



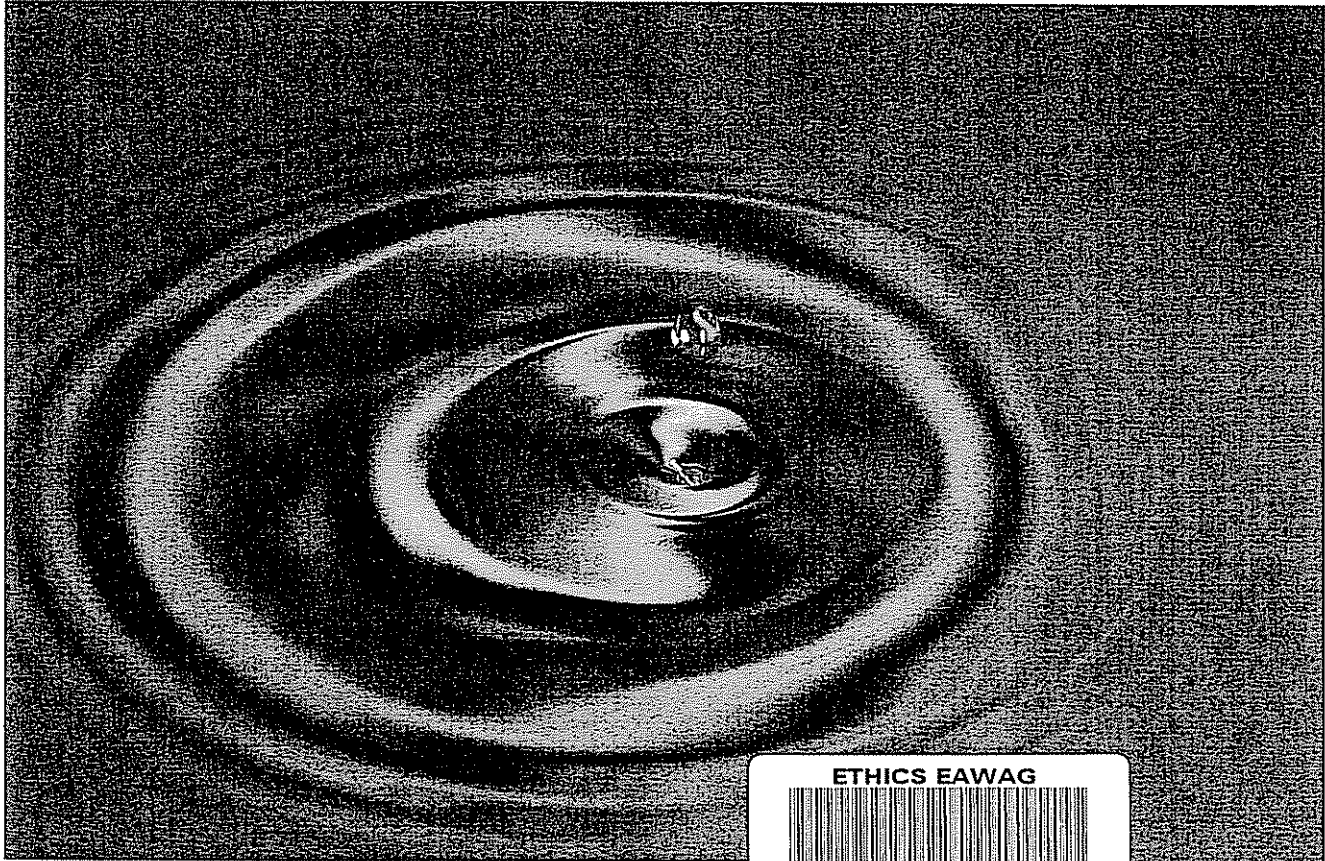
EAWAG

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B I B L I O T H E K
 Ekfg. Anstalt für Wasserversorgung
 Abwasserreinigung u. Gewässerschutz
 Unterlandstr. 131 8600 Dübendorf

Understanding Material Fluxes – Controlling Material Fluxes



effectiveness. The examples demonstrated a broad spectrum of collaborations and levels of analysis. A number of projects depended on collaboration with private industry and the public sector. This partnership, involving actors outside the traditional realm of science, is most important for research at EAWAG in that it reinforces the *practical relevance of research* and assures EAWAG its role in developing and assessing innovative processes in our society.

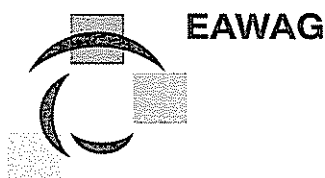
This issue of *EAWAG News* attempts to make the material presented at our Open House accessible to a broader public. How can a print shop influence the larger system? How can thermal waste treatment contribute to more efficient use of resources? What effect does roof remodeling have on water quality? How do we evaluate changes in the formulation of detergents? How is food production linked to availability and management of energy, nutrients and water? What is the role of the distributor? What is your role? Please read for yourself how EAWAG approaches this broad spectrum of questions.

Dr. Thomas Lichtensteiger
Head of the Research Group "Petrolology", in the Department of Resource Use and Waste Management, EAWAG.

Sustainable management requires us to more consciously deal with material and energy fluxes. Important questions that arise: How do decisions we make today affect the *options for future generations*? How can humanity shape its activities, such as "cleaning", "feeding", "transporting", "living", "working", in a way that makes more frugal use of raw materials and energy? What are the *key processes*? In order to answer these questions we need to know the inner workings of the systems involved, which is a major research challenge. EAWAG is developing the tools needed to uncover how different systems interact and to *understand material fluxes and their impacts*. Depending on the question, the system boundaries may be on a local, regional, or global scale.

Provided that we have a sufficient understanding of processes within systems and interactions between systems, we can evaluate proposed measures for *managing and directing* fluxes. Since directing measures will always be brought to bear within the anthroposphere, we need to know about processes within the field of human activity: classic ecosystem studies must be combined with system evaluation of the anthroposphere.

As part of the annual Open House, EAWAG presented case studies on how current projects already contribute to the evaluation of directing measures and how projected scenarios or measures already in place can be judged as to their



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EAWAG, 8600 Dübendorf, Switzerland
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Editors
Diana Hornung (EAWAG),
Patricia J.S. Colberg (USA)

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Cover
In order to be able to manipulate material fluxes, one has to understand them first. Even the waves from a small droplet may have an effect which is outside of our current comprehension.
High-speed photography by R. Bramaz (A droplet falling past an infrared sensor triggered the flash from a stroboscope which "froze it in time").

Hans-Peter Bader* and Ruth Scheidegger*

Models and Simulation Software in Environmental Management



Hans-Peter Bader*



Ruth Scheidegger*

* In collaboration with Reto Burler¹, Willy Frey¹, Ruedi Lisibach¹, Markus Rea², Patrick Plüss, Susanne Kytzia and Peter Baccini.

¹ NZZ Zürich

² Alpha Real AG, Zürich

Markus Rea is owner of Alpha Real AG and has documented expertise in solar cell technology.

Both the number of models and the availability of simulation software in the field of environmental management have exploded in recent years. Until recently, numerical models were used primarily to model and evaluate products and the performance of enterprises and ecosystems; the current trend is leading towards the modeling of regional environmental management. The potential of such an approach, namely the analysis of material fluxes, will be demonstrated in two examples: the printing plant of the NZZ (Neue Zürcher Zeitung) and the development of photovoltaic plants on a scale larger than yet realized in Switzerland.

Environmental management is comprised of strategies, measures and control of an organizational unit (commercial or public entity from small commune to whole nation) with the goal of shaping its activities in the most environmentally compatible way, while still allowing it to fully function. Criteria for "environmental compatibility" include compliance with environmental laws and sustainable development, a loftier goal which may dictate limitations on resources use.

Within a very few years, environmental management has become a widely-used term. The most important ingredient in actual practice is a good understanding of the environment (in terms of science, economy and politics) in which the system to be managed is embedded. Such knowledge can be enhanced by the use of mathematical

models that are able to simulate the behavior of the system.

In this article, we present the basic types of environmental models and briefly discuss the characteristics of various approaches. Two examples will be used to illustrate one of these approaches (material flux) in more detail:

- Environmental management in the "Printing Plant NZZ"
- Development of photovoltaic power plants in Switzerland.

Simulation in Environmental Management

Figure 1 presents a simplified classification system for environmental system models as arranged by *application area* [1]. This classification is by no means complete, but is based on "history". Models have traditionally been developed independently by two very different disciplines:

Natural Systems (Ecosystems)

These models are based on scientific descriptions of interdependencies and range from simple population models to models describing complex ecosystems (e.g., forest development models). Their purpose is system identification and gaining a basic understanding of the system.

Economically-Oriented Anthropogenic Systems

Well-known representatives of this group include ecological balance mod-



Comments by
Reto Burler, NZZ,
at the EAWAG Open
House on 11.9.98:

"One of the most important realizations that came out of the detailed materials accounting project was the fact that the hidden energy consumption in newsprint production is by far the largest environmental factor. Despite the assumption that our plant would not lend itself to the use of newsprint containing recycled paper, we were able, in cooperation with the paper producer, to gradually increase the content of recycled paper to over 50% and thus reduce the amount of "gray energy" used in the overall production process".

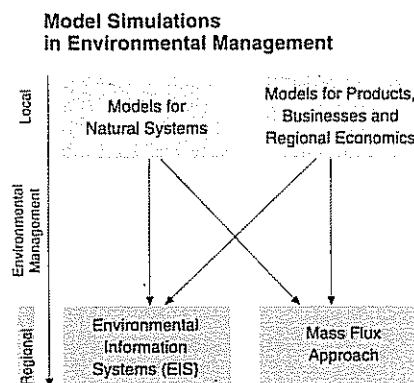


Fig. 1
Classification of models used in environmental management.

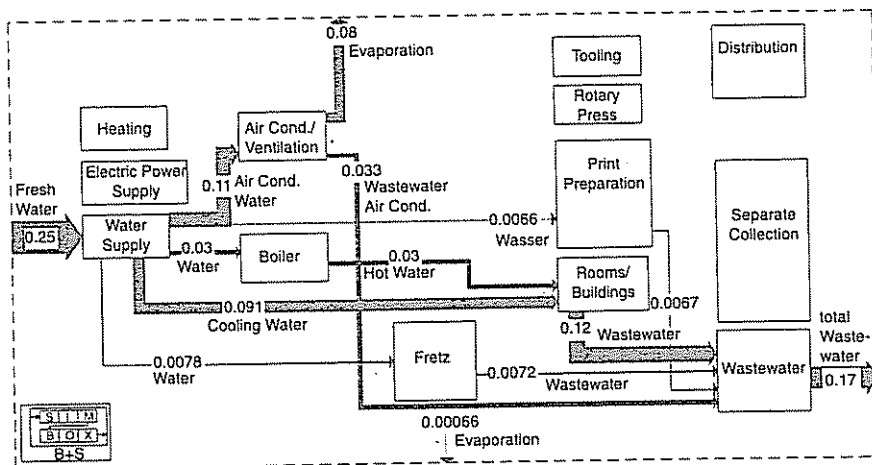


Fig. 2
Water flux in liters per copy for 1966 in the printing plant Schlieren.
Fretz is a "daughter" company of the NZZ.

els and input-output models describing individual products, factories, or regional economies. They are based on large data sets and typically allow evaluation of a product or plant; it is sometimes possible to provide a trend analysis.

As indicated in Fig. 1, both types of models describe *local* environmental management. Over the last few years, however, environmental management models have shifted ever increasingly to the *regional* scale. These models have to be able to describe all the subsystems of a region (e.g., enterprises, households, ecosystems) as well as the interactions among them.

The best known examples of this trend are environmental information systems (EIS), which are based on a common data base for all the subsystems of a region and compile as much detailed information as possible (air, water, soil, noise, settlement statistics, etc.). These systems allow for an extremely accurate analysis of the current state as well as trend analyses. To date, simulations and predictions are possible only in a few areas (e.g., pollutant transport). Recently, a complementary approach has been developed which is based on material fluxes [2]. Compared to EIS, this approach is much "cruder" and attempts to describe the behavior of a system based on a few of its basic properties. Usually, the system description is limited to *material* and *energy* fluxes. Expansion to include *economic* aspects are in progress [3]. Because of these limitations, the formulation of models using

this approach is far cheaper than EIS, both financially and in terms of time [1].

The Material Flux Approach

This method is described in detail in [2]. Basically, it consists of the following steps:

- *System Analysis*: determination of processes and material fluxes relevant to the question.
- *Data Evaluation*: administration, visualization and evaluation of measured or estimated data.
- *Model Calculations*: at the center of a model calculation is the *model formulation*, where the properties of a system are described mathematically. Important applications include the development of different scenarios or predictive calculations. It is a tool to simulate how a system will behave under various conditions. Different options for the manipulation of material fluxes can be demonstrated both in data evaluation and in model calculations. EAWAG has developed a program, SIMBOX, which allows both kinds of applications.

Example: "Printing Plant NZZ"

Factories and plants are important components in the chain of human activities. The manipulation of material fluxes is very effective in this area, both in a forward sense (environmental impact) and in a reverse direction (use of resources).

In a joint project between NZZ and EAWAG, the material flux for

the printing plant of the NZZ was recorded in detail during 1996 [4]. As part of the ISO 14001 certification process, this study served to identify environmental benefits (although not required for ISO 14001 certification). The detailed accounting of material fluxes is the basis for *internal plant environmental management*, where the management attempts to optimize resource use and environmental benefits.

Visualize material fluxes: Figure 2 shows the first step in material flux accounting in the example of the simplified schematic representing the print shop in Schlieren. The five columns, from left to right, represent:

- Energy sources and water
- Boiler and air conditioning
- Daughter company Fretz
- Print shop and waste disposal
- Newspaper delivery.

In a second step, data were gathered for the material and energy fluxes identified in the scheme and converted into graphical representations using SIMBOX. Figure 2 also shows the average water use per newspaper copy in 1996.

Contributions from human use (kitchen and toilets) and air conditioning are of comparable magnitude, and roughly one order of magnitude higher than the use of process water. As a comparison, the total amount of water consumed during the printing of one copy of a newspaper is about 0.25 l, which is in the one per thousand range of the daily per capita water consumption in Switzerland.

Directing material fluxes: After comparing water fluxes in Fig. 2 with reference values, NZZ has adopted technical measures to reduce the amount of water used. Water consumption in 1997 was reduced by 17% compared to 1996 levels.

Another option for directing material fluxes lies in simulations using models. Model calculations allow the comparison of different scenarios and options with respect to technical and organizational changes, such as the effect of replacing old printing presses on energy and material consumption.

Finally, an extension of the system allows inclusion of suppliers and customers [5]. This represents the first step from plant level to regional environmental management. As an example, consideration of the entire paper production process may be mentioned.

Development of Photovoltaic Plants

This study was conducted as part of the dissertation research by Markus Real [6]. His questions included the following:

- Could photovoltaic electricity generation become a significant source of renewable energy in Switzerland?
- Does the construction of photovoltaic plants on a large scale entail significant material and energy fluxes?

His system analysis included the production of solar cells as well as the glass used to cover the cells, their installation, and the distribution of the produced energy.

Model Approach

The fundamental assumptions made were as follows:

- Determination of the area available for solar cells: numbers are based on careful studies of available surface area, orientation, and so on. Figure 3A shows the assumed development of the solar cell area per person as a function of time.
- Technological parameters: material and energy consumption during production, life time, efficiency, and degree of recycling.

All assumptions were made by extrapolating the current state of technology into the future. We think they

are reasonable based on the recent pace of technological development. As an example, Fig. 3B shows the efficiency of crystalline solar cells. The curve represents the average of currently available cell technologies.

The model approach used by Real [6] to describe the dynamic system leads to approximately 70 coupled differential equations. SIMBOX was used to solve this system of equations for various scenarios. One such scenario is represented in Fig. 4, demonstrating the contribution from various energy sources over time. Model assumptions made in this case were as follows:

- Hydroelectric power will slightly increase.
- Wind and biomass energy production are increasing according to current best estimates.
- Solar energy increases as described above.
- Fossil fuels: energy production in fuel cells.
- Nuclear energy: production levels based on current permits.

Interpretation

A transition to energy production from renewable sources (i.e., solar cells) appears to be feasible within the next 60 years, while maintaining total energy consumption near today's levels. If a transition were to be forced more rapidly, the production capacities that could be built would be mostly of short-term use [6].

Conclusions

The first step in environmental management is a basic understanding of the system and its essential components. Models and simulations can assist substantially in this task, as demonstrated for the material flux approach in two examples. In general, these studies [7–9] demonstrate:

- The material flux approach is able to identify key fluxes and simulating options for directing them.
- *Stationary* models may be satisfactory in the case of environmental management on an enterprise level, but regional environmental management requires *dynamic* models.

In summary, we can conclude that models are very useful tools if applied appropriately.

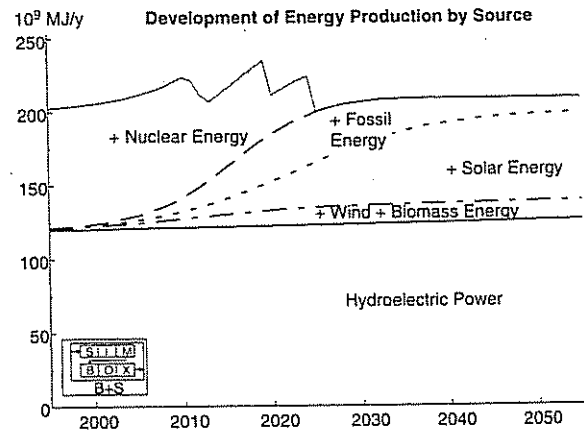


Fig. 4 Contributions of various energy sources to Switzerland's electricity production in 10⁹ MJ/year.

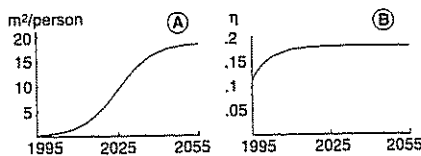


Fig. 3 Assumptions about increases in solar cell area (A) and its efficiency (B) over time. For comparison, the surface area required per person in Switzerland: 18 m² for reservoirs and 18 m² for windows.

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Christoph Zeltner and Thomas Lichtensteiger

Product Design in Thermal Waste Treatment



Thomas Lichtensteiger



Christoph Zeltner

The grate system technology of today's waste incinerators permits specific treatment of hazardous compounds. The technology's possibilities in resource management are limited. To date new processes are being developed which are more suitable for the management of secondary resources. How can a knowledge of systems permit a product design which efficiently uses the reaction potentials of the materials?

Motivation

"No junk – just scrap metal", says the slogan of the Swiss steel industry (Fig. 1). The secondary resource "scrap metal" covers 100% of the industry's demand in iron. Random products cannot be used as resources for manufacturing high quality products. Constant qualities with specific properties are needed. A specific product design is actually needed for many secondary resources [1]. This is a new challenge for waste management.

Most important along the line of production processes from ore to the metallic material is the *smelting process*. In contrast to the supply, few smelting processes are yet being applied in the disposal of wastes. The thermal treatment of municipal solid waste is currently being carried out in waste incineration plants using the grate system. An essential effect of the grate system is that the behavior of the residues in landfills (monofills) is more favorable by several orders of magnitude than that of directly disposed municipal solid waste [2, 3]. Current grate system technology thus permits specific *treatment of hazardous compounds*. In addition, the energy of organic compounds is being utilized. Most inorganic compounds, however, are still excluded from efficient high quality utilization. This is true for copper for example. This is unfortunate, seen from the resource managements side, as municipal solid wastes are important carriers of copper: The situation in 1990 shown in Fig. 2 is based on a dynamic SIMBOX model calculation [5].

The example indicates that already more copper is deposited in landfills or is locked in constructions or mobile goods in the USA than still exists as a primary minable resource. The reserves in the primary deposits amount to about 350 kg per person. In the areas of "consumption" and "landfills", an amount of approx. 450 kg per person exists. The annual input into the landfills from the area of "disposal" amounts to 3 kg a year per capita.

A new generation in thermal waste treatment processes should be able to utilize such resource potentials better.



Fig. 1 Information campaign of the Swiss steel industry. The poster expresses the fact that high quality products demand well-defined material qualities and not just random material.

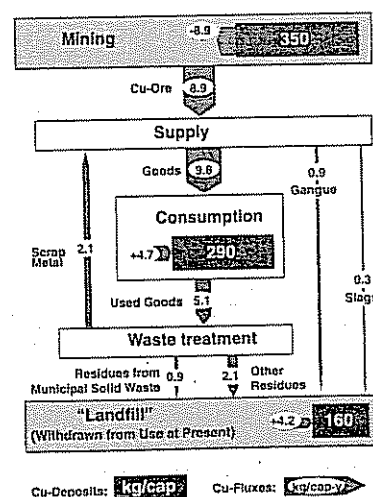


Fig. 2 Stocks and fluxes of the copper resources from the mine to its disposal (data from the USA). Situation in 1990, based on a dynamic SIMBOX model [5]. Approx. 1 kg per capita (cap) and annum (a) enter the landfill via municipal solid waste. This is a relevant contribution for resource management.

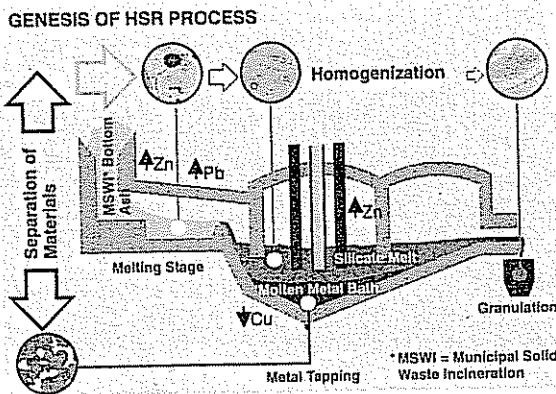


Fig. 3

Diagram of a smelting process for treating municipal solid waste according to metallurgical principles (HSR = Holderbank-Schmelz-Redox).

The plant, in this design, is constructed for the secondary treatment of waste bottom ashes from grate systems. The genesis of the flow of material leads towards an increasing homogenization and a separation into a copper-rich metal melt and a purified siliceous melt. Volatile substances such as zinc or lead are separated via the gaseous phase. In the treatment of the melt metal droplets form which precipitate and so raise the level of the molten metal bath. The siliceous melt continually flows into a water bath where it granulates. The molten metal bath is "tapped" occasionally as metallurgical processes.

The separation of compounds via the gaseous phase, currently under trial in conventional plants, will be combined with smelting processes such as those being used in metallurgy. Siliceous and metallic products separate out from the melt; 80% of the treated residues remain in the siliceous melting product. A rock-like quality is being sought for this product with specific properties for high-quality utilization in construction [4]. Copper with its low volatility is separated via the melting product and can thus be added to the copper smeltery for further processing.

Partnership

The investigations on product design were carried out in collaboration of EAWAG with plant constructors and the cement industry. The cement industry is mainly interested in the further processing of the siliceous granulate (an additive for cement and concrete). The following criteria in choosing research partners were important for EAWAG: objectives, state of development, accessibility of the plant and complementary systems being compared (e.g., with or without mechanical separation stages).

Approach

Three pilot plants with different new processes were compared. The processes were discussed in the context of geogenic and metallurgical melting processes. In addition, the genesis of the melting products were determined using a petrologic approach. The focus was on the processes of homogeniza-

tion and separation. The petrologic approach combines methods from geology, materials science and chemistry using the instrument of materials flux analysis. Experimentally determined data, microscopic investigations and thermodynamic and kinetic considerations were linked together to form a picture of the chemo-physical processes taking place.

The genesis of the melting products leads through four stages: treatment of bulk goods, melting stage, treatment of the melt, discharge and cooling. Figure 3 shows the HSR process of the firms Von Roll Umweltechnik AG and Holderbank Management and Consulting AG. The diagram corresponds to the pilot plant's stage of development. The latter was constructed for the follow-up treatment of grate system bottom ash and filter dust from municipal solid waste incineration plants; in this case, the treatment of bulk goods essentially corresponded to that in the waste incineration plant. In the melting stage, the smelting down occurs under oxidative conditions in

the first part of the reactor. The treatment of the melt occurs under reducing conditions in the second and third parts of the reactor.

The following questions arise: in which phase should a reaction ideally take place, and how can these be determined and controlled? One can differentiate here between reactions which are *essential* or beneficial and *disruptive* reactions. Apart from these, there are also *indifferent* reactions (Fig. 4).

Results

The genesis of the melting products is marked by an increasing separation of materials and an increasing homogeneity (Fig. 3).

The results show that if the oxygen supply, the residence times and the temperatures are high enough, a satisfactory *homogenization* can be attained. The siliceous melts are more homogeneous than metallurgical slags. They are often also more homogeneous than geogenic magma melts.

Differentiated treatment is needed for the optimal *separation of materials*. Here the point is to utilize the reaction potential contained in the municipal solid waste. Our chosen classification of essential (beneficial), indifferent or disruptive reactions is helpful in this approach: Figure 5 clearly shows what evidence can be gained from *microscopic investigations* on the behavior of copper: metallic copper as well as copper sulfides can be found in the metal and in the silicate products as independent phases. The type of copper phases in the silicate product can be traced back to the course of the separation process: during a fast cooling of the

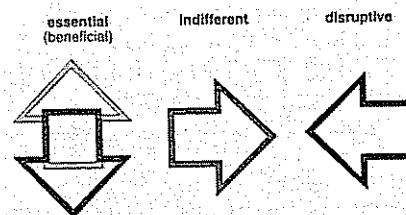


Fig. 4

The genesis of the flow of material can be classified into essential (beneficial), indifferent and disrupting reactions regarding aspects of "homogenization" and "separation of materials". This becomes the basis for further management measures.

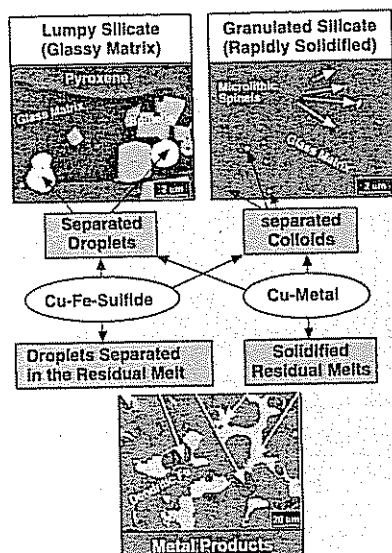


Fig. 5
Copper-rich phases in the metallic product (below) and in differently cooled siliceous products under the scanning electron microscope. The minute colloids and microliths were redrawn. Microscopic investigations on the microstructure of slowly solidified siliceous products reveal whether copper is present as an oxide or sulfide. Specific optimizing measures can be derived from this.

silicate melt (granulation in the water bath), little time remains for the separation process, so that the latter occurs incompletely. In the glassy granulates, colloids are segregated forming streaky domains. The colloids are minute (less than $1 \mu\text{m}$) and are thus difficult to analyse singly. If the siliceous melt is cooled slowly by casting into a mold instead of a granulation, more time remains for the separation of the copper species dissolved in the siliceous melt. In this case droplets form which are ten times larger than the colloids. Their composition can then be analyzed with the scanning electron microscope. The equilibrium of copper between the metal and siliceous melts can be modelled thermodynamically if the elementary amounts of the copper phases in the metal product, the temperature and the partial pressure of oxygen are known. The latter can be calculated using the ratio of Fe(II):Fe(III) of the siliceous melt. Thus the limiting factors for the separation of copper during the treatment of the melt can be determined. It could be shown that in most of the investigated

samples copper exists mainly as a sulfide. Sulfur disturbs the separation of copper: the more sulfur present, the more the copper sulfides also influence the equilibrium, apart from the metallic copper and the copper oxides. If the temperature in the reduction reactor is very high and if the partial pressure of oxygen is especially low, then the solubility of the copper sulfides in the siliceous melt is raised. As such conditions would be beneficial for the reduction of copper oxide and also for the transfer of zinc to the gaseous phase, this would mean a conflict of interests.

In spite of the limitations mentioned above, the separation of copper is more complete than in slags from copper metallurgy. If we could succeed in separating the sulfur earlier on, the copper could be enriched better in the molten metal bath.

The separation of materials and homogenization should be coordinated. The processes of homogenization are beneficial to the separation of materials. They can, however, disrupt it in several aspects; the more homogeneous the process, the more easily its process technology can be influenced. A rapidly occurring homogenization causes few beneficial and many indifferent and disruptive processes (e.g., unwanted formation of zinc silicates or metal sulfides). A detailed description can be found in [6]. Apart from the HSR process, the Thermoselect process and the Siemens-Schweibrenn process are also taken into consideration.

Consequences

The smelting processes change waste disposal systems in a fundamental way. The question arises as to which role they should play. Smelting processes with separation of materials are primarily appropriate where flows of material have to be treated which are relevant carriers of valuable compounds. Mechanical separation processes will not become superfluous. Mechanical separation and milling processes also have their definite role in metallurgy.

The reorganization of our waste disposal systems necessitates long-term approaches from the constructors of plants and also from the other actors. Smelting processes are complex processes with high demands on automatic control systems, refractory materials and security. The approach presented here can contribute to detecting and working on potentials for improvement. The research carried out in the industrial plants should continue. The constructors mentioned above have large commercial scale plants under construction or being put into operation.

We can speak of improved resource management when the material potentials of the various waste fractions can be utilized in a better way. More beneficial instead of disruptive processes should take place. It is conceivable that a plant originally built for treating municipal solid waste would also treat fractions containing even higher levels of metals in a later phase. The material separation potentials of municipal solid waste could thus be used even more efficiently.

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Laura Sigg, Renata Behra, Markus Boller, Rik Eggen,
Werner Meier, Barbara Sulzberger, and Hanbin Xue

Relevance of Copper Inputs into Natural Waters



Laura Sigg

Does copper from roof runoff and gutters cause problems in natural waters and in the ground? Are emissions from these sources even relevant? These and other questions concerning the inputs of copper into natural waters are currently being discussed by building trade and environmental experts.

In this overview we present various aspects of the material fluxes of copper in the environment, of the fate of copper in natural waters and of its ecotoxicological effects.

Material Flux of Copper

The most important emission sources of copper in the environment, especially into the ground and into natural waters, include:

- the copper components used in encasements of buildings and in sanitary installations
- the copper compounds used in agriculture for fertilizers and pesticides (e.g., fungicides),
- copper contained in sewage sludge and

• copper abrasion from road and rail traffic [1–3].

Using the example of the catchment area of the Töss, the copper flux of an area was calculated using empirical data from other areas ([3], Fig. 1). The highest copper turnover is caused by the import and export of copper into and out of the area, by its accumulation in industries and households and by its amount of deposition in landfill sites. These large material flows have to be considered in the management of copper as a limited resource. Concerning water and soil, the relatively low *diffuse* inputs as compared with the total balance are, however, of great importance, as they lead to an accumulation in soils and sediments as well as to increased concentrations in natural

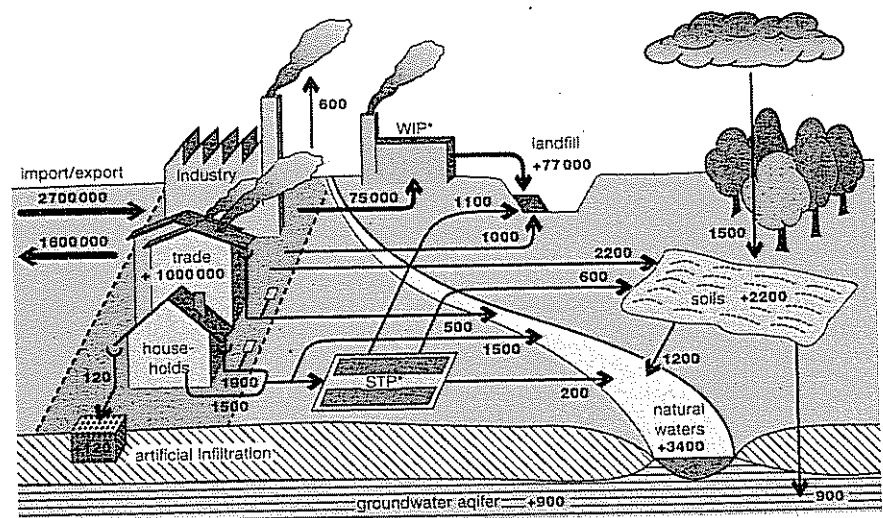


Fig. 1
The most important fluxes of copper in the catchment area of the Töss in kg/year (area: 430 km², population: 180,000 [3]).
(* WIP = Waste Incineration Plant, STP = Sewage Treatment Plant)

| Body of water | Cu dissolved | Cu total |
|--------------------|--------------|----------|
| Greifensee | 0.5–1.0 | |
| Rhine-Rekingen | 0.1–0.7 | 0.4–1.6 |
| Rhine-Village-Neuf | 0.5–1.6 | 0.9–2 |
| Kleine Aa | 2–4 | |
| Birs | 2–6 | 4–11 |
| Thur-Andelfingen | 1.5–2.0 | 2.0–2.5 |
| Glatt | | 3–6 |

Tab. 1

Dissolved and total copper concentrations in $\mu\text{g/l}$. (random samples; annual mean values for the Glatt).

waters. The considerable amount of copper accumulating in agricultural soils will merely be referred to here [1]. In this balance, the copper contamination of the Töss mainly comprises the erosion of agricultural soils, effluents from sewage treatment plants and storm water overflow catchments and direct inflows of storm water. The latter issuing from streets and roofs contributes significant relative amounts of copper in canalized wastewater (approx. 56%) and in uncontrolled wastewater. In addition, a considerable amount of copper in domestic sewage seems to come from domestic sanitary installations [2].

Concentrations and Speciation in Natural Waters

In Table 1, several typical "dissolved" ($<0.45 \mu\text{m}$) and total copper concentrations in Swiss waters have been summarized. The concentrations measured in these waters have to be compared to the typical background concentrations (approx. $0.2\text{--}1 \mu\text{g/l}$) and the newly proposed and ecotoxicologically substantiated quality standard of $2 \mu\text{g Cu/l}$ (dissolved) [4]. Low Cu concentrations can be measured in lakes. Increased Cu concentrations can, however, be observed in several smaller rivers and streams, whereby the main sources are different for each one (i.e., agricultural input for the Kleine Aa, metal-working industries for the Birs and diffuse input from wastewater and agriculture for the Thur and Glatt rivers). Using the Thur as an example, the increase in copper concentrations can be shown at three different sites along the river (Fig. 2), compared to

the first unpolluted site on the Necker (tributary). The average annual copper concentrations (total) from 1975–1997 fail to exhibit a definite temporal trend in the Glatt [5]. In this case, the copper originates mainly from domestic sewage, whereby both the use of installations containing copper and the extension/renovation of sewage treatment plants may possibly compensate for one another. In the Rhine below Basel, however, the mean annual copper concentrations have decreased within the same time span, the current levels (Cu_{total}) being about $1.5 \mu\text{g/l}$. The remediation of point sources may have played a more important role in the decrease of levels in the Rhine.

As to estimating ecotoxicological effects, knowing the dissolved or total copper concentrations is not enough. The different chemical forms of copper (its speciation) determine its effects. It is usually assumed that free copper aquo ions determine the effect on aquatic organisms, i.e., cupric ions which are exclusively bound to water molecules. Copper becomes strongly bound to organic complexing agents in solution. In natural waters, the complexing agents are largely of natural origin (humic and fulvic acids as well as other ligands of biological origin), but may include synthetic complexing agents (e.g., EDTA). On the one hand, copper is divided experimentally into different categories according to size (dissolved, colloidal, or suspended solids, Fig. 2). During dry weather, and at low concentrations of suspended matter, copper usually exists in its dissolved form. On the other hand, it can be shown that dissolved copper in natural waters is typically bound to strong organic complexing agents and that only a very small amount is present in the form of aquo ions [6]. Thus, in the examples in Fig. 2, the ratio is $[\text{Cu}^{2+}]/[\text{Cu}]_{\text{total}} \approx 10^{-6}\text{--}10^{-7}$, where $[\text{Cu}^{2+}]$ is the concentration of free cupric aquo ions and $[\text{Cu}]_{\text{total}}$ the concentration of dissolved copper. The influence of light on organic Cu complexes can lead to the reduction of Cu(II) to Cu(I) and to the formation of

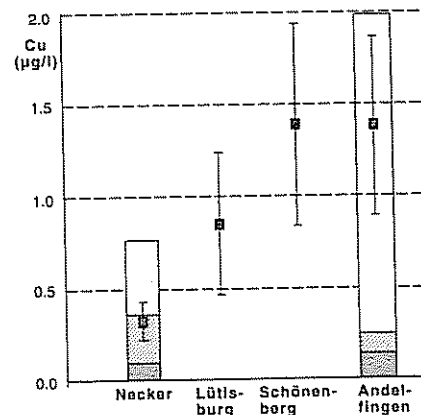


Fig. 2

Concentrations and distribution of copper at four sites along the Thur.

The points represent the mean values of the concentrations of dissolved copper measured in 4 samplings. The 3-colored bars by the Necker and by Andelfingen show the distribution of copper between dissolved (molecular weight <10000 , white), colloidal ($\text{MW} >10000$, $<0.45 \mu\text{m}$, shaded) and suspended solid ($>0.45 \mu\text{m}$, dark) species.

reactive oxygen species (radicals), which, in turn, can damage the genetic material of cells, described in the next section. Copper in its particulate form can sorb to different types of particles or exist as a precipitate (e.g., as a sulfide).

Ecotoxicological Effects of Copper

Copper is essential for living organisms, but in higher concentrations it

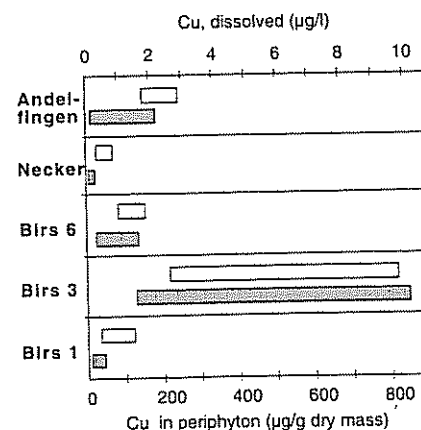


Fig. 3

Copper levels in the "Aufwuchs" (periphyton) ($\mu\text{g/g}$ dry weight, bottom scale, shaded bars) compared to concentrations of dissolved Cu in the water ($\mu\text{g/l}$, top scale, white bars) at various sites along the Birs and the Thur.

is toxic. There are difficulties in the assessment of the effects of low concentrations in the environment. The sensitivity of different species of algae to copper is variable. Investigations on algal growth at different concentrations of free cupric aquo ions indicate that even low concentrations (e.g., 10^{-10} M Cu^{2+}) inhibit the growth of sensitive species [7].

The assimilation of copper can be detected in the "Aufwuchs" (or periphyton, the "living coating" of stones, an association of microorganisms) at polluted sites in rivers (Fig. 3). At unpolluted sites in the Birs and the Necker (Thur area), low levels of copper can be detected in the "Aufwuchs". Slight increases in the Cu concentrations in natural waters are reflected in increased Cu assimilation by the "Aufwuchs", with a larger range of varying Cu levels.

Experiments involving the addition of copper to natural river water (upper reaches of the Glatt) provide information on the effects of copper on natural algal communities, whereby the composition of the species was quantified in several aquaria (Fig. 4, [8]). As expected, there were large shifts in the composition of species at higher copper concentrations. Tolerant species, e.g., *Oocystis nephrocytioides*, began to dominate. Notable were the effects of slight increases in copper concentrations within the range of actual levels found in river waters (see Table 1), which caused sensitive species, especially the blue-green bacteria, to disappear.

Several molecular mechanisms are linked to the harmful effects of copper. Little known are the mechanisms through which copper acts in combina-

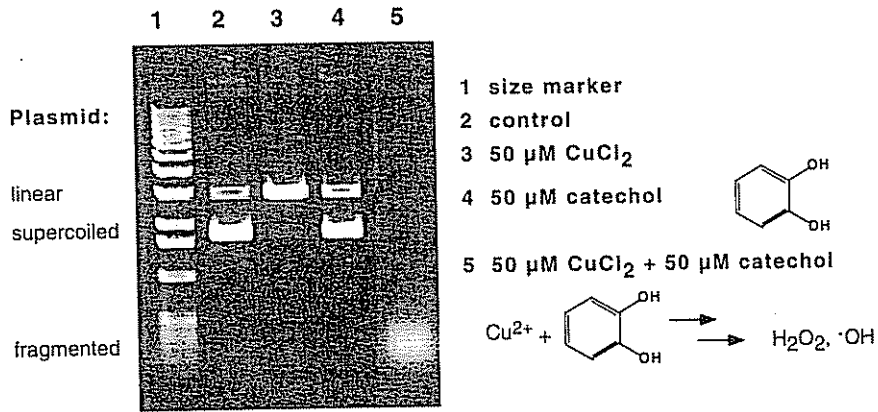


Fig. 5 Degradation of DNA induced by copper and catechol. The control sample (2) in the depicted gel shows the plasmid DNA in the form found when isolated from cells. Neither Cu (3) nor catechol (4) alone cause any detectable changes. A combination of Cu and catechol (5) causes a fragmentation of the DNA [9].

tion with reactive organic compounds. For example, the effect of both copper and catechol on the degradation of DNA (deoxyribonucleic acid, genetic material of the cell) has been studied [9]. The reaction of copper with catechol results in the formation of reactive oxygen species, i.e., hydrogen peroxide and probably hydroxyl radicals. These highly reactive species cause the degradation of a bacterial plasmid [DNA] *in vitro*, i.e. the DNA becomes fragmented through these reactions (Fig. 5), whereas copper or catechol alone do not cause any detectable damage.

Conclusions

The examples mentioned above show that the anthropogenic inputs of copper into natural waters lead to measurable levels and that these, in turn, cause changes in the composition of natural associations of organisms.

For this reason, the diffuse inputs of copper into natural waters (and also into the ground) should remain as low as possible. Copper is often used in

long-lived products which will emit copper for many years in the future. The inputs should at least not increase, i.e., the use of copper in encasements of buildings being subjected to weathering as well as its use in agriculture should be open to critical examination.

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| Cu in aquaria, μM + | 0 | 0.05 | 0.1 | 0.5 | 1 | 5 |
|---------------------------------|---|------|-----|-----|----|-----|
| $\mu\text{g/l}$ + | 0 | 3 | 6.3 | 32 | 63 | 315 |
| <i>Oocystis nephrocytioides</i> | ○ | ○ | ○ | ○ | ○ | ○ |
| <i>Scenedesmus</i> spp. | ○ | ○ | ○ | ○ | - | - |
| <i>Oscillatoria</i> sp. | ○ | ○ | - | - | - | - |

Fig. 4 Changes in the natural composition of an algal community after the addition of copper. The circles indicate the relative frequency of three species of algae for the given Cu concentrations [8].

Walter Giger, Eva Molnar, Slavica Ibric, Claudia Ruprecht,
Marijan Ahel, Christian Schaffner, and Jean-Marc Stoll

Chemicals from Detergents and Cleansing Agents in Swiss Rivers

Something is Always Left



Walter Giger

Some chemicals from detergents and cleansing agents enter natural waters through domestic and industrial wastewater discharges. The concentrations of whitening agents in Swiss rivers suggest that different input sources exist. This information can be used to assess the material flows of these substances in Switzerland. The levels of non-ionic active surface compounds (tensioactifs) of the nonylphenol polyethoxylate type and their intermediate degradation products in Swiss waters suggest that the measures dictated by the Swiss Ordinance on Substances of 1986 may be inadequate.

Large amounts of detergents are being used in household products, industry and trade. The annual consumption in Switzerland amounted to approximately 145,000 tons, or 20 kg per capita, in 1996 [1]. The disposal of most of these chemicals occurs through domestic and industrial wastewater discharges, while small amounts from domestic sewage treatment plants can also enter natural waters.

Today's detergents are composed of a relatively complex mixture of substances with up to 20 different components. The individual components exhibit different behaviors during sewage treatment process and in natural waters [2]. Modern chemical analysis can detect most detergent chemical components selectively and sensitively as well as measure them quantitatively [3].

In this article, we will discuss our research efforts to assess inputs of (a) whitening agents and (b) non-ionic surfactants of the nonylphenol polyethoxylate type to Swiss waters. These two groups of compounds have been comprehensively studied at EAWAG in several doctoral theses [4, 5, 6, 7]. These projects include the development of chemical analytical methods, studies in the laboratory and field, as well as modelling the environmental fate of detergent chemicals.

Whitening Agents from Detergents

Whiter than White –
even in Rivers and Lakes

Many detergents contain whitening agents in small amounts (ca. 0.1%) which give textiles a whiter color by radiating light. The two most important whitening agents are DAS (a diamino stilbene) and DSBP (a distyryl biphenyl). Previous studies [5, 6] have resulted in the development of analytical techniques assaying these substances in sewage and sewage sludge and have produced considerable information both on the behavior of these compounds in sewage treatment plants and their photochemical degradation.

In order to carry out such investigations in natural waters, the development of a quantitative method for measuring trace concentrations of the whitening agents was needed [7]. In this procedure, the whitening agents are concentrated from aqueous and solid samples and subsequently measured using high-pressure liquid chromatography (HPLC).

During our investigations in the Greifensee, the occurrence of whitening agents in sediments and their dynamic behavior were studied by measuring water samples from 10 sampling sites in six Swiss rivers for one

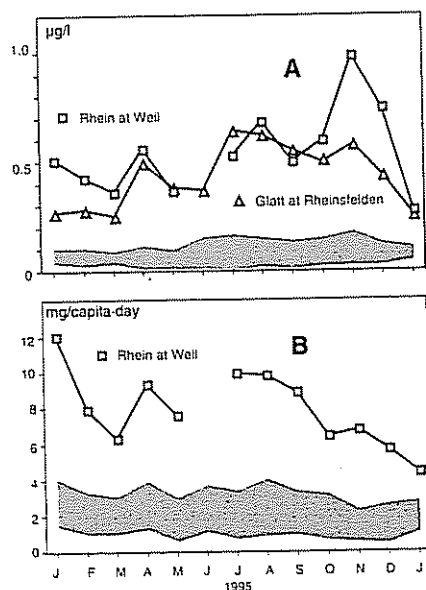


Fig. 1
Concentrations (A) and loads (B) of the whitening agent DAS found at NADUF sampling stations in 1995. Levels for several sites not shown are in the gray band. Among these are: Rhine at Diepoldsau and Reckingen, Thur at Andelfingen, Aare at Bern and Hagneck, Saane at Gümnenen and Rhone at Chancy.

year. The measured concentrations generally between 10 and 120 ng/l, with values as high as 1000 ng/l. Two week samples were collected flow-proportionally at the measuring sites of the national program for the continuous monitoring of Swiss rivers (Nationalen Programmes für die analytische Daueruntersuchung der schweizerischen Fließgewässer, NADUF). Fig. 1 shows the results for DAS as concentrations (ng/l) and as loads (mg/inhabitant and day). The two sites, Rheinsfelden (Glatt, ZH) and Weil (Rhein below Basel), exhibit elevated DAS concentrations. After converting the concentrations to loads, or material flows, the Weil site illustrates a special case where much of the DAS originates from industrial wastewater discharges being discharged into the river from a chemical plant at Grenzach on the Rhine. The whitening agent DAS is produced there, and a small amount of this product is lost through industrial wastewater. At the site Porte du Scex on the Rhone, a similar situation for the other whitening agent, DSBP, is observed, which is produced at Monthey in the Canton Valais. This type of environmental monitoring enabled us to identify the locations of the plants manufacturing these compounds; the whitening agents function as *molecular indicators* for the industrial wastewater inflows.

Material Fluxes for Switzerland

Known concentrations in rivers and in the inflows at the various sampling sites permit a materials flux analysis to be carried out – the system boundaries defined by the national borders. The results are shown in a simplified form in Fig. 2. The results indicate that 13% of the whitening agents used in households reach natural waters which corresponds to 8 t/year for a consumption of 60 t for the year 1995. Certain amounts of whitening agents enter wastewater during production of these substances, although their technical syntheses have been optimized to limit such discharges. The relatively large amount of 18 t/year corresponds to

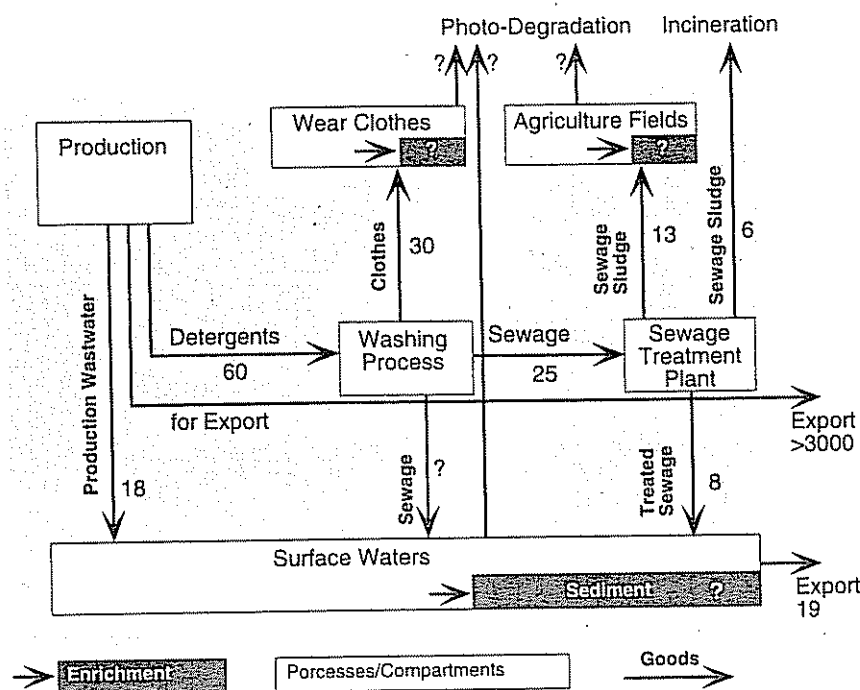


Fig. 2 Material fluxes for whitening agents in Switzerland. Material flux estimates for 1995 are indicated in tons per year.

0.5% of the annual production. Such materials flux analyses permit a comparison of the various inputs and outputs in a larger system. As both whitening agents are being produced in the catchment area of Swiss waters, a special situation arises concerning the relationship between input from industry and input from households.

Nonylphenol Compounds: Consequences of the Swiss Ordinance on Environmental Pollutants of 1986

Non-ionic Surfactants in Municipal Wastewaters

Investigations on nonylphenol polyethoxylates (NPnEO, non-ionic surfactants), were carried out at EAWAG from 1980 to 1984. Also studied were their biodegradation metabolites, nonylphenol (NP), nonylphenol monoethoxylate (NP1EO), and nonylphenol diethoxylate (NP2EO) [4, 9, 10]. The results of these studies were partially responsible for the ban on the use of the NPnEO surfactants in detergents as dictated by the Swiss Ordinance on Substances of 1986. Furthermore, the producers no longer added NPnEO surfactants in detergents used by the general public. The

1997/98 studies investigated the effects of both the NPnEO and the measures of the manufacturing industry on the residual concentrations of nonylphenol compounds in the aquatic environment.

The analysis of the NPnEO surfactants as well as their metabolites in wastewater and river water samples is based on a solid phase extraction with subsequent normal phase HPLC and fluorescence detection. In 1998, NPnEO surfactants could still be detected at concentrations of 0.1–0.2 mg/l in municipal sewage (Fig. 3A). In comparison to pollution levels in 1983, there has been a reduction of NPnEO by a factor of 5–10. In the weekly course of concentrations in treated wastewater from the sewage treatment plant Zurich-Glatt (mechanical and biological steps) shown in Fig. 3A, a clear decline can be seen on Sunday, suggesting substantial inputs from industrial and institutional sources.

To date, the origin of the detected NPnEO surfactants is unclear, as in 1997 only 23 t of NPnEO were used in manufactured products according to reports from industry. A total of 3450 t of LAS surfactants (the most important anionic active compounds) was pro-

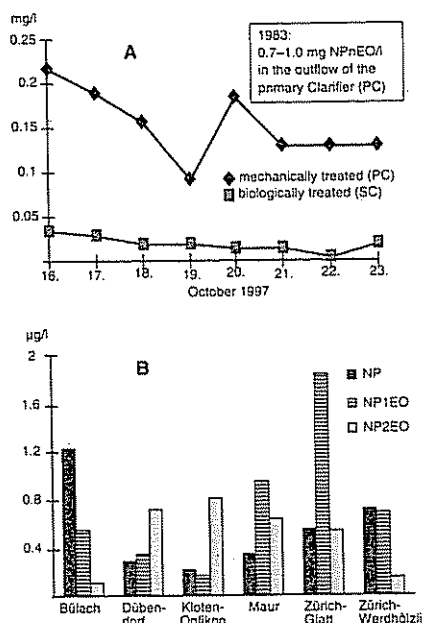


Fig. 3

(A) Concentrations of nonylphenol polyethoxylate surfactants in mechanically-treated sewage effluents of the City of Zurich.

(B) Concentrations of nonylphenol (NP), nonylphenol monoethoxylate (NP1EO) and nonylphenol diethoxylate (NP2EO) in biologically treated effluents from sewage treatment plants in the Canton of Zurich.

duced that same year. Conversely, in the region of the European Union, the annual amount consumed is given as 65,000 t, a large part of which is being used in applications not relevant to wastewater. The results presented here should contribute to our ability to detect inputs of NPnEO surfactants in domestic sewage. Furthermore, these results may be used as evidence for the necessity of the implementation of additional measures for reducing pollution levels. Further clarification of the existence of "hot spots" in certain wastewaters with elevated levels is needed. For example, the wastewater of a community in Eastern Switzerland contained 0.4 mg of NPnEO/l and this elevated high level could be traced to wastewater from textile plants.

Toxic Degradation Metabolites in Treated Wastewaters and Rivers

The investigations carried out in the early 1980's have already shown that intermediate biodegradation products of NPnEO surfactants can be detected in the outflows of sewage treatment plants as well as in rivers [4, 9, 10]; these include the less water-soluble,

lipophilic NP, NP1EO and NP2EO which are more toxic than the parent surfactants used as active compounds. It has recently been determined that the lipophilic metabolites, especially the non-ethoxylated nonylphenol, act as estrogen mimicking substances, i.e., as female sexual hormones and may participate in the disruption of the endocrine system.

Figure 3B shows the concentration levels for NP, NP1EO and NP2EO in the outflows of sewage treatment plants from the Canton Zurich. Plants in Eastern Switzerland exhibit even higher levels in some cases (max. concentration for the sum of NP, NP1EO and NP2EO: 24 µg/l), where the sewage treatment plants receive contaminated wastewater from the textile industry. During the winter months, higher levels are generally found, which may be explained by the slower rate of biodegradation at lower temperatures.

Figure 4 shows the concentrations for NP, NP1EO and NP2EO in weekly composite samples from the Glatt River near Rheinsfelden. Conspicuous are the significantly higher NP levels in winter, reaching a maximum concentration of nonylphenol of 0.45 µg/l. The sampling site near Andelfingen on the Thur resulted in a somewhat different picture where the highest NP2EO concentration of 2.5 µg/l occurred in February of 1998. Two of the three NADUF sampling sites along the Rhine (Diepoldsau and Rekingen) showed distinctive winter maxima for nonylphenol, whereas at Weil am Rhein below Basel, no seasonal fluctuations were observed.

The contamination of the Glatt by NP, NP1EO and NP2EO has been reduced substantially over the past ten years as illustrated by levels measured in the Glatt in 1983/4 (Fig. 4). It should also be noted that over this period of time, two important sewage treatment plants have been extended and better removal of organic compounds from wastewater has been achieved.

The PNEC level used today (predicted-no-effect-concentration at

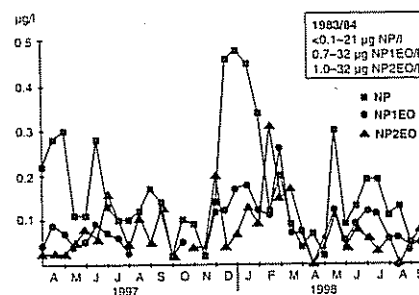


Fig. 4

NP, NP1EO and NP2EO concentrations in the weekly composite samples from the NADUF sampling site at Rheinsfelden on the Glatt (Canton of Zurich).

which no damage can be expected) in the risk assessment of environmentally active compounds is 0.7 µg/l for nonylphenol; the NP concentrations found in the Glatt in 1997/98 were between 20 and 60% of the PNEC level. It is currently being discussed in Switzerland and internationally whether the use of NPnEO surfactants should be further reduced.

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Werner Aeschbach-Hertig, Markus Hofer, and Rolf Kipfer

Tracers in the Study of Water Cycles



Werner Aeschbach-Hertig

How fast can polluted water reach drinking water wells? How quickly are groundwater reserves renewed? Selected environmental tracers provide answers to such questions and hence foundations for a rational, sustainable management of water resources.

The Time Dimension in Aquatic Systems

How quickly is the oxygen-poor, nutrient-rich deep water in a lake replaced by fresh water? Does the ground water travel longer than 10 days through the ground, as required from a hygienic point of view, before it is pumped? When has a contaminant been brought into the ground water? How fast is it degraded? How long will it take until it will arrive at the next drinking water well?

All of these questions deal with the transport of water and dissolved substances in natural aquatic systems, though we often lack the temporal information to answer them. In those parts of the water cycle that are invisible – the deep water of lakes and oceans and the ground water – water exchange rates or water residence times are often unknown.

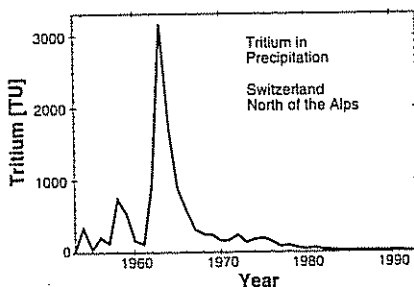


Fig. 1
Development of tritium concentrations in precipitation over time. The "bomb peak" in the early 60s served hydrologists for a long time as marker. Nowadays in most cases the decay product ^3He has to be measured in addition, in order to date water.

1 TU (tritium unit) is equivalent to a $^3\text{H}/\text{H}$ ratio of 10^{-18} (per TU this are only 6.7×10^7 atoms ^3H per litre, e.g., Lake Baikal with its huge volume of $23,000 \text{ km}^3$ contains only 150 g tritium.

Environmental Tracers to Date Water

We, therefore, need methods to measure time in aquatic systems. Such methods are based on so-called "environmental tracers". These are tracers that we do not purposely add to the water, but which are already present in the environment. The temporal information is derived from their time-dependent behavior, e.g. a time-variable input or a radioactive decay. Since environmental tracers usually enter the water cycle from the atmosphere, the contact of water and air defines the starting point of the time measurement. As a result, we obtain a "water age" which corresponds to the

residence time of the water beneath the surface, i.e., in a system sealed off from the atmosphere.

The best known dating tracer in hydrology is tritium (^3H). Tritium was released to surface waters in a pulse in the early 1960s (Fig. 1). The cause of this so-called "bomb-peak" was atmospheric nuclear weapons testing. Ever since then, the resulting global environmental pollution serves as a marker of the rainwater of that time. Today, however, the input curve has flattened so that tritium on its own is no longer sufficient for many applications. Yet, there is the possibility to also measure ^3He , the decay product of tritium. The combined $^3\text{H}/^3\text{He}$ method allows reliable dating in the range of weeks to several decades.

A Broad Palette of Methods Available

In addition to the $^3\text{H}/^3\text{He}$ method [1, 2], a whole palette of tracer methods is presently available at the EAWAG [3] and co-operating university institutes [4]. Several noble gas isotopes are suitable for dating, on time scales ranging from days [5] to millions of years. For young waters, anthropogenic trace gases such as CFCs [6] or SF_6 are used; for longer time scales, the radioisotopes ^{14}C and ^{36}Cl are appropriate.

Other tracers do not yield time information, but serve to discern waters of different origin, and thereby contribute to the determination of mixing ratios. The simplest example is electrical conductivity. Boron isotopes serve as markers of anthropogenic sources [3]. The stable isotopes deuterium and ^{18}O as well as the noble gases

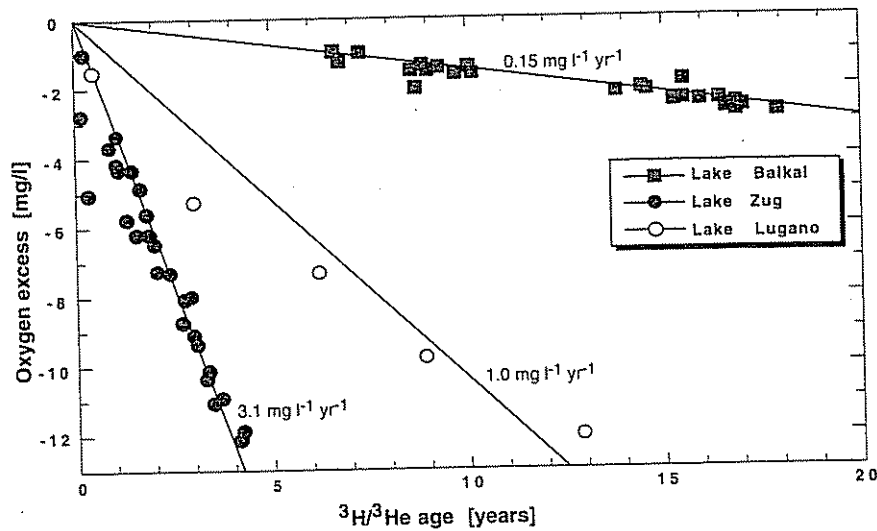


Fig. 2
Comparison of oxygen depletion rates in three lakes. Displayed is the consumed oxygen (negative oxygen excess) as a function of the $^3\text{H}/^3\text{He}$ water age.

can provide information about the conditions at the infiltration [7].

Oxygen Depletion

The excess of nutrients in lakes leads to an accelerated depletion of oxygen in the deep water. Only by mixing with surface water can oxygen be replenished. The longer the deep water remains isolated (the older the water), the more oxygen vanishes. In Siberian Lake Baikal, with its small anthropogenic load, we always find sufficient amounts of oxygen, despite enormous depths (1600 m) and high water ages

(18 years). No more than 3 mg/l have been consumed (Fig. 2). The situation is totally different in Lake Zug, where already at a water age of 4 years, the complete oxygen reserve of 12 mg/l has been consumed. The consumption rate is 20 times greater than in Lake Baikal. In Lake Lugano as well, there is no oxygen left beneath 100 m depth, but there the water residence time of 12 years is already surprisingly high. The main problem in Lake Lugano is not the large depletion rate, but the weak mixing [1].

In ground water, the oxygen content also decreases with increasing residence

time. In the Linsental, a reach of the Töss Valley near Winterthur, oxygen saturated river water infiltrates the subsurface. But in the ground water immediately below the riverbed, which is still very young (less than 100 days), 2–3 mg O_2/l have already disappeared [8]. Later on, the oxygen content decreases only slowly with increasing age. Thus oxygen consumption occurs predominantly during the infiltration of the river water in the riverbed, where the highest biological activity takes place.

Vertical Stratification in Aquifers

In the Linsental, drinking water for the city of Winterthur is pumped from the ground water. Could this exploitation be affected by the planned natural rehabilitation of the river? The pumping stations draw water from a depth of about 10 m (Fig. 3). In addition, there are deeper boreholes as well as a group of shallow bores near the river, which were constructed for the study of river infiltration. At the time of sampling in November 1996 and 1997, the mean $^3\text{H}/^3\text{He}$ -age in the shallow wells was 80 and 30 days, respectively. In the deep boreholes and the pumping stations, the age was high throughout, ranging between 270 and 940 days [8]. It seems that in the deep aquifer a large-scale groundwater circulation dominates, whereas the local river infiltration affects only the uppermost part of the aquifer; therefore, changes in the course of the river are not a threat to the pumping stations, as long as they are installed at sufficient depth.

We also found a strong vertical stratification of the ground water in the Blenio Valley, based on the indicators of conductivity and water age. The stratification was particularly evident in a borehole next to a tributary of the main river Brenno, which is screened over a depth interval of 10 m. In the upper part, the inflowing water is young and fresh with a low conductivity; in the lower part, it is old and has a high conductivity. A comparison of the conductivities with the values in

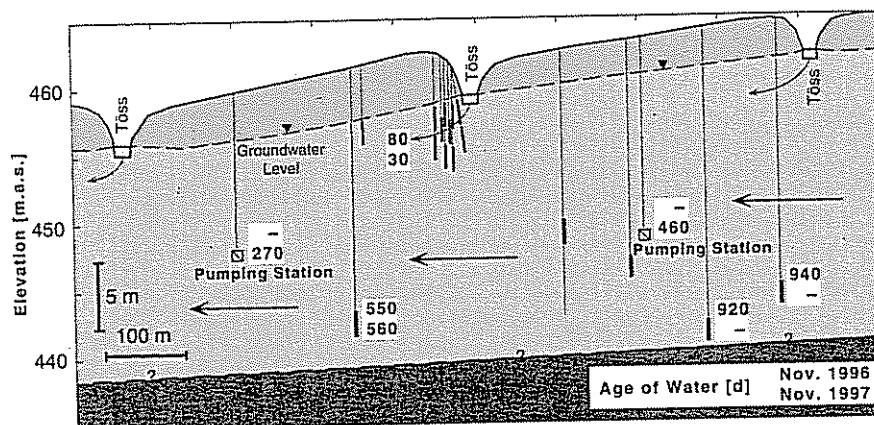


Fig. 3
Vertically enlarged section through two river bends in the Linsental. Vertical lines correspond to bores with their screens (bold). The pumping stations draw water from about 10 m depth. The $^3\text{H}/^3\text{He}$ -ages measured in November 1996 and 1997 exhibit a mostly vertical structure of the age distribution. Young infiltrate from the river is found only in the shallow bores of the proving ground (stated ages there are averages over several boreholes).

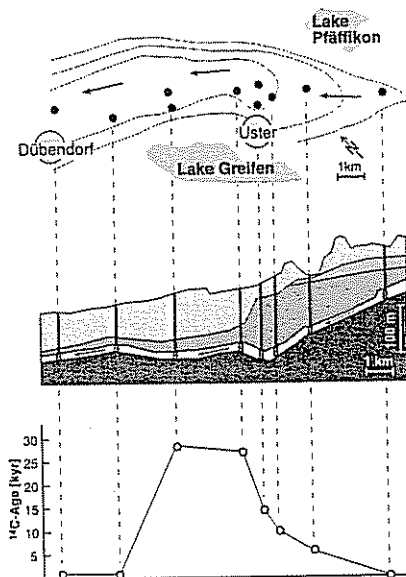


Fig. 4 Map and longitudinal section through the upper Glatt Valley, as well as development of the ^{14}C -ages. In the aquifer confined by a thick clay layer the ages increase to almost 30,000 years. The lowermost part of the system has been disturbed by a drinking water well near Dübendorf, where today much younger water is being pumped.

the rivers suggests that the upper water has locally infiltrated from the tributary. The deeper ground water may originate from the Brenno, but from a location distinctly upstream, and thus has already experienced a long residence time in the ground.

Environmental Tracers as Tools for Groundwater Protection

Such results demonstrate the relevance of environmental tracers for questions of groundwater protection. The mean water age of the drinking water pumped from wells yields clues as to the effectively relevant catchment area and the endangerment of the well with respect to contamination. If the mean water age in a well lies in the range of weeks or a few months, the major part of the water probably originates from the immediate surroundings. Hence strict measures within a restricted protection zone appear necessary. If in contrast the mean water age is in the range of years, which according to our experience is more often the case than expected, a larger area, possibly the whole drainage area, should receive some protection. In return, large water

ages render some time for interventions, and therefore more moderate measures of protection may suffice. A better knowledge of groundwater residence times would so contribute to a more appropriate quality management of this vital resource. With tracer studies on existing wells one might experience some surprises, as in the Glatt Valley, where for some time unknowingly groundwater was pumped which had infiltrated during the last ice age. At about 100 m depth in the Glatt Valley there is an aquifer which is covered by a thick, impermeable clay layer (Fig. 4). Tracer data – in this case mostly ^{14}C -activities – show clearly that the water reaches an age of almost 30 000 years, before it is pumped in Dübendorf [7].

As a result of the pumping apparently the flow conditions changed in such a way that today younger water is attracted, probably from an upper aquifer through the confining layer which is relatively thin here. In the past, the pumped water contained no tritium and no oxygen, yet today it does. Hence, the pumping does not simply deplete an old water deposit, but due to the inflowing young water a new steady state has formed which can be sustained in the long term.

Sustainable Use of Groundwater Reserves

The sustainable exploitation of old groundwater reserves constitutes an important problem in arid areas, where hardly any water is renewed and old groundwater deposits often form the only reliable water resource. Tracer methods and flow models shall more often be used in such areas to determine the recharge rate and hence the amount of water available for a sustainable management. An example comes from Botswana, where the capital Gaborone is supplied with water via a pipeline from a remote reservoir. A groundwater bearing area along the pipeline shall serve as a stock for times of need. One wants to infiltrate excess water and store it in the aquifer. If

water is lacking, groundwater shall be pumped and admitted to the pipeline. The question is how fast the stock can be renewed. CFC measurements show that the groundwater is at least 35 years old. The renewal is hence very slow and the aquifer can only to a limited extent serve for water storage.

Conclusions

Environmental tracers allow the measurement of water ages in the sense of residence times beneath the surface as well as quantification of fluxes of water and dissolved substances in aquatic systems; therefore, tracer methods provide an indispensable tool for the rational and sustainable management of water resources.

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Alexander J.B. Zehnder

Water Use and Food Production – An International Collaboration?



Alexander J.B. Zehnder

Food production accounts for the largest portion of fresh water in use today. Countries with a fresh water shortage compensate by importing food. The rapid population growth predicted in the next few decades will rather dramatically increase the demand for basic foods, which will especially affect those nations with limited freshwater resources. Because of the close linkage between water and food production, water will be one of the determining factors in future economic development.

Water Demand

In industrialized countries, the per capita consumption of fresh water for basic human needs, such as drinking water, hygiene, living and food (2500–3000 kcal per day), as well as industrial activities, lies between 1400 and 1800 cubic meters (m^3) of fresh water per year. By increasing efficiency, especially in agriculture, this amount could be reduced to 1000 m^3 . Three quarters of this volume of water is used in food production [1].

Water Household

In Switzerland, approximately 1800 m^3 of fresh water are available per person per year. This amount results from the amount of rainfall (ca. 6400 m^3) plus influx from neighboring countries (ca. 1100 m^3), minus export via major rivers, namely the Rhine, Rhône, Ticino and Inn (about 1800 m^3). Germany and The Netherlands also have about 1800 m^3 of water available per person per year. The water balance in their case is as follows: Germany: rainfall = 1200 m^3 , input from rivers = 1300 m^3 , export by rivers = 700 m^3 ; The Netherlands: rainfall = 700 m^3 , input from rivers = 5300 m^3 , export by rivers = 4200 m^3 . Both countries depend on water influx from other countries for meeting their fresh water needs [2, 3].

Israel has an annual amount of only 566 m^3 per person available and compensates for this water shortage by importing food. The amount of food

imported corresponds to an annual volume of 828 m^3 of "virtual" water per person (Table 1). Other countries in the southern Mediterranean region exhibit a similar pattern (Table 2).

Food Production

On a global scale, there are six countries reporting a net export of food (Table 3). By definition, a country with a net export of food does not import substantial volumes of one food type in order to produce and export another type of food. Typical "non-net" exporting countries, such as the Benelux states, import substantial amounts of grains and soybeans for the production and export of meat. The virtual water that is being exported annually in the form of the five food types listed in Table 3 corresponds to 380.3 m^3 .

Food contains nutrients such as nitrogen (N) and phosphorus (P). For soybeans, the average content is 64.5 g N and 6.5 g P per kilogram dry weight. Other foods are as follows: grains, 23.2 g N, 4.7 g P; legumes, roughly like soybeans; meat, 123.4 g N, 6.6 g P per kilogram dry weight; milk, 42 g N, 8 g P per whole milk [4]. The exported foods listed in Table 3 correspond to $10.7 \cdot 10^6$ tons of N and $1.6 \cdot 10^6$ tons of P. Based on fertilizing practices commonly used in Switzerland, only 25% of the nitrogen and roughly 30% of the phosphorus applied to crops (including amounts from deposition and nitrogen fixation) is contained in the produced foods [5], which means that

| | m^3 Water/cap/a |
|------------------------------------|-------------------|
| Fresh Water | |
| Renewable (Rain) | 392 |
| Fossil Ground Water | 25 |
| Influx from Neighboring Countries | 89 |
| Desalination and Recycling | 60 |
| Total Fresh Water | 566 |
| Virtual Water | |
| $3.8 \cdot 10^5$ t Wheat | 661 |
| $0.6 \cdot 10^5$ t Soybeans | 107 |
| $0.05 \cdot 10^5$ t Meat | 45 |
| $0.08 \cdot 10^5$ t Dairy Products | 15 |
| Total Virtual Water | 828 |
| Total Water Volume | 1394 |

The amount of virtual water was calculated based on assumptions in [1]: the production of 1 kg of wheat, soy beans, legumes or dairy products requires a minimum of 1 m^3 water, while production of 1 kg of meat requires 5 m^3 water.

Tab. 1

Water availability in Israel in m^3 of water per capita and year. Numbers are average values calculated for the years 1992–96, in part taken from [6] and based on a population of approximately 5.7 million in 1995.

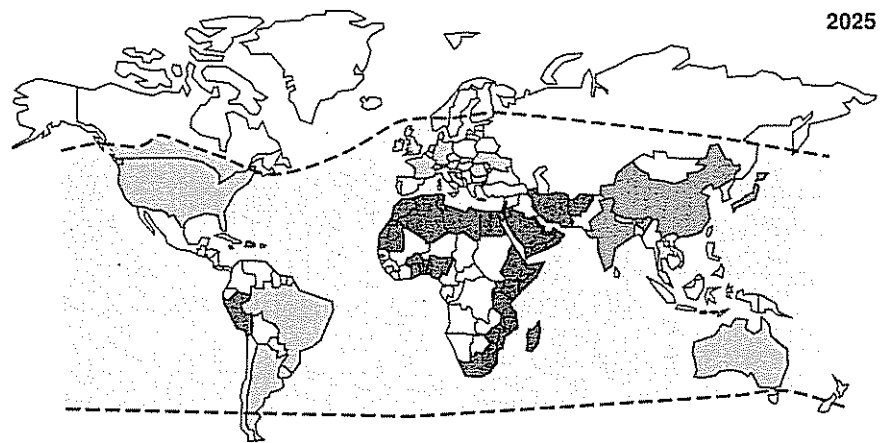
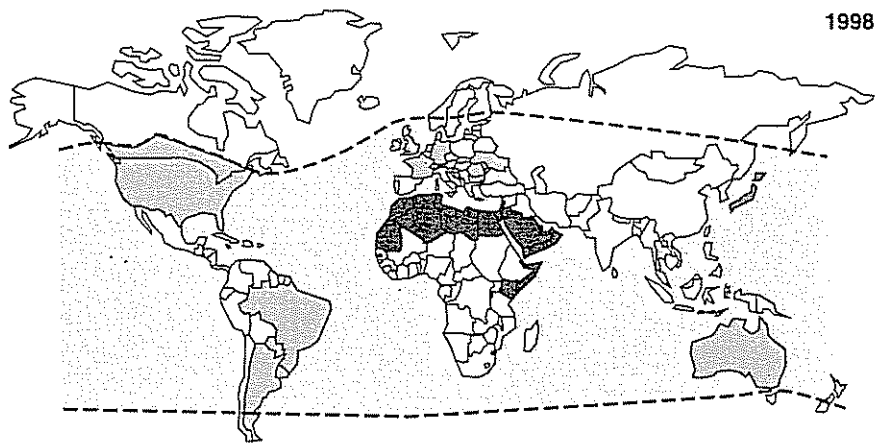
the production of the “export” food requires $47 \cdot 10^6$ tons of N and $5.5 \cdot 10^6$ tons of P in the form of fertilizers of any kind. Currently, synthetic fertilizers produced industrially amount to $120 \cdot 10^6$ tons of nitrogen fixed annually. A little more than one-third of that amount is, therefore, being used in the production of “export” food. The remaining nitrogen is recycled through denitrification (29%), volatilization of ammonia (26%) and nitrate leaching (22%). The excess phosphorus is accumulating in the soil [5].

A Glance toward the Future

Demographic developments projected for the next few years will increase the number of countries with less than 1000 m^3 of fresh water per person per year. The countries most affected by this trend will be many African countries as well as Afghanistan, Iran, Peru and Haiti. With current flow volumes of major rivers like the Ganges and the Jangtse, large areas of India and China will also experience water shortages (Fig. 1). The construction of dams may provide some relief; however, none of the rivers can be used to 100% capacity, which would be necessary for complete coverage of the fresh water shortfall.

The number of countries with sufficient water, fertile soil and appropriate climate conditions for food production is not likely to increase over the next 25 years (Fig. 1). The countries with good conditions will, therefore, have to undergo a paradigm shift. In the next century, they will have the obligation to increasingly produce food for export purposes. Western European countries will have to increase agricultural production, while Eastern Europe will have to employ more intensive farming practices.

In order to maintain overall economic health, however, there has to be a financial balance between import and export of goods in countries with water shortfalls. Israel is a good example of how this can be accomplished. Significant amounts of food must be im-



- Food production areas with northern and southern boundaries
- Water, soil and climate allow substantial food production for export
- Not enough water for domestic food production is available
- Sufficient water available only if all streams are dammed and used to capacity and no water reaches the ocean
- Sufficient water for domestic food production is available

Fig. 1 Water as the limiting factor in food production. Actual and potential food exporting and importing countries, today (top) and in the year 2025 (bottom).

ported to alleviate water shortages, and yet the economy is healthy. Tourism is well developed, and Israel produces industrial and agricultural goods of small volume but with relatively high

prices (so-called “cash crops”). If countries threatened by a lack of water are able to compensate by producing high-value export goods, any threat to the overall economy posed by water defi-

| | Morocco | Algeria | Tunisia | Libya | Egypt | Israel |
|-----------------------------------|---------|---------|---------|-------|-------|--------|
| Renewable Water Sources | 1100 | 515 | 463 | 110 | 28 | 392 |
| Fossil Ground Water | n | 16 | 40 | 770 | 22 | 25 |
| Influx from Neighboring Countries | n | 15 | 102 | n | 880 | 89 |
| Desalination and Recycling | <1 | 2 | 3 | 28 | 4 | 60 |
| Total Fresh Water | 1100 | 548 | 605 | 908 | 934 | 566 |
| Virtual Water in Food | 163 | 305 | 257 | 619 | 175 | 828 |
| Total Volume of Water | 1273 | 853 | 862 | 1527 | 1109 | 1394 |

Tab. 1 Actually available and virtual (imported) water in countries of the Southern Mediterranean. Numbers are calculated as m^3 of water per person and year and are averaged for the years 1992–96 using census numbers for 1995. Calculations are based on data from [2, 3, 6].

| Producers | Argentina | Australia | Denmark | France | Canada | USA | Total of 6 Major Producers | Remaining Countries | World Total |
|----------------|-----------|-----------|---------|--------|--------|------|----------------------------|---------------------|-------------|
| Soybeans | 2.6 | * | * | * | 0.5 | 21.3 | 24.4 | 7.1 | 31.5 |
| Grains | 12.4 | 14.4 | 2.0 | 29.9 | 24.4 | 90.8 | 173.9 | 67.5 | 241.4 |
| Legumes | 0.2 | 0.5 | 0.1 | 1.0 | 1.0 | 0.5 | 3.3 | 3.8 | 7.1 |
| Meat | 0.4 | 1.3 | 1.3 | 1.7 | 0.6 | 2.6 | 7.9 | 10 | 17.9 |
| Dairy Products | 0.1 | 0.4 | 0.2 | 1.7 | 0.1 | 0.3 | 2.8 | 8.0 | 10.8 |

* Australia, Denmark and France import soy beans; volumes are 0.07, 0.1 and 0.6 million tons per year.

Tab. 3
Annual food export (million tons).
Average of the years 1992–1996 [6].

ciencies is much smaller than would be assumed based on analysis of the water budget alone.

Consequences for the Future

- The strict linkage between food production and the availability of fresh water will make water the driving force in future economies. The rapid population growth in countries with small fresh water resources will at least quadruple global food exports by 2025. Based on current grain prices, this would be approximately 300 billion US\$, which is roughly the size of the current market for fossil fuels.
- Increasing food exports and the correlating nutrient exports will further open up and accelerate nutrient

cycles, which will have corresponding environmental consequences (mostly eutrophication), for both producing and consuming countries. New and stronger environmental protection and management measures must be put in place.

- Food shortages increase economic and political dependencies. Food-exporting countries (which are, with a few exceptions, the same as the industrial countries) are challenged to increasingly support economic development in countries with serious water shortage; otherwise, migration pressures will increase on countries with sufficient water and food supplies. The international community will have to show solidarity towards countries that are less fortunate with respect to water

resources, soil conditions, natural resources or climatic conditions.

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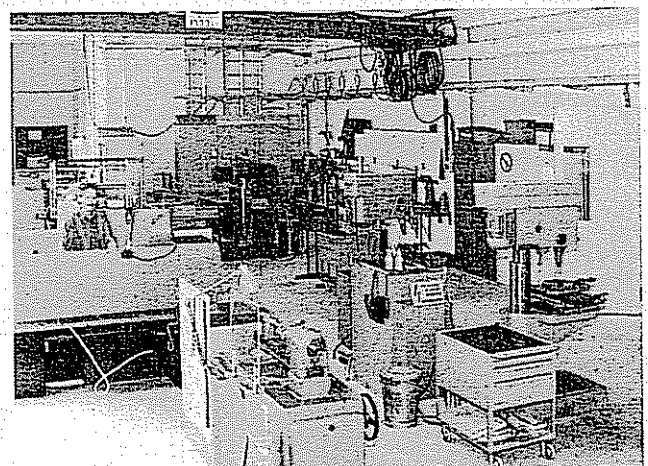
Opening of the New EAWAG Workshops

Up until last year, the EAWAG workshops were located at Tüffenwies in Zürich-Altstetten, about 12 km from the main EAWAG buildings in Dübendorf. At a reception held on June 18 1998, the new EAWAG workshops, situated in newly renovated rooms in the so-called North-East Building of the EMPA/EAWAG complex, were officially opened. The new facilities were introduced to the rest of the EAWAG employees, who only had to go on a short walk to reach the new locality.

The "ETH Advisory Office for Wastewater Treatment and Drinking Water Supply" (the former name of EAWAG) established its first field experimentation facilities on the grounds of the Wastewater Treatment Plant Werdhölzli in 1937. In 1953, EAWAG obtained a new space in Tüffenwies. There was room for offices, workshops, laboratories and a large experimentation hall (180 m²), as well as outdoor installations, such as an experimental wastewater treatment plant, a channel system used for experimentation on receiving bodies of water, and other installations which were changed and adapted depending on the focus of the research.

The significant distance between EAWAG's main buildings and the experiment station has always been perceived as a rather severe disadvantage. It was decided several years ago, to move the entire facility to Dübendorf. The recent dedication of the new workshops is only the beginning of the end of a long and tortuous path which had to take various detours and hit several dead-ends. Moving the main experimentation hall took place in 1998 to the new location on

the area of the old EMPA storage tank facility next to the Chriesbach. The employees of the EAWAG workshops are looking forward to having closer contact with the rest of the EAWAG crew and to interacting more directly when working on all the various projects requiring the assistance of the workshops. *Hans Burkhalter*



The Open House was celebrated with several new pieces of machinery and a well organized stockroom.

Tove A. Larsen

Nutrient Cycles in Urban Water Management

Technical Capabilities of Elimination and Recycling Processes



Tove A. Larsen

Sanitation of urban areas is an invention of the 19th century; water protection is the child of the 20th century. What challenges will the 21st century pose to urban water management? Sustainable management of water resources, as proposed at the conference in Rio de Janeiro in 1992, is a possible candidate. Nutrients represent one of these resources.

Environmentally Relevant Nutrient Emissions in Switzerland

In an environmental context, the elements nitrogen (N) and phosphorus (P) are considered "nutrients" because they contribute to excessive growth in ecosystems. The major *environmentally relevant* emissions (i.e., excluding the emission of nitrogen gas, N₂) are summarized in Fig. 1. Atmospheric emissions have a bad reputation mostly because of their role as pollutants, but they also play a significant role in the eutrophication of terrestrial ecosystems.

Environmentally relevant N and P emissions from municipal water systems are released into aqueous environments only. There are no atmospheric

emissions: ammonia (NH₃) is not released from waste water (essentially a dilute solution), and it can be demonstrated that emissions of nitrous oxide (N₂O) do not play a significant role [3].

Nitrogen is released into aquatic environments predominantly in the form of nitrate (NO₃⁻). Emissions from agriculture and municipal wastewater systems are of the same order of magnitude. Nitrate from agriculture is mostly released into the ground water, while inputs from municipal wastewater mainly ends up in surface waters. Measures restricting nitrate emissions from agriculture usually have higher priority, because they are, on the one hand, more cost-efficient and, on the other hand, more effective in protecting the atmosphere and ground and surface waters [1].

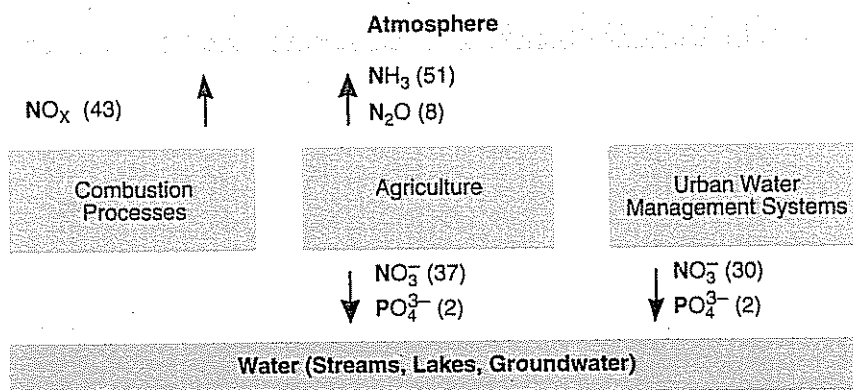


Fig. 1 Environmentally relevant N and P emissions in Switzerland in 1994. Units are ktons N or P per year [1, 2].

Nutrient Cycles in Wastewater Treatment Plants

Figure 2 presents the distribution of N and P in the process units of a typical wastewater treatment plant. Three distinct mass fluxes are represented: waste water, outgassing, and sewage sludge.

The biological treatment step typically retains 20% of the nitrogen and 40% of the phosphorus as a consequence of incorporation into biomass during the degradation of organics. Depending on the subsequent treatment of the sludge, more than half of the nitrogen can be released and fed

Nutrient Fluxes in a Sewage Treatment Plant

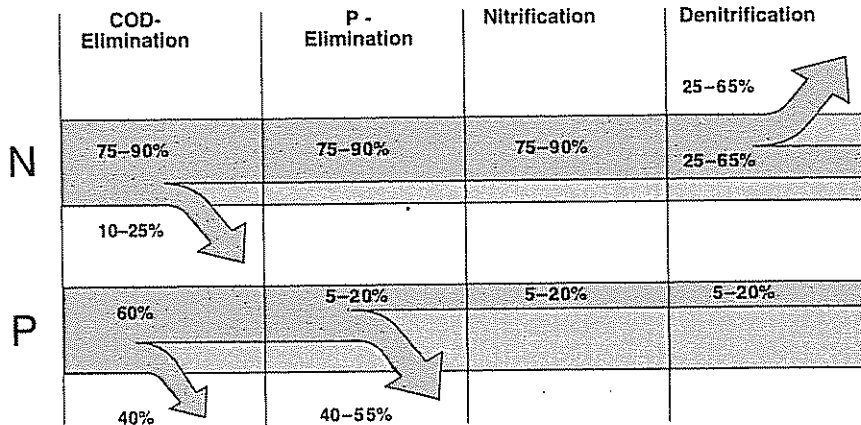


Fig. 2
Nutrient fluxes in a typical wastewater treatment plant. Arrows indicate the distribution of nutrients into sewage sludge (↓), outgassing (↑), and effluent (to the right).

back into the biological treatment stage via the digester supernatant. Any phosphorus released is retained in the concentrated sludge because of precipitation reactions [4].

In chemical P-elimination, 80-95% of the phosphorus can be retained in the sludge by the addition of iron or aluminum salts. When strict effluent restrictions apply, an additional filtration step may be necessary at an additional cost. Biological N-elimination (denitrification) typically removes 30-40% of the nitrogen and can be achieved by relatively simple means (i.e., a small preceding denitrification zone). If further denitrification is required, larger basins are needed, and the cost increases faster than the degree of nitrogen elimination.

Trends in Nutrient Elimination

In Switzerland, the discussion is concentrating on denitrification and biological P-elimination. A reduction of nitrogen emissions by 2 kt/yr (based on 1995 levels) is projected for the year 2005. A new and promising process for N-elimination in the digester supernatant is currently being investigated at EAWAG [5]. The process appears to be working best in ammonia-rich water which is at the same time poor in organic material, presumably according to the following principle: half of the NH_4^+ is oxidized to NO_2^- , with subsequent oxidation of the remaining NH_4^+ by the NO_2^- under anaerobic conditions. The final product is pure N_2 .

This will significantly increase overall denitrification by removing another 15% of the influent nitrogen. The major advantages of this process are that it does not require organic substrates and overloading can be prevented by the addition of concentrated digester supernatant.

Biological P-elimination is mostly suited for larger plants, since it is operationally rather demanding. If the plant uses nitrification, a denitrification step is also needed (because of process engineering requirements); as a consequence, the reactor basins have to be significantly enlarged. EAWAG is currently investigating biological P-elimination with respect to optimizing the combination of nitrification and denitrification steps.

Nutrient Recycling: A New Mission for Urban Water Management?

An obvious alternative to nutrient elimination is nutrient recycling in agriculture. A few arguments for this solution are:

- Phosphorus reservoirs are limited; current estimates predict depletion in a few hundred years.
- The quality of phosphorus reservoirs is decreasing; the concentration of heavy metals and the cost of production will increase.
- Sooner or later, phosphorus will have to be recycled, and it could, therefore, be economically advantageous to

simultaneously recycle other nutrients (especially nitrogen and potassium which occur in the same amounts as phosphorus).

• The minimization of material fluxes is one of the main strategies in reducing anthropogenic impacts on the environment and, at the same time, fits into the concept of ecological agriculture.

But are levels of nutrient emissions from urban water systems relevant for agriculture? Table 1 presents the budget for N and P in Swiss agriculture. Only imports and exports are considered, while the internal recycling of agricultural waste products is not included.

Nutrients exported under the category "foods" will mostly re-enter the urban water system. It is obvious that these nutrients could replace a significant portion of artificial fertilizers; however, interpretation is complicated by the relatively high losses (N) and massive storage (P). Today's agricultural practices target smaller nutrient losses in order to reduce imports [1]. In the case of phosphorus, it is clear that due to permanent storage of P in the soil there will always be a demand for phosphorus fertilizers (weathering processes are being ignored at this point).

The export of nitrogen (in its nutrient form) could be, theoretically, compensated for by the use of biological N-fixation, although we will not discuss here whether this is desirable from an agricultural point of view.

| | | Phosphorus [kt _y /year] | Nitrogen [kt _y /year] |
|---------|-----------------------|------------------------------------|----------------------------------|
| Import | Feeds | 6 | 25 |
| | Mineral Fertilizer | 17 | 70 |
| | Fertilizer from Waste | 2 | 5 |
| | Deposition | 1 | 36 |
| | N-Fixation | | 45 |
| Export | Foods | 7 | 41 |
| | Losses | 2 | 141 |
| Storage | | 17 | |

Tab. 1
N- and P-budget for Swiss agriculture [5].

Technical Possibilities of Nutrient Recycling

Current nutrient recycling practices in urban water management are practically limited to phosphorus. Conventional processes (i.e., precipitation with iron salts) concentrate phosphorus in the sludge, while newer processes try to achieve precipitation of a crystalline form of phosphorus in a separate step [6]. Precipitation products are calcium phosphate or $MgNH_4PO_4$. These processes require the intensive use of chemical reagents, and it is, therefore, uncertain at this point whether or not they will be economically competitive. (Note: this is not true for similar processes which are already being used in the treatment of digester supernatant and have proven to be economically feasible).

Nutrient Recovery at the Source

If nutrient recycling in urban water systems is extended from phosphorus only to the rest of the nutrients, recovery at the source is the only realistic alternative. Currently there are two approaches which are being discussed: *A separate vacuum dehydration step for toilets or a separate collection of urine*, which contains the majority of the nutrients (approximately 90% of N, 50–60% of P and close to 100% of K excreted by the body's metabolism is found urine).

Vacuum dehydration is being tested in Lübeck [7]. In a semi-decentralized installation, toilet waste is being collected by a vacuum system and digested in an anaerobic process. This process

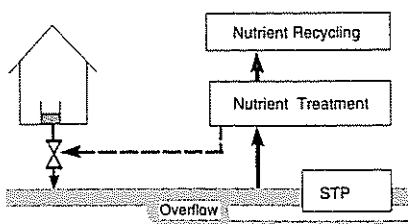


Fig. 3
Storage of urine in households and transport via the normal sewer system at night. After [9]

uses very little water and produces biogas in addition to fertilizer. The major advantage is the high content of nutrients which can be recovered, while the need for a separate infrastructure is the major disadvantage.

The separate collection of urine, on the other hand, in principle only requires a so-called "no-mix" toilet (a demo toilet can be used and admired at EAWAG) and a storage tank for the urine. The storage tanks have to be emptied, and the urine has to be moved to be used or cleaned up. The treatment of the remaining waste is then reduced to the removal of organic material. This process is being studied intensively in Scandinavia, particularly in Sweden [8]. The urine is used directly in agriculture. EAWAG has developed a proposal for transporting the urine [9] which is represented in Fig. 3. The basic idea is to temporally separate the two waste streams and empty the urine tanks at night when there is very little toilet use. It is not clear at this point (and will therefore have to be investigated) whether the urine may contain potentially toxic components (antibiotics, hormones, etc.), and whether ammonia may be outgassed, as is known from agriculture (Fig. 1). From a process engineering point of view, the separate collection of urine opens a number of possibilities: if the processing of urine into fertilizer is not feasible in smaller communities during the winter months, elimination processes are probably cheaper when applied to concentrated solutions as opposed to the diluted waste stream. In a transitional period, when only some of the households are switched over to the new system, wastewater treatment plant operators could benefit significantly. Peak levels of nitrogen-rich wastewater would decrease and less use of mix-water would be required.

Conclusions

The technical development of nutrient elimination in urban water management is far from complete. A rather new aspect is nutrient recycling, which

Question from Info-Day Participant

"Our urine is far from being a natural product – we consume vast numbers of medications and other biocidal substances. Is it responsible to turn such a mixture into fertilizer?" (Werner Kanz, Canton Aargau)



Tove Larsen: "No, not without precautions! However, today this urine is being fed to wastewater treatment plants without any such precautions, and even directly released into streams during high rain events. With a targeted process to turn urine into fertilizer, we expect fewer problems with these compounds in the future, although this still has to be proven and documented by research!"

has been relatively well developed as far as phosphorus is concerned. Measures at the source open up a number of new options and possibilities, but need significant research and development before being marketable.

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Mireille Faist and Susanne Kytzia

Food Production and Resource Utilization

How Can a Food Retailer Contribute to Efficient Resource Utilization?



Susanne Kytzia (with daughter Julia) and Mireille Faist.

The major food retailers in Switzerland have introduced a number of initiatives over the last few years to make their product lines more "environmentally friendly". Programs such as COOP "Natura-Plan", "M-Sano" or "M-Bio" allow them to influence agricultural production while, at the same time, distinguishing themselves on the market. The question today is what direction the long-term development of these distributors should take, how much the environment has benefited from their initiatives thus far, and where the emphasis for future changes should be.

Influence of Food Retailers

As recently as 100 years ago, food was primarily supplied through regional agricultural production. In local markets, consumers were in direct contact with producers. Today, the food supply is virtually global and independent of season. The food retailers occupies a key position and can use it in two ways: on the purchasing side, the distributor can influence food production and processing through procurement strategies (also called "pull"-strategy in ecologically-oriented business administration theory [1]); on the consumer side, the access to the distribution network and the range of its distribution area determine the success of a product. The distributor can, therefore, use product selection and availability to influence consumer behavior, which is often called "push"-strategy.

In Switzerland, the key role of large-scale distributors is even more pronounced due to the structure of the food sector [2]. Migros and COOP share over 40% of the food market. Because of their co-operative structure, they are each able to provide up to 1.5 million households with company-specific information. Both companies own numerous processing companies, such as JOWA Back- und Teigwaren (bakery and pasta products) or Konserverfabrik Bischoffzell (canned fruits and vegetables). This high degree of retro-integration is especially pronounced at Migros and is evident in the large number of food products sold under Migros' own label (90%).

Initiatives for Sustainable Development

Food retailers in Switzerland have begun to use their role as intermediaries between producers and consumers to actively promote ecological management practices. In the food sector, programs like M-Sano or the COOP Natura-Plan have created certain production standards in agriculture. Among consumers, COOP's Natura-Plan has, in particular, had a very positive resonance over the last few years. In urban areas, products marketed under this label account for 10% of the total fruit and vegetable volume sold. Equally well received have been

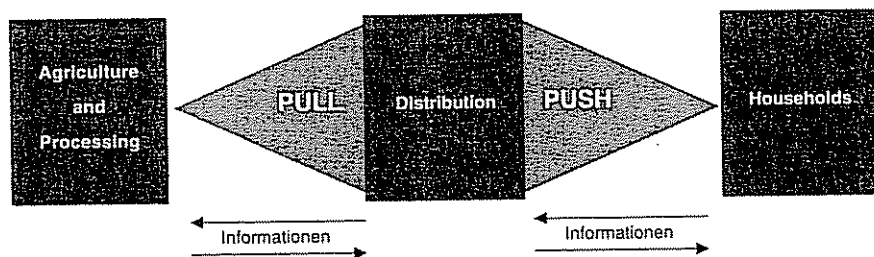


Fig. 1 Because of its intermediary position between producers (agriculture and food processors) and consumers (households), distributors can exert their influence in both directions (Figure after Hansen, 1988).

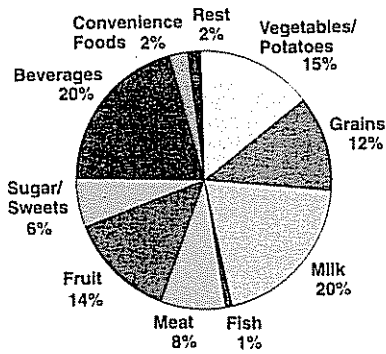


Fig. 2
Composition of product selections in our case study. Annually, 150,000 tons of food are put through the system (source: survey by the authors).

Migros' effort to find more environmentally friendly packaging options. An example is the "tube bag" used for milk which has largely replaced the material-intensive "Tetra Pak" option (cardboard, plastic and aluminum layers). These changes, which may be obvious to the consumer, are also accompanied by company-internal, technical, and organizational changes in food processing and distribution such that the overall environmental benefit is further enhanced.

Until now, however, large-scale distributors like Migros or COOP did not have an adequate way of measuring the benefit – or the damage – of such initiatives. Without complete system analysis, one cannot say, for example, whether programs influencing agricultural practices are more or less efficient than the optimization in product packaging. Similarly, a distributor cannot evaluate whether the success of ecologically-oriented initiatives is negated by the introduction of new, resource-intensive products aimed at different target groups.

The presented on-going research project of the EAWAG focuses on this question. It studies in collaboration with Migros to what extent a food retailer can contribute to efficient resource utilization in the food sector.

Case Study

One of the Migros cooperatives has agreed to participate as a partner in the study and has supplied data for this

study. It supplies an area of approximately 760,000 people in the Swiss Midlands and accounts for roughly 10% of the total market volume Migros has in Switzerland.

Food volumes sold during 1996 form the basis for the material and energy flux analysis which was performed after [3] (Fig. 2). The analysis includes production, processing, transport, distribution and consumption of the food. Values for energy, water and soil consumption are used as indicators of ecological improvements.

Figure 3 is a simplified representation of the system "food production" which is being shaped by activities of the Migros cooperative. The Migros cooperative is mostly described in the process "distribution", which includes the distribution center and all of the branch stores. The total field of activities, however, extends beyond the distribution process; it includes a large portion of the food processing and transport from processing to distribution. Roughly two-thirds of the foods sold are processed in some form, while the balance are sold as fresh produce. Agricultural production takes place

either domestically or abroad, depending on the product, which mostly impacts the transportation aspect. The final leg in the long path of all the products sold is their transport to households, their storage and finally their consumption.

Based on a first assessment of the status quo, the following hypothesis could be formulated:

Hypothesis 1: The selection on the goods in the shopping basket is very significant (PUSH- and PULL-strategy).

The process area "agriculture" dominates the use of soil and water in the system. All other processes combined use only ten percent of the soil and one percent of the total water consumed. One of the reasons is the high water consumption and soil usage in meat and dairy production. This food group is also one of the major energy consumers (40%, see Fig. 4). A reduction in the consumption of meat and dairy products, therefore, leads to a significant reduction in resource use.

Even within a certain food group, energy consumption can vary dramatically from one product to another.

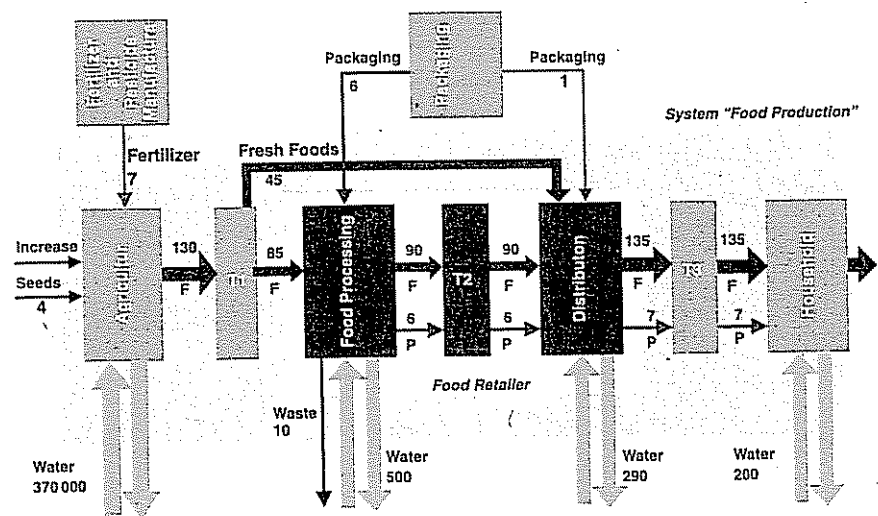


Fig. 3
Simplified representation of the material flux in the system "food production" for our case study. Volumes are given in thousand tons (ktons) per year. Based on the total throughput of food in the regional cooperative studied here, the corresponding fluxes of related processes were estimated either from literature data or from surveys by the authors. The following abbreviations were used in the figure: T1, T2 and T3 for transport processes; PF for processed food, F for foods/food fluxes; P for packaging materials.

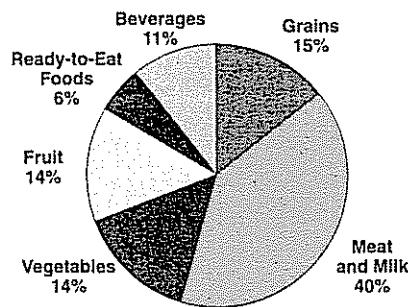


Fig. 4
Energy consumption by food category. The total energy used in the system as a whole (i.e., the total energy consumed related to the food produced and sold by the regional cooperative in our case study) was calculated to be 1200 terajoules per year (calculation by the authors).

Some products requiring high energy use are:

- frozen products (such as fruits and vegetables),
- highly processed foods (such as potato chips),
- products which have to be transported over long distances (e.g., tropical fruits).

Targeted changes in the product selections available in stores can, therefore, significantly reduce overall energy consumption and affect all other processes in the system.

Hypothesis 2: Exerting influence on the supplier side (PULL-strategy) primarily results in lower energy consumption.

A reduction in the use of water and soil could theoretically be achieved by intensifying agricultural practices instead of changing product selections in stores. It is doubtful, however, that this would lead to more sustainable development, since more intensive practices typically entail more severe pollution, erosion and soil compaction.

As far as energy consumption is concerned, several processes offer opportunities for improvement (see Fig. 5). Agriculture, for example, uses 33% of the total energy in the system; 23% is used in fertilizer and pesticide production, while only 10% is used in planting and harvesting. Increasing the use of extensive farming practices could, therefore, reduce overall energy consumption.

Food processing and packaging consume one quarter of the total energy used in the system, with *both* processes using roughly equal amounts. The development of new products and processes could, therefore, reduce energy use, not only by reducing energy used directly in the process, but also in subsequent storage and handling in households (e.g., replacing freezing with other forms of food conservation).

Hypothesis 3: Private households have to change their consumption behavior (PUSH-strategy).

Private households consume 17% of the overall energy used in the system, mostly for cooking and refrigeration. Transport of foods from the store to the household, mostly by the consumer, adds another 4%. Changes in the way foods are purchased and stored – even innovations in household technology – could lead to significant energy savings.

Hypothesis 4: The food retailer is presented a challenge (environmentally conscientious business management).

The cooperative itself uses roughly 15% of the total energy within the system in its distribution centers and branches. Because of the high degree of retro-integration, many of the processing steps are also under the direct influence of the distributor, which raises the total energy consumption under the control of the distributor to approximately 30%.

Summary

The following factors are important in developing future action plans and strategies for food retailers:

- The cultural aspect of food consumption is more important than the technical-organizational optimization of individual processes. Actions of large-scale distributors are closely tied to behavioral changes of the population. Through innovations in product processing, selective availability and consumer information, the distributor can exert a great deal of influence.

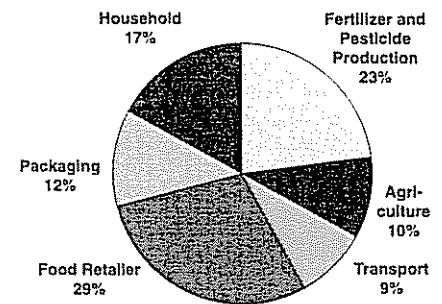


Fig. 5
Energy consumption by processes from production to final use by consumer. The process "food retailer" includes food processing, distribution and all transport processes needed along the way. All transports from agriculture to processing plants were lumped into one "transport process", as were all transports from the distributor to the households (source: calculations by the authors).

- The large-scale distributor can primarily influence energy consumption. The main consumer of soil and water, agriculture, is facing a dilemma of conflicting goals; namely the reduction of resource use versus the maintenance of quality.

- The food retailer can influence energy consumption throughout the system. Up to 30% of total energy use are attributed to food processing and distribution. If both processes are managed by the same entity – as discussed in our case study – it controls a large portion of the overall energy use and can, therefore, contribute significantly to energy savings.

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This article was published in the proceedings of the "Kolloquium zur Entwicklung umweltgerechter Produkte" (Colloquium on the Development of Environmentally Responsible Products), held November 3–4, 1998 in Darmstadt, Germany. The colloquium was held under the umbrella of the Special Research Area 392, "Development of Environmentally Responsible Products – Methodology, Approaches and Tools".

Christine Bratrich, Bernhard Truffer and Bernhard Wehrli*

Green Hydropower

The aim of the project "Oekostrom" (green electricity) is the development of an eco-label for the promotion of environmentally compatible electricity production for which environmentally-sensitive customers voluntarily pay an additional small fee. It is not always clear, however, what "environmentally compatible" means in the field of energy production.

The use of hydroelectric power presents a particular dilemma between an emission-free production process and the often serious effects that dams exert on local ecosystems. This conflict necessitates a credible certification of "green hydropower". EAWAG's project "green hydropower" is aimed at developing a scientifically sound procedure to do so.

Green Hydropower?

The ubiquity of Swiss hydropower does not warrant building additional hydroelectric plants through the promotional effect of increased fees for green electricity. For this reason, EAWAG is concentrating on the environmental enhancement of existing plants. In some 20 different projects, scientists from various disciplines have investigated what a *certification procedure* for green hydropower plants should entail. It should guarantee adherence to general environmen-

tal requirements (see box) and, at the same time, should permit local upgrading suited to the catchment area. The environmental measures should be covered by an increased cost for green electricity.

Transdisciplinary Research

In order to become environmentally effective, the idea of "green hydropower" should also be translated into action. This can only be credible and successful, however, if it is supported by the most important representatives of the economy, government and environmental organizations. For the project "green hydropower" itself, this implies that, apart from carrying out scientific research, social and economic questions are being addressed, and close contact is being maintained with various interest groups. Furthermore, the green hydropower project is participating in an association (under civil law) with the purpose of guar-

anteeing independent administration for awarding a general eco-label for electric power.

Current State of the Research

On April 1, 1998, the project "green hydropower" was officially initiated. Four thematic groups are working on four parts of the project:

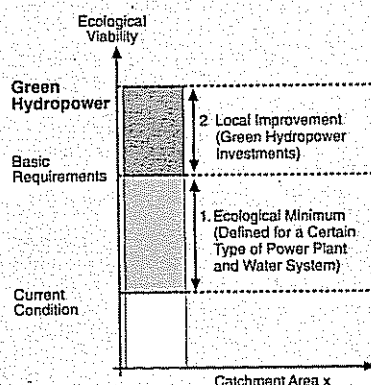
- The *assessment group* is working on the concept and certification process for "green hydropower plants".
- The *residual water group* is concentrating on determining environmentally sound minimum flow regime regulations.
- The central question for the *floodplain group* is how much water a floodplain needs to sufficiently maintain its ecological function.
- The *marketing and politics group* is researching the basic questions of management and energy policies for a successful launching of the product "green electricity".

The empirical work is concentrated on the catchment area of the Brenno river in the Canton Ticino.

In spite of the diverse investigations, each group's results support not only the contents of the individual research but will actively

The Classification of Green Hydropower

The certification procedure defines "green hydropower plants" as all power plants that fulfill so-called general requirements for green electricity and, secondly, invest a certain sum in the remediation of the waters in their catchment areas ("green electricity investments") per green-power-kilowatt hour sold.



1. The Basic Requirements for Green Electricity

- describe the general and scientifically justified requirements for green hydropower plants.
- are formulated specifically for various types of power plants and types of natural waters.
- guarantee certain basic ecological functions in the utilized waters and their environments.
- form the basis for a supra-regional standardized certification of green hydropower plants.

2. Green Hydropower Investments Guarantee

- an ecological upgrading which is individually directed towards the most important problems within a specific catchment area.
- maximum transparency towards the environmentally-sensitive customers through the increased fares they pay which directly benefit the ecological enhancement of the catchment area.

contribute to the development of the eco-label assessment procedure – this being the really new aspect of this transdisciplinary project. The certification process consists of four steps.

1. It describes the basic requirements of a green hydropower plant and provides a systems overview of the main upgrading potentials in the catchment area concerned.
2. It contains an extensive detailed study which assesses local upgrading measures according to their environmental impact and costs.
3. It establishes the measures for improvement to be undertaken within the framework of a procedure for finding consensus which includes the most important representatives of local interest groups.
4. The certification itself is then carried out by an independent institution.

The working groups can present the following results to date:

- the prototype of the certification procedure.

- a systems overview of the morphology and fish biology providing an indication for ecological improvement potentials in the catchment area of the Brenno.

- Data on the benthos and fish biology which permit the use of simulation models for determining environmentally sound residual water regulations.

- Groundwater data which show that parts of the flood plains of the Brenno are fed more by water from the slopes and lateral tributaries than by the main river affected by the hydroelectric power plant.

- Market analyses which emphasize that, especially from the customers' point of view, the cred-

ibility of the label is of central importance. A market potential of 15 to 20% may be attainable if professional marketing for green electricity is pursued.

Perspectives: Further Activities

During the next year, the assessment procedure will be extended and verified. Apart from the development of procedures for alpine hydropower plants with reservoirs, its application to other types of power plants and natural waters will be prepared.

The certification of the first alpine hydroelectric power plants with reservoirs has been planned for the beginning of the year 2000.

Also working in EAWAG's green hydropower project are (in alph. order): Gianluca Ambrosini, Lisbeth Bieri, Jürg Bloesch, Matthias Brunke, Ueli Bundi, Gabriele Carraro, Moreno Celio, Christian Dinkel, Gregor Dürrenberger, Barbara Fassnacht, Andreas Frutiger, Rene Gächter, Mark Gessner, Tom Gonser, Erwin Grieder, Estelle Grüter, Eduard Hoehn, Markus Hofer, Doris Hohmann, Klaus Jorde, Bernd Kiefer, Rolf Kipfer, Susanne Kytzia, Fabio Losa, Antonin Mares, Vijay Matta, Werner Meier, Beat Müller, Armin Peter, Tom Ravens, Peter Reichert, Roman Rudel, Mathias Schneider, Michael Schurter, Lorenzo Sonognini, Sarah Strauss, Michael Sturm, Francisco Vazquez, Walter Wagner, Rolf Wuestenhagen, Kornelia Zepp, Alois Zwyssig.

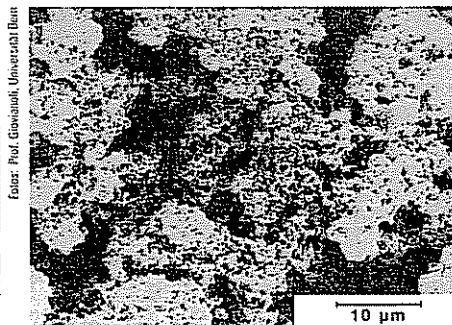
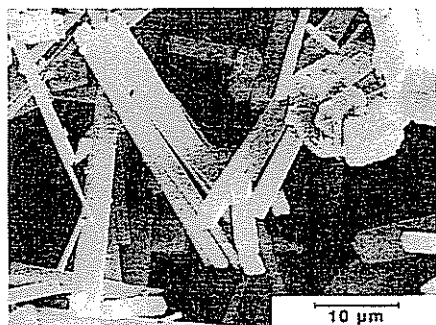
Influence of Electromagnetic Fields on Crystallization Processes

Commissioned by the BUWAL (Swiss Agency for the Environment, Forests and Landscape), a doctoral research project investigated the feasibility of using electromagnetic fields to prevent the formation of mineral deposits in pipe systems (see publication

Nr. 2377 and ETHZ dissertation 12 644). In three case studies, strongly oversaturated systems were investigated; one was a drinking water supply with hard water and two were sludge treatment stages in wastewater treatment plants. Results from the waste-

water treatment plant Worblental, as well as from the drinking water supply study, indicated that electromagnetic fields can indeed prevent the formation of mineral deposits. The electromagnetic fields were modified and especially adapted for this purpose.

Regula Müller Dick



Scanning electron microscope image of the cooling pipe surface from the cooling compressor at 200x magnification: well-crystallized aragonite needles form in the control experiment (left; no magnetic fields), while deposits formed in the presence of magnetic fields do not show any discernable crystalline structure (right).

Habilitations

As per decree of July 8, 1998, Dr. **Hasan Belevi** has received the *Venia legendi* effective October 1, 1998. Dr. Belevi is an EAWAG collaborator in the research area "material fluxes and waste disposal technology". As a lecturer, he will be assigned to the Department of Civil Engineering and Surveying at ETH Zürich. His teaching area will be environmental engineering of waste disposal systems. His habilitation paper is entitled "Environmental Engineering of Municipal Solid Waste Incineration".



Dr. **Peter Huggenberger**, who is a former EAWAG collaborator and now Cantonal Geologist for Baselstadt, recently obtained his habilitation at the University of Basel in the area of "Applied and Environmental Geology". He gave a talk on "River Gravel – Archives of Landscape Forming Events" on December 11, 1998.

During the summer semester of 1998, Dr. **Barbara Sulzberger** received the *Venia Docendi* from the University of Berne, by request of the Faculty of Philosophy and Natural Sciences. The title of her habilitation is: "*Environmental Photochemistry, with Special Emphasis on Iron and on Surface Reactions*". Starting in the winter semester of 1998/99, she will lecture two hours a week at the University of Berne. Dr. Sulzberger decided to work towards her habilitation at the University of Berne, and not as would seem more obvious, at the ETHZ, because she perceived a particular need for lectures in environmental chemistry, especially environmental photochemistry, in Berne. EAWAG has strongly supported her in her work towards habilitation at the University of Berne.



Since becoming an EAWAG employee in 1986, Dr. Sulzberger has been very active in her research on environmental photochemistry. She is concentrating her research on the effect of sunlight on nutrient cycles, in particular, the iron and carbon cycles.

During a sabbatical at the Woods Hole Oceanographic Institution in the USA (1994–95), she developed a particular interest in marine environmental photochemistry, especially the role of iron as a limiting nutrient in certain surface waters, also known as "high nutrient, low

chlorophyll" areas of the ocean. In terms of environmental systems, she is increasingly interested in the interactions between rivers and lakes or oceans as well as coastal waters. She was, among others, involved in the European EROS (European River Ocean Systems) program.

Dr. Sulzberger is convinced that first class research in environmental photochemistry requires solid knowledge of fundamental photochemical processes as well as a detailed understanding of environmental systems. She is working hard towards recognition of environmental photochemistry by "classical" photochemists. During 1992 and 1993, she was president of the "Swiss Society for Photochemistry and Photophysics". In this function, she organized an "International Workshop on Environmental Photochemistry" in Adelboden in the Fall of 1993.

Dr. Sulzberger obtained her degree in Chemistry at the University of Berne. As part of her dissertation research, she worked on photochemical conversion and storage of solar energy. During her subsequent post-doctoral research at "The Royal Institution of Great Britain", she worked on applications of flash-photolysis under the guidance of Nobel Prize winner Lord George Porter.

Visit of Secretary of State Charles Kleiber

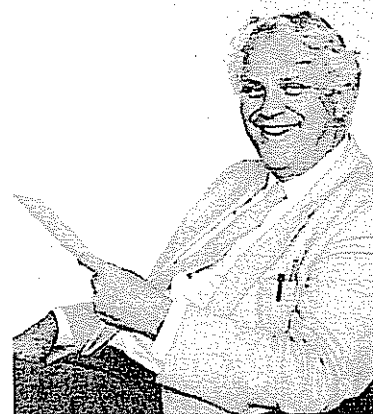
Secretary of State and Director of the Group for Science and Research, Charles Kleiber (photo), who has been in office since October 1997, visited EAWAG on June 30, 1998. Together with Francis Waldvogel, the President of the FIT Board (Board of the Swiss Federal Institutes of Technology), he gained a picture of the goals, mission and methodologies pursued at EAWAG. The prominent visitors toured the research center for limnology



in Kastanienbaum as well as the main laboratories in Dübendorf. All EAWAG employees had a chance to meet the two dignitaries at a reception. The visitors toured the laboratories and were given short presentations on selected topics in natural, engineering and social sciences. All presentations were made in French. In Kastanienbaum, the dominant topics were fisheries, lakes and streams, as well as the interdisciplinary project "ecolectricity".

In Memoriam Professor Werner Stumm

Professor Werner Stumm, Director of EAWAG from 1970 to 1992, died on 14 April 1999 at the age of 74. Under his directorship, EAWAG evolved into an internationally recognized scientific institute. Werner Stumm was the father of "aquatic chemistry", a field that he initiated and developed during his career. He taught with enthusiasm as a Professor at the Swiss Federal Institute of Technology in Zurich and is remembered by generations of students that have enjoyed his classes on aquatic chemistry and water pollution control.



Werner Stumm graduated from the University of Zürich with a Ph.D. in inorganic chemistry and worked briefly at EAWAG, where he first encountered water quality problems. In 1954, Werner Stumm went to Harvard University as a young postdoctoral fellow, soon became a professor, and started his work in aquatic chemistry by applying the theoretical basis of solution and coordination chemistry to chemical processes in natural waters and in water technology. His book "Aquatic chemistry", co-authored with James J. Morgan, first appeared 1970, immensely influenced the water and environmental chemistry field. The 3rd edition was published in 1996 and has also been translated into other languages, and sold over 40,000 copies worldwide.

Werner Stumm was guided by the idea that chemical processes need to be understood at the molecular level in order to gain insights into global geochemical cycles, anthropogenic perturbations and the fate of pollutants. His research activities focused on processes at the interface of solid phase and solution and application of these reactions (adsorption, dissolution, redox reactions) on processes in natural waters (weathering, dissolution and nucleation of minerals) and in water technology. These processes play a major role in the local and global cycles of various substances. The surface complexation model, that was developed by Werner Stumm and Paul Schindler (University of Berne), provides a basis for

the understanding of dissolution reactions of oxides, as well as for the catalysis of redox reactions at surfaces, and has been widely influential in aquatic surface chemistry. Many of Werner Stumm's former Ph.D. students and collaborators, both in Switzerland and in the USA, are now active in water and environmental chemistry or in pollution control at universities, environmental agencies and consulting firms.

Werner Stumm emphasized the necessity of a solid scientific basis and of multidisciplinary collaboration to deal with environmental issues. He always considered the importance of global environmental issues, in addition to the local ones. Under his directorship at EAWAG, various disciplines developed to a high scientific level. As a chemist, Werner Stumm especially encouraged the development of aquatic and surface chemistry, as well as of modern analytical and organic environmental chemistry. He stimulated collaboration between various disciplines at EAWAG and in national research

programs, as well as studies on the interactions between water, soil and air. Under his guidance, EAWAG was engaged in establishing scientifically well-founded concepts for water pollution control and environmental protection in Switzerland.

Werner Stumm received numerous awards from professional and academic societies for his research and educational achievements. He received the 1998 Goldschmidt Medal of the Geochemical Society for lifetime achievement and was honored by publication of a special issue of *Environmental Science and Technology* (October 1998). Only a few weeks before his death, he was elected co-Laureate of the 1999 Stockholm Water Prize, together with his long-time co-worker James J. Morgan.

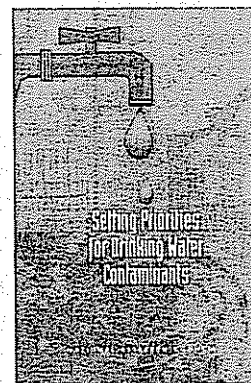
Werner Stumm's generous, strong personality, his extraordinary energy and passion for his work and his vast knowledge have imprinted generations of environmental scientists who recognize his preeminent influence.

Laura Sigg

New Brochure

"Setting Priorities for Drinking Water Contaminants"

The brochure was published by the Committee on Drinking Water Contaminants, which is part of the American National Academy of Science. Walter Giger, EAWAG, is a member of this committee. The brochure was commissioned by the U.S.EPA and is an off-spring of the new Drinking Water Act. A second brochure, on "Emerging Drinking Water Contaminants", is to be published shortly.



Honorary Doctoral Degree for Prof. Zehnder

Prof. Dr. Alexander Zehnder, Professor at ETH Zürich for Environmental Biotechnology and Director of EAWAG, has received an Honorary Doctoral Degree from the Université Henri Poincaré in

Nancy, France. Dr. Zehnder was recognized for his accomplishments in environmental science and their application to the betterment of society.



Otto Jaag Prize 1998

The 1998 Otto Jaag Prize for Water Protection has been awarded to **Thomas Bucheli** for his dissertation entitled "*Occurrence and behavior of pesticides during storm water infiltration*". The results of his detective work on transport paths of pesticides from the atmosphere, down to roof tops and finally into ground water or into runoff

represent one of the corner pieces in the qualitative evaluation of rainwater infiltration. For example, he has found that a herbicide which is added to asphalt as a root suppressant accounts for 50% of the pollutant load in Lake Greifen. In addition to his dissertation, Thomas Bucheli has published his work in several journals in the field of analytical and environmental chemistry.



New IAD-President

In April 1998, **Jürg Bloesch** was elected president of the International Working Group of Danube Research (IAD), an independent section of the International Association for Theoretical and Applied Lim-

nology (SIL). Until his election, he was Switzerland's representative to the IAD. Dr. Pius Stadelmann, from the office of environmental protection of the Canton Lucerne, will replace him in this post.



Can be ordered separately from the EAWAG library (use last page)

Publications

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