EAWAG

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EAWAG news

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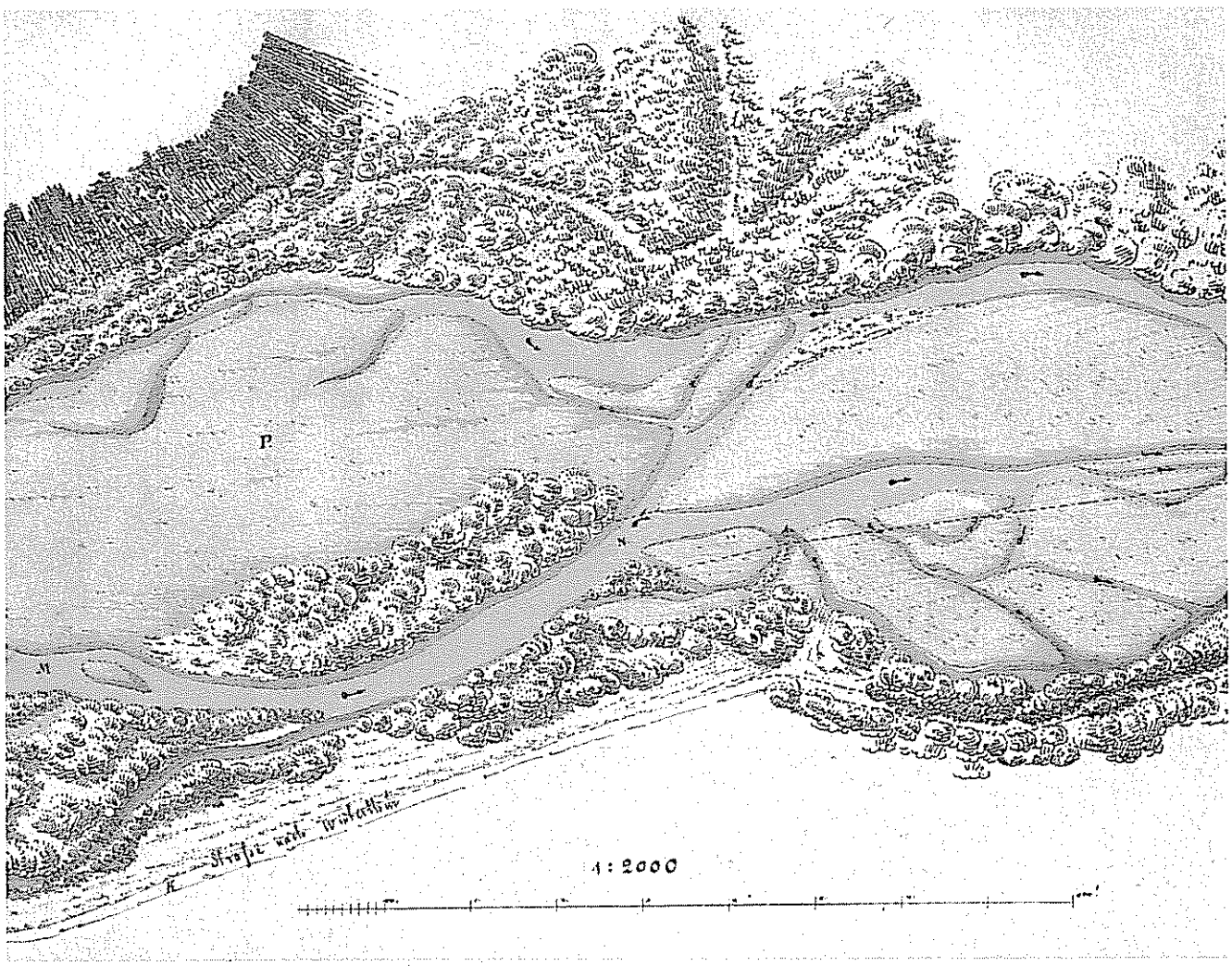

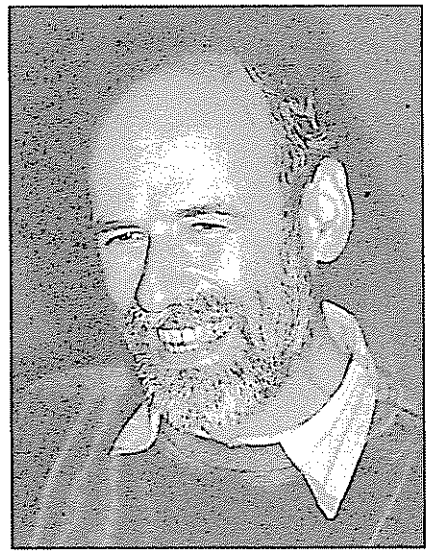

The Inheritance of Future Generations

During the winter term of 1994–95, EAWAG organized a seminar to discuss sustainable development. The impetus for this seminar was provided by the Info Day in 1993 when EAWAG Director Alexander Zehnder announced to the public that 30 years from now consumption of the decisive resources in Switzerland should be reduced by two-thirds without any reduction in our standard of living. The idea of a massive drop in the utilization of resources appealed to many at EAWAG, but resulted in a few awkward questions. Can such an increase in ecological efficiency be achieved solely through technical measures? Can our research really contribute to such a development? Would it not be better to concentrate on the research areas we know best, instead of striving for such long-term goals?

It was decided in 1994 to hold an EAWAG seminar on these issues which resulted in lively debate. It became clear during the course of the ensuing lectures and discussions that, like "peace", the term "sustainable development" suggests a general direction for practical action by allowing diverse interpretations. As a result, it invites a variety of people to join in the effort. It also became clear during these seminars that the motivation is indeed present within the EAWAG to carry out research aimed at bringing about a marked drop in resource consumption in Switzerland over the next decades. New technology alone will not suffice, however, but then neither will the attitude changes that are advocated by so many. Only by creatively coupling social and technological innovations are we likely to see significant conservation of resources.

These goals bring fascinating questions to the research endeavor. For instance, if market solutions are warranted to ensure resources remain sustainable, should a new tax be introduced to control the use of each of those resources? Or can they be grouped together and controlled through a small number of effective measures? To answer these questions requires a deeper understanding of the interrelationship of different environmental problems. It is necessary to study ecosystems and the interaction of humans within the environment, even though forecasts about these relationships only hold for a limited time as these systems are continually learning about their environment. How are such complex systems to be characterized scientifically? The presently popular conception of a reality which can be described and controlled with any desired precision is starting to crumble. New models are being developed to reflect the complexity of real systems which, in turn, never cease to surprise researchers.

Carlo C. Jaeger
Human Ecology

EAWAG

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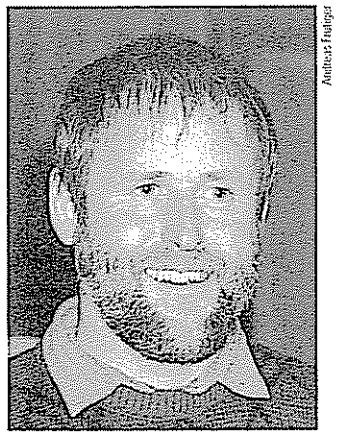
Title page picture
A sketch of the river Töss near Kollbrunn, dating from 1811.
At that time the river was up to 150 meters wide. Today it has been artificially restricted to approx. ten meters.

Micheal Hütte and Ueli Bundi

Methods for the Evaluation and Development of Streams

Michael Hütte, hydraulic engineer and biologist, studied in Cologne and Constance. He obtained his Ph.D. at the University of Innsbruck with a dissertation on the ecological importance of alpine water intakes. He has worked at EAWAG since 1991, applying freshwater ecology data to the drafting of running water regulations and the use of hydropower. He is also a lecturer in limnology and water conservation at the University of Innsbruck.



Ueli Bundi is the vice-director of EAWAG and deals with aspects of the development of watercourses.

Research Aims

Most running waters in Switzerland are adversely affected by obstructions and the intensive use of surrounding land. Many of them have even been enclosed within culverts. Various laws now aim to convert such streams back to near-natural habitats or to protect them from further damage. The overall aim for bodies of waters and their environment above or below ground is to (1) achieve near-natural conditions for flora, fauna and microorganisms and (2) form an ecological network close to that seen in Nature. Near-natural conditions are intended to ensure the development of plants, animals and microorganisms which can reproduce and regulate themselves in the running waters. The species composition and their numbers should be characteristic for the waters (free of, or with only slight, contamination) which are shaped by various natural factors and human activities.

Purpose and Content of the Methods

Where active measures are necessary to satisfy these requirements, it necessitates a knowledge of the relationships between the organisms and the conditions in streams. Such differentiated knowledge is, in general, only available to a very limited extent. Although specific data may be lacking, some of the important factors which mainly determine fluvial conditions are known; however, important ecological principles are established. The method for evaluating watercourses are based on these principles and should take the most important causal factors for the development of biocenoses into consideration. The regional characteristics and the uses to which the running waters will be put are important criteria for their development. The uses and unavoidable loads must be compatible with the streams and with improving running water ecology where possible. This creates the conditions requisite for streams to fulfill their manifold functions in the long term.

The methods discussed herein are intended to establish the framework and measures needed for such a lasting development and require complete documentation of the running waters and their systems. The upper and lower regions of this linear "Lebensraum" have a reciprocal effect on one another, so that local measures will have effects of varying intensity. The methods developed at EAWAG focus on the physiographical/biological properties of running waters and comprise:

- complete qualitative and quantitative characterization of important ecomorphological and hydrological properties of entire running water systems
- identification and reciprocal evaluation of ecological deficits in the running water systems
- biological studies to underpin physiographical deficits
- elaboration of measures for the future development of running water systems to yield near-natural conditions.

Methodological-Ecological Guidelines

Establishing the Reference State

As a result of the intensive use of land and water, Central Europe no longer has any natural streams, with the exception of a few streams in the high Alps. It is, therefore, no longer possible

to base water modelling measures on a natural state since this is unknown. Consequently, a pragmatic approach is adopted and the reference state defined as "the near-natural state in the given man-made environment". Certain marginal conditions are thereby accepted as immutable (or subject to only limited change), such as the draining of large areas of marshland. By contrast, the morphology of waters and their surrounding land can in principle be altered.

A stream in its reference state is not subject to regulation or stabilization. The course of the stream and the bank and bed structure are solely shaped by the morphology of the land and the dynamics of water and debris flow. The bank and surrounding vegetation will be typical for that location and is not landscaped in any way. The water has to be free of chemical contamination – at least to a large extent.

Apart from high alpine areas, running waters in Switzerland are very rarely found in a reference state. The course and bed characteristics of rivers and streams are, in most cases, greatly changed. Although ravine streams have a near-natural course, they often have artificial bed drops. The reference state, therefore, has to be theoretically reconstructed in most cases when evaluating a stream and describing target water conditions. The fluvial course in its reference state (constrained, braided, anastomosed, meandering) can often be established from old maps.

The theoretical reconstruction of the reference state requires a good knowledge of local conditions and geomorphology. Nevertheless, there will always be room for interpretation. This subjective element is unavoidable and must to be conceded.

Importance of Longitudinal Connectivity

Various abiotic and biotic factors of a running water will often change from its source to its mouth in a specific sequence: the flow rate increases while the bed gradient generally decreases and, as a consequence, the grain diameter of the bed material diminishes. Greatly simplified, the transport of bed material can be divided into 3 zones: the upper reach of a stream in which there is bed erosion, a central reach in which the incoming bed material is transported further downstream and the lower reach in which the transported bed material is deposited. The channel form of larger rivers often follows the sequence "straight or constrained", "braided" or "anastomosed" and "meandering". A further important biological factor is the water temperature. The further downstream from the source, the more the water temperature (and the range within which it fluctuates) is influenced by the air temperature. The changes in all the above abiotic parameters also affect the composition of the biocenoses. This relationship is expressed through different concepts ("division into fish regions", "Biozönotische Gliederung" [1], "river continuum concept" [2]).

Longitudinal connectivity includes

both the downstream-directed abiotic, dynamic processes (i.e., flow, transport of suspended matter and debris) as well as the upstream and downstream-directed biological gradients (i.e., the active and passive movement of organisms upstream or downstream).

Maintaining longitudinal connectivity means retaining or restoring the longitudinal gradient of activity seen under natural or near-natural conditions both within a running water and within entire running water systems.

Although these concepts are all greatly idealized, they demonstrate how a natural running water can change from the source to its mouth (more or less continually) and that the organisms which have colonized it also vary with the change in the "Lebensraum". The degree to which aquatic life can move upstream or downstream is one aspect of the longitudinal connectivity. Some fish species migrate along the course of rivers and streams. Some small invertebrates which live on the bed are to a greater or lesser extent continually transported downstream with the flow. To counter this effect, many of these animals have developed a movement pattern against the flow. Some aquatic insects, which in their larval stages live for one or more years in water, fly upstream as fully grown insects before laying their eggs – another way of compensating for drift.

In principle, all organisms attempt to colonize into new "Lebensräume"

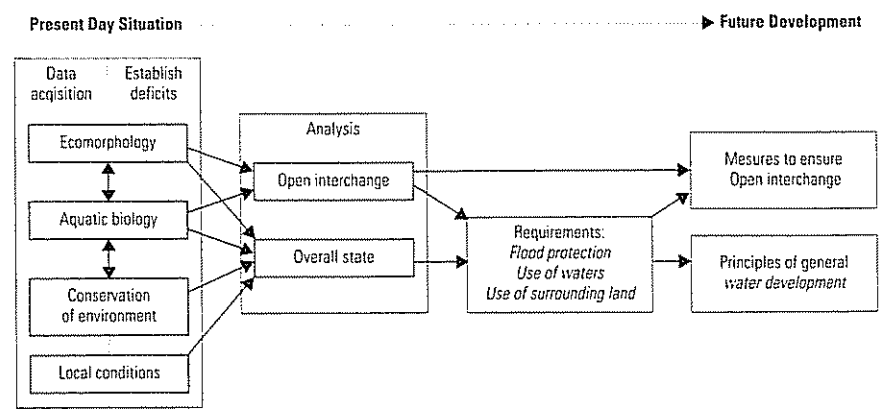


Fig. 1
Flow chart of the stream development concept for the Canton of Zurich.

through active or passive movement. There are, however, a multitude of anthropogenic disruptions of the continuum and of longitudinal connectivity. Water flow and debris dynamics are strongly affected by reservoirs, ponds, weirs (and stretches of residual water) and bed constructions, as well as by changes in the course and cross-section of a stream. This naturally leads to a completely re-structured "Lebensraum". Moreover, the continuum described above is upset by reservoirs and fish ponds [3, 4]. Similarly, all of the specified construction measures represent barriers for the migration and colonization of new territories by aquatic life [5]. Culverts or sections of watercourses with a very artificial morphology (such as concrete river beds) are not only barriers to colonization but can also prevent movement up or downstream.

Fig. 2
The obstruction of longitudinal connectivity along the Sagentobelbach, some 400 meters above the point where it feeds into the river Glatt. The 40 cm bed drop is the first artificial impediment to longitudinal connectivity, viewed from the point of influx, and prevents seven species of fish from moving upstream.

The Stream Development Concept for the Canton of Zurich

EAWAG, together with other Zurich cantonal authorities (Office for Water Pollution Control and Hydroconstruction, Office for Regional Planning, Fishing and Hunting), has elaborated a concept for the documentation, evaluation and development of streams in the canton [5, 6]. The concept focuses on ecomorphology. Documentation and evaluation methods further embrace stream biology (aquatic and marsh plants, small invertebrates, fishes), aquatic chemistry and the protection of the environment, flora, fauna, and aspects of the local environment (Fig. 1).

Methods

Ecomorphology

The fluvial ecomorphology is established before implementation of all the planned measures (regulation, development, restoration) for the body of water and its surrounding land. The stream is to be investigated along its entire length. Ideally, all feeder streams are also included.

The stream is divided into sections of constant ecomorphological conditions in the course of inspection on foot. For each section the ecomorphological characteristics are entered onto record sheets prepared in advance and various parameters which shape the "Lebensraum" are recorded:

- Width and depth of the stream cross-section
- Variability of water depth and the width of the water surface
- Bed drops and other bed steps (artificial/natural, height of drop, position in stream system)
- Constructions over the stream and culverts
- Large organic debris
- Morphology of the stream (straight, meandering)
- Bed material
- Shadows cast over the bed by vegetation on the bank
- Bank material and vegetation
- Use of surrounding land and vegetation
- A short recorded description of the deficits of the stream for the above parameters.

The reference state must be estimated for some of the structural characteristics – the course, width and depth of the stream and its variability.

Biology

If additional information is needed and changes to the waters have to be demonstrated in biological terms then supplementary data is collected for different groups of organisms. Ecomorphological deficits can generally be demonstrated very well on the basis of fish data. Such data can be qualitative (requiring relatively little effort) or quantitative (considerable input required). The qualitative approach allows conclusions to be drawn about whether waterfalls prevent certain fish species from moving upstream and shows how a monotonous stream morphology has an effect on fish stocks. Once the qualitative results are available, a decision can be made as to whether a quantitative approach is warranted. Studies of small invertebrates are warranted where hydroconstructions fundamentally change the existing stream morphology or to check the success of revitalization measures. A list of 68 taxa has been drawn up for the canton of Zurich, with descriptions of their "Lebensraum" requirements. Here, too, evaluation is based on a comparison with the theoretical colonization of the "Lebensraum" in the reference state. In instances of massive morphological

Fig. 3
A near-natural section of the Sagentobel stream.

changes such as bed drop steps or sealing of the bed, deficits can also be established using colonization by small animals as the criterion. In areas free of bank vegetation, mapping of the aquatic and marsh plants can be valuable to establish the plant areas worthy of protection.

Additional Considerations

Simple chemical studies (e.g., ammonium, nitrite, nitrate, phosphate, dissolved organic carbon and chloride) allow for localization of sources of contamination of nutrients and organic matter. A specialist in nature conservation inspects the stream system on foot (possibly excluding woods and built-up areas) and records those bodies of water, banks and surrounding land which are worth protecting. A specialist in environmental protection notes the important aspects of the local environment for all stream sections within urban areas.

Implementation of Results

Once all the data is collated, it is evaluated and modelling measures are worked out (Fig. 1). In addition to describing the most important deficits of channel morphology, biology and chemistry, the special areas worthy of protection and the characteristics of the area are also described. A detailed analysis of the degree of interchange is made on the basis of the ecomorphological and biological findings. The nature and degree of any obstructions and the length of the stream affected by them are compared and evaluated. The modelling measures are then developed from this information and can be classified in terms of their ecological priority and cost.

Use of the Concept

The entire concept, in addition to all of the described measures, was tested and evaluated for the "Sagentobelbach" (northeast of Zurich). All the results and conclusions are described in [5]. Ecomorphological data was collected for the river Töss along its entire length as part of the main area of research of EAWAG. Various methods within the concept have been and continue to be used and tested by undergraduates at the Swiss Federal Institute of Technology and the University of Innsbruck to determine whether and to what extent, they can be adopted for streams outside the canton of Zurich. The first practical application of the ecomorphological methods on a comprehensive basis is presently underway for running waters in the Austrian Tyrol.

Methods for the Evaluation of Swiss Running Waters

Together with the Federal Office of the Environment, Forestry and Landscape (BUWAL), EAWAG is currently developing methods of evaluating the ecomorphology, (eco)hydrology and fish biology of running waters in Switzerland. The ecomorphological and fish biology methods are based in large part on the concept described above [5]; however, they must be adapted to the specific conditions in other parts of the country (especially the Alps and the Jura). For methodological reasons, the largest rivers in Switzerland (the Alpenrhein, Hochrhein and Limmat, the Reuss downstream from Lake

Lucerne, the Aare downstream from the lake of Thun and the Rhone downstream of Sierre) have been omitted.

The ecomorphology aspect requires adaptation especially for the streams in the Alps which have steep gradients and numerous rockfalls, which are either completely free of obstructions or which have only traps for debris and which often cannot be walked along. A streamlined data collection procedure is warranted here in which the different parameters (water depth, width, natural waterfalls, bed and bank parameters) are captured as a whole. With larger streams which would naturally overflow their banks during high water periods (alluvial running waters), it is important to establish the potential spatial requirement (i.e., the spatial requirement of the running water in its reference state).

The (eco)hydrology embraces a general characterization of flow as well as an estimation of the change in flow brought about by direct measures (water outlets and inlets, flushes). Such information can only be obtained from maps (such as The Hydrological Atlas of Switzerland) and from measurements performed by the Canton, Federal Government and hydropower users.

Table 1 cites the different effects of "direct" hydrological measures on running waters in Alpine regions. The effects are generally combined; that is, a stretch of residual water will, in most cases, also be affected by water releases. The changes in flow which are the result of human activity are compared to flow conditions without direct intervention (i.e., without water inlets or outlets). One criterion for evaluation is the degree of change to the flow: as a general rule, the greater the difference between the original flow and that subjected to anthropogenic influence, the more grave the ecological effects. However, various marginal conditions have to be taken into consideration (such as the morphology of the running waters, the groundwater level, etc.). In the event of flushes, the ratio of maximal flow during flushing to flow before flushing is the deciding factor. The number of flushes also must be accounted for. The ecological effects of the hydrological changes can then be estimated using an evaluation chart.

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[2] Vannote R.L., Minshall G.W., Cummins K.W., Sedell J.R. Cushing C.E. (1980): The river continuum concept. Can. J. Fish. Aquat. Sci. 37: 130–177.

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[5] Hütte M., Bundi U., Peter A. (1994): Konzept für die Bewertung und Entwicklung von Bächen und Bachsystemen im Kanton Zürich. EAWAG, Swiss Federal Institute for Environmental Science and Technology, Dübendorf, und Kanton Zürich, ISBN 3-906484-10-6, 1-133.

[6] Hütte M., Bundi U., Peter A. (1995): Bachentwicklungskonzept für den Kanton Zürich. Wasserwirtschaft 85: 16–20.

Nature of Effect		Description of Intervention
Water extraction	Regions which dry out	Downstream of water intakes
	Discharge of residual water with overflow	Downstream of weirs which hold back the entire flood water flow
	Discharge of residual water without overflow	Mostly downstream of dams which hold back the entire flood water flow
	Affected by flushing of desilting chambers	Downstream of water intakes with desilting chambers which are regularly flushed
	Affected by flushing of impounded zone	Downstream of dams; the damned area is flushed annually or every few years
Water return	With fluctuations in section flow over 24 hr period	Downstream of power stations with intermittent power generation; at times high power consumption (especially mornings & midday) water throughput is greater
	Flow quantity variable over the year	Downstream of power plant with water inflow from annual-torage reservoirs; these reservoirs store water during the summer months which is then used up in winter when power consumption is greater
Damming		Held back by reservoirs, river power stations and weirs for water extraction (except the Tiroler Weir)

Table 1
Effects of direct hydrological interventions on running waters (in the Alpine region)

Guest commentary by Josef H. Reichholf*

Biodiversity – Global Pattern and Local Impact

The Earth's Diversity of Species

Biodiversity and its maintenance took center stage at the United Nations Earth Summit in Rio de Janeiro in the Summer of 1992. The subject on which biologists and conservationists have been demanding action for decades was suddenly shunted into the limelight of world politics. It is now incumbent upon those countries that signed the Biodiversity Convention in Rio to put their declared intentions into practice. The fact that this will not be quite as straightforward as some had previously assumed is due to the nature of biodiversity, whose distribution is not uniform across the globe. Strictly speaking, we do not even know how many different animal and plant species currently exist.

Until about 1980, the total number of species worldwide was estimated at 2–3 million, some half of which were known and formally described in scientific terms. Preliminary results from diversity studies undertaken in the tropical rainforest canopy, however, have clearly demonstrated that the number of species on earth has been drastically underestimated. Current estimates range from at least 5 to over 50 million different species, with the majority inhabiting the tropics [1]. The variety of most animal and plant species increases markedly as one moves towards the equator. The increase in the number of bird species as one travels from the north of North America down through Central America to the Amazonian Region illustrates this global trend of biodiversity (Fig. 1). The Tropics are also home to most of those rare and very rare species, usually confined to very limited areas (endemic species) that are now the focus of international protection efforts.

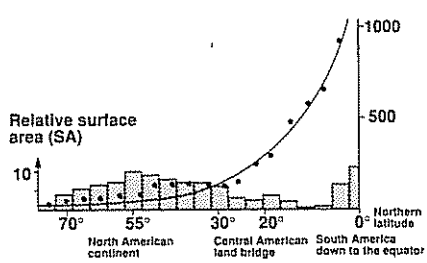

Fig. 1
Increase in biodiversity from the pole to the equator: The number of bird species increases considerably (exponentially) from the north of North America, through Central America to Amazonia.
Sp = Number of species (findings = dots); curve = idealized trend
SA = Relative surface area (North American continent, Central American land bridge, South America down to the equator) (from [2]).

Causes of High Biodiversity

Although we have known for many years that the number of species increases toward the tropics, we have only recently discovered that the much greater proliferation of species, compared to regions outside the tropics, is most likely not due to the particularly favorable living conditions within this region. In fact, the findings tend to draw the almost opposite conclusion. It is because of a deficiency of important mineral nutrients that the Tropics are so highly blessed with species. Biodiversity has been the evolutionary response to a shortage of essential resources. The increasing specialization and geographical small-scale separation of species has allowed the growing diversity of species to utilize scarce resources in the most efficient manner. They proliferate as a result of the need to survive, rather than benefiting from any "extravagance of Nature".

That the development of high biodiversity does not necessarily require tropical living conditions is illustrated by the diversity of species observed in inland waters. Where nutrients are in very short supply, as is the case in large areas of the world's largest river system, Amazonia, high biodiversity will not necessarily prevail, even in tropical areas. In fact, central Amazonian running waters are fairly deficient in species since, as far as mineral content is concerned, the water in this region is purer than rainwater. This finding agrees with similar results obtained in biodiversity studies investigating tree species. An extremely deficient nutrient supply is associated with a low level of diversity. As soon as conditions improve, however, the diversity increases, only to decline sharply again as the nutrient supplies become abundant.

Reasons for the Decline in Species

The crucial problem thus far has been our inability to predict which species will be able to cope with extreme deficiencies or extremely difficult living conditions and which will prove to be highly productive under favorable conditions, as is generally the case. Biodiversity may be viewed as a kind of double insurance for favorable and unfavorable conditions. This is clearly demonstrated in inland waters. As habitats, aquatic environments, rivers and lakes have been considerably affected, both directly and indirectly, by human activities – particularly in Central Europe. Almost no major river now flows in its "natural state". Conservationists and fishermen complain of a decline in the numerous animal species in rivers and lakes and call for stringent approval procedures for hydraulic construction projects. Since the running waters of Central Europe

* *Prof. Dr. Josef H. Reichholf gave a seminar on this topic at EAWAG on 28.4.95. His address: Zoologische Staatssammlung, Münchhausenstr. 21, D-81247 München, Fax (89) 8107123*

are – or once were – very rich in species, binding international rulings have been agreed with the aim of safeguarding biodiversity in European waters. All of the relevant studies [2] have confirmed that, in Central European inland waters, the diversity of species is dependent on water quality, generally achieving the highest levels with water quality class II and decreasing as quality progresses toward both class I (organically unpolluted water) and classes III and IV. The contrary situation prevails as regards the biomass of aquatic organisms, which increases markedly in line with eutrophication, although only a few species reach high densities or biomass. These general conclusions only apply, however, where toxic contamination remains low or absent, in which case the prevailing level of diversity is a function of structural variety and nutrient supply (trophic state). In structurally-deficient watercourses, diversity may be fairly low even under favorable trophic conditions. Conversely, a great variety of structures will be of little use if the nutrient supply for organisms is inadequate.

Development of Biodiversity in Running Waters

The two principal components for producing diversity were once combined in natural, unregulated running waters, which were structurally rich and enjoyed a moderate supply of nutrients. While an increase in the trophic level led, on the one hand, to an increase in biomass (e.g., in fish and in the numbers of swarming aquatic insects), it also resulted in initial reductions in species. As watercourses were subsequently standardized and developed along canal-based lines, structural variety also declined considerably. Large numbers of species were lost and fish yields dropped, even though the organic nutrient supply (organic detritus), and thus eutrophication, had reached a high level. While the development of sewage treatment plants led to a drastic reduction of primarily organic pollution, it was not accompanied by corresponding structural improvements to the "receiving waters". The consequence in many cases was a sharp decline in the stocks of species that were neither suffering from high levels of toxic contamination nor had suffered previously from structural depletion. Simply improving the water quality is not, therefore, sufficient in itself. Take the case of the reed warbler for example (Fig. 2), a species of small bird that serves as a bioindicator for the productivity in the reeds along the banks of lakes, ponds, fairly large running waters and marshes (i.e., the area where those insects that live in water during their developmental stages finally emerge as adults). In terms of quantity, this emergence is dependent on the degree of "contamination" of the water with organic detritus. The cleaner the water, the greater the decline in emergence and thus the number of reed warblers, a reduction amounting to around 90% when the water is improved from a polytrophic to a mesotrophic state. It is no surprise to discover, therefore, that the numbers of reed warblers have sharply declined in many places where attempts have been made to improve water quality. Its nomination as "Bird of the Year" in 1989 was an attempt by bird protection associations in Germany to highlight this – in some places alarming – reduction in the stocks of reed warblers and other reed-inhabiting bird species. But what can we do to resolve the problem? Pour increasing quantities of wastewater into natural watercourses?

Sustainability and the Protection of Species

Perhaps an excessively pure state is not such a good idea? Such considerations should encourage us to think about how we evaluate our "environmental standards" and whether the same standards should necessarily apply in all locations and under all conditions [3]. Even the idea that quality should come before quantity, roughly corresponding to the notion that diversity is better

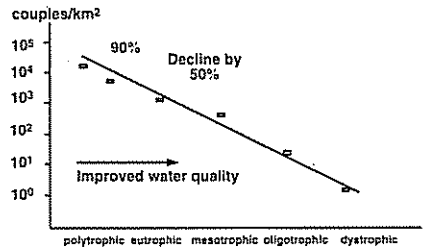

Fig. 2
Decline in the numbers of reed warblers (breeding pairs per km²) resulting from improved water quality. The decline amounts to 90% when a polytrophic state becomes mesotrophic and 50% when a eutrophic stage becomes mesotrophic.

than the excessive proliferation of a small number of species, is subject to limitations. Achieving "quality" requires basic preconditions in sufficient quantity. We cannot fall back on the all too superficial view that says we only need concern ourselves with the survival of a few key species that will perform all those tasks that need to be undertaken in order to maintain the correct aquatic balance of nature. Unfortunately, aquatic ecosystems do not operate in this way and no one can predict the potential significance of any one species. Thus, the preservation of biodiversity serves as a kind of reassurance for all eventual situations, and its promotion is more than a simple ruling resulting from the Rio summit. In order to develop useful, target-based programs, we first need to collate and evaluate existing findings on biodiversity in watercourses, on structural variety and on trophic stages and toxicity. Only then can we specify the objectives and get to the heart of the matter which is sustainability.

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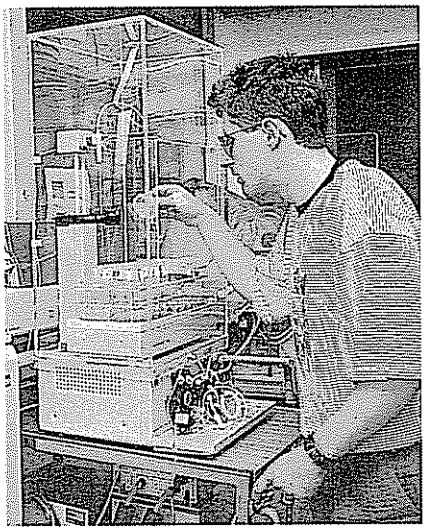
Hans Christoph Moor

Decreasing Lead Contamination in the Sediments of Lake Zug



Christoph Moor studied chemistry at the ETH-Zürich and completed his Ph.D. dissertation under the direction of Professor Magyar in the working group for inorganic analysis. From April 1993 to March 1995, he was a postdoctoral fellow with Dr. Laura Sigg at the EAWAG. During this period, he introduced the technique of inductively coupled plasma mass-spectrometry to the EAWAG and worked on metals in lakes, sediments and drainage waters. Since April 1995, he has been supervising inductively coupled plasma mass-spectrometry analyses at the EMPA.

Legislative regulations enacted for environmental protection are often controversial. It is, therefore, important to investigate their effectiveness as well as their impacts. Since the introduction of unleaded gasoline in Switzerland in 1985, lead emissions in Lake Zug have been drastically reduced.

Lead Emissions over Time

For centuries, lead has been known to be a toxic metal which enters the environment, sometimes in considerable amounts. In Switzerland, lead emissions are mainly caused by the use of fuels with leaded additives (as anti-knock compounds), by discharge of exhaust gases during incineration of solid wastes and from the metal producing and working industries. Figure 1 is an overview of the the sources of lead emissions in Switzerland since 1950 [1].

Release of lead and its transport in the atmosphere is followed by washing through of precipitation. In this way, lead can enter bodies of water. In lakes, it adsorbs strongly to sinking particles and eventually reaches the sediment. Since lead naturally occurs in small amounts in rock and soils, a certain amount is constantly being released through erosion within the catchment area and transported into the body of water. This source represents the natural background input of lead contamination in Lake Zug.

Over the past twenty years, the use of leaded anti-knock compounds in fuels has been drastically reduced globally. In the U.S., for example, lead emissions have been reduced from 250'000 tons of lead in 1970 to about 50'000 tons in 1985 [2]. In Switzerland, unleaded gasoline was introduced in 1985. The lead content of the leaded "super" gasoline, which is still in use today, was also heavily reduced.

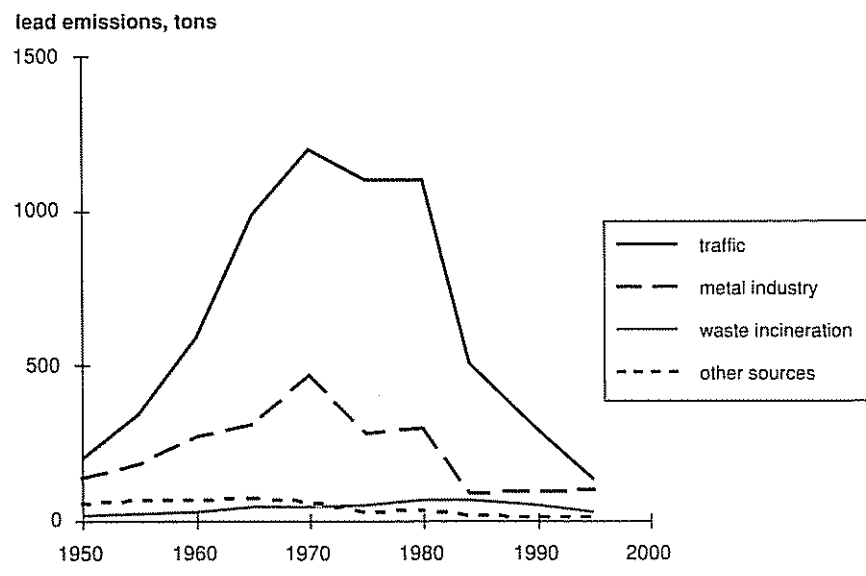


Fig. 1
The most important sources of lead emissions in Switzerland [1].

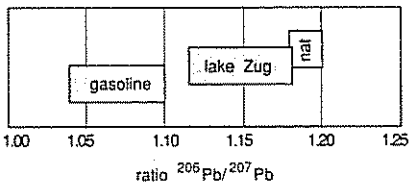


Fig. 2
Ratio of lead isotopes ^{206}Pb and ^{207}Pb. "nat" is naturally occurring lead from Central Europe; "gasoline" is lead which is used as a gasoline additive in Switzerland; "Lake Zug" is lead found in sediment cores [4, 6].

Snow cores from Greenland suggest that lead pollution, which primarily originated from North America, showed a decrease after the mid-1970s [2]. In Switzerland, a 50% reduction in the lead content of dry depositions was measured at five of six monitoring stations between 1988 and 1992 [3].

Isotope Ratios Reveal Origin of the Lead

Three of the four stable (not radioactive) lead isotopes are end products of the natural radioactive decay of uranium and thorium. As opposed to most other elements, the ratios of the four isotopes are not constant and depend on the geological age of the corresponding lead ore. A commonly used indicator is the ratio of ^{206}Pb to ^{207}Pb. If the ratios of two separate sources of lead are different enough, then the measurement of an unknown sample can indicate from which source it originates.

Most of the lead used for producing gasoline additives in Europe comes from Canada and Australia, having $^{206}Pb/^{207}Pb$ ratios between 1.04 and 1.10, whereas the $^{206}Pb/^{207}Pb$ ratios for naturally occurring lead in Central Europe are barely 1.20 [4]. The emissions from leaded fuels are the only source with a measurably lower $^{206}Pb/^{207}Pb$ ratio; therefore, the $^{206}Pb/^{207}Pb$ ratios found in environmental samples reflect the proportions of the various lead sources, the ratio ranging between the original ratios of the corresponding sources (Fig. 2).

Modern Methods of Analysis Benefit the Environment

An inductively coupled plasma-mass spectrometer has been in use at the EAWAG since 1994. With this instrument, metals in trace amounts can be analyzed faster and at lower detection levels than ever before. This method of "inductively coupled plasma-mass spectrometry" is abbreviated "ICP-MS".

The principle on which this relatively new technique is based was derived from the field of atomic spectrometry (Fig. 3). Solid samples first have to be lead over into a liquid form; liquid samples can be measured directly. The solutions are atomized and blown into an "electric flame", an argon plasma in the center of an induction coil. The droplets are dried at temperatures of 6000–8000 °K, and most of the atoms present are ionized. An ion extraction system is used for separating neutral particles (mainly argon atoms) and for leading the ions into the high vacuum of the mass spectrometer. The ions pass through two conical, water-cooled metal apertures and are then focused by electrostatic lenses onto the inlet of the mass spectrometer. The pressure is reduced in two steps to about 10^{-8} bar. The quadrupole mass spectrometer consists of four parallel rods which are placed under an alternating electrical field. Only the ions with a certain mass achieve a stable trajectory and can hit upon the detector after passing the analyzer. By continually changing the electrostatic field, different masses can be successively determined. All isotopes from lithium to uranium can be measured several times in one second, so that identification of the elements occurs almost simultaneously.

This method allows identification of elements with detection limits of several ng/L (10^{-9} g/L), which previously could only be achieved by graphite tube-atomic absorption. The older method, however, allowed measurement of only one element per analysis. Because a mass spectrometer is used as an analyzer in ICP-MS, concentrations as well as isotope ratios can be determined within certain limits. Until now, this was only feasible with special mass spectrometers, requiring much

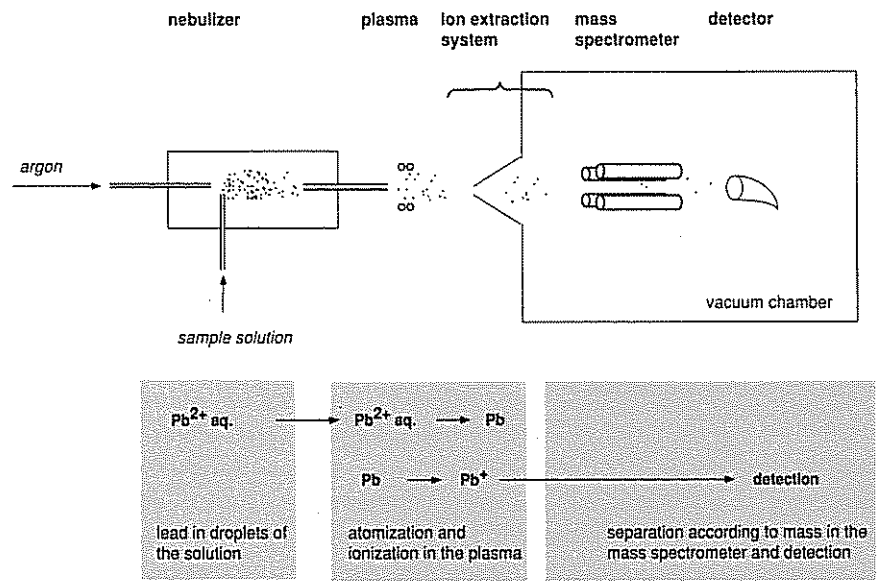


Fig. 3
The principle of inductively coupled plasma-mass spectrometry (ICP-MS). The dissolved sample is atomized and evaporated in a plasma at 6000–8000 °K. The resulting ions are separated in a mass spectrometer and detected individually.

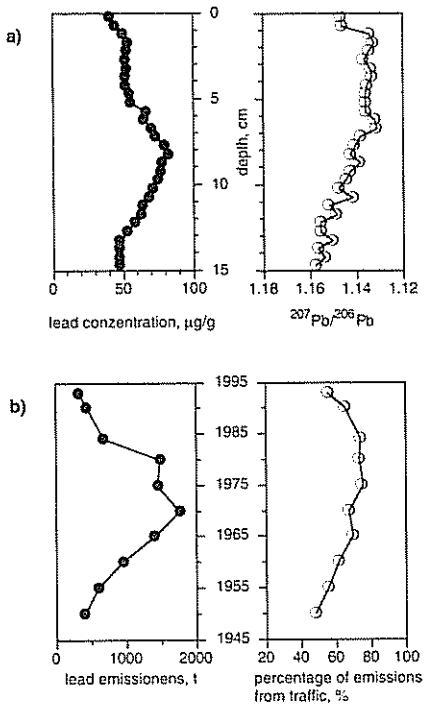


Fig. 4

a) Lead in the uppermost 15 cm of a sediment core from Lake Zug. (In order to facilitate the comparison with Fig. 4b, the scale of the isotope ratio is depicted the other way around).

b) Total lead emissions and the lead fraction from traffic. The sediment layer in (a) corresponds to about the past 50 years. The concentrations reflect the total emissions, whereas the isotope ratio runs parallel to the fraction of the emissions caused by traffic.

more effort (but which were more precise). An additional advantage of ICP-MS is the high rate at which samples can be measured: a total of 4 minutes per sample is needed in order to quantitatively measure 20 elements. As the method can easily be automated, samples can be run at night, which frees the day for preparing samples and interpreting results.

Lead in the Sediment of Lake Zug

Within the framework of two projects (doctoral dissertation of T. Schaller [5a] and a feasibility study concerning the remediation of Lake Zug [5b]), 12 sediment cores were taken from Lake Zug in 1993. The cores were opened and analyzed for lead content and other elements. Using ICP-MS, both the concentrations of lead and the isotope ratios of $^{206}Pb/^{207}Pb$ as a function of depth were determined.

The results obtained can be most easily explained using the example of a typical core [6]. The graphs of the lead concentration to the isotope ratio are given in Fig. 4a. The concentrations show a maximum at a depth of about 8 cm; they clearly decrease in the uppermost two cm. The $^{206}Pb/^{207}Pb$ ratio lies quite constantly at a minimum between 1.5 and 7 cm in depth and increases above 1 cm. This behavior was seen in all cores which contained a layered sediment without perturbations. It can be explained by comparison with emissions over the past 40 years.

Comparison of the Results with the Emissions

In Fig. 4b, the emissions data were presented in such a way as to make them easily comparable to the results in Fig. 4a. Two factors were taken into consideration: (1) the lead concentration in the sediment depends on the sum of the emissions, a natural influx being a constant addition, and (2) the $^{206}Pb/^{207}Pb$ ratio depends on the proportion of the total lead emissions originating from traffic, since the lead used in gasoline has a much lower value than all other sources. If the emissions were only caused by traffic then, at most, values of 1.10 would be found; if no lead at all came from traffic, then a "European" ratio of 1.20 would be expected. The resulting curve is thus an indicator for the traffic's share in the emissions.

The correlations of the corresponding curves corroborate the courses predicted from the emission data contained in the lake sediments. Based on the known rates of sediment accumulation, we can calculate that the maximum of the emissions around 1970 can be expected at a depth of 7–9 cm. The increase to a higher $^{206}Pb/^{207}Pb$ ratio in the uppermost centimeters means that, since about 1990, more "European" lead has been deposited in the sediments – originating from various other sources as well as from natural input.

Summary

The combination of determining lead concentrations and isotope ratios enables detailed statements as to the origin and course of lead contamination in the sediments to be made. Reducing the lead content in gasoline has led to a dramatic decrease in lead emissions caused by traffic since about 1970. Traffic, however, remained the main source of lead in Lake Zug, as lead emissions from other sources were reduced at the same time. Only when the use of unleaded gasoline increased after 1985 did traffic lose its position as the main source of lead emissions.

Acknowledgments

My heartfelt thanks to Tobias Schaller and Alois Zwyssig for sampling and processing and to Mike Sturm and Michael Kersten for valuable suggestions and discussions. I especially thank Laura Sigg, David Kistler and all the others with whom I had the pleasure to work with at the EAWAG.

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Hanbin Xue, Andrea Oestreich, David Kistler and Laura Sigg

What Forms of Copper are Present in Different Lakes and Rivers?

Hanbin Xue

The concentration of free cupric aquo ions can vary greatly in different lakes and rivers, even when the total concentrations of copper are in a similar range. These free cupric aquo ions, which are only accessible through elaborate, indirect analytical methods, are decisive in the influence of copper on organisms.

Copper enters natural waters from various sources; for example, from copper piping, from industry and from the erosion of agriculturally cultivated soils. In most lakes and rivers in Switzerland, the copper concentrations are higher, to a variable extent, than the naturally occurring background concentrations [1].

On the one hand, copper is an essential element; on the other hand, high concentrations have a toxic effect on aquatic organisms such as algae. Determining total copper concentrations in water is not sufficient for estimating its effect on organisms. Information on chemical speciation, i.e., on the chemical forms in which copper is present, is required. Various investigations have shown that the toxicity of copper for algae depends on the concentration of "free" metal ions; that is, on the metal ions in solution which are directly surrounded by water molecules [2]. The ratio of free metal ions to the concentration of total copper, that is, to dissolved Cu (as Cu_{diss} in the tables), depends strongly on the composition of the water. This ratio is especially dependent on pH and on the presence of organic complexing agents. It is generally true that copper, as compared to other metal cations, is especially strongly bound to organic complexing agents. This means that for the same total concentration of copper, the concentration of free cupric aquo ions can differ greatly in various waters depending on the presence of organic complexing agents and on the pH. These factors likewise influence the effects of copper on organisms.

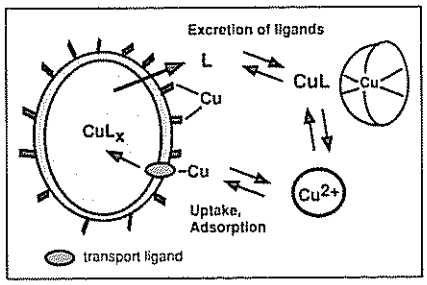

Fig. 1
Schematic diagram of the interactions between algae and metal ions. The effect on algae depends on the concentration of free cupric aquo ions. CuL represents a complex of copper with an unknown ligand; CuL_x are complexes which lie within the algal cells. Cu is probably taken up into the cells through transporting ligands. Note that ligands which are excreted from a cell are not identical to the transporting ligands.

Apart from inorganic ligands like carbonate and hydroxide, a broad spectrum of organic compounds can act as complexing agents for copper in natural waters. These compounds include organic decomposition products such as amino acids as well as the polymers of humic and fulvic acids. More specific ligands of biological origin may also be present. Finally, ligands of synthetic origin, such as NTA (nitrilotriacetic acid) and EDTA (ethylenediaminetetraacetic acid), may also play a role in these processes.

In order to find differences in the copper complexation, free cupric aquo ions were measured in various lakes and rivers, differing widely in their degree of eutrophication and in their contamination with sewage effluents. In most cases, investigations on chemical speciation could not be carried out using routine methods. Very sensitive and elaborate techniques had to be applied in order to experimentally determine the speciation, e.g., the concentration of free aquo ions at low concentrations of total copper (in the range of about $5x10^{-9}$–$1x10^{-7}$ M). In this study, a ligand exchange method (see below) was used for determining the concentration of free cupric aquo ions (represented by $[Cu^{2+}]$), which allows very low $[Cu^{2+}]$ levels to be determined via calculations of chemical equilibria.

Cupric ions and Algae

Possible interactions between cupric ions and algae are schematically represented in Fig. 1. Cupric ions, which are in chemical equilibrium with the

various complex species in solution, are bound to the surfaces of algae as well as to ligands involved in the uptake of metals. At high copper concentrations, a correspondingly larger amount of copper is bound to the cells. Toxic effects are manifested at high copper concentrations. As the ligands specific to the algae are in competition with the ligands in solution, these reactions depend on the concentration of free cupric aquo ions. The strong ligands (mostly chelates) which bind copper in solution could, in part, be algal excretion products; the presence of strong ligands reduces the toxic effects of copper.

Toxic effects on marine algae were found in the concentration range of $[Cu^{2+}] = 10^{-12}$–10^{-10} M [2,3]. An example is shown in Fig. 2. In the presence of the strong ligands Tris and EDTA, $[Cu^{2+}] > 10^{-11}$ M is toxic for a marine algae. In the presence of these two strong complexing agents, the toxic effect at different total concentrations depends on the concentration of free copper (from [3]). Little is known at present about the toxic range for freshwater algae.

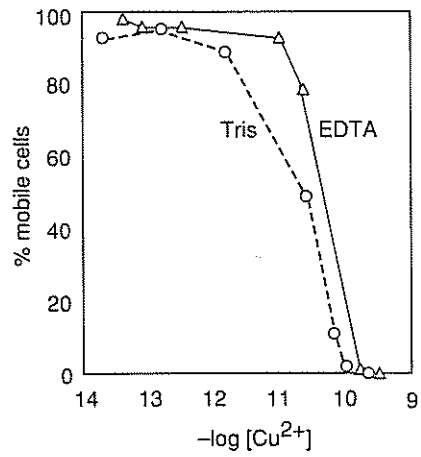

Fig. 2
The effect of the concentration of free copper in a study on toxicity (Anderson and Morel [3]). The mobility of the algae Gonyaulax tamarensis is depicted as a function of the free $[Cu^{2+}]$; the decrease in mobile cells is a measure for the toxic effect.

Method for Determining Free Cupric Aquo Ions

The method which was applied here is based on ligand exchange, i.e., on the exchange of copper, originally bound to unknown natural ligands, with a known ligand. In order to determine the free cupric aquo ions, a certain concentration of a known ligand (catechol) is added to a water sample [4, 5]. This ligand binds a certain proportion of the copper according to the existing competition with the naturally occurring ligands. The copper-catechol complexes which are formed can be specifically determined by cathodic stripping voltammetry. Based on the equilibria with catechol, the free copper concentration ($[Cu^{2+}]$) can be calculated; $pCu = -\log[Cu^{2+}]$ is defined analogously to the pH. In order to completely characterize the natural ligands (the concentration and binding strength of the ligands), a water sample is titrated with copper; for every titration step (at different given total concentrations of copper), the concentration of free copper is again determined by the reaction with catechol.

Cupric Aquo Ions in Various Lakes

Samples from lakes with a broad spectrum of conditions were investigated: lakes of the Swiss Plateau as well as alpine lakes. Lake Greifen and Lake Sempach are typical examples of the small, very eutrophic lakes of the Swiss Plateau. In Lake Greifen, the primary production rate is about 500 g of carbon per m^2 per year and in Lake Sempach about 350 g C/m^2 per year. The pH in the euphotic zone is in the range of 7.5–8.5. In both lakes, samples were examined at different seasons [5]. Lake Lucerne was used for comparison, representing an oligotrophic lake with a low primary production of about 150 g C/m^2 per year, yet within the same pH range.

As Part A in Table 1 illustrates, copper is complexed to a similarly strong extent in Lake Greifen as in Lake Sempach. In these two lakes, both extremely low Cu^{2+} concentrations (10^{-15} M) and very high ratios of total copper to free copper, were observed. In contrast, in Lake Lucerne, higher $[Cu^{2+}]$ levels (i.e., by a factor of ten) were found at similar total copper concentrations. Thus >99% of the copper in these lakes exists in the form of organic complexes. This extreme complexation of copper must be due to the presence of very specific, strong complexing agents, probably of natural origin. These results, together with variations with depth and time (over different seasons), in the eutrophic lakes seem to suggest that the complexation of copper is correlated to algal productivity [5]. Copper is more strongly bound in lakes with a higher algal productivity, the concentration of strong ligands being high. These strong ligands could be excretion products of living algae or be released upon their decomposition. The structures of these strong ligands are not yet known.

By way of comparison, some samples from alpine lakes on crystalline rock were also investigated. The alpine lakes of the upper Maggia Valley are characterized by low pH levels (5–7), low ionic strengths, low concentrations of nutrients and correspondingly low algal production. The copper found here originates from atmospheric inputs (precipitation) and from the native rock. The results of shown in Part B of Table 1 suggest that in these lakes the concentrations of free copper are within the range of about 10^{-10} M at a natural pH level. Similar conditions can also be observed in the Italian Lago Orta (pH around 7.0); this lake used to be strongly contaminated with copper. Compared to the eutrophic lakes, a much lower degree of complexation and a lower ratio of total to free copper is observed. These findings can be explained by the lower pH levels, which decrease complex formation, ans well as the lower content of organic carbon and the much lower algal productivity.

In comparing these different lakes, it becomes obvious that higher concentrations of free copper ions are found in waters characterized by low pH, low concentrations of organic material and low biological productivity.

Part			Date	pH	$[Cu]_{diss}$	$[Cu^{2+}]$	pCu	log $([Cu]_{diss}/[Cu^{2+}])$	COD
A	**Productivity**								
	Oligotrophic lake	$gC/m^2 \cdot yr$			nM	M			mg/L
	Lake Lucerne	150	1991/94	8.0	9.1	14.9×10^{-15}	14.0	6.15	1.0
	Eutrophic lake								
	Lake Greifen	500	1993	8.0	15.8	1.7×10^{-15}	15.0	7.36	3.6
	Lake Sempach	350	1994	8.0	6.4	1.0×10^{-15}	15.2	7.20	4.2
B	**pH lake**								
	Acid lakes								
	Val Sabbia	6.9	Aug. 92	6.0 7.5	2.8	1.7×10^{-10} 2.3×10^{-12}	9.8 11.7	1.22 3.06	0.8
	Laghetto Inferiore	6.0	Aug. 92	6.0	5.4	5.9×10^{-10}	9.3	0.93	0.4
	Zotta	5.7	Aug. 92	5.3	5.5	1.5×10^{-10}	9.9	1.55	0.3
	Orta	7.0	July 94	7.0	70.8	1.5×10^{-10}	9.8	2.67	1.1
C	**River**	**location**							
	Birs	Münchenstein	18.5.1993	8.0	28.2	1.26×10^{-14}	13.9	6.34	2.0
	Birs	Münchenstein	6.7.1993	8.0	47.4	5.01×10^{-14}	13.3	5.93	2.2
	Glatt	Niederglatt (below STP)	24.5.1993	8.0	31.3	7.9×10^{-14}	13.1	5.61	3.6
	Glatt	Niederglatt (above STP)	28.6.1993	8.0	20.0	1.6×10^{-14}	13.8	6.11	3.5
	Glatt	Niederglatt (below STP)	28.6.1993	8.0	21.4	7.9×10^{-14}	13.1	5.43	3.9
	Rhine	Rekingen	18.5.1993	8.0	10.0	1.0×10^{-15}	15.0	6.95	1.8
	Rhine	Rekingen	6.7.1993	8.0	43.2	3.2×10^{-14}	13.5	6.15	2.7
	Rhine	Village-Neuf	18.5.1993	8.0	10.1	4.0×10^{-16}	15.4	7.40	1.8
	Rhine	Village-Neuf	6.7.1993	8.0	15.8	5.0×10^{-14}	13.3	5.52	2.3

Table 1
Complexation of copper in lakes and rivers:
A: various lakes (averages of measurements at different times in the productive layers of the lake);
B: acid lakes (measurements of single samples);
C: some rivers (single samples).

$[Cu]_{diss}$ *represents the dissolved (<0.45 µm) concentration, in nM (10^{-9} M);*
$[Cu^{2+}]$ *the experimentally determined concentration of free aquo ions;*
$pCu = -\log [Cu^{2+}]$

Cupric Aquo Ions in Various Rivers

The speciation of copper was also investigated in several rivers in order to identify various relevant factors [6]. We assumed that in running waters input from sewage treatment plants could be a source of strong ligands; furthermore, products of biological excretion and decomposition are likewise present in rivers. Strong ligands could also originate from lakes in the catchment area of a river. Some typical results are summarized in Part C of Table 1. In general, the concentration of total dissolved copper is higher ($1–7 \times 10^{-8}$ M) than in the lakes. The extent of complex formation, expressed as the ratios of total to free copper, is in most cases lower than in the eutrophic lakes. A remarkable observation is the rather lower extent of complex formation that was measured just below the influent of a sewage treatment plant compared to that above it. EDTA, which enters the Glatt by way of the sewage treatment plant, does not appear to play a significant role in the complexation of copper in the river. This minor effect of EDTA is probably related to competition with the natural ligands for copper, competition with other cations, and to the presence of Fe(III)-EDTA [7] (FeEDTA would only perform a very slow exchange with other cations).

The rivers investigated in this study have different contents of dissolved organic carbon (DOC). There seems to be no connection, however, between DOC and the extent of complex formation. DOC is thus too insensitive a parameter for determining the presence of specific ligands for copper.

Complex Formation and Ecotoxicological Assessment

The results of the study on complex formation of copper in lakes and rivers

suggest that copper in different types of freshwaters is bound to very different extents. A broad spectrum of concentrations of free cupric aquo ions can result from the same total concentration of copper, depending on what kinds and amounts of strong ligands are present. The ecological consequences of these differences in concentrations of copper are not yet well understood, because the optimal range of the concentrations of copper and other trace elements for freshwater algae are still largely unknown. The very low copper concentrations that were measured in eutrophic lakes are certainly below toxic levels, whereas those in the acid lakes could reach a toxic level for sensitive organisms. It is also not certain what influence the interaction between different metal ions (e.g., different relative levels of copper, zinc or manganese) may have on algae and other organisms. In order to better assess ecotoxicological effects, speciation measurements, such as those presented in this article, are a necessary precondition.

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Book Review

Weidenhaupt, A.N.J.: "Trialkylzinnverbindungen: Speziierung im Oktanol/Wasser-System, Sorption an Mineraloberflächen." Diss. ETHZ Nr. 10940, Zürich 1995.

André Weidenhaupt was appointed to a research post in the group "Safety and Environmental Protection in Chemistry" under Prof. Hungerbühler, Laboratory for Technical Chemistry, Swiss Federal Institute of Technology, on 1 February 1995. His main research interest is the integrated design of products in the chemical industry.

Organotin in Underwater Coatings: Its Distribution in Water

Because of their widespread use and toxicity to aquatic life, trialkyl tin compounds (R_3SnX) are among the most problematic substances found in natural waters around the world. They are used as biocides and, until recently, were the main constituents of underwater paints (antifouling coatings). Using a lake as an example, Fig. 1 schematically shows those processes which affect the behavior of trialkyl tin compounds in natural waters.

Trialkyl tin compounds may enter surface waters by several different routes:

- through diffusion from the hulls of boats which have been treated with antifouling paints containing organotin compounds
- from feeder rivers and water treatment plant effluents containing organotin compounds
- runoff from agricultural fields
- diffuse entry due to resuspension of sediments containing trialkyl tin compounds.

Bioaccumulation and adsorption to sedimentary particles are the most important processes for removing trialkyl tin compounds from the water column.

Degradation

Sunlight induces photolytic dealkylation of trialkyl compounds in the upper water layer. Other (presumably biotic) dealkylation reactions proceeding in the sediments and in various organisms are responsible for their breakdown into inorganic tin (IV). This process can proceed via oxidative dealkylation through cytochrome P-450, although at high R_3SnX concentrations, the monooxygenases involved would probably be inhibited.

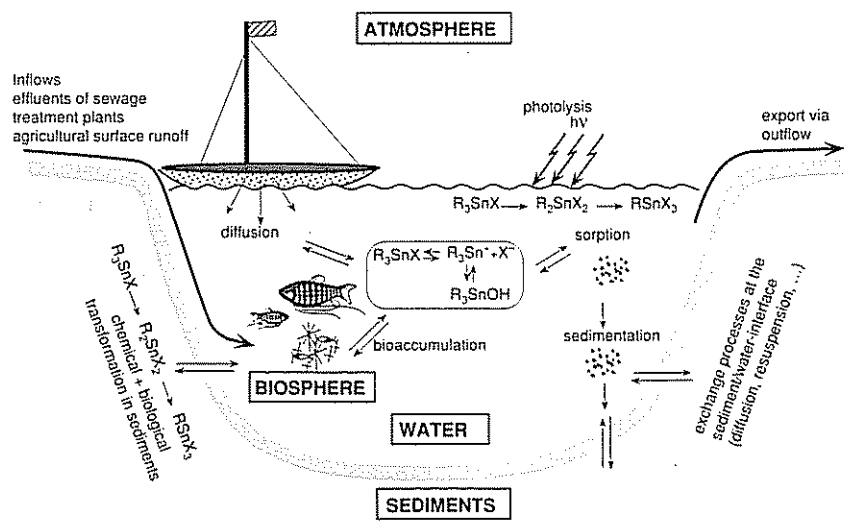


Fig. 1
Processes which determine the behavior of trialkyl tin compounds in a natural lake.

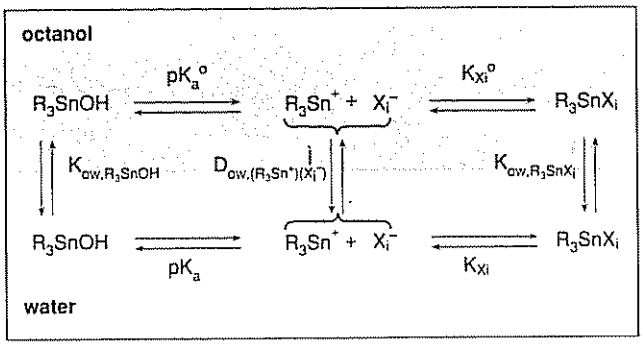


Fig. 2
Overview of the equilibrium reactions of the trialkyl tin species under study in an octanol/water system.
(X_i^- = Cl^-, Br^-, $H_2PO_4^-$, ClO_4^-...)

Under anaerobic conditions, R_3SnX is biologically methylated, leading to a more volatile tetraalkyl tin. It, in turn, is evolved and undergoes additional transformation processes in the atmosphere.

Model Systems

Understanding the distribution of R_3SnX in lipophilic material and its sorption to mineral phases as a function of speciation in aqueous solution is essential to an understanding of the transport, distribution, bioaccumulation and bioavailability of R_3SnX in natural waters. The distribution behavior of R_3SnX in two model systems (octanol/water and mineral oxide/water) was, therefore, studied in detail. These systems have allowed basic principles to be established which enable improved interpretation of existing data and more reliable predictions of the distribution of R_3Sn in the environment.

The hydrolysis of R_3Sn^+ cations and their ability to form complexes has been a central focus of the work. Where the water composition is known, the octanol/water distribution ratio can be calculated from the speciation of R_3Sn (cf. Fig. 2). In addition, sorption to mineral surfaces can be understood as an interaction between the R_3Sn^+ cations and negatively-charged surface groups.

Need for Additional Studies

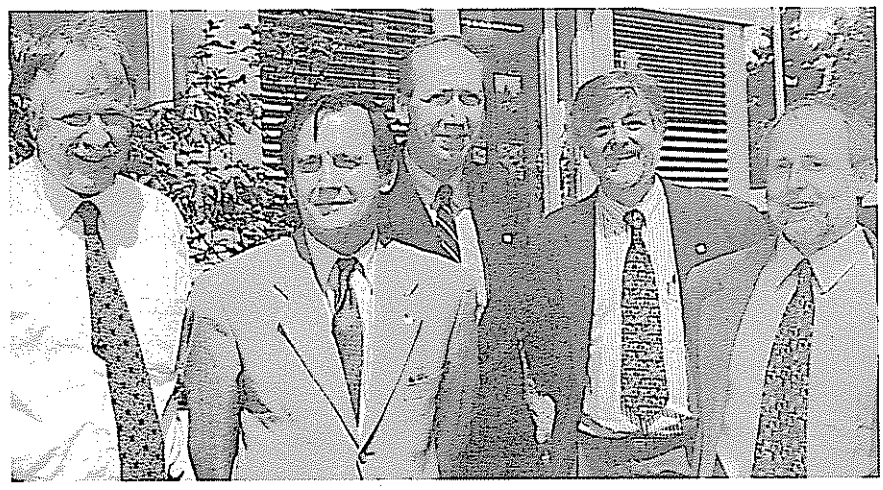
Additional information about the distribution of R_3Sn compounds in dissolved and/or particulate organic material is needed to quantitatively describe their environmental behavior. The possibility of specific interactions between the R_3Sn^+ cations and functional groups of the organic matter makes it conceivable that this distribution cannot be described exclusively in terms of nonspecific hydrophobic interactions. The underlying mechanisms should be investigated in greater detail.

The Problem of Substitutes

Organotin compounds exert highly toxic effects in the environment into which they are introduced, e.g., as constituents of biocidal underwater paints. A number of countries in the West have now prohibited the sale and/or use of antifouling paints containing organotin compounds, but the question of alternatives needs to be addressed. The actions of substitutes, such as 2-*tert*-butylamino-4-cyclopropylamino-6-methylthio-1,3,5-triazine, are similarly based on the biocidal properties of the dissolved molecules; undesirable properties cannot be ruled out. In general, coatings such as Teflon, which render the boats smoother due to optimized surface tension, are preferred since their effect is based on strictly physical properties.

It is hoped that in the future the environmental effects of xenobiotics will be investigated before such substances become environmental problems. The environmental compatibility of a new chemical should be investigated at the time of its development. In this context, this project has made a contribution to our understanding of the distribution behavior of organic compounds.

André Weidenhaupt



Visit of the Board of the Swiss Federal Institutes of Technology

Inaugural visit, June 15, 1995, of the newly-elected directors of the Board of the Swiss Federal Institutes of Technology (BSIT), President Prof. Dr. Francis Waldvogel (2nd from the left) and Vice-President and Delegate, Dr. Stefan Bieri (in the middle). After a meeting with Prof. A.J.B. Zehnder, the Director of the EAWAG (2nd from the right), Deputy Director H. Wasmer (1st from the left) and Vice-Director U. Bundi (1st from the right) the guests participated in an inspection tour. In selected laboratories specific research projects were presented.
The previous week approx. 20 members of the Senior staff of the Board of the Swiss Federal Institutes of Technology have been invited to Kastanienbaum. The Group attended a guided tour through the Research Center for Limnology and was accompanied by the Directors. Several research activities mainly focussed on problems from the practice were presented.

Interview

Interview with Markus Hofmann

Avoidance – Reduction – Insurance

The Insurance of Environmental Risks

Markus Hofmann, born in 1965, studied chemistry and economics in Ulm. The Deputy Director of EAWAG, Hannes Wasmer offered him the opportunity to write an interdisciplinary thesis on this topic – one which reflected his interests. He has now completed his study and has presented the results at national and international meetings as well as to insurers.
His new address is:
Dr. Markus Hofmann, Berliner Ring 3, D-65779 Kelkheim i.T.

Insurance and the environment: just what do these terms have in common?

The level of environmental awareness in society has increased over the last decades in line with growing environmental problems. This development is also reflected in recent legislation. Environmental laws in general, and especially Environmental Impairment Liability, have become increasingly strict in many industrial nations. In Germany, for instance, a wide-ranging Environmental Impairment Liability law came into force on 1 January 1991 which makes plant operators liable for personal injury and property damage related to environmental impacts. The plant operator is, therefore, now held liable in cases for which he would not have been responsible in the past. Similar changes are being discussed in Switzerland in the context of revising environmental legislation. Companies whose operations pose a threat to the environment will attempt to pass on these new risks to their insurers, so that stricter environmental laws will also impact the liability of insurance companies.

How has damage to the environment become a problem for insurers?

The costs of environmental impairment, especially under liability insurance, have increased greatly over the last decades. Improved measurement methods, which allow much lower levels of toxic compounds to be detected as well as the discovery of ecotoxicological effects of substances which were previously thought to be innocuous (e.g., chlorinated hydrocarbons), have resulted in more losses and higher claims. The cost of clean-up measures for chlorinated hydrocarbons can easily reach several million Swiss francs. In addition, it is difficult to assess the consequences of the change in liability and of the complexity of environmental risks in actuarial terms. This makes underwriting environmental risks more difficult. Another problem is that the causal factors of environmental damage often cannot be established, thereby complicating claims handling. Consequently, risk assessment and coverage are problematic for insurers.

How are coverage and liability established?

Insurers faced with a claim first must establish a number of facts which depend on the principles established in the policy – causality (the event giving rise to the claim), ascertainment of damage, and lodging of the claim. The first question to be answered in the event of a claim is whether the insured party is really liable. Only when this has been established can the question be answered as to whether or not the loss is covered by the policy. Under Swiss law, for example, liability for environmental damage is established on the basis of a "breach of public order". Any party who through its actions or inactions violates the public order is liable under the terms of "common liability law". Parties who exercise actual or legal powers over components and who are responsible for violation of a public order are liable under "tortious liability".

The first question to be clarified by a claims adjuster is the type of liability involved. The next step is to check whether the claim falls within the policy period and whether it is covered. It is often

difficult though to determine the causal relationship between the time of occurrence and the extent of damage attributed to a particular claim in a particular policy. Legal recourse is, therefore, often required. More recent insurance conditions are frequently claims-based. This allows the time of the damage to be established with precision. Moreover, under recent environmental legislation there has been a switch from tortious liability to strict liability. This means, for example, that the operator of a plant is automatically liable for damage caused by the plant without establishing any fault on his part. In Germany, this more stringent interpretation of liability is already contained within the environmental impairment liability legislation. The introduction of this change is currently being discussed for revision of Swiss environmental legislation and in drafts for European environmental liability laws.

To what extent do insurers reduce risks?

By insuring risks, insurers make a substantial contribution to the function of our economic system. No enterprise can succeed today without insurance. Because insurers investigate risks qualitatively and quantitatively and may insist on the implementation of risk reduction measures before granting coverage, they do have a certain risk-reducing effect. On the other hand, the insured may have too great a feeling of security because of the insurance coverage and, as a result, be prepared to take greater risks. It is difficult to say precisely to what extent insurers really reduce risks.

What can governments do to protect the environment from "environmental risks"? What is the role of insurers?

As the current environmental problems demonstrate, regulations based solely on concentration limits are perhaps not the best solution. An attempt is now being made to resolve these problems by tightening up liability. We will have to wait to judge the success of this approach. On the whole though, the indications are that this alone will be insufficient.

It is presently being considered to make insurance for environmental risks compulsory. The reasoning is that insurers will only cover those environmental risks which they consider manageable. With compulsory insurance, the costs of any damage would also be covered. If, for instance, the approval to operate a facility were made contingent upon it being insuredit would allow a certain minimum standard for environmental risks to be enforced.

As business enterprises, insurers would have to assume the role of the authorities; that is, they would have to qualitatively and quantitatively assess and establish the level of risk which society can bear. As far as I am aware, very few insurers want to take on this role. They have no desire to act as "environmental police". This would only work if all insurers were to adopt the same methods of risk assessment and premium calculation and would base their risk and business policies on exactly the same conditions. But coverage is, in principle, dependent on how much a client is willing to pay for the premiums, so that coverage would remain a question of price. Moreover, there are "black sheep" amongst insurers who will cover certain risks at low premiums, but in the event of a claim will be unable to pay or will have long ceased to exist.

Under present legislation, what means do insurers have of calculating environmental risks and costs?

With environmental risks, there are not only the complex problems associated with assessing the risk but also the fact that risks change over time. Insurers now have to estimate *ex ante* the cost of damage for possible future events. They must include factors such as future trends in the environmental awareness of society, environmental law, court rulings and the consequences of a greater understanding of environmental processes.

The premiums are normally calculated on the basis of statistical experience of losses for a specific insurance area. In the past, environmental risks were covered under general business liability insurance and were never separately documented anywhere. As a result, this data, important for environmental risk assessment,

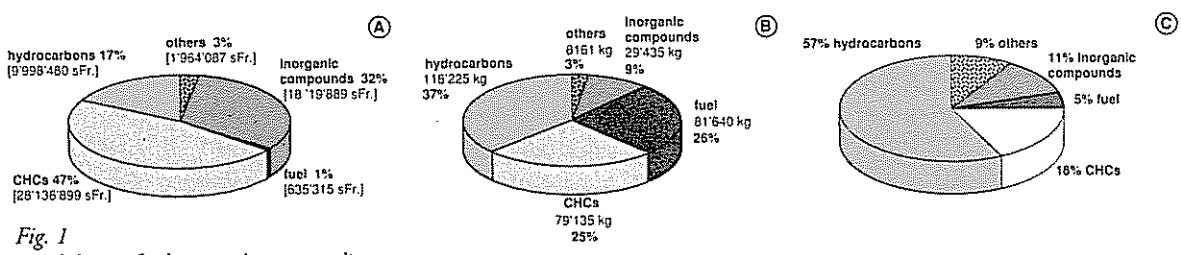


Fig. 1
Breakdown of substance classes according to:
A) Costs with reference to claims
B) Emissions
C) Number of cases analyzed

$$\text{Cat. of total costs} = f\begin{pmatrix}\text{Cat. of Substance}\\ \text{Cat. of Soil}\\ \text{Cat. of Environment}\\ \text{Cat. of amount of Substance}\\ \text{Cat. of Time}\end{pmatrix}$$

Cat. of Total Costs	Cat. of Substance	Cat. of Soil	Cat. of Environment	Cat. of Amount of Substance	Cat. of Time
9 ordinals	5 nominals	3 ordinals	3 ordinals	11 ordinals	8 ordinals
<5000 Sfr. = a 5000–9999 = b ... 10^5–2'999'999 = h <3 Mio. Sfr. = i	CHCs Fuel Inorganic compounds Hydrocarbons others	*Permeability* A (low) B (medium) C (high)	*Risk to environment* A1 (low) B1 (medium) C1 (high)	under 20 kg to above 20'000 kg	Under 6 h to above 3 years

Fig. 2
Model for estimating the extent of magnitude of financial loss.

remains unevaluated in the large archives of liability insurers.

To allow this wealth of data to be evaluated, I set up a database of environmental losses covered by liability policies. A total of 100 claims under the liability policies of one German and two Swiss direct insurers for the years 1985–1993 were collated. Environmental impairment here embraces instances in which the emission of a toxic substance led to damage to at least one environmental medium, water, soil or air, and which resulted in the insurer having to pay claims. I was able to establish a relationship between scientific and technical factors and the resultant costs to the insurers for environmental damage. Usually risk is understood to be the potential of loss; often it is defined as probability times severity. In my model, I concentrated on the financial consequences (claims costs) of environmental risks in the event of a loss.

How large were the sums insurers had to pay for the environmental impairment claims you examined?

The total cost of claims in my database was approximately Sfr. 59 million for a total of 300 metric tons of chemicals discharged into the environment. The average cost per event was Sfr. 590'000. The highest percentage of costs was attributable to just a few groups of substances (see Fig. 1). The emission of inorganic substances and chlorinated hydrocarbons (CHCs) proved especially expensive, while damage caused by hydrocarbons was comparatively cheap.

Approximately one third of the sums paid out by the insurers (Table 1) was for remediation and associated construction. Some 20% of the sums paid out were purely for disposal of the contaminants while less than 10% was paid out for geotechnical work and for operating costs such as power and water consumption.

The cost of chemical analyses, expert reports, and compensation paid to third parties accounted for less than 10% of the total. Astonishingly, legal fees and court costs, as well as the sums paid to the environmental authorities totalled only 1%. These costs would be much higher in the United States. Legal costs there (mainly through the defense or distribution of possible claims) amount to 60–80% of overall costs. Such exaggerated legal costs were never intended by those who conceived Superfund.

In your analysis of the database, which factors proved to be most relevant in calculating costs?

By applying scientific and technical considerations to the analysis of loss data, by making use of actuarial risk and loss management, and by employing statistical correlation analysis, the following factors showed to have an influence on costs:

- Type of substance
- Quantity of substance
- Type of soil
- Type of environment
- Time lapse between when clean-up is initiated and when remediation begins to have an effect.

A hypothetical model was constructed to enable a statistical estimation of these factors: The dependent variable (regressand) is "total costs" and is a function of the five independent variables, the regressors. The most appropriate approach to statistical estimation would be to use linear regression (the method of least error squares); however, the data set does not meet the conditions for this type of analysis (i.e., there would have

%	Key to costs
1	Litigation/authority costs
2	Compensation to third parties
3	Remediation/Replacement costs
4	Salvage costs
6	Costs of experts/consultants
7	Laboratory analysis costs
11	Operating costs
12	Drilling/geotechnical costs
17	Disposal costs
37	Plant construction costs

Table 1
Breakdown by percentage of the sums paid out for 100 environmental claims under general business liability insurance for the years 1985–1993.
(100% = Sfr. 59 million)

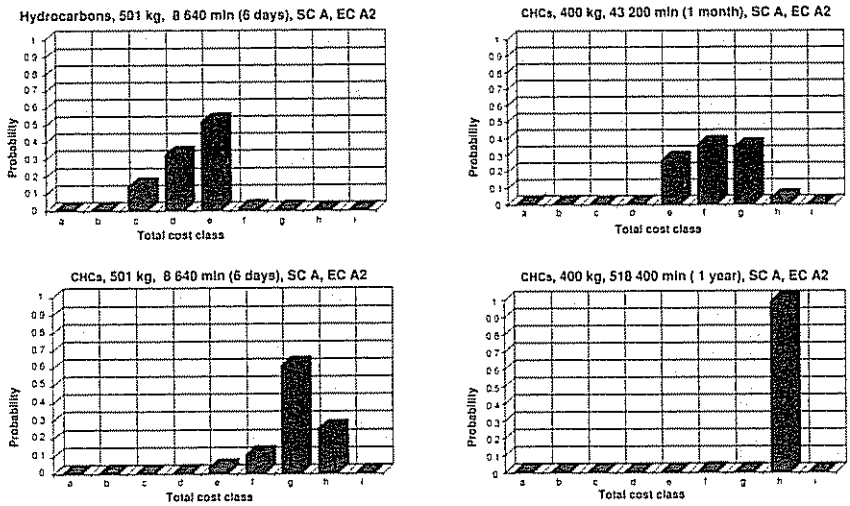


Fig. 3
Estimated probability of occurrence of environmental loss scenarios, based on Category of total cost (a, b,..., h, i)
CHC = chlorinated hydrocarbon
SC = Cat. of soil
EC = Cat. of Environment

to be a normal distribution of residues). Moreover, a variety of categorical and ordinal data would need to be taken into consideration. Consequently, I used logit analysis which is a model for categorical analysis derived from the social sciences. I used a linear, categorical, multinomial and ordinal logit model. For insurers it is the general order of magnitude of costs due to environmental claims which is of interest – not the cost down to the last penny. The model enables different ordinal classes of the regressands to be estimated.

The logit analyses confirmed the high significance of the hypothetical regressors and of the model as a whole. Comparison of the costs estimated using the model with the actual costs incurred yielded a correlation of over 90%. Insurers may, therefore, use such a model to estimate the order of magnitude of the costs of environmental risks *ex ante*. The model is a dynamic one and allows new loss data to be incorporated and further regressors or other categories to be taken into consideration.

These examples illustrate the influence of the regressors on the probability of the individual cost categories. The likely costs of environmental impairment can be simply and reliably estimated by liability insurers using this model. This information is also available for actuarial analysis to help underwriters to calculate premiums (see Fig. 4), and for drafting new environmental impairment liability policies.

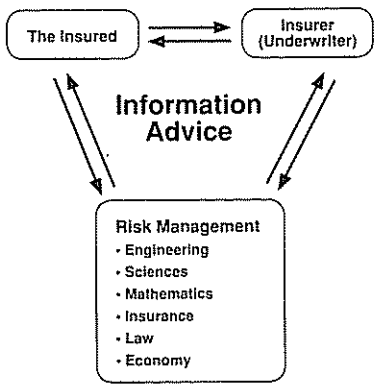


Fig. 4
Insurance as the partner of the insured party

What influence do the factors have on overall costs?

I found that the regressors have different effects. The Cat. of substance, the Cat. of amount of substance and the Cat. of time all have a greater influence than the Cat. of environment or Cat. of soil.

Have your computer-aided estimations of cost already been used in the field?

Yes, they are already being used to some extent by insurers for the assessment of risk. Insurers have expressed considerable interest in them.

The problem of CHCs is well known. Which substances are likely to be controversial in the future, the products of genetic engineering?

Many insurers are already searching for an answer to this. Unfortunately I cannot answer it. The potential of genetic engineering to give rise to claims is naturally a topical theme. Exactly which substances will be the next to be recognized as problematic will depend on future ecotoxicological findings and on the impact of such findings on society and the law.

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Research

In Cooperation with the World Bank

Improved Traditional Nightsoil Disposal in China: An Alternative to Conventional Sewage Systems?

Traditional Nightsoil Disposal Practices in Chinese Cities

Most Chinese cities have no sewage systems or, at best, only rudimentary ones. For example, only 13% of Shanghai's 7 million inhabitants are connected to a conventional sewage disposal system, while some 2.5 million residents still use the traditional bucket latrine for nightsoil disposal. The excreta of an additional four million people are discharged directly into the surface water drainage system, either without any treatment or after minimal treatment in a usually overloaded septic tank. The nightsoil and fecal sludges from the bucket latrines, communal latrines and septic tanks are collected more or less regularly by vacuum trucks, pumped onto barges and transported on the rivers for transport to agricultural areas. There they should be stored in tanks for at least 30 days (to attain advanced pathogen die-off) as prescribed by national guidelines before being used as manure on fields or in fish ponds. Since this minimum storage time is rarely achieved, the nightsoil often reaches the fields and fish ponds in a raw and untreated state. This type of nightsoil disposal/reuse system is typical for most of China's urban population (ca. 360 million).

Although no systematic epidemiological studies have been conducted, it is generally assumed that the existing nightsoil disposal/reuse practices are responsible for a high risk of infectious disease transmission and are considered by Western experts to be one of China's major environmental problems. Consequently, several urban environmental projects financed by the World Bank and other development agencies are aimed at improving the present nightsoil and wastewater situation.

Is the Conventional Sewage System the Best and Only Alternative?

In order to solve this problem, almost all of the projects propose to equip the cities with conventional sewage systems patterned after the industrialized countries of the North. Unfortunately, since their construction is extremely capital intensive, the limited financial resources available in most Chinese cities only allow the construction of a rudimentary system serving mainly commercial centers and high-income areas. Taking this approach will mean that a large segment of the population will not benefit from the new systems and pollution of surface waters will continue. Phosphorus and nitrogen will be lost as valuable nutrients and end up in rivers and lakes. In contrast to this, the traditional nightsoil management system allows them to be recycled in agriculture and pisciculture.

The question should, therefore, be posed as to whether or not the introduction of conventional sewage systems provides an appropriate and sustainable solution for the China's urban population of approx. 360 million. This is the main purpose of a study financed by SDC (Swiss Development Cooperation) and being conducted by EAWAG's Department for "Water and Sanitation in Developing Countries (SANDEC)" in close collaboration with the World Bank, the Swiss Tropical Institute in Basel and local consultants. A concrete example is being studied to determine whether the current system should be discontinued for hygienic reasons, or whether the implementation of specific technical and non-technical measures could lead to an adequate improvement of the situation and offer a real alternative to conventional sewage treatment, at least on a short- and medium-term basis. This study is being carried out in the Hubei Province and is part of a planned World Bank project. Close collaboration with a World Bank project should ensure rapid and efficient practical implementation of the results.

Is an Improvement of Traditional Nightsoil Disposal Practices Possible?

In 1994, initial phases of work were comprised of the following substudies:

a) Epidemiological studies on the public health risk from existing excreta disposal practices.

b) A market study on the developmental trend of the demand and use of fecal sludges in agriculture and pisciculture.

c) A sociocultural study on health and hygiene education and its

The World Bank

The World Bank, formed by the International Bank for Reconstruction and Development (IBRD) and the International Development Association (IDA), is a multilateral development institution. Its aim is to promote economic and social progress in developing countries through financial and technical support, mainly for specific projects of the public and private sector.

Fecal sludge used to fertilize a vegetable field in China.

causal relationship with the unhygienic nightsoil collection and reuse practices.

d) A study on a gradual improvement of the current situation with the implementation of technical solutions.

Some of the results obtained from these initial investigations are as follows:

- The rate of worm infections among farmers and field workers in direct contact with nightsoil was indeed higher than in the control sample; however, the personal hygiene behavior was identified as being equally important in determining the actual health risk. Improved hygiene education and strict adherence to basic hygiene behavior could, therefore, significantly reduce the risk of infection.
- The farmers have expressed their desire to continue using nightsoil and fecal sludges on their fields and in fish ponds. Since the demand is generally greater than the supply, nightsoil and fecal sludges are often directly collected from the "producers", and the prescribed 30-day storage period is ignored. In areas where nightsoil is strongly diluted with flush water, the farmers prefer to use chemical fertilizers as their source of nutrients. This seems to be related to the fact that the transport and handling of diluted fecal sludge is more difficult and costly, and its application cannot be targeted to individual plants.
- Public health and hygiene education varies significantly among the different population groups; however, the farming population is the most neglected group with regard to health and hygiene education.
- Existing septic tanks and sludge storage tanks are generally undersized and poorly maintained, if at all. The wastewaters and fecal sludges are thus practically untreated when discharged into surface waters or used on agricultural fields. Relatively simple construction and operational improvements of existing installations as well as the introduction of new processes (e.g., septic tanks with anaerobic filters, joint composting of fecal sludges and domestic refuse, etc.) could significantly improve current sanitary and environmental conditions without significantly altering the existing system.

Planned Pilot Activities

In the second phase of study curently underway, specific pilot activities in two selected cities (Huangshi and Yichang) shall examine suitability and efficiency of gradual improvement measures regarding traditional nightsoil disposal. The quality of the effluent, as well as the fecal sludges produced in correctly dimensioned and operated "traditional" installations, shall be determined. The capacity to increase the efficiency by simple modifications and additions to the existing installations will also be examined. Two key questions remain in this context:

1) Can the wastewaters primarily originating from households be treated by simple (decentralized) technical measures in order to be discharged "without damage" into surface waters?

2) Can the hygienic quality of fecal sludges used in agriculture and pisciculture be improved by simple technical and operational measures to reduce the risk of disease transmission to an "acceptable level"?

Only scientifically sound answers to these questions will allow us to determine whether the improved traditional nightsoil disposal system in China offers, at least on a short- and medium-term basis, a real alternative to conventional sewage systems. The subjective criteria "without damage" and "acceptable level" have been used quite deliberately in the above questions since the criteria for assessing improvement measures should primarily be based on the current hygienic and environmental situation. The choice of standards that are too ambitious, which are not realistic for socio-economic reasons, have always proved counterproductive.

Roland Schertenleib, SANDEC
(Sanitation in Developing Countries, formerly IRCWD)

Research

EAWAG Seminar of 15.3.95

Pesticides in the Atmosphere

Storm Water

The regulations governing the discharge of wastewater allow rainwater with low levels of contamination to percolate into the soil, in order to avoid unwanted dilution in combined sewer systems. The objective of such efforts is to insure that within 15 years sewage treatment plants will no longer be adversely affected by the continuous inflow of uncontaminated wastewater.

Questions arise as to whether or not the percolation of storm water (rainwater runoff from sealed surfaces) is a suitable means of municipal drainage and if the soil and ground water will become severely contaminated with organic material. If so, then suitable measures must be proposed to reduce the levels of identified contaminants.

The input and infiltration processes for selected plant protection agents (PPA; a synonym for biocides and pesticides) are being investigated in a Ph.D. dissertation entitled "Organic Compounds in Storm Water". To date, the project has focused on the identification of various triazines in rainwater and in runoff from roofs (Fig. 1).

New data were presented at a recent meeting of researchers which allowed discussion of questions concerning the most important input processes. The meeting benefited from the presence of colleagues from the chemical industry (Messrs. Steinemann and Stamm, Ciba, Basel) and from atmospheric physics (J. Stähelin, Dept. of Atmosphere Physics, Swiss Federal Institute of Technology, Hönggerberg, HPP). The titles of the papers presented are given in Table 1.

Triazines in the Environment

As the most important representatives of the class of the triazines the compounds simazine, terbutylazine and atrazine (together with its degradation products deethyl atrazine and deisopropyl atrazine) were sampled. Atrazine use is now subject to various restrictions in Switzerland. For example, it can only be used against weeds in corn production, the application rate is limited to 1 kg per hectare per year, and it can only be used until 30 June. As a result, the quantity of atrazine in use has dropped by about 50% in recent years to approximately 60 metric tons for 1994 [1]. Since under some circumstances appreciable quantities of pesticides can enter the atmosphere during spraying and through evaporation, triazines are still of relevance with respect to their presence in the atmosphere and in rain.

Summer Rain with High Atrazine Values

While most other PPAs appear only sporadically and in varying concentrations in rainwater throughout the year, the triazines are detected almost exclusively during the application period (spring/summer). The concentrations measured in rainwater (see Fig. 2) are in general agreement with those reported by other investigators (e.g., [3, 4]). Still, the most important representative of this class, atrazine, reaches values of up to 150 ng/L in rainwater, clearly exceeding the maximum limit of 100 ng/L in drinking water.

Pesticides in Storm Water

To date, there have been very few studies of organic substances in the runoff from roofs. Förster [2] studied various overall parameters as well as the runoff characteristics of polyaromatic hydrocarbons, organochloride pesticides and nitrophenols from model roofs. The "first flush" (peak concentrations in the first phase of roof runoff), a phenomenon which he often observed, was also seen with

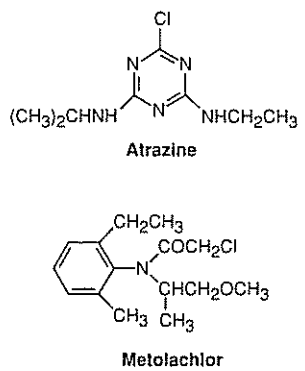


Fig. 1
Two important representatives of the triazine and acylanilide pesticide classes: atrazine and metolachlor.

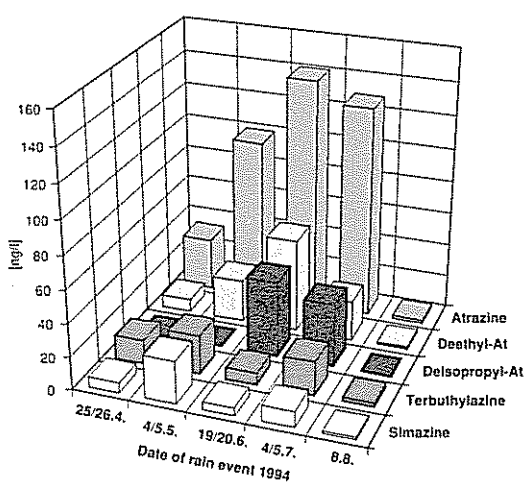


Fig. 2
Triazines in rain: the Tüffenwies site in 1994. The measured concentrations clearly mirror the period during which pesticides were applied. In Switzerland, atrazine can be sprayed only until the end of June.

1994 Graduate Student Awards in Environmental Chemistry

The Division of Environmental Chemistry of the American Chemical Society has selected Franz-Günter Kari, EAWAG, to be given a Graduate Student Award, for his thesis work on *speciation and phototransformation of the organic complexing agent EDTA in sewage treatment and in surface waters.*

the triazines (see Fig. 3), but was dependent on characteristics of the roof. A flat roof with a humus layer, for instance, does not exhibit the characteristic concentration peaks at the onset of rainfall typical of steep-pitched or clay tile roofs.

A Proven Need for Research

In principle, there was consensus at the meeting about current gaps in our knowledge and the need for further research. The fate of PPAs in the atmosphere is to a large extent still unknown. Key aspects to be clarified include their distribution, transport, degradation kinetics and identification of metabolites. These processes cannot be understood simply by sampling rainwater, but must be studied experimentally in controlled laboratory systems and through systematic studies using the individual atmospheric phases (gas, liquid and particle phases).

The meeting confirmed that the study of PPAs in surface waters is a very timely topic. A few months ago, a number of European countries submitted an application with the EU to conduct a large scale project to monitor PPAs in rainwater. The meeting enabled contacts to be forged with scientists involved in that project. In addition, agreements were reached about the further exchange of information.

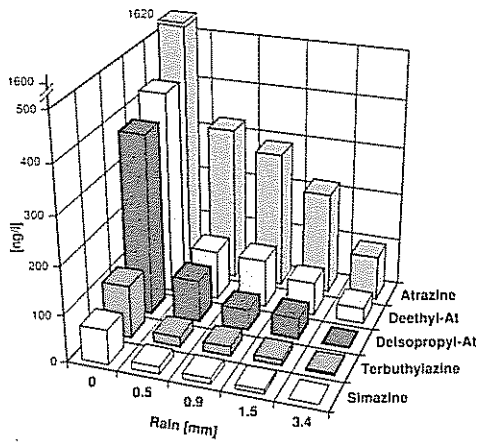


Fig. 3
Triazine in runoff from a steep-pitched roof on the Tüffenwies site at the end of June 1994. The compounds show a pronounced "first flush" behavior, with considerably elevated concentrations with the onset of rainfall.

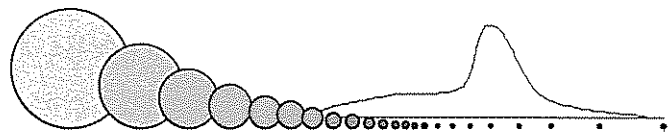
Franca Grüebler is presently integrating some representatives of both the acylanilide and the phenoxyacid class – which are also found to some extent in rainwater – into the analysis of triazines. A sequential rain sampler will soon be available which will allow characteristics of the deposition of the substances under study to be estimated. The construction of a sampling shaft in the percolation plant of the central operations unit of Migros in Winterthur this autumn will allow in situ sampling of percolation waters.

Thomas Bucheli, Stephan Müller, René Schwarzenbach

Name	Title
Stephan Müller, Organic Environmental Chemistry, EAWAG	FoSP/ Percolation of Storm Water
Thomas Bucheli, Organic Environmental Chemistry, EAWAG	Organic Compounds in Storm Water
Bettina Gath, Center for Environmental Research, J. W. Goethe University, Frankfurt	Deposition Monitoring of PPAs
Dietmar Gortschild, Federal Biological Office for Agriculture and Forestry Department for the Licensing of Pesticides, Braunschweig	PPAs in Precipitation
Jürgen Förster, Chair of Hydrology, Bayreuth University	Roof Runoff of Environmental Chemicals

Table 1
Papers presented at the meeting on 15 March 1995 (PPA = biocides and pesticides).

[1] Bucher, D. (1994), Wie man das Klima entgiftet – Ciba, Produzentin von Atrazin, schränkt den Einsatz ihres Pflanzenschutzmittels selber ein. Zürich, CASH 30/94.
[2] Förster, J. (1993). Dachflächen als Interface zwischen atmosphärischer Grenzschicht und Kanalsystem: Untersuchungen zum Transportverhalten ausgewählter organischer Umweltchemikalien an einem Experimentaldachsystem. Dissertation, Bayreuth.
[3] Gath, B., Jaeschke, W., Kubiak, R., Ricker, I., Schmider, F., and Zietz, E. (1993). Depositionsmonitoring von Pflanzenschutzmitteln: Teil 2 Süddeutscher Raum. Nachrichtenbl. Deut. Pflanzenschutzd., 45, 134–143.
[4] Siebers, J., Gottschild, D., and Nolting, H.-G. (1994). Pesticides in Precipitation in Northern Germany. Chemosphere, 28, 1559–1570.



Particle Analysis at EAWAG

Particles play an important role in the environment in very different ways: mass transfer as particulate matter in bodies of water (e.g., erosion and sedimentation), particles as carriers of numerous substances, and reaction sites for microbiological reactions on particle surfaces. A knowledge of particle size distribution is a prerequisite for the study of any of these phenomena.

During the period when research mainly concentrated on the "particulate" range (>1 mm), sieving and filtration methods were sufficient to enable qualitative statements about the distribution of particle mass. Research today, however, focuses increasingly on colloids (<1 mm), since this range is the definitive one for surface reactions. This, together with the need to make quantitative statements about colloids, means that higher demands are placed on particle analysis.

Efforts were made at an early stage in industrial process technology to find suitable methods for determining particle distribution. The distribution of grain size is an important parameter in a large number of processes since size is a primary determinant of the properties of products (paints, cosmetics, foods, etc.). The invention of the laser resulted in the application of an increasing number of optical measurement methods (i.e., scattered and diffracted light analysis). Industrial samples do not generally prove too much of a problem since the refractive indices of the materials are known, and the particle concentrations are either sufficiently high, can be selected, or are extremely low (clean room monitoring). Furthermore, the manufacturing processes are often designed to yield particles which are uniform and of just one size.

The picture is completely different in environmental research where the particle sizes in most cases span a very wide range. The particle concentration in surface waters is usually very low, and we have only a vague idea about the composition of such particles. Consequently, the determination of colloids in the natural environment can seldom be performed as a matter of routine and remains a challenge.

EAWAG has maintained a particle laboratory since 1972 which is responsible for the physical characterization of colloids in the environment. The laboratory was set up to resolve engineering problems and now undertakes particle analysis for all EAWAG departments. The laboratory was managed by Anna Vagenknecht for about 15 years. She more or less laid the foundation for the new laboratory through the introduction of the BET (Burnauer-Emmet-Teller method) of surface determination and the development of a flow-laser particle counter. Daniel Kobler assumed responsibility for the laboratory in November 1993. Particle analysis research was intensified after a move to another lab room within EAWAG and an increase in the range of apparatus in the Spring of 1994. In addition to the instruments installed directly in the laboratory, EMPA and ETH instruments are now also available.

The most suitable measurement methods and appropriate instrumentation are used in projects spanning EAWAG's entire research realm. When a method is well matched to the properties of a given sample (i.e., concentration, particle size range, sample quantities, etc.), particle determination is generally a simple procedure. In situations in which samples are more problematic, test measurements are often carried out under different conditions and using different systems. In some cases, a successful measurement is only possible if the results of all stages – from sampling to the graphic presentation of results – are optimally matched to one another.

The particle laboratory is responsible for a wide range of activities, including maintenance of the laboratory and instruments and ensuring conformance of the various measurement methods to relevant quality standards. Similarly, general information about new methods and instrumentation for particle analysis are also acquired and contacts maintained with other institutes and firms active in this area of work.

*Daniel Kobler**

The following methods of particle analysis are currently available:

- Flow-laser particle counter with automatic sample dilution (PMS; 0.2–150 mm)
- Laser particle counter for smaller sample quantities (Galai CIS; 0.5–150 mm; ETH-ERDW)
- Laser scattered light analysis with Photon Correlation Spectroscopy (Malvern ZetaSizer; 5–5000 nm)
- Laser diffracted light analysis (Malvern MasterSizer X; 0.1–2000 mm; EMPA)
- Determination of zeta potential by Laser-Doppler Analysis (Malvern ZetaMaster)
- Determination of the specific surface by the BET Method (Nitrogen adsorption; Carlo Erba)
- Sedimentation Analysis (SediGraph; 0.1–300 mm; KB)

* Daniel Kobler is an engineer specializing in electronics, instrumentation and control. He has a postgraduate degree in Biomedical Technology and several years of work experience. He has been with the EAWAG since November of 1993.

Arnold Hörler †

Professor Dr. h.c. Arnold Hörler died on 5 March 1995 at the age of 92. He was a pioneer in urban water resources management and water pollution control in Switzerland and made many valuable research contributions during his lifetime.

From 1948 to 1973, he was a lecturer in waste technology for civil engineers at the ETH in Zürich; from 1963 onwards, an honorary professor. Many engineers will remember him as a committed teacher, an outspoken critic and a modest colleague. His lecture notes on "sewerage" have become a standard and form the basis for urban wastewater management in Switzerland.

At the time a partner in an engineering firm, he was appointed Head of the Technical Department of EAWAG in 1954. He was awarded an honorary doctorate by the Hanover Technical University in 1967.

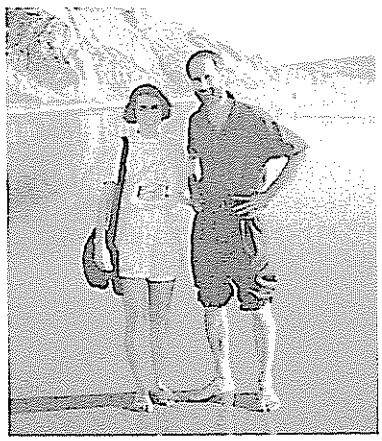
Arnold Hörler was the initiator and a founding member of the VSA (Swiss Water Pollution Control Association). He successfully combined his extensive practical experience with the latest research findings. Engineers from beyond the Swiss borders will remember Arnold Hörler as one of the "old masters" of wastewater technology.

Willy Gujer

Professors

From Lake Lucerne to Lake Superior

Noel Urban and Judith Perlinger have both worked at the EAWAG Research Center for Limnology in Kastanienbaum near Lucerne since 1990. Dr. Urban undertook postdoctoral research in biogeochemistry, studying the sulfur cycle in various Swiss lakes. His studies have demonstrated that small-scale redox cycles close to the sediment surface greatly promote sulfate reduction. He has been a Humboldt Fellow at the Geo-ecological Institute of the University of Bayreuth in Germany since March of 1994.



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Dr. Perlinger's main research interest is the behavior of xenobiotic compounds in aquatic systems. She completed her Ph.D. at the EAWAG in 1994. Her work concerned the reduction of polyhalogenated alkanes by electron transfer mediators in aqueous solution. She also worked as a postdoctoral research associate for a short time in René Schwarzenbach's laboratory.

In May of 1995, both Urban and Perlinger were appointed assistant professors in the Department of Civil and Environmental Engineering at the Michigan Technological University. Their research will focus on the environmental behavior of xenobiotics and biogeochemical material cycles. They will lecture in aquatic chemistry, organic environmental chemistry and biogeochemistry.

Dual function

Since the summer of 1994, Carlo Jaeger has combined his position as Head of EAWAG's Department of Human Ecology with an appointment as Professor of Sociology at Darmstadt University in Germany (Technische Hochschule Darmstadt, THD).

Carlo Jaeger obtained his undergraduate degree in sociology from the University of Berne in 1972. He completed his doctoral work in economics at J.W. Goethe University in Frankfurt in 1979. In 1992, he was appointed senior lecturer in human ecology in the Department of Natural Environmental Sciences at the Swiss Federal Institute of Technology (ETH) in Zürich.

His dual functions are governed by a cooperative agreement similar to that of ETH professors who also hold positions at the EAWAG. The arrangement allows students with a diploma in the social sciences to write doctoral dissertations with mentors in the Human Ecology Department. This would only be possible at the ETH as an exception, where a diploma in the social sciences cannot be obtained.

Professor Jaeger's courses at THD focus on questions of environmental management and regional development. They are intended for students in the social sciences as well as other disciplines such as industrial engineering.

Carlo Jaeger may still be reached in the Department of Human Ecology at EAWAG. His Darmstadt address is:

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