Ordinance on Compensation for Losses relating to Hydropower Exploitation (VAEW).

Hydropower: vast potential worldwide

Hydropower accounts for around 20 per cent, or 3.4 trillion kilowatt-hours (kWh), of global electricity supplies. In a third of all countries, the share of hydropower is more than 50 per cent (56 per cent in Switzerland). Particularly in developing countries, however, the potential of hydropower remains largely unexploited. According to the World Bank, only 23 per cent of the economically feasible hydropower potential in these countries has been exploited [7]. For example, China alone has an untapped hydropower potential of about 1.4 trillion kWh, Latin America 1.2 trillion kWh, and Africa almost 1 trillion kWh.

"Capacity has been growing continuously for some years," says Anton Schleiss of the Federal Institute of Technology Lausanne (EPFL). This is reflected by increasing World Bank investments in water infrastructure projects, which rose from USD 250 million in 2002 to more than USD 1 billion in 2008. In the coming years, the institution plans to invest another USD 2 billion. "China, in particular, is investing huge sums in the expansion of hydropower," says Schleiss, "but it's also being expanded in other countries – Turkey, Iran, India, Japan, Vietnam, Laos, Myanmar, the Philippines and Brazil."

Hydropower resources need to be developed, as far as possible, in an environmentally sound and socially acceptable manner. In the Zambezi river basin, for example, Eawag researchers are investigating the biogeochemical effects of the Itezhi-Tezhi hydropower reservoir on wetlands lying downstream – and how the operation of large dams and the planning of future projects can be adapted so as to minimize environmental impacts. Other researchers are studying emissions of the greenhouse gas methane from tropical reservoirs.

www.eawag.ch/forschung/surf/schwerpunkte/project/adapt

www.eawag.ch/forschung/surf/gruppen/methane

Limited potential for small plants. In addition, the federal strategy envisages an increase of 1.9 billion kWh in small hydropower capacity via "KEV" (cost-covering remuneration for feed-in to the grid). This scheme, introduced in 2009, is designed to promote renewable energy sources, including hydropower plants with a capacity of less than 10 megawatts. According to Hans-Heiri Frei of Swissgrid, which manages the KEV programme on behalf of the federal authorities, applications have already been received

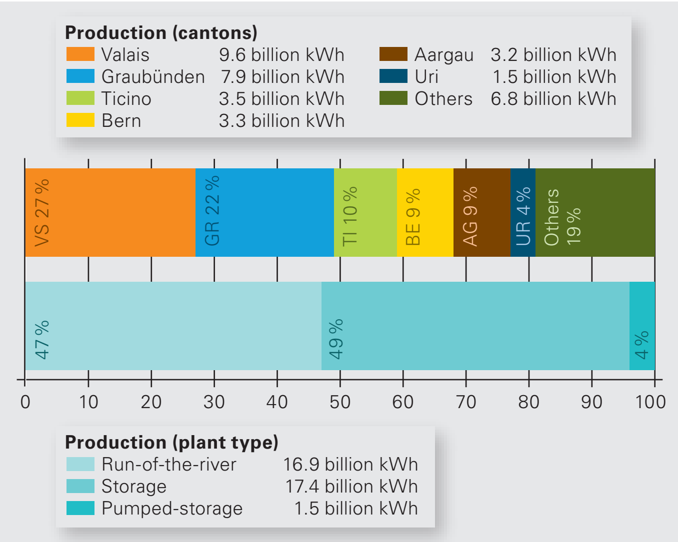


Fig. 2: Swiss hydropower statistics. Switzerland has around 1,300 hydropower plants, with 185 large plants (> 10 megawatt capacity) accounting for 90 per cent of the total electricity produced. Run-of-the-river plants supply continuous, base-load energy, while storage and pumped-storage plants are mainly used to meet peak-load requirements.

for hydropower plants which would produce a total of more than 2 billion kWh.

However, since ecological criteria are not used in the assessment of projects for KEV approval, many of these plants – especially those in previously unexploited waters – would seem to be unsuitable from the viewpoint of biodiversity and water protection. This deficiency has been recognized by the federal authorities, and (non-binding) guidelines have been developed which should enable cantons to determine which watercourses deserve special protection and where moderate exploitation would be appropriate [4]. But, as Schwander of the SFOE points out, "Approval of KEV projects remains a cantonal responsibility."

If, in the interests of a sustainable energy policy, ecological constraints are taken into account in selecting appropriate sites for small hydropower plants, the potential is substantially reduced. Thus, a WWF Switzerland study concludes that an increase in capacity of no more than about 1 billion kWh would be acceptable [5]. For his part, Wüest believes that investments in the expansion of small hydropower would be misguided: "In terms of filling the energy gap, it contributes virtually nothing, and the impacts on aquatic ecosystems and landscape are disproportionately large."

The ecological costs of hydropower. The effects of hydropower operations on the aquatic environment are numerous, as has been shown by various Eawag research projects. Weirs and dams lead to habitat fragmentation, posing major obstacles to migratory fish, such as salmon or nase. In addition, as Armin Peter of the Fish Ecology and Evolution department explains, "Artificial barriers alter the sediment dynamics – gravel and sand are prevented from moving downstream. If there is a lack of sediment, then gravel-bed spawning grounds are not replenished, and they are no longer functional." In rivers, flow regulation and water withdrawals can affect the composition of biotic communities – from algae to fish – and thus have an impact on the entire food web.

The operation of storage hydropower plants leads to unnatural fluctuations in flow rates ("hydropeaking"). Animals and plants are washed away by the artificial surges produced at times of peak demand. Conversely, their habitats frequently dry up during the daily low-flow periods when little or no water passes through the turbines. Peter says: "Sudden reductions in flow rates often lead to the death of juvenile fish, as they are stranded. So hydropeaking operations on the Alpine Rhine adversely affect the natural reproduction of brown trout or grayling."

Inadequate residual flows in river stretches below reservoirs or at diversion hydropower plants lead, for example, to poor connectivity, temperature changes and insufficient water levels or flow rates. As fine sediment accumulates in the riverbed, clogging may also occur.

Water protection efforts under threat? To mitigate the impacts of hydropower operations, Switzerland's water protection legislation has been revised several times. Under the 1991 Water Protection Act, the cantons are required to ensure adequate residual flows by 2012. But as Peter observes, "Implementation of these regulations has been unsatisfactory, and some cantons are seriously behind schedule." Under the latest revision of the Act (2010), the federal government is making additional resources available to reduce the adverse effects of hydropeaking and river fragmentation. For example, the longitudinal continuity of rivers is

Energy efficiency in the water sector

Alongside the development of renewable energy sources, improving energy efficiency is a key component of the federal government's future strategy. There is substantial potential for savings in the water sector – water supplies and wastewater treatment plants currently account for more than 30 per cent of municipal electricity consumption for public infrastructure in Switzerland.

For both wastewater management and drinking water treatment, Eawag scientists are working on optimized, energy-efficient methods. For example, process engineers have helped to develop the so-called anammox method for removing nitrogen from sludge digester liquid. With this method, compared to the conventional nitrification/denitrification process, significantly less aeration is required and no external carbon source is needed. This saves energy – and considerably reduces operating costs. Another Eawag project is studying the use of energy-efficient gravity-driven membrane systems to produce drinking water from polluted lake or river water.

www.eawag.ch/forschung/eng/schwerpunkte/abwasser/nitrations_anammoxprozess/index_EN

www.eawag.ch/forschung/eng/gruppen/gdm

to be improved by rehabilitation projects. Some experts are highly optimistic about these efforts, going so far as to speak of the reconciliation of river engineering and ecology.

Does the impending expansion of hydropower not run completely counter to the advances made in water protection? Armin Peter says: "If hydropower is to be expanded in line with the federal proposals, then a reversal of ecological progress is to be expected, especially in connection with small hydropower." In his view, aquatic habitats are already so severely fragmented that no further fragmentation can be contemplated. With new small hydropower plants, the progress achieved through rehabilitation measures at one site would be immediately cancelled out at another.

To date, landscape areas deserving special protection have been exempted from electricity production under the Ordinance on Compensation for Losses relating to Hydropower Exploitation (VAEW). The SFOE sees some potential for hydropower in these areas, too. But Schwander, of the SFOE, puts the proposals into perspective: "This is merely an initial assessment. We are currently – together with the cantons – analysing the realistic potential for expansion." For most experts, at any rate, development of this kind is not an option. Anton Schleiss of the Laboratoire de Construction Hydraulique at the EPF Lausanne concurs: "In my view, protected areas such as the Greina high plateau are ruled out."

Unrealistic assumptions. Commenting on the federal proposals for an overall increase in capacity of 4 billion kWh, Schleiss says: "That's just the net increase – in practice, hydropower would have to be expanded by a total of 6.7 billion kWh." Moreover, according to Schleiss, the energy losses due to residual flow regulations are underestimated: if the legal requirements were met, a decrease in production of 1.4 billion kWh would be expected. On the other hand, the losses of production due to climate change appear to him to be overestimated. This assessment is in agreement with a study recently published by the Swiss Society for Hydrology and Limnology and the Commission for Hydrology, which concludes that only limited changes are to be expected in the period up to 2035 [6].

In any case, many experts consider the federal scenario to be impracticable. The Association of Swiss Electricity Companies (VSE), for example, has stated that there is practically no remaining scope for expansion of hydropower in this country. While the Swiss Association for Water Resources Management (SWV) essentially welcomes the proposals for expansion, it says that they are unrealistic within the existing legal framework. It therefore calls for greater weight to be given to resource-use concerns when they are weighed against protection interests.

Schleiss also finds the figures unrealistic: he regards a net increase in capacity of around 2 billion kWh as feasible –"and even that is very optimistic." This would mean, he adds, that Switzerland would have to build at least one new large reservoir.

Wüest, of Eawag, says: "Rather than squeezing every last drop of energy out of our rivers, we need to resolutely expand photovoltaics – a sector with a far greater potential." Where hydropower could make a contribution, he believes, is in the area of energy storage with pumped-storage plants. In future, because energy will increasingly be obtained from renewable sources such as solar and wind power, which are not continuously available, there will be a need for greater storage capacity. However, pumped-storage plants do not, in net terms, produce any additional electricity.

Switzerland: a battery in the European grid. "Switzerland has a very substantial potential for pumped-storage plants," says Schleiss – and he believes this should be exploited for the European electricity market. Switzerland could increasingly assume the function of a battery within the European grid, also supplying neighbouring countries with pumped-storage electricity. "Conversely," he says, "we will be increasingly dependent on European wind and solar power."

In the coming years, the SFOE expects pumped-storage capacity to increase by around 5 billion kWh. Some facilities – e. g. Nant de Drance in Canton Valais or Linth-Limmern in Canton Glarus – are already under construction.

Naturally, pumped-storage plants also inevitably involve disruption to the environment. In an environmental impact assessment for the Lagobianco project in Poschiavo, for example, Eawag scientists demonstrated that the operation of a pumped-storage plant would have significant impacts on the temperature and turbidity of the two connected lakes. At the same time, they found that the project would also lead to ecological improvements, such as the elimination of hydropeaking, higher and more dynamic residual flows, and various rehabilitation measures.

Schleiss is convinced that moderate expansion of hydropower in Switzerland would not necessitate major sacrifices on the environmental front. In his view, it is very important that all stakeholders should be involved in the planning process, so that solutions can be sought jointly; this, he stresses, will require certain compromises on all sides. ○○○

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Lukas Indermaur, biologist, received his doctorate from the Aquatic Ecology department of Eawag. He is currently responsible for the WWF project "Living Alpine Rhine".

More space and deadwood for toads

In terrestrial habitats, common and green toad populations require an area the size of a number of football pitches and sufficient structural elements – especially in the form of woody debris. But in many cases even protected areas fail to meet these demands. The creation of deadwood piles would be a simple and low-cost way of significantly enhancing the quality of existing amphibian habitats.

Many amphibian species spend only a small part of the year – and of their lives – in or near water. Most of their time is spent in terrestrial habitats, such as forests, gravel or farmland. Accordingly, as recent studies suggest, terrestrial habitats are of particular importance for the survival of amphibian populations [1]. In the design of conservation areas for amphibians, special attention needs to be paid to structural characteristics and the minimum size of the habitat.

For the practical management of amphibians, however, this insight is of only limited value as long as most scientific studies produce data – e. g. on minimum habitat size – which relates to individuals rather than to populations. A study designed to remedy this deficiency has therefore been carried out by a team of Eawag researchers in cooperation with Benedikt Schmidt of Zurich University.

Studying natural behaviour. Over a period of 2 years, we studied the habitat requirements of populations of common and green toads in the structurally rich, roughly 800 metre wide floodplain of the Tagliamento. Flowing through the Friuli region of north-eastern Italy, the Tagliamento is the last unregulated major Alpine river in Central Europe. For conservation practitioners, it is extremely

The king of Alpine rivers: the Fiume Tagliamento in the Friuli region of Italy is the last extensive wild river landscape in the Alps.

Green toads seek refuge from high temperatures in deadwood piles.

valuable – here, the behaviour and requirements of amphibian populations can still be studied in a pristine natural habitat.

In settled or agricultural areas, which are cleared and structurally modified, amphibians generally have to make do with structures that do not fully meet their needs. For example, river stretches subject to rapid variations in flow regimes (hydropeaking) are far from ideal for the breeding and development of amphibians (or indeed fish). If the minimum demands of a species in terms of structural and habitat size requirements are not met, population density will be reduced as a result. But what are the minimum habitat size and structural requirements of amphibian populations? And do protected areas in Switzerland satisfy these needs?

In our research on the Tagliamento, we focused on species with contrasting ecologies so as to have a broader evidence base for recommendations on amphibian conservation. While the common toad *(Bufo bufo)* is also indigenous to Switzerland, the green toad *(Bufo viridis)* only occurs in neighbouring countries, but its ecology is very similar to that of the indigenous natterjack *(Bufo calamita)*. The common toad is described in the literature as a widely ranging and widely distributed generalist species. The green toad, like the natterjack, is a typical pioneer species. Species of this kind are dependent on open areas, which they are able to colonize rapidly. The species selected for the study are thus representative of a broad range of habitat types and requirements. We fitted 56 common and 59 green toads with mini-transmitters and used radio-tracking to record their day- and night-time location and movements during two summers.

Protected areas often too small. Our studies indicate that, while the two toad species have a significant preference for deadwood over other types of structure, they differ in their resource use behaviour. Whereas green toads use wood deposits primarily for thermoregulation in high temperatures, common toads use this resource mainly for foraging [2].

The amount of deadwood available also determines the size of the summer habitat for both species. In areas with little deadwood the summer habitat is very large, while abundant deadwood is associated with a small home range size [3]. The animals extend their home range until the minimum requirements for large wood deposits are fulfilled. Using our data, we calculated the minimum habitat size and minimum deadwood requirements for individual common and green toads. On the basis of the individual-level requirements, we then used a mathematical model to calculate the habitat and deadwood requirements for populations of 100 individuals [4]. Populations of this size or larger have a very low risk of undergoing complete local extinction as a result of chance events.

According to our investigations, with abundant supplies of deadwood, a common toad population on the Tagliamento requires a minimum terrestrial habitat of 4.3 hectares, while a green toad population needs 17.9 hectares. Expressed in differ-

	Common toad			Green toad		
Area required for 100 individuals	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Terrestrial habitat* (ha) (no. of football pitches)	6.0 (8.1)	4.3 (5.8)	7.7 (10.5)	24.8 (33.7)	17.9 (24.4)	32.7 (44.5)
Deadwood** (m^2/ha)	756.9	214.5	1983.5	233.2	85.5	534.4

* Not corrected for mean home range overlap of 2.6 % among species or among individuals of the same species (common toad 2.7 %, green toad 11.2 %).

** Corrected for home range overlap among species and among individuals.

Habitat and deadwood requirements for common and green toad populations.
Minimum = lower 95 per cent confidence limit; maximum = upper 95 per cent confidence limit.

ent terms, a common toad population requires an area the size of around 6 football pitches, and the figure for a green toad population is more than 24 football pitches (see Table).

In Switzerland, areas of this size are not always available for amphibians. For example, the amphibian spawning areas of national importance are generally significantly smaller [5]. In many cases, cantonal reserves are also too small, as our analyses show: for the cantons of Thurgau, Bern and Graubünden, we calculated the average size of 77 protected areas in cultural landscapes with a forest component. Of these protected areas, 52 per cent were smaller than the minimum habitat size required by common toads; for green toads – or rather for the ecologically similar indigenous natterjack – as many as 75 per cent of the areas investigated were too small.

Insufficient deadwood available. For a common toad population on the Tagliamento the minimum amount of deadwood required is 214.5 square metres per hectare (m^2/ha), and for a green toad population the requirement is at least 85.5 m^2/ha. If these figures are applied to Switzerland, it is apparent that the amount of deadwood available for indigenous toads is insufficient in many areas. In farmland almost no deadwood is to be found, and even in forests the amount available is generally much too small: according to the latest Swiss National Forest Inventory, the country's forests have on average only 0.77 m^2/ha deadwood on the ground, with the lowest values being recorded in the Central Plateau (0.43 m^2/ha) and in Canton Schaffhausen (0.06 m^2/ha) [6]. Even if one only considers the minimum requirements for an individual animal, these amounts are inadequate.

Only in the northern Alps (1.29 m^2/ha) and in Canton Fribourg (1.5 m^2/ha) would the individual-level minimum requirements for deadwood be met for the green toad or natterjack; for the common toad, however, the amount of deadwood available is not sufficient in any region of Switzerland (see Figure). For comparison, it

The amount of deadwood found in the floodplain of the Tagliamento is around 115 m^2/ha, compared with a mere 0.43 m^2/ha in the Central Plateau.

may be noted that the amount of deadwood lying in the floodplain of the Tagliamento averages around 115 m^2/ha. This is mainly distributed across exposed gravel sediments – a situation which can be readily compared with a mosaic-type landscape structure. In the adjoining alluvial forest, the availability of deadwood is probably equally good or even better.

Since the habitats mainly colonized by amphibians in Switzerland are farmland and forest, inadequate supplies of deadwood and other small structural elements are likely to severely restrict their distribution in the generally intensively used areas, leading to declining populations.

Low-cost conservation measure. The creation of deadwood piles, however, would be an inexpensive and effective way of establishing new small structural elements in cleared agricultural areas. The quality of terrestrial habitats – both for amphibians and for other organisms – could thus be readily improved. Deadwood arises in the course of routine management and can easily be piled up and left lying.

To support a number of different species, it is best to establish piles of different sizes. As our study shows, toads use wood deposits ranging in area from 1 to 60 m^2. For the common toad, the size of the deposit is not crucial; in contrast, the green toad (natterjack) prefers free-standing piles with an area up to 5 m^2. However, since very little deadwood is available in Swiss forests, despite the increasing forested area, amphibian populations would benefit in particular if more wood were left lying.

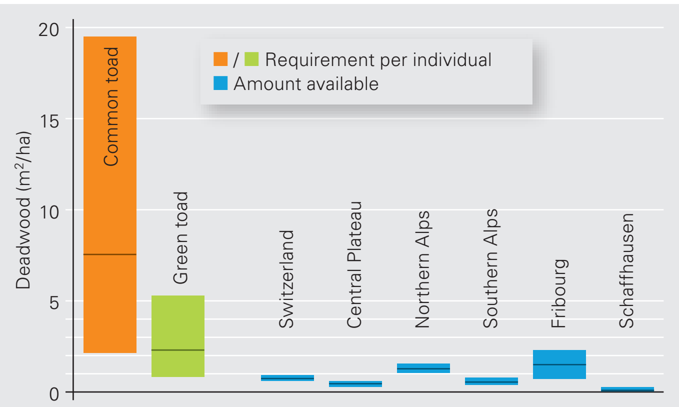
Deadwood piles can also be used to enhance the connectivity of existing habitats – e. g. for protected areas that are too small. Amphibian habitats can be extended by arranging lines of piled-up deadwood (so-called Benjes hedges) so as to link up isolated habitat patches. This measure can also be implemented if protected areas themselves cannot be enlarged.

But ultimately, a suitable terrestrial habitat is of little use if no spawning waters are accessible for breeding. New waterbodies should therefore be established if necessary. Temporary spawning waters have proved to be particularly productive [7]. Because these dry up periodically, they harbour fewer predators – which has positive effects on tadpole survival. Temporary spawning waters are characteristic of the bed of braided rivers and usually arise as a result of deposits of woody debris.

In view of our studies on the Tagliamento, we consider the creation of deadwood piles and the establishment of temporary spawning waters to be particularly effective measures for amphibian conservation in cleared farmland and forest habitats. ○ ○ ○

The creation of deadwood piles is an inexpensive and effective way of improving the structural diversity of open landscapes and the connectivity of amphibian habitats. Pictured here is the bank of the Aare near Rubigen (Canton Bern).

The amount of deadwood required per individual and the amount of lying deadwood available per individual in Swiss forests. The bars show the minimum (lower 95 per cent confidence limit), mean and maximum value (upper 95 per cent confidence limit).



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Jürg Beer, physicist in the Surface Waters department, studies the influence of solar activity on the climate.

Traces of the sun in polar ice

The sun – our primary source of energy – powers the Earth's climate system and hydrological cycle. But increasingly it also poses a hazard to our high-tech world. So it is important to improve our understanding of the sun, and long-term solar activity in particular. Ice cores allow us to look back over the past 10,000 years – and to make tentative predictions about future activity.

Since antiquity, humans have intuitively appreciated the importance of the sun for life on earth. Not surprisingly, therefore, the sun was venerated as a deity in almost all early cultures. From the dawn of the Enlightenment, scientists sought to understand the sun. In the 19th century, however, a major difficulty arose. William Thomson (later Lord Kelvin), one of the most famous physicists of the age, estimated that the sun's energy reserves could last for no longer than 30 million years. This was in sharp contrast to the findings of another famous scientist: on the basis of rates of geological erosion and biological evolution, Charles Darwin concluded

A researcher with a Greenland deep ice core, which provides a record of the sun's history.

Marc Steinmetz, Visum

that the Earth must be at least 300 million years old. How could these two scientific luminaries possibly arrive at such different results? In fact, there is a simple answer – the sun has a special source of energy which was not yet known at that time.

Temperatures of 16 million degrees. The sun's core is a fusion reactor, where hydrogen is continuously converted into helium at a temperature of 16 million degrees Celsius. In the process – according to $E = mc^2$ – 0.73 per cent of the mass is turned into energy, which is transported to the sun's surface and radiated into space. As the total amount of radiation emitted by the sun is 4×10^{26} watts, this means that 4.4 million tonnes of mass is converted into energy per second. The process is so efficient that, with a mass of 2×10^{30} kilograms, the sun can easily burn for 10 billion years, while losing only about 0.5 per mil of its mass.

Around 30 per cent of the solar radiation striking the Earth is reflected back into space, e.g. by clouds, snow or ice. The remainder of this energy, which is absorbed, is equivalent to 8.4×10^{16} watts, or the output of 100 million nuclear power plants. This is 6,000 times more energy than humankind currently requires. Almost half of this solar energy is responsible for the evaporation of water, thus powering the global hydrological cycle. Incoming solar radiation is not evenly distributed over the Earth, but is most intense near the equator. To compensate for these differences, the climate system continuously transports energy, in the form of water (ocean currents, water vapour) and wind, to higher latitudes.

Powering the hydrological cycle. Those of us fortunate enough to have access to safe drinking water may take it for granted that almost unlimited supplies are available at the turn of a tap. We often forget that we owe this precious resource largely to the action of the sun. As around two thirds of the Earth's surface are covered by oceans, a large proportion of incoming solar radiation (4×10^{16} watts) falls on water. This leads to the evaporation of 430,000 cubic kilometres per year. Of course, about 90 per cent of this is returned directly to the sea in the form of rain. The volume of precipitation falling on continents, however, is more than the remaining 10 per cent (i.e. 43,000 cubic kilometres); in fact, it totals around 100,000 cubic kilometres since evaporation naturally also occurs on land masses.

Evaporation is a highly efficient cooling system, as a lot of energy is required to form water vapour. (The human body, likewise, starts to perspire when we exert ourselves.) What made the summer of 2003 so exceptionally hot was the fact that, after a prolonged period without rain, the ground dried out, thus losing its cooling effect.

The processes whereby water and air are transported are subject to variations – what we know as weather. Longer-term processes, extending over a number of decades, are classified as changes in the climate. While these are usually taken to refer to the temperature, the effects on the hydrological cycle are much more important – and they are of course also associated with changes in temperature. In addition, small causes can have large effects. For example, if for some reason just 1 per cent less precipitation fell on the oceans, while evaporation remained unchanged, then continental precipitation – rising from 10 to 11 per cent of the total – would be increased by 10 per cent.

Here, the question arises of whether the sun, as the engine of the climate system, also contributes to climate change.

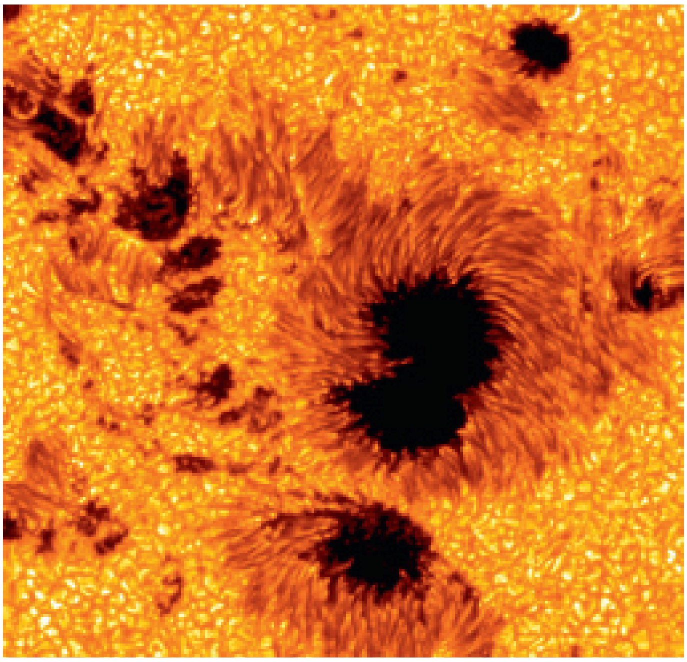


Fig. 1: Sunspots visible on the surface of the sun.

The sunspot cycle. Viewed in visible light, the sun looks like a smooth, luminous disc. So it is not surprising that, until recently, most scientists assumed that the intensity of solar radiation on Earth depended solely on the distance from the sun. Accordingly, the amount of incoming solar radiation (irradiance) – approximately 1,360 watts per square metre – was generally known as the solar constant. However, it has also long been known that the sun's surface is not completely homogeneous. Over the years, astronomers repeatedly observed the appearance of dark spots, which were often seen as an ill omen and therefore kept secret (Fig. 1).

With the invention of the telescope around 1610, it became possible to detect even smaller spots. In 1843, the apothecary Heinrich Schwabe published the findings of a 18-year series of observations, postulating the existence of a sunspot cycle of roughly 11 years. One of the scientists impressed by this discovery was Rudolf Wolf, who in 1855 became the first professor of astronomy at the ETH Zurich. He subsequently concentrated on solar research, and systematic sunspot counting was thus initiated at the Semper Observatory in Zurich (Fig. 2).

Apart from the waxing and waning of sunspots over an 11-year cycle – in fact, the cycle length varies between 8 and 15 years – a longer-term trend towards higher sunspot counts can be observed, as well as periods of low sunspot activity. Particularly striking is the period between 1645 and 1715, known as the Maunder minimum, when almost no sunspots could be

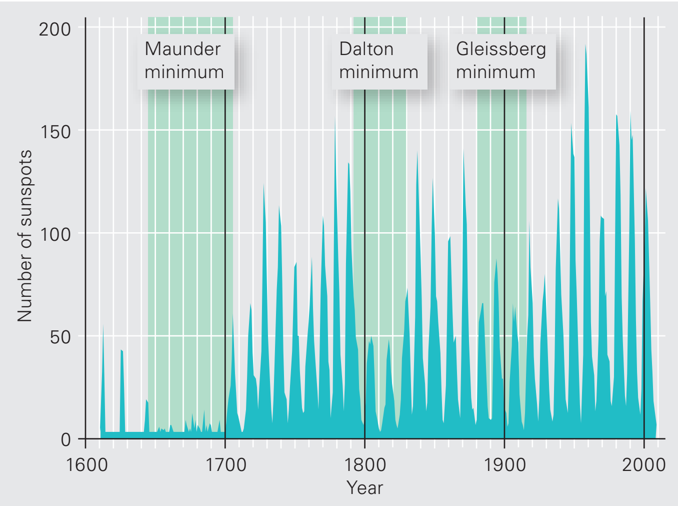


Fig. 2: Sunspot counts recorded since 1609 by direct observation (e. g. at the Semper Observatory in Zurich). The number of sunspots varies cyclically, reaching a maximum about every 11 years.

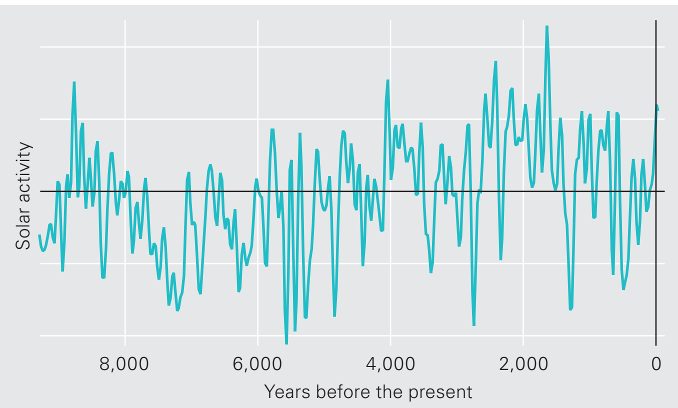
observed. Much less pronounced minima also occurred around 1800 and 1900.

Sunspots were found to be Earth-sized areas where concentrated magnetic fields penetrate the sun's surface, thereby inhibiting the flow of hot gases (approximately 6,000 degrees) from the interior. This leads to a cooling of around 1,500 degrees, visible as darker regions. Schwabe's 11-year cycle is thus the result of changes in magnetic activity on the surface of the sun.

Archive in polar ice. While the 400-year history of solar activity shown in Fig. 2 is certainly interesting, it represents a mere snapshot in the 4.5-billion-year life history of the sun. But how can we look further back into the past, to the period preceding the invention of the telescope, for which no direct observations exist? The key to this riddle lies in polar ice.

Ionized gas is continuously ejected into space from the surface of the sun. This solar wind – causing a further loss of mass of around 4 million tonnes per second – forms an immense bubble around the entire solar system, with a diameter 100 times the distance from the Earth to the sun. This bubble (the "heliosphere") acts as a shield against cosmic radiation – the high-energy particles which criss-cross the galaxy at velocities approaching the speed of light. How strongly the solar wind "blows", and how dense the protective shield is, depends on the activity of the sun. If solar activity is high, more solar wind is generated and fewer cosmic particles can penetrate our solar system; if it is low, the converse is true.

Fig. 3: Solar activity over the last 10,000 years, reconstructed from beryllium-10 concentrations measured in Greenland ice [4].



If cosmic rays enter the Earth's atmosphere, they can collide with and shatter atoms, leading to the formation of various radioisotopes – e. g. beryllium-10, which decays to boron-10 with a half life of around 1.4 million years [1]. Shortly after they are formed, beryllium isotopes become attached to aerosols and are thus washed out of the atmosphere within 2 years. If this occurs in polar regions, they are deposited in the ice.

As a result of this process, polar ice now harbours an archive, stretching back over millennia, which can be used to reconstruct the sun's history over the past 10,000 years on the basis of changes in beryllium-10 concentrations [2, 3].

Slight cooling on Earth. The nature of this history is revealed by an analysis of several thousand beryllium measurements carried out in ice cores retrieved from central Greenland (Fig. 3). This indicates that the past few decades – a period of intensive solar research – are atypical, as the sun has been considerably more active over this period than it has on average over the past 10,000 years. Clearly visible in the ice core record are the grand minima such as the Maunder minimum, when practically no sunspots were observed. Our studies also show that, in addition to the 11-year periodicity of solar activity, cycles of 87, 104, 208, 350, 500, 1,000 and 2,200 years occur.

It is thus apparent that, despite major scientific advances in direct solar observation, certain questions cannot be answered, as they concern long-term dynamics in particular. However, if the detailed short-term information obtained from Earth-based telescopes and satellite-borne instruments is combined with the long-range data from ice cores, we can gain a significantly more comprehensive picture of the star without which life on Earth would not exist.

If these two perspectives can be synthesized – and this is what we are currently working on – it should be possible not only to better understand the sun itself, but also to make tentative predictions about the development of solar activity and the possible consequences for the future climate. Initial findings indicate that solar activity will tend to decline in the coming years and decades [5]. The maximum of the latest 11-year cycle has indeed been very prolonged and pronounced, which may be interpreted as the first sign of an approaching decline.

As solar radiation is linked to solar activity, this will lead to a cooling of the Earth's atmosphere. However, this will be very slight and will by no means offset the warming caused by the greenhouse effect. In addition, it will be restricted to a few decades, followed by a renewed rise in solar activity.

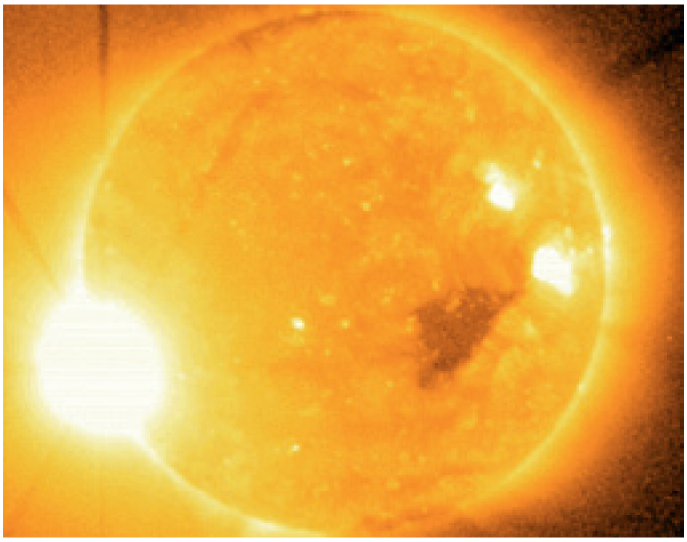

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Fig. 4: A solar flare observed on 5 December 2006. It was so powerful that it damaged the detector on the GOES-13 satellite, which produced this image.

Solar wind hazard. On the morning of 1 September 1859, a young astronomer named Richard Carrington was sitting in his private observatory sketching sunspots projected onto a screen by his telescope, when he suddenly saw two patches of intense white light, which disappeared again within a minute. The next day, shortly before dawn, the sky over Europe was lit up by red, green and purple auroras, bright enough to read a newspaper by. At the same time, telegraph systems went haywire, sometimes even discharging sparks which set telegraph paper on fire.

The phenomenon which Carrington was the first to observe directly is known as a solar flare. Flares occur when intense magnetic fields on the sun short-circuit (Fig. 4), releasing huge amounts of energy, equivalent to hundreds of millions of hydrogen bombs.

While the exceptionally powerful flare of 1859 (known as the Carrington event) is remembered in particular for the spectacular Northern Lights display, a similar solar storm today would cause a global disaster, with damage running to a trillion dollars. This is due to the increasing vulnerability of our high-tech civilization. In 1989, for example, a geomagnetic storm disrupted electric power transmission in Canada, causing a 9-hour blackout for 6 million people. Today, not only power grids would be affected, but entire communication systems, GPS satellites and much else besides.

To ensure more effective protection against this elusive hazard and to improve our ability to make reliable predictions – scientists now use the terms "space weather" and "space climate" – it is important to carry out statistical studies of the intensity and frequency of solar flares. Here, too, ice cores can yield valuable information.

Slow death of the sun. The sun and its planets were formed about 4.5 billion years ago from a gaseous cloud of matter left over from a supernova explosion. As a result of gravitational attraction, matter became more concentrated at the centre of the nebula; however, because of the conservation of angular momentum, only 99.9 per cent of the mass condensed to form the sun [6]. The rest orbits the sun as planets.

The release of gravitational energy caused the temperature inside the proto-sun to rise to over 16 million degrees, setting off the fusion reactor. Models have shown, however, that solar energy output was initially about 25 per cent lower than today and has since risen continuously. This raises the interesting question of why the Earth did not turn into a lump of ice at that time. It is possible that the lower solar radiation was offset by higher concentrations of greenhouse gases in the Earth's atmosphere and the somewhat larger original mass of the sun.

The gradual rise in solar energy output will continue, reaching a level about 50 per cent higher than today in around 5 billion years. But at that point, the sun's hydrogen reserves will start to run out and it will expand into a red giant, extending almost as far as the Earth, where all life will be destroyed. When the sun's energy production finally ceases, it will shrink into a white dwarf about the size of the Earth, slowly cooling and descending into darkness. ○○○

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Markus Boller, engineer, was formerly head of the Urban Water Management department and Professor at the ETH Zurich.

Research and teaching for practitioners

During a career at Eawag which spanned almost 40 years, Willi Gujer helped to shape the urban water management sector both in Switzerland and internationally. As a researcher, he always attached great importance to training young specialists and reaching out to practitioners. Here, to mark his retirement, we look back over his career and celebrate his achievements.

When Willi Gujer joined Eawag in 1974, structural water protection was flourishing in Switzerland. Over a period of 2 decades, large amounts of public funding were used to create sewer networks and construct or expand wastewater treatment plants (WWTPs). At this time, there was an acute lack of experts capable of designing biological treatment and the so-called 3rd and 4th treatment steps for the removal of phosphorus from wastewater in accordance with the latest scientific findings. In order to strengthen wastewater treatment research in the area of process engineering, the then Director of Eawag, Werner Stumm, was pursuing a strategy of recruiting young professionals who had been trained abroad.

Wastewater treatment: new approaches. Having received his MSc in civil engineering from the ETH Zurich and his doctorate in environmental engineering from the University of California in Berkeley, with a dissertation on the activated sludge process, Gujer was ideally equipped to develop Eawag's existing research

Willi Gujer – a cogent advocate of his views.

Tom Kawara

on biological wastewater treatment, using the latest methods. In particular, with his knowledge of mass balances and kinetics data for activated sludge systems, he was able not only to study treatment processes experimentally but also to describe them mathematically. Thanks to Gujer and other members of the evolving Engineering Sciences department, Eawag very soon became established as a centre of expertise, providing valuable support in numerous projects for the construction and upgrading of WWTPs.

The expansion of the Werdhölzli WWTP in Zurich was an exemplary case where Gujer pursued new approaches to the design of activated sludge tanks, aeration systems and secondary clarifiers for the degradation of organic substances and for the bacterial oxidation of ammonium (nitrification). In the 1970s and 1980s, through training programmes run by the Swiss Water Association (VSA), he familiarized a wider professional audience with the relevant modelling theories and methods. The associated publications attracted considerable interest around the world and were presented at numerous national and international conferences.

Originally recruited in 1974 as a young, foreign-trained expert, Willi Gujer devoted himself to the cause of urban water management at Eawag for almost 40 years.

Modern modelling methods. Gujer developed his particular speciality – the mathematical description of biological wastewater treatment processes – into a complex structure of sets of equations. Here, biological processes were linked to the description of reactor technology in such a way that the entire system became mathematically tractable even under variable conditions. In his postdoctoral thesis, published in 1985, he laid the foundations for the development of a series of activated sludge models – ASM1, ASM2 and ASM3 – by international task groups, of which he was a key member.

These models, together with software developed for wastewater engineers, paved the way for the adoption of modern modelling methods in the design and evaluation of WWTPs. Thus, it is largely thanks to Gujer that we can now dimension activated sludge systems with complex flow schemes on the basis of input data on wastewater quantity and quality, simulate their dynamic behaviour under the variations in nutrient content, temperature, pH, oxygen supply and other process parameters which occur in practice, and predict effluent quality at a high temporal resolution.

In the early 1980s, with active support from Eawag staff, a postgraduate course (NDS) on "Urban water management and water protection" was introduced at the ETH Zurich. This meant it was now possible for the first time to receive training in this highly topical discipline at a Swiss institution. Gujer, serving as the first NDS Secretary, helped to develop the syllabus and teaching in the wastewater technology field. This was the beginning of his career as a lecturer, which was crowned by his appointment as Professor of Urban Water Management at the ETH Zurich.

Models of biofilm processes. In his research, Gujer continued to concentrate on biological wastewater treatment processes. In pursuit of increased efficiency, he focused on wastewater treatment options involving sessile biofilms. But here, mathematical description proved to be considerably more complex than for activated sludge processes. Nonetheless, he successfully developed models and associated software for biofilm processes, making it possible to predict the behaviour of fixed biofilms under a wide variety of operating conditions.

The models, however, turned out to be somewhat difficult to apply in practice, as they demanded a great deal of model-specific knowledge. Even so, together with the underlying theoretical approaches, these models provided new insights into the behaviour of biofilms, thus leading to optimizations of various processes.

In 1991, in recognition of his successful work in the field of biological wastewater treatment, Gujer received the Association of Environmental Engineering Professors' Distinguished Lecturer Award, which includes a sponsored US-wide lecture tour.

Agile thinker. People who discussed scientific questions with Gujer were always struck by the agility and precision of his thought. His arguments and visions for the future, cogently presented, made him a driving force within Eawag. Accordingly, having served as head of the Engineering Sciences department from 1976, he became a member of the Eawag Directorate in 2001.

In 1992, he was appointed Professor of Urban Water Management at the ETH Zurich. From 1994, when he relinquished some of his responsibilities in the Engineering Sciences department, he was able to focus on the elaboration of new teaching programmes in urban water management at the ETH, developing the associated lecture and exercise materials with his staff. In the course of his work with undergraduates and doctoral students, he came to realize that training at the grass-roots level was the most effective way of enhancing professional expertise in practice.

He used his lecture notes as the basis for his first book, entitled "Siedlungswasserwirtschaft", which is now not only a "bible" for students but also provides guidance for practitioners planning wastewater and drinking water plants. Towards the end of his career, Gujer published a second book, Systems Analysis for Water Technology, which is particularly valuable for advanced students and professionals concerned with process engineering in water and wastewater treatment.

On the practical benefits of a good theory

To mark the retirement of Willi Gujer at the beginning of 2011 and to honour his achievements in the field of urban water management, a symposium was held in October at the Empa Academy in Dübendorf. The event, entitled "On the practical benefits of a good theory", was attended by more than 130 scientists and water professionals. It was divided into three thematic blocks, with presentations given mainly by former doctoral students of Gujer's, who reported on their current activities in research or practice. The title of the symposium and the choice of speakers were designed to underline Gujer's commitment to building bridges between research and practice – a point emphasized in several of the presentations.

Joint projects. Eberhard Morgenroth, Gujer's successor as head of the Process Engineering department at Eawag and as Professor of Urban Water Management at the ETH Zurich, spoke on the subject of biofilm processes in wastewater treatment. He mentioned two publications co-authored by Gujer which appeared in 1985 and 1986. These, he said, had been his constant companions over the years, and he had consulted them repeatedly: "In fact, we haven't made that much progress since then."

Morgenroth also stressed the importance of projects involving cooperation between researchers and practitioners: many of the questions leading to a better understanding of systems cannot, in his view, be answered by scientists alone. For example, although flow channels in the laboratory are useful, they do not always adequately explain the processes occurring in a wastewater treatment plant. For biofilm processes, in particular, it makes a considerable difference whether they are studied in a

beaker or in a full-scale plant. Accordingly, Morgenroth argued the case for joint projects, rather than for knowledge transfer from research to practice.

Pressing need for action. In his presentation, Reto von Schulthess – the branch office manager of an engineering consultancy active in the wastewater treatment technology sector – raised the question of whether research findings are actually applicable in practice. This will generally be the case, he believes, if researchers are enthusiastic about practice – and practitioners about research. Only then, in his view, is wastewater technology research worthwhile. "On the one hand," he said, "there must be researchers who are prepared to conduct large-scale tests and who are willing and able to engage in discussions with practitioners on an equal footing; and on the other hand, there must be plant operators who are open to experiments of this kind."

A key success factor for truly relevant research, according to von Schulthess, is the existence of a pressing need: if urgent problems are addressed by researchers, practitioners will also benefit. Today, he argued, there is a pressing need for action, for example, in the management of micropollutants, in the optimization of energy consumption for wastewater treatment, or in the recovery of phosphorus – a finite resource. "Here," he said, "we need support from research." He added that many rapidly expanding cities in the developing world were crying out for solutions adapted to their needs. In China, for example, explosive urbanization was associated with high levels of water pollution, and water scarcity was a permanent problem.

Attractive training. Von Schulthess also emphasized the importance of collaboration with the private sector in assuring the transfer of knowledge from research to practice: researchers alone could not turn projects into marketable products, while industry, for its part, was scarcely able to develop processes of its own. Knowledge transfer is also facilitated by conferences and courses, such as those organized by the Swiss Water Association (VSA) or Eawag. Publications in which the results of research are presented in a practice-friendly manner also serve an important function.

Lastly, von Schulthess pointed out that attractive training for undergraduates and doctoral students is also crucial. Because the subject of wastewater is obviously not intrinsically attractive, the material needs to be presented in a way that is interesting, relevant and beneficial for the future. Here, Gujer – a gifted teacher – set an example. On two occasions, he received the "Golden Owl" from the ETH Zurich student association for his excellent and dedicated teaching. He was also a recipient of the "Credit Suisse Award for Best Teaching". (aj)

Urine source separation: a concept of the future. During his tenure as Professor, Gujer broadened and diversified his research interests. He gave fresh impetus to the study of sewer systems, a topic which had previously received peripheral attention at Eawag and the ETH Zurich. With the aid of several dissertations, he pursued research on sewer exfiltration and infiltration processes and on interactions between wastewater transport and treatment systems.

He was also keen to introduce water professionals to his ideas on new, decentralized wastewater management concepts as an alternative to the disposal systems established over the past 60 years. For example, with active support from his wife, he managed to arouse national and international interest in urine source separation via new sanitary systems, which has led – at least in some cases – to initial applications in practice. The recovery of important nutrients from wastewater, together with the control of various micropollutants, is a concept which will certainly become increasingly relevant in the future. At any rate, the ongoing pursuit of research on the technical implementation of urine separation and treatment in the post-Gujer era reflects the interests of the concept's initiators.

Legacy in good hands. In recent years, Gujer turned his attention to a question which has been largely neglected in urban water engineering, namely, just how meaningful measurement data and model parameters are. Here, once again, his capacity for abstract thought and his knowledge of the mathematical treatment of stochastic processes came into play. Under his supervision, several doctoral students investigated this topic, elucidating the meaningfulness of measurements and modelling. Even though few of these insights have so far been adopted in process engineering practice, the work of the "Gujer school" will be carried on by a number of former doctoral students well beyond their supervisor's retirement.

The continuing relevance of Willi Gujer's achievements was confirmed by a conference held in his honour in October 2011 (see Box). Here, for a colleague of several decades' standing, it was gratifying to note that, over a generation, engineering in the urban water management sector has made great strides, and that the professionals trained during this period have now become key figures who can manage and advance Gujer's legacy in research and practice.

In brief

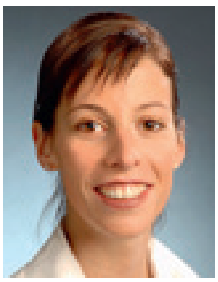
Award for Sandec

In November 2011, the Department of Water and Sanitation in Developing Countries (Sandec) was the recipient of an International Water Association (IWA) Development Solutions Award presented at the 2nd IWA Development Congress in Kuala Lumpur (Malaysia). The award is made in recognition of outstanding innovations or contributions to science and practice which have had a demonstrable impact at the national, regional or international level. According to the Awards Committee, Sandec's "applied research and high-quality science provide leadership and partnership for the academic community working in low- and middle-income countries". Christian Zurbrügg, the Head of Sandec, who accepted the award on behalf of the Eawag department, stresses the importance of alternative and innovative approaches in the sanitation field, as well as partnerships between local governments, the private sector, practitioners, researchers and development agencies. A Development Solutions Award was also presented to the Bremen Overseas Research & Development Association (BORDA).
www.iwahq.org/sn/about-iwa/honours-and-award

New Head of Environmental Microbiology

Since July 2011, the Environmental Microbiology department of Eawag has been led by Martin Ackermann, who is an Associate Professor of Molecular Microbial Ecology at the ETH Zurich. He and his research group investigate fundamental questions concerning the evolution and ecology of bacteria in their natural environment.
www.eawag.ch/forschung/umik

New Chair of Policy Analysis



In August 2011, Karin Ingold was appointed Assistant Professor, leading the Policy Analysis group with a special focus on the environment. This tenure-track position (with the possibility of a permanent professorship) has been newly established at the Bern University Institute of Political Science and is co-funded by Eawag. It is intended to promote joint Eawag/Bern University research in the field of water resource management and water policy. Karin Ingold is a political scientist concerned with water, energy and climate policy, focusing on the analysis of political processes and questions relating to the management of natural resources. The Policy Analysis research group is based at Bern University.
www.ipw.unibe.ch/content/team/karin_ingold

Transfer from FDHA to FDEA

From 2013, responsibility for the ETH Domain – which includes Eawag – will be transferred from the Federal Department of Home Affairs (FDHA) to the Federal Department of Economic Affairs (FDEA). In the summer of 2011, the Federal Council decided to reorganize the various departments and to integrate the education, research and innovation sectors within the FDEA, to which the Federal Office for Professional Education and Technology already belongs.

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Projet Lac: documenting fish diversity

Led by Professor Ole Seehausen, an international research team from the Fish Ecology & Evolution department of Eawag and the Natural History Museum of Bern has begun an in-depth study of lakes in and around the Alps: In the "Projet Lac", fish populations are to be scientifically documented and described. Little is currently known about biodiversity in Europe's largest lakes. So far, populations have been systematically sampled in Lake Murten and in two French lakes (Annecy and Bourget). The survey data indicates that more than a third of the fish species previously described have disappeared from Lake Murten. At the same time, several previously unknown species have been found.
http://www.eawag.ch/medien/bulletin/20110901/index_EN

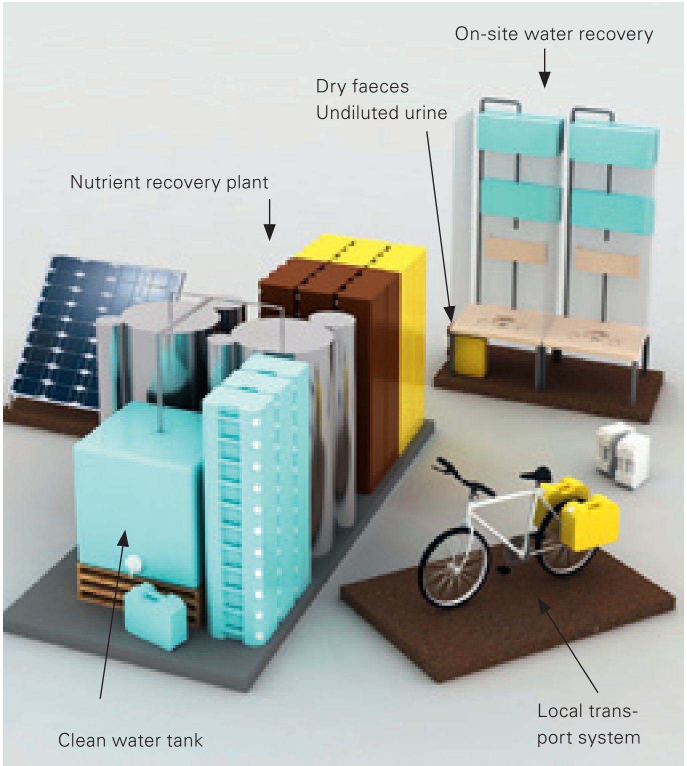
Stefan Kubli

Fine-tuning PEAK courses

Practice-oriented Eawag (PEAK) courses, as the name suggests, promote exchanges between researchers and practitioners, pass on the latest research findings and help participants to establish networks among themselves. They are designed for specialists from industry, administration, consultancies and NGOs. To meet the needs of these groups even more effectively in the future, Eawag has set up an internal committee which will seek to align the content of courses more closely with participants' requirements.
Contact: Evelin Vogler, evelin.vogler@eawag.ch
www.eawag.ch/lehre/peak/index_EN

Reinventing the toilet

An interdisciplinary team led by Tove Larsen of the Urban Water Management department has taken up the challenge of reinventing the toilet. The end product of this ambitious project is to be a toilet which collects source-separated urine and faeces for further treatment, while recycling used water on site. The project is receiving around USD 400,000 in funding from the Bill & Melinda Gates Foundation and is thus the second Eawag research project to obtain support from this source.

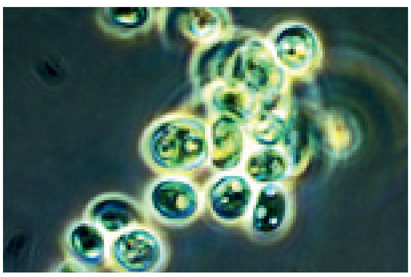


Awards for young Eawag scientists

Andreas Kretschmann, an environmental chemist and former doctoral student at Eawag, has received the Young Scientist Award of the Environmental Chemistry and Ecotoxicology Division of the German Chemical Society (GDCh) for his paper "Toxicokinetic model describing bioconcentration and biotransformation of diazinon in Daphnia magna", published in Environmental Science & Technology 45 (2011). The award was presented at the EuCHeMS International Conference on Chemistry and the Environment held in September 2011.
Saskia Zimmermann, a doctoral student in the Water Resources and Drinking Water department of Eawag, received this year's Otto Jaag Water Protection Prize of the ETH Zurich for her dissertation "Enhanced wastewater treatment by ozone and ferrate: kinetics, transformation products and full-scale ozonation" at the ETH Day awards ceremony on 19 November 2011.

Green algae affected by nanotubes

Nanoparticles are found in ever-increasing numbers of products, but very little is known about how they affect the environment – and aquatic ecosystems in particular. To answer these questions, scientists from Eawag are cooperating with Empa researchers in this area. According to a study recently published by Empa and the Agroscope Reckenholz-Tänikon Research Station, in which Eawag was also involved, carbon nanotubes are not directly toxic to green algae, but they do inhibit growth by depriving them of light and space.



www.empa.ch/plugin/template/empa/1256/113921/---/l=1

In Brief

Agenda

Courses

28–29 March 2012, EPF Lausanne
Introduction à l'écotoxicologie

10–11 May 2012, Eawag Dübendorf
Erfolgreiche Revitalisierung von Fliessgewässern

4–8 June 2012, Eawag Dübendorf
PhD Summer School in environmental systems analysis

6 June 2012, Eawag Kastanienbaum
Fachtagung Schadstoffe in Seesedimenten

Guided tours

8 December 2011, Eawag Dübendorf
Public tour of Eawag Dübendorf (in German)

Events

12 January 2012, Eawag Dübendorf
Abwassereinleitungen in Gewässer bei Regenwetter – Erfahrungsaustausch und Diskussion nach vier Jahren STORM

22 June 2012, ETH Zurich
Infotag 2012: Lebensraum Wasser – was er leistet, was er braucht

28–29 June 2012, Eawag Dübendorf
Conference of the European network for alternative testing strategies in ecotoxicology

Further information: **www.eawag.ch/veranstaltungen/index_EN**

ERC-funded ATHENE project launched

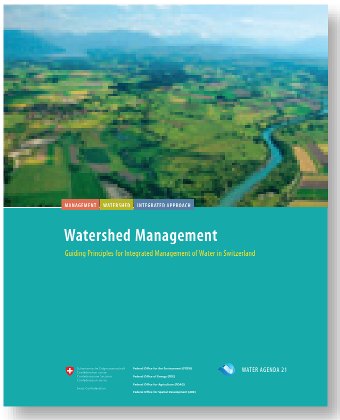
October 2011 saw the launch of the ATHENE research project, led by Adriano Joss of the Process Engineering department of Eawag and Thomas Ternes of the German Federal Institute of Hydrology (BfG). The aim of the project is to improve our understanding of microbial degradation of organic micropollutants – e.g. from antibiotics, analgesics or biocides – in biological wastewater treatment. The identification of degradation pathways and the elucidation of enzymatic reactions should permit the development and testing of innovative technical solutions for biological wastewater treatment. The project will run for 5 years, with a budget of around EUR 3.5 million.

Eawag publications

A database of all publications by Eawag researchers (including article summaries) is available online at:
www.lib4ri.ch/institutional-bibliography/eawag.html

Open access publications can be downloaded free of charge. If you have any queries, please contact: info@lib4ri.ch

Just published



Water Agenda 21 (the network of Swiss water management stakeholders) and the Federal Offices for the Environment, Energy, Agriculture and Spatial Development have just issued **Watershed Management – Guiding Principles for Integrated Management of Water in Switzerland.** These principles are designed to promote modern, cross-sectoral water management, addressing both protection and resource use interests.
http://wa21.ch/index.php?page=303

What exactly do river rehabilitation projects involve? What points need to be considered? What are the benefits for fish, and what role is played by the fishing community? Answers to these questions can be found in a new brochure on **River rehabilitation** issued (in French and German) by the Fishery Advice Centre (Fiber). The brochure provides a useful overview of the theory and practice of rehabilitation measures.
www.fischereiberatung.ch/docs

On its website, Eawag publishes **Factsheets** on a variety of topical issues. Recent additions to the series deal with hydropower and ecology, water and energy and rainwater usage.
www.eawag.ch/medien/publ/fb/index_EN

The **Community-Led Urban Environmental Sanitation Guidelines** issued by Eawag are designed to facilitate the planning and implementation of water management infrastructure projects in developing countries. The guidelines for decision-makers involve seven planning steps and are written in accessible language, suitable for use by non-experts. One of the key success factors emphasized is the participation of all stakeholders in the planning process.
www.eawag.ch/forschung/sandec/gruppen/sesp/clues