EAWAG news

38 E August 1995

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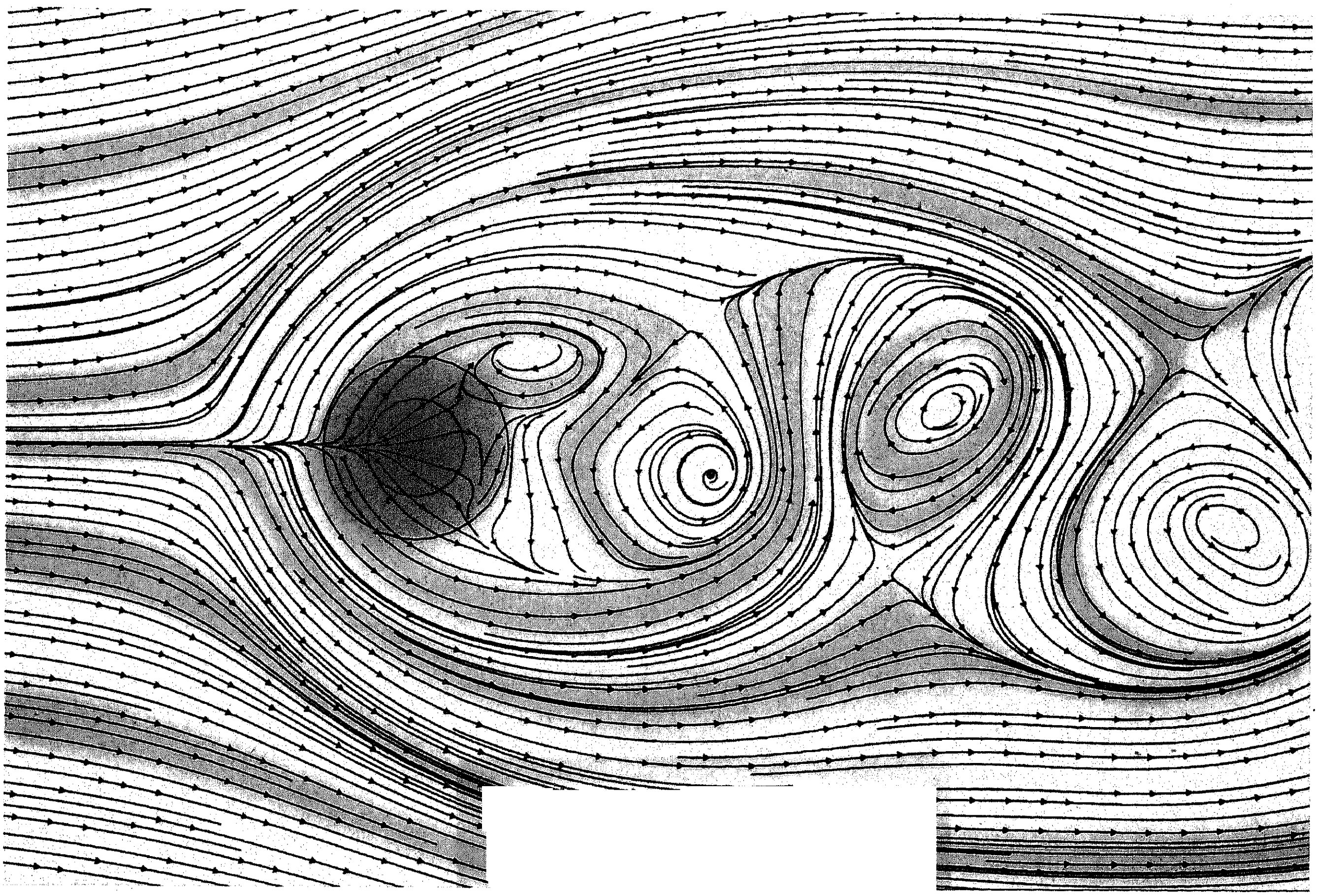

EAWAG

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Title page picture
The cover picture shows air currents around an idealized mountain. In the lee of the "ordered" currents, "chaotic" turbulence occurs (seen from above: cf. Climate Change and Alpine Regions by Urs Dahinden).

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Stefan Wey

Dear reader

Over the past several years, EAWAG has staged an annual Info-Day *(Infotag).* The planning process begins in the spring, gains momentum during the summer months and culminates in the conference in September. The system functions on a wide range of levels: A theme is first developed encompassing a wide range of possible topics. The contents are eventually agreed upon and arranged in a logical sequence. Finally, in the demanding concluding phase, the subject matter is coordinated and checked for its practical relevance. The visual presentation of the material frequently gives rise to lively debate that offers great scope for mutual constructive criticism. Since technical developments are currently offering more and more exciting possibilities of presentation, we are also constantly having to justify the expense involved.

However, this stimulating process is not always characterized by an atmosphere of constant and complete harmony, and tempers can sometimes flare. Tolerance, energy and personal commitment are demanded from all involved. The title of the conference for instance usually provokes endless discussions. It should be succinct, related to the theme, effective in media terms, appealing and trip lightly off the tongue. But it's not always easy to express scientific terms in media-friendly language.

From July onward, a hive of activity prevails throughout the organization. Behind the scenes, people are telephoning, negotiating, writing and ordering. After all you can't hold a conference without coffee and *"Gipfeli"* (croissants) or a book table and media conference. Everything has to function smoothly, not least the temperamental overhead projectors.

On the big day, the atmosphere resembles that of a gala night at the opera – even the most experienced speakers are slightly nervous, and that's as it should be. Tension, ambiance and joy are closely intertwined and fortunately result in ideal conditions for presenting effectively the technical messages.

The scientists are asked to present their results in comprehensible form and to convey their own enthusiasm for their work to the audience. Their efforts, if successful, considerably enhance the effect of other public relations activities and lead to positive feedback: the participants obtain a response from their audience and recognition for research that is not always readily understood.

Theresa Büsser

Theresa Büsser
Public Relations EAWAG

Jürg Beer and Stephan Baumgartner

Climate Information from Polar Ice Cores

Jürg Beer

"Man is changing the climate" is a common phrase. The climate has, however, also been changing for a long time without human influence. How can we distinguish between natural and anthropogenic causes of change? Data from natural archives can be useful in finding answers to the burning questions of global change.

Natural Climate Changes

The climate is strongly determined by the short-term regular rotation of the Earth around its own axis, the diurnal cycle, and its orbit around the sun, the annual cycle. Disturbances of the Earth's orbital parameters caused by the other planets over longer periods of time can be calculated for millions of years. According to the theory of Milanković, they lead to climate changes with periods of approximately 100'000, 40'000 and 20'000 years [1].

In contrast, local weather conditions largely show chaotic behavior and cannot be forecast more than a few days in advance, even with the best available computer models.

Human Influences

The industrial revolution in this century has created a totally new type of situation for both nature and mankind. Whereas climate changes could be regarded as natural processes in the past, we are now at a point where we should ask ourselves whether the climate is not being influenced over a long period of time by the increasing interference of mankind in the environment – with all the negative consequences which are linked to every abrupt change in environmental conditions. A typical example for the significant interference of mankind in natural systems are disturbances in geochemical cycles. As a result of the more intensive combustion of fossil fuels large amounts of carbon dioxide (CO_2) have been released into the atmosphere during the past decades, which has lead to a marked global increase of this greenhouse gas. This has been corroborated by well-known measurements from Mauna Loa (Fig. 1). At the same time mankind began to produce increasing amounts of new chemical compounds which do not occur naturally, and to store them in disposal sites, where their long-term fate in the environment is either not yet or only insufficiently known.

Natural versus Man-made Climate Changes

In this context there are two basic questions: do the human activities mentioned above lead to climate changes

Environmental Archives – Order and Chaos

"Environmental Archives – Order and Chaos; Natural and Man-Made Deposits as Sensitive Indicators for Environmental Development" was the theme of last year's "Infotag 1994", an event arranged as part of the PEAK series of applied EAWAG courses. This issue contains the edited papers of this meeting. German and French versions are also available.
Lake sediments, polar ice masses, soils produced by weathering and the large numbers of man-made landfills were the types of environmental archives dealt with at the EAWAG Info-Day held on 20 September 1994. While artificial landfills tend to show a chaotic structure, natural deposits can be highly organized, storing a great variety of information on past environmental conditions and thereby giving us some insight into the history of our earth. The knowledge of this history can help us assess the impact of current human activities and draw useful conclusions for predicting the future. Both are essential when drafting future guidelines for sustainable development.

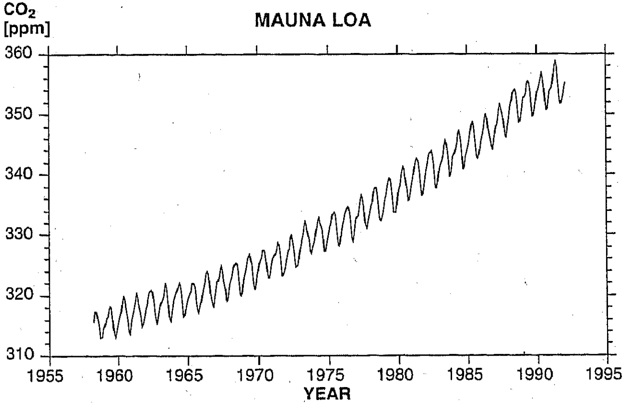

Fig. 1
Measurements of the CO_2 concentrations in the atmosphere show a definite increase as a result of the combustion of fossil fuel [2].

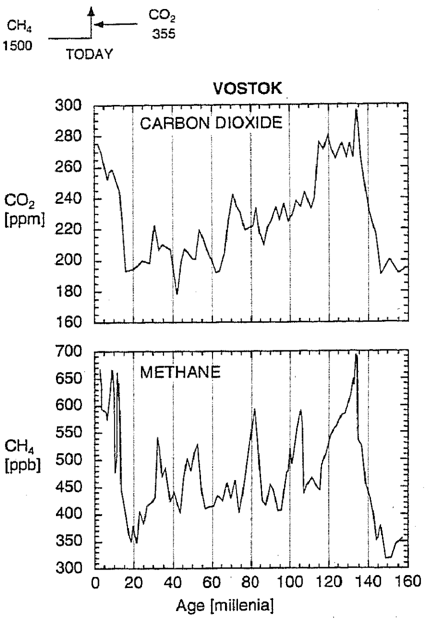

Fig. 2
Analysis of the gas bubbles in the ice core of Vostok clearly reveal fluctuations in the greenhouse gases CO_2 and CH_4 during the past 160'000 years [3,4]. Current concentration levels (355 ppm CO_2 and 1500 ppb CH_4), however, were never attained by far.

and, if so, how can we distinguish them from natural changes?

Apart from such basic questions there are other very practical ones. If one assumes that, as a result of human activity (greenhouse effect), the climate is becoming warmer, an increasing frequency of extreme precipitation occurrences, including flood waters, and a higher incidence of avalanches and landslides can be expected. Precise predictions are, however, impossible because of the chaotic nature of the climate system.

How can we determine whether the global warming observed at this point in time is anthropogenic or whether it is just a natural fluctuation? One possibility is to try to describe the current weather developments as realistically as possible by utilizing a large amount of direct measurements and by modelling the physical, chemical and biological processes involved. In this way possible future developments can be simulated, although the inordinate complexity of the climate system makes this task extremely difficult.

A further complementary approach which can yield information on the extent of anthropogenically-caused climate changes is the historical reconstruction of the climate and its variability in the past when the influence of mankind was certainly still negligible.

Environmental Archives – the Key to Understand Global Change

Information on the historical course of the climate can either be gathered from direct and indirect human records or from natural archives. From the time that mankind has made use of permanent written records there has been some direct recording of the weather, but also indirect information e.g. crop yields, which reflect climate changes to some extent. In addition to these man-made sources of information, there are also natural archives in our environment whose information we have continuously learned to decipher more precisely with the use of ever more sensitive and refined methods.

Lake sediments, which are continuously formed by precipitating particles, provide an important record. The type, size and composition of the particles as well as the biological structures stored in it reflect the climate conditions which prevailed at the time the sediment was formed (see contribution by Sturm and Lotter).

On high mountains and in polar regions where the temperature lies below freezing all year round, the snow accumulates continuously and slowly forms an ice record through the pressure of overlying layers. Thus samples of all solid, liquid and even gaseous components of the atmosphere are trapped in the ice. Investigations on gas bubbles in the ice core of Vostok (Antarctica) suggest that, although the contents of the greenhouse gases CO_2 and CH_4 have been fluctuating in the atmosphere during the past 150'000 years, their present concentrations are by far higher than anything measured during this period! (Fig. 2)

Interestingly enough, the fluctuations in the concentrations of the greenhouse gases seem to almost parallel those of the temperature for the observed period. Data on the latter can be gathered by using measurements of the isotope ratios of $^{18}O/^{16}O$ in the ice. This ratio changes as a result of temperature-dependent fractionation effects during the condensation of water vapor. The high-resolution $^{18}O/^{16}O$ measurements made on the ice core from Summit in Greenland show very impressively how unstable the climate was during the last glaciation (between ~100'000 and ~10'000 years before present) and how comparatively stable it has been since then (Fig. 3).

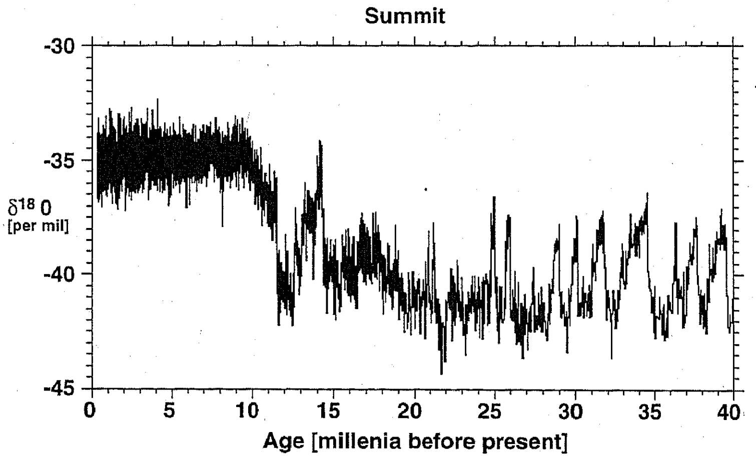

Fig. 3
The change in the $^{18}O/^{16}O$ ratio ($\delta^{18}O$) in ice (in per mil, relative to a standard value, which represents the average ratio in sea water) reflects the temperature (more negative $\delta^{18}O$ values indicating a colder climate). Whereas between 40'000 and 10'000 years before present the temperature in central Greenland was fluctuating irregularly, it seems to have remained relatively stable during the past 10'000 years [5].

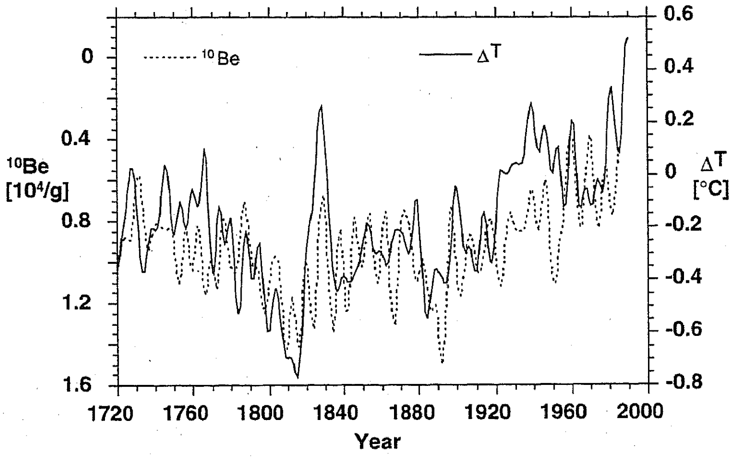

Fig. 4
The relatively good agreement between the ^{10}Be concentration measured in Greenland ice and the average temperature of the northern hemisphere seems to suggest a connection between solar variability and climate change [6].

The Role of the Sun

Further information from the ice, which can only be deciphered since the development of the extremely sensitive accelerator mass spectrometry method, concerns the sun. The sun is the engine which drives the climate. Even minimal changes in the amount of solar radiation reaching the Earth's surface can lead to corresponding changes within the climate system. An example: even minimal disturbances in the parameters of the orbital parameters of Earth caused by the other planets are believed to be the cause for the observed cyclical changes between warmer interglacial and colder glacial periods. (Theory of Milankovič).

Since satellites observe the Sun from above the atmosphere we also know that the amount of radiation from the Sun fluctuates with an amplitude of tenth of a percent in phase with the so-called 11-year sunspot or Schwabe cycle. This relatively new result has had far-reaching consequences; among others it means that not only is the solar constant not really constant, but also that, apart from fluctuations in greenhouse gases and aerosol contents in the atmosphere, changes in the solar constant have also to be considered as a potential cause of climate fluctuations.

How Constant is the Solar Constant?

How can we know whether and to what extent the solar constant has changed in the past? Here the archive ice can yield information once again, albeit rather indirectly. During periods of increased solar activity when the sun shines more "warmly" it also emits more solar wind which fills the entire solar system. Magnetic fields frozen into the solar wind deflect the charged cosmic ray particles and thus reduce the cosmic ray flux. As a result, less particles penetrate into the Earth's atmosphere where they generate radioisotopes such as ^{10}Be and ^{14}C through nuclear reactions. ^{10}Be becomes attached relatively easily onto atmospheric aerosols and eventually reaches the earth through precipitation (rain, snow), some also being stored in the ice. So we can assume that during periods of increased solar activity less ^{10}Be is produced as a result of the shielding effect of the solar wind, causing the ^{10}Be concentration in the ice to decrease. Conversely, calm solar periods lead to an increase in the ^{10}Be concentration. However, we have to keep in mind that the atmospheric transportation and deposition processes can also cause changes in the ^{10}Be concentration in the ice and that, therefore, a perfectly clear reconstruction of the history of solar activity is not unproblematic. Nevertheless, the results have been encouraging so far.

Assuming that the connection between the solar constant and solar activity which has been measured by satellites during the past 15 years was also valid during the past, then we can expect cooler climate conditions during times of less solar activity. If we compare the ^{10}Be concentration record measured in an ice core from Greenland with an average temperature curve compiled from many different data sets for the northern hemisphere, we find an agreement (Fig. 4) which is good enough to at least justify the continuation of these investigations which are still in their preliminary stage.

Summary – a Warning

Summarising we can say that the records in natural archives demonstrate very clearly that the climate has always been changing, sometimes even quite dramatically. However, they also show that the concentrations of greenhouse gases in the atmosphere have currently reached levels which are far higher than those recorded for the past 200'000 years. This, as well as the fact that we do not yet know well enough what consequences our actions may have, should act as a warning to treat our environment more considerately in the future.

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Michael Sturm and André F. Lotter

Lake Sediments as Environmental Archives

A Means of Distinguishing Natural Events from Human Activity


Yvo Weidmann

Michael Sturm

Assume that the authorities of a Swiss mountain canton would have to estimate the frequency of extreme floods over a time scale of decades and centuries without adequate instrumental measurements stretching back over such a long time period. Assume further that a local community, concerned about the state of a polluted lake, is discussing remedial measures and therefore needs to know the history of the lake in the absence of studies of the relevant water quality. In both cases the environmental information stored in the sediments of the lakes could provide solutions to these problems

Sediment Archives

Similarly to ice cores (see the contribution of Beer and Baumgartner), lake sediments represent ordered natural archives of past environmental conditions. Whereas ice cores store primarily physical signals of the global atmosphere, sediments additionally store information on a whole range of biological, geochemical and anthropogenic environmental processes. Fig. 1 shows (schematically) a number of such processes which influence the deposition of lake sediments.

Allochthonous Material

By far the greatest amount of *allochthonous* (i.e., formed outside the lake) material enters a lake via rivers and streams. It is deposited in the lake in

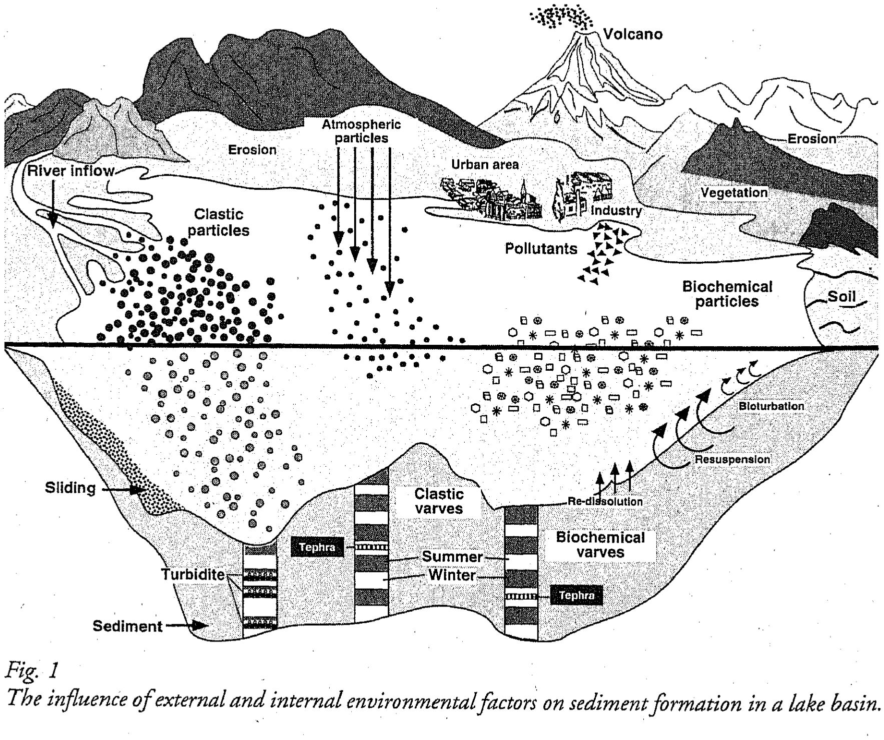

Fig. 1
The influence of external and internal environmental factors on sediment formation in a lake basin.

characteristic layers, providing information on exceptional events such as floods, mud flows, earthquakes etc. or seasonal fluctuations; alluvial fans and deltas form where the rivers flow into the lake. In addition, allochthonous fluxes enter the lake via the atmosphere as wind-borne, rain-borne or snow-borne particles (pollen, volcanic ash, aerosols etc.), by diffuse inflow (groundwater, soil drainage) or through artificial inflows from sewage systems.

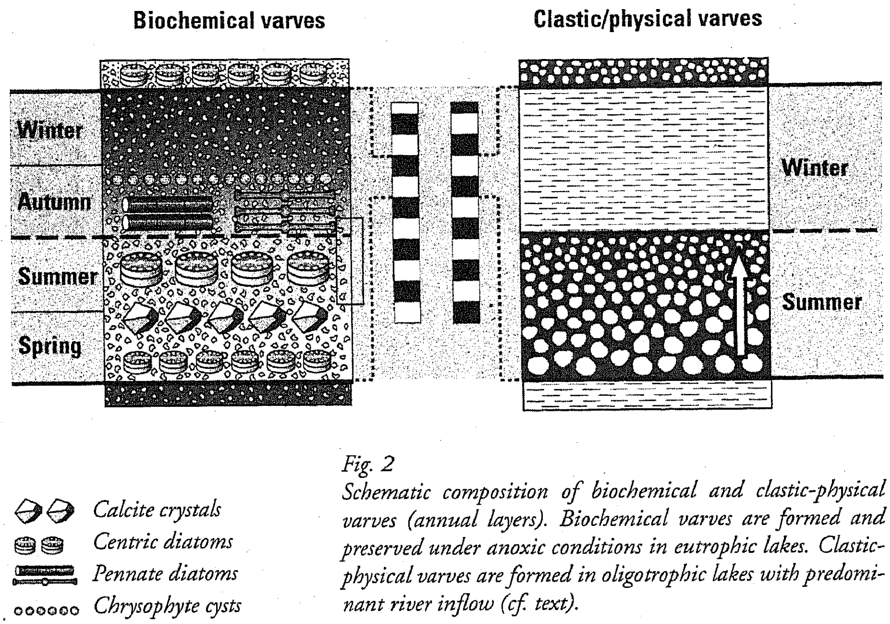

Fig. 2
Schematic composition of biochemical and clastic-physical varves (annual layers). Biochemical varves are formed and preserved under anoxic conditions in eutrophic lakes. Clastic-physical varves are formed in oligotrophic lakes with predominant river inflow (cf. text).

Autochthonous Material

Most *autochthonous* (i.e., formed within the lake) particles are produced in spring and summer by algal growth in the epilimnion of a lake. In addition, sediment formation in a lake can also be influenced by biogeochemical redissolution or precipitation processes or physical displacement processes such as landslides, resuspension or bioturbation (see the contribution of Bloesch and Wehrli).

Annual Lamination (Varves)

Annually or seasonally recurring sediment-forming processes lead under certain conditions to the formation of regularly laminated, light/dark coloured sediments (see Fig. 5). After a Swedish word such sediment structures have been termed *varves* [1]. They represent one year and are therefore exceptionally well suited for accurate dating of sediments. The composition of two of the most important lacustrine varve types is shown in Fig. 2.

Biochemical Varves

Biochemical varves are formed in eutrophic lakes and under anaerobic (oxygen-free) conditions. They are characterised by the seasonal sequence of particles resulting from biological and chemical processes [2, 3, 4]. The spring/summer layers are light coloured due to biogenically precipitated calcite ($CaCO_3$) crystals, which may be up to 40 mm in diameter. Centric diatoms (disc-shaped siliceous algae) are deposited at the same time. Sedimentation of pennate (oblong) diatoms and spherical Chrysophyceae cysts occurs during August and September. The deposits of autumn and winter months are characterised by organic material which is responsible for the dark colour of the "winter" layer of biochemical varves.

Clastic-physical Varves

Clastic-physical varves are formed in inflow-dominated oligotrophic lake basins and result from the seasonal variation in input of solid matter [5]. The dark "summer" layers consist of particles of spring meltwater and of floods occurring during summer, which may transport large amounts of organic material (residues of wood and leaves) to the lake. An upward grading from coarse to fine particles is often developed in the dark "summer" layer. The light, homogenous "winter" layer contains primarily fine clay particles and virtually no organic material. Thus it represents the low sedimentation time of the year.

Palaeolimnology

Characteristic sedimentary features of lake sediments, such as varves, slide deposits and delta sediments, can be supplemented by biological (pollen, diatoms), chemical (nutrients, principal and trace elements) and physical parameters (isotopes) from sediment archives. An integral evaluation of all "palaeolimnological" (i.e., derived from the history of the lake) data provides information on natural processes vs. human activity, as well as on past environmental changes and on the temporal and spatial extent of such changes. Examples are given below, based on sediment studies of Urnersee and Soppensee.

The Urnersee

200m deep Urnersee, with its steep relief and large river inflows, is one of the pre-alpine lakes, which is primarily influenced by physical sedimentation. As it is situated in a tectonically active region with mountain slopes, adjoining glaciers and intensive erosion activity, there occur recurrent natural disasters such as earthquakes, floods or rockfalls in both the catchment area and the lake itself. Such natural events have left characteristic traces in the sediments of Urnersee. The effects of approx. 20 different environmental events have so far been established in sediment cores, which are up to 9m long and represent a time scale of approx. 1000 years [6].

These events include local rockfalls from the Axen (14./15.5.1801) and from Schwanden (8.12.1769) as well as deposits of material from tunnels, which were excavated for road constructions and train tracks between Brunnen and Sisikon (1958, 1951/52, 1862–1864). Regional and global events have also been recorded in the deposits of Urnersee, such as the earthquakes of 1774, 1755 and 1601, and the deposition of radioactive *fallout* products (^{134,137}Cs) following atmospheric nuclear bomb tests in 1963 and the Tschernobyl nuclear reactor catastrophe (25.4.1986).

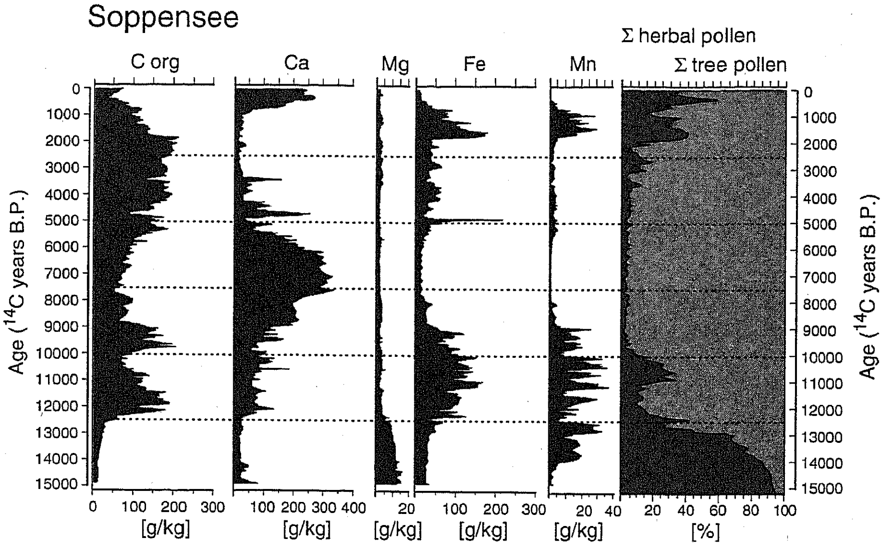

Fig. 4

The sediment archive of Soppensee during the last 15'000 years. The right side of the diagram shows the cumulative percentage of tree pollen and herbaceous pollen. The other curves (from left to right) show the concentration [g/kg] of organic material (Corg), calcium (Ca), magnesium (Mg), iron (Fe) and manganese (Mn).

1987 Floods

The extraordinary rainfall of summer 1987, causing large floods with massive destruction of houses and disruptions of many roads throughout the Alps are clearly documented in the Urnersee sediments. The cost of damage in Switzerland alone was over SFr. 1.2 billion [6]. The valley of the river Reuss in canton Uri was affected for weeks by the floods of 24/25 August 1987. An analysis of the individual flood layers in the sediment cores from Urnersee shows that the Reuss flood in 1987 was not the highest flood in the lake's history (Fig. 3). With its sediment volume of 1 million m³ it is just comparable to the Schächen flood of 31.7.1977. The Reuss flood on 3.10.1868 actually deposited twice the quantity of material (2 million m³) in Urnersee. But the largest flood of Reuss River (2.2 million m³ of sediments) occurred in Summer 1342 when constant heavy rainfall over all of the Alps and over large areas of Europe resulted in catastrophic floods [8]. The Urnersee sediments show that about 10 floods occur every 100 years, but events with disastrous consequences have happened only three times in the last 1000 years – 1987, 1868 and 1342. Nevertheless, floods are of considerable importance for sediment accumulation in Urnersee: the major events shown in Fig. 3 are responsible for over 60-fold the average annual sedimentation of about 100'000 m³.

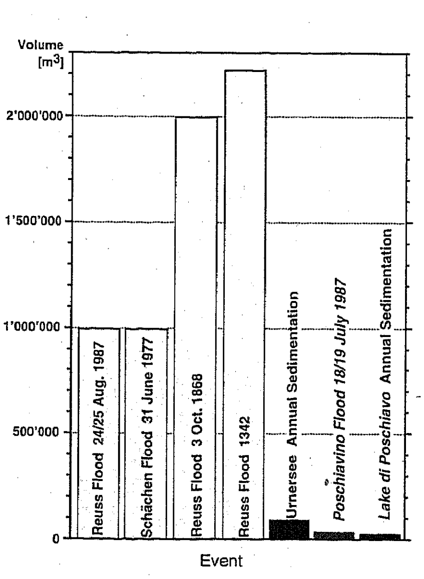

Fig. 3

Comparison of the sediment volumes of large floods of Urnersee during the last thousand years.

Soppensee

Soppensee, a small lake, just one km² large, lies at a height of 596 m above sea level in the foothills of the Alps in the canton of Lucerne. Its 27 m deep basin represents a glacial relict formed during the rapid retreat of the Reuss glacier approx. 15'000 years ago [9]. Approximately 8 m of sediment have been accumulated in Soppensee since. Sediment formation in Soppensee was primarily the result of autochthonous biogeochemical sedimentation processes. The sediments of this small lake are exceptional in many ways and have been the subject of a range of interdisciplinary palaeo-ecological research projects.

15'000 Years of Vegetation History

The sediment archive of Soppensee represents a complete document of environmental history for the past 15'000 years. Evaluation of high resolution pollen profiles showed that after retreat of the glacier the vegetation in the catchment area of the early Soppensee was characterised by a cold-resistant open and treeless vegetation ("tundra"). The subsequent increase in tree pollen 12,700 years ago (Fig. 4) is evidence of a rapid and persistent rise in temperature. This rise was followed by another cold period lasting some 1'000 years, the so-called Younger Dryas, which came to an end approx. 10'000 years ago. Then came the postglacial climatic optimum with a major reduction in herbaceous pollen. The first indicators of human presence around Soppensee are cereal pollen, already present 6'000 years ago. More pronounced effects of human influence on the environment (e.g. through forest clearance) can be observed at the end of the Bronze Age approx. 3'000 years ago. Colonisation of Central Switzerland by the Romans and the associated more pronounced anthropogenic changes in the environment began 2'000 years ago. Evidence for this is provided by the change in the pollen spectra from assemblages dominated by trees and shrubs to assemblages rich in herbs and cereals (Fig. 4).

15'000 Years of Lake History

The dynamic picture of vegetation is supplemented by the signals of different geochemical parameters in the lake sediments. The lake was oligotrophic in its early phase and mainly influenced by the input of allochthonous material. However, some 12'700 years ago there occurred a dramatic change, leading to nutrient-rich, anoxic lake conditions. This development is indicated in Fig. 4 by a decrease of Mg concentration and a simultaneous increase of concentrations of organic C, Ca and Fe. The cold phase of the Younger Dryas, already proved by the development of vegetation, is also recorded in the lake sediments by a distinct reduction in primary production shown as decrease of C_{org} values. Rising temperatures approx. 10'000 years ago again led to more eutrophic, anoxic lake conditions which have persisted until today. Soppensee thus represents an example of natural lake eutrophication which lasted thousands of years and which was to a large extent unaffected by human influence.

Thousands of Annual Layers

The biochemical varves (Fig. 5), stretching back many thousands of years, are the major palaeolimnological attraction of Soppensee. They began to form approx. 12'000 years ago and required eutrophic lake conditions with bottom water free of oxygen for their conservation (see above). Once established that they were real annual layers [4], they were used to extend the ^{14}C calibration curve and to establish an accurate chronology for the Soppensee sediments [10]. No varves are found any longer in the youngest deposits of Soppensee even though the conditions for a formation of biochemical varves are still present: larvae of a *Chaoborus* species destroy the existing varves and thereby provide an example that bioturbation can also occur under anoxic conditions.

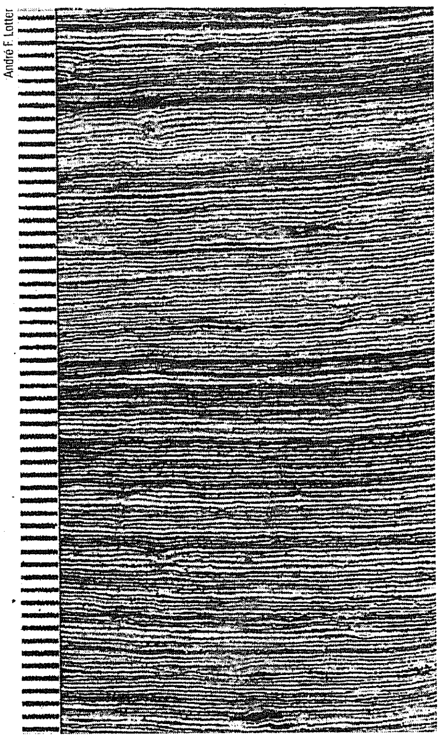
André F. Lotter

Fig. 5
Biochemical varves from the Soppensee. The regular cyclic light/dark annual layering is clearly visible. The scale is in mm.

The Importance of Sediment Archives

The study and interpretation of environmental archives such as lake sediments provide the answers to the questions put at the beginning of this article: the deposits of Urnersee show that extreme events such as exceptional floods in a tectonically active, steep mountain region are rare but not unique. Furthermore, the results of Soppensee show that even several thousand years ago lakes could be naturally rich in nutrients and could develop anoxic conditions. These studies also demonstrate that natural and anthropogenic effects of environmental changes can be distinguished.

- Sediment archives are thus not only an important tool for interpreting environmental processes but also form the basis for
- Evaluating the stability and dynamics of environmental systems;
- Estimating ecological risks
- Planning courses of action, and
- Formulating environmental protection concepts on the basis of a knowledge of long-term natural conditions.

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Jürg Bloesch and Bernhard Wehrli

Formation of Natural Sediment Records

Within geological timescales our lakes will fill up and disappear, as each year several new millimeters of fresh sediment are being deposited on the lake bottom. In this way various types of information about the lake ecosystem and its catchment are continuously being recorded. This article is focused on the formation of sediments and their current function in the cycling of substances within lakes. In order to be able to interpret sedimentary records, we first have to understand the processes of sediment formation.

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Origin and Sedimentation of Particles

As an example we have followed the fate of sinking particles on their way down to the sediment in the 200 m deep southern basin of Lake Zug [1]. The settling particles either originate from the catchment area (allochthonous) or they are formed in the lake itself (autochthonous) (see Fig. 1 in contribution by Sturm and Lotter). Especially during high discharge the inflowing rivers import large amounts of eroded soil particles and nutrients into the lake. The deltas, both large and small, are visible signs of this phenomenon. The material consists mainly of oxides and silicates, apart from plant debris. Additionally, the lake ecosystem produces a "rain" of sinking particles originating from algae and zooplankton, which consists of dead biomass (organic carbon) and freshly precipitated calcium carbonate. In this process diatoms act as crystallization nuclei for the precipitation of calcite, as photosynthesis creates a local supersaturation of calcium carbonate ("biogenic decalcification").

On their way into the permanent sediment record, the sinking particles are subject to various transformations. Processes such as dissolution, precipitation, adsorption (scavenging), coagulation, bacterial decomposition and the formation of aggregates are very effective. The extreme change in the C:P ratio of the particulate material throughout the vertical profile illustrates this fact: in the epilimnion the C:P ratio lies far above that of the algal biomass, which is 106:1; in the hypolimnion, however, it can decrease to 50:1 [2]. On the one hand, decomposition processes cause the sinking particles to release carbon, on the other hand they pick up phosphorus by adsorbtion as well as through attached mineralizing bacteria.

The grazing activity of the zooplankton also contributes significantly to the transformation of particles [3]: the formation of fecal pellets by the zooplankton increases the sinking velocity of algal material. The rate at which particles sink determines their residence time in the water. The settling velocity not only depends on the size, density and form of the particles, but also on temperature, density, viscosity and turbulence of the water. Stokes' basic formula for calculating the sinking velocity can, however, only be applied under certain conditions, as most particles are not simple spheres. Most algae typically sink at the rate of several meters per day [4]. Smaller algae and mineral particles typically remain longer in suspension and sink at the most just a few centimeters to tens of centimeters per day. Thus sinking algae take from several days to weeks to reach the bottom of 200 m deep Lake Zug.

The flux and the decomposition of sinking particles in various water depths can be determined using sediment traps. Most sediment materials of

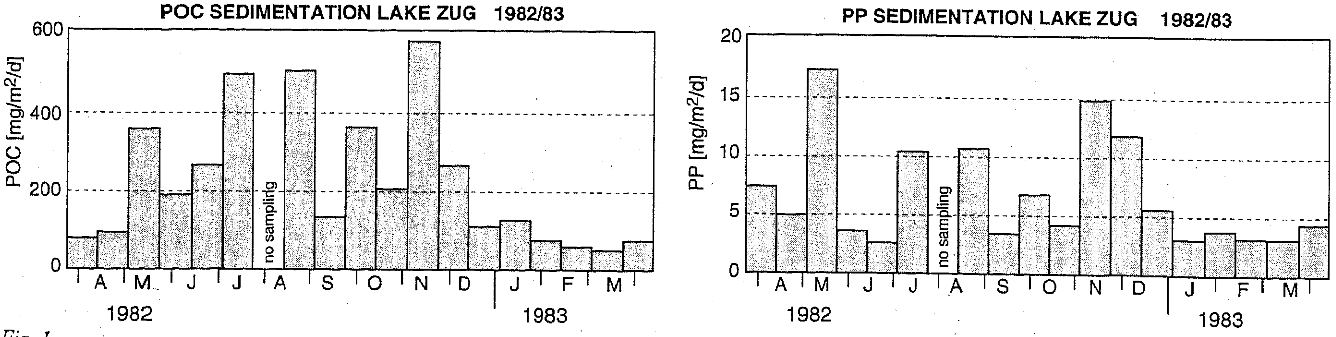

Fig. 1
Seasonal pattern of particulate organic carbon (POC) and particulate phosphorus (PP) sedimentation in Lake Zug, 1982/83. *The highest settling flux was measured during the time of highest algal production.*

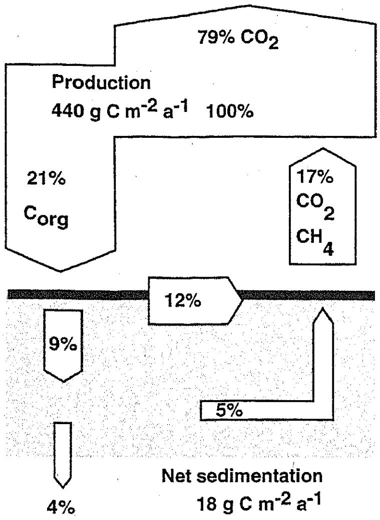

Fig. 2
Production and mineralization of particulate organic carbon in Lake Zug. The processes in the water column and in the upper 15 cm of the sediment are represented schematically.

Lake Zug are produced in the lake itself as typical for most lakes of the Swiss Plateau. Inflowing rivers, which dominate the processes of sedimentation in Lake Lucerne or in the alpine Lake Öschinen [5,6], only play a minor role in Lake Zug. Maximum sedimentation takes place in summer (Fig. 1) when algal blooms occur which, as described above, cause the precipitation of calcium carbonate.

The Sediments as a Layered Reactor

The seasonal variations in sedimentation rates lead to a clear annual layering (varves) of the sediments in eutrophic lakes such as Lake Zug. The ensuing light-colored layer (= calcium carbonate) is the deposit of summer, the dark layer (= organic substance) is the winter layer (see Fig. 4 in contribution by Sturm and Lotter). If the oxygen supply is sufficient at the lake bottom, such annual layers can be disturbed by burrowing worms and insect larvae ("bioturbation"). This is the case in oligotrophic or aerated eutrophic lakes. Furthermore, strong wind events cause waves and internal currents which resuspend sediments in shallow lake areas and wipe out the information of the record [7]. The resuspended sediments are usually transported to the center of the lake where they are redeposited (sediment focusing).

The annual sedimentation rate can be transformed into an annual accumulation rate (Tab. 1) by converting the dry weight of the sedimenting material into fresh weight and volume, taking into consideration the compaction of the sediment [4]. Normally the annual increase in sediment amounts to 3 to 10 mm; the estimated 2.2 mm for Lake Zug thus lie at the lower end of the scale.

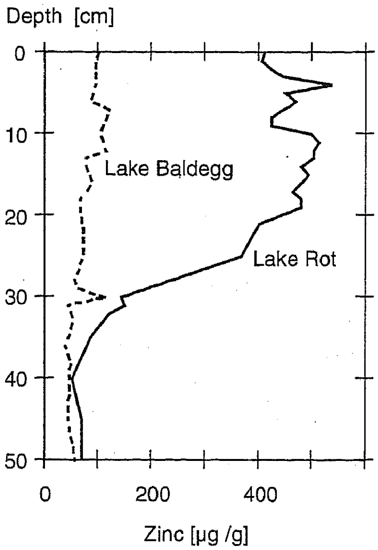

Fig. 3
Zinc concentrations in the sediments of Lake Baldegg and Lake Rot.
[Unpublished data from M. Sturm.]

The flux of particulate organic carbon (POC) in Lake Zug can be quantified in the following way (Fig. 2): the primary production amounts to about 440 g C $m^{-2} \cdot a^{-1}$ and is, in contrast to an oligotrophic lake, very high (e.g. Lake Lucerne with about 150 g C $m^{-2} \cdot a^{-1}$ and Lake Öschinen with about 11 g C $m^{-2} \cdot a^{-1}$ [6]). Only around 21% of this production is deposited in the sediment; about 348 g C $m^{-2} \cdot a^{-1}$ already become mineralized mainly in the epilimnetic cycle but also during sinking in the hypolimnion. The POC reaching the sediment is a source of energy and nutrients for the benthic animals and bacteria.

As soon as material is deposited in the sediment, diagenesis begins: the sediments are transformed by chemical and biological processes. By using flow chambers and dialysis plates (peepers) the release of substances from the lake bottom can be measured. Around 57% of the deposited carbon is decomposed by bacteria in the uppermost mm of sediment within 1 to 2 years, a further 24% being decomposed in the depth range of 0.5–15 cm (Fig. 2). Carbon dioxide (CO_2) is formed as a result of the rapid decomposition processes in the upper aerobic regions. The slower decomposition processes in the deeper anaerobic regions produce methane (CH_4). Merely 19% of the deposited organic material, or 4% of the net biomass being produced, are permanently stored in the sediment. Other substances, e.g. the shells of diatoms, pollen, ashes from volcanic eruptions or radionuclides from the atmosphere are more or less preserved in the sediment forming "fingerprints".

Lake Sediments: Chemical Time Bombs or Final Deposits?

Apart from natural particles, heavy metals and organic chemicals from anthropogenic sources are being deposited in the sediment. By investigating pollutants in dated sediment cores the increasing contamination of surface waters can be documented (Fig. 3). Contamination with zinc, for example, mainly originates from galvanized piping and is higher in Lake Rot, i.e. in an urbanized region, than in the rural Lake Baldegg. An obvious question arises: can the sediment be regarded as a time bomb or rather as a final deposit for anthropogenic pollutants? Investigations on release rates in pore water on the lake bottom suggest that most toxic heavy metals remain practically

Sedimentation: dry weight	770 $g\ m^{-2}\ a^{-1}$
Sedimentation: fresh weight (f = 3.3)	2'540 $g\ m^{-2}\ a^{-1}$
Sediment volume (f = 2.9)	2'230 $cm^3\ m^{-2}\ a^{-1}$ = 2.2 mm a^{-1}

Tab. 1
Sedimentation and sediment accumulation in Lake Zug.
(f = conversion factor).

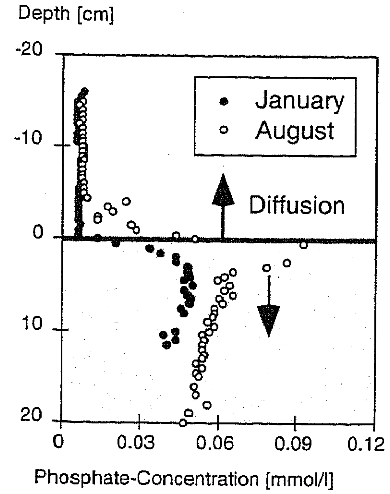

Fig. 4
Phosphate concentrations at the sediment–water interface and in the pore water of the sediments in the northern basin of Lake Zug, 1993.
Redissolution along the concentration gradient occurs all year round. In summer, however, phosphate diffuses both into the overlying water as well as down into the sediment.

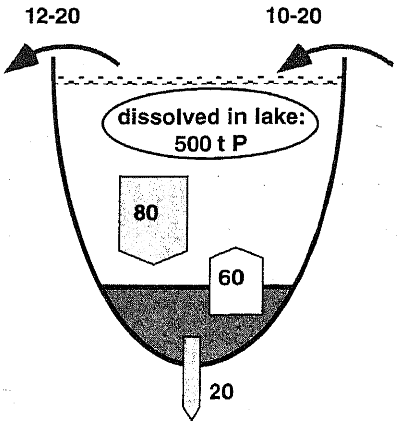

Fig. 5
Phosphorus balance of Lake Zug in tons of phosphorus per year, 1988–1993.
Only about one fourth of the sinking particulate phosphorus is burried in the sediment. The export of phosphorus via the outflowing river and via final deposition in the sediment are around twice as high as the import through inflowing rivers. The current phosphorus content of about 500 tons is therefore slowly decreasing.

irreversibly bound in the sediment. In heavily contaminated sediments, however, these toxic substances can be incorporated by benthic organisms and enter the food chain ("bioaccumulation").

In contrast, nutrients such as ammonium and phosphate can be remobilized at the sediment–water interface. The intensive mineralization of biomass triggers this process. Fig. 4 shows phosphorus gradients in the pore water of sediments from Lake Zug: phosphate diffuses from the sediment into the deep water layer throughout the year. In summer, however, the intense phosphorus release leads to a concentration peak of dissolved phosphorus at the sediment surface and hence to diffusion into the sediment, where precipitation reactions can bind the nutrient in the form of iron(II)phosphate, or vivianite.

While in an oligotrophic lake almost all of the sedimenting particulate phosphorus (PP) is deposited in the sediment, the capacity for the uptake of PP into the sediment is exhausted in a eutrophic lake. Only 20 out of 80 tons of PP that sink to the bottom of Lake Zug every year get burried in the sediment (Fig. 5). Three fourths of the sedimenting phosphorus reaches the deep water of the lake again as "internal fertilizer". The uptake capacity of the sediments cannot be enhanced further, even with internal aeration measures [8]. Internal restoration is not considered for Lake Zug, as the upper 100 m of the water column contain enough oxygen [9]. The redissolution of phosphorus can only be stopped when the sedimentation of PP becomes smaller than the uptake capacity of the sediments. In order for this to occur the phosphorus loading from the catchment area has to be limited. If we succeed in keeping the phosphorus load clearly below 20 tons per year for longer periods of time, the concentration of this algal nutrient should slowly decrease, and so would algal growth and production, and consequently the sedimentation of PP. However, Lake Zug will take about 40 years for this external restoration.

From this overview of the formation of sediment records we can draw the following conclusions: the quantity and quality of the sediment record depends mainly on the production of particles in the lake. The decomposition of organic material and the dissolution of minerals partially "wipe out" part of the information which reaches the bottom of the lake. This decomposition continues in the sediment. Only a small part of the sinking particulate matter remains permanently stored in the sediment. The rest reaches the waters of the lake again in dissolved form.

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Christof Holliger and René P. Schwarzenbach

The Transformation of Organic Pollutants in Oxygen-free Sediments

Christof Holliger

Polychlorinated biphenyls (PCBs), chlorinated solvents, trinitrotoluene (TNT) and numerous other organic pollutants can undergo chemical and biological reduction in anoxic environmental compartments such as sediments and aquifers. The products of such reactions can be non-toxic, better biodegradable or more toxic than the parent compound. An understanding of such redox processes is not only important for assessing the environmental compatibility of organic compounds but also for the development and use of measures to remediate polluted sites.

Innumerable Organic Compounds in the Environment

Increasing quantities of organic compounds, not naturally-occurring, have been released into the environment in recent decades. Approximately 70'000 different synthetic chemicals are currently in everyday use. A large number of these synthetic chemicals (eg., medicines, cosmetics, food additives) do not have a great direct impact on the environment. However, some of these synthetic compounds enter the environment in large quantities, not only through spectacular accidents but also through their direct use in the environment (eg. pesticides) and through inconspicuous diffuse events such as leaks from storage tanks, evaporation etc [1]. Examples of such chemicals are *nitroaromatic* compounds such as the explosive TNT und the pesticide parathion, as well as *halogenated* compounds such as the pesticides lindane and DDT, the solvents trichloroethylene and perchloroethylene and the widely used PCBs. The reductive transformations of both these groups of compounds in oxygen-free (anoxic) compartments of the environment will be discussed in detail below.

"Absence-of-Oxygen" Does Not Mean "Absence-of-Life"

Anoxic conditions are seen above all in lake sediments and polluted aquifers. The absence of oxygen is the consequence of a surplus of degradable organic matter. This excess organic matter is often the result of human activity, for instance too much fertiliser flowing into rivers and lakes or the pollution of groundwater by leachates from landfill sites. Although many forms of life can only survive in the presence of oxygen, its absence does not mean that no life is present. The function of oxygen in the respiration of higher organisms can be assumed in bacteria by nitrate, iron, manganese, sulphate or carbon dioxide. The degradation activities of microorganisms are thus not dependent on the presence of oxygen.

Transformation of Nitroaromatic and Chlorinated Compounds in Anoxic Environmental Compartments

Pollutants such as nitroaromatic and halogenated compounds enter sediments and aquifers either bound to particles or dissolved in water. Taking PCBs as an example, it has been demonstrated that the build-up of organic compounds in an environmental compartment may be closely correlated to the quantity sold and used, even if the compound was not, and is not, used directly in the environment. The highest PCB accumulation rates in lake sediments were found at the end of the 1960s, the time when the largest

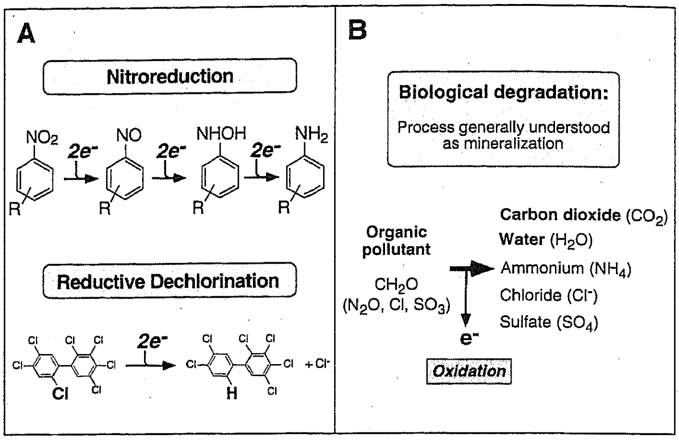

Fig. 1
Reductive transformation of nitroaromatic and chlorinated compounds compared to "biodegradation".
The reduction of nitroaromatic compounds and reductive dechlorination (A) are processes in which electrons are accepted rather than donated – the case in biodegradation (B). These processes do not result in mineralization of the pollutants.

quantities of PCBs were produced and sold. Some synthetic chemicals were used precisely because they were resistant to degradation. It was generally assumed that because they were resistant in the presence of oxygen they would also be resistant in its absence. However, it has since been found that pollutants such as nitroaromatic and halogenated compounds are transformed under anoxic conditions. The sediment of an American river, for instance, was polluted with Aroclor 1260. This product contains PCBs with five, six, seven and eight substituent chlorine atoms on the two benzene nuclei. Chemical analysis of the sediments showed that after a short period there were practically no PCBs with seven and eight substituent chlorine atoms remaining, but an increased number of PCBs with five and new compounds with three and four chlorine atoms. Similar studies of sites contaminated with nitroaromatic compounds showed that their nitro groups had been transformed into amino groups.

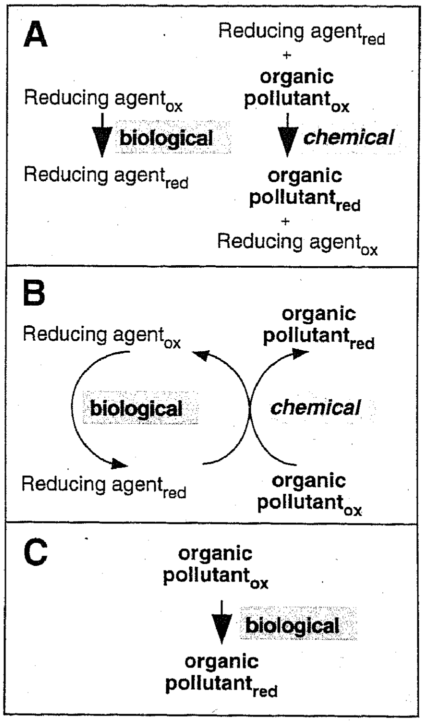

Fig. 2
Reductive transformations of organic pollutants as a consequence of chemical and biological processes.
Reductive transformations can be purely chemical (A + B) or purely biological (C) processes. The regeneration of the reducing agent for the chemical reductions is often a biological process which is either independent (A) or directly coupled (B). ox = oxidized, red = reduced.

In chemical terms these transformations – the cleavage of chlorine and the transformation of a nitro group into an amino group – are reductions. A chemical reduction is a process in which electrons are transferred to a molecule (Fig. 1A). This process is the opposite of what is generally meant by biodegradation. The term biodegradable means that a compound can be converted to its mineral components, ie., to carbon dioxide and water and – depending on which other elements the molecule contains – ammonium, sulphate, chloride etc. This mineralization is an oxidation process, ie., one in which electrons are removed from molecules (Fig. 1B).

The Advantages and Disadvantages of the Reductive Transformation of Organic Pollutants

The positive aspect of reductive transformations is that non-toxic or relatively harmless compounds may be formed, or alternatively compounds which are easily degraded in the presence of oxygen. The reductive dechlorination of perchloroethylene is a good example of such an advantage. Perchloroethylene is a solvent used in dry cleaning and the metal industry and is completely inert in the presence of oxygen. Complete dechlorination of perchloroethylene yields ethylene which is relatively harmless. This transformation has already been observed in laboratory fixed-bed reactors and still proceeded at a high rate at 10 °C. Ethylene, as the product of perchloroethylene dechlorination, has also been found in an aquifer which was polluted with this solvent, although no clean-up measures were deployed. However, if dechlorination is incomplete then trichloroethylene, dichloroethylene and vinyl chloride are formed which – in contrast to perchloroethylene – are degradable in the presence of oxygen.

Possible disadvantages of reductive transformations are that more toxic or more mobile compounds are formed. An example of the former is the production of vinyl chloride from perchloroethylene. Vinyl chloride is a known carcinogen. If it is produced and escapes from a site as a gas it can pose a real danger to all life forms. The disadvantage of the production of more mobile compounds can be illustrated with PCBs. Sediments in which PCBs have accumulated may not only act as sinks but can subsequently become sources. It has been shown that PCB-contaminated sediments later released the PCBs – they are not bound indefinitely. This release was a consequence

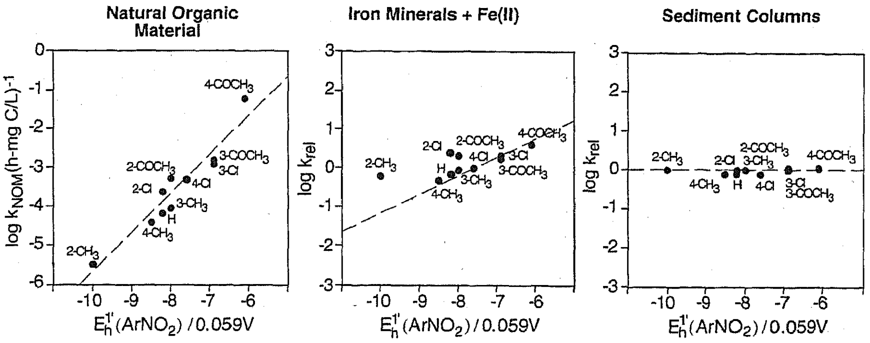

Fig. 3
Comparison of the one-electron reduction potentia ($E_h^{1'}(ArNO_2)/0.059V$) with the reactivities of ten different nitroaromatic compounds (y axes) in three different systems.

of the production, through reductive dechlorination, of less chlorinated PCBs which are more soluble in water.

Chemical and Biological Reductions

In order to use reductive transformations in technical applications or to more accurately predict the way a compound will behave in the environment it is necessary to have a good understanding of these processes in terms of their scope, rate and rate-limiting steps. Studies to date have shown that reductive transformations can be either chemical or biological (Fig. 2). The term chemical in this context means that no living organism is directly involved in the reduction, and biological means that although the reaction is chemical it is catalyzed in an organism by enzymes. In chemical reductions the reducing agent, ie., the compound supplying the electrons, is often made available through a biological process (Figs. 2A + B). In such cases the biological supply of reducing agent and the actual chemical reductive transformation can proceed either independently of each other (Fig. 2A) or be closely coupled to each other and interdependent (Fig. 2B).

An Example of a Chemical Process: the Reduction of Nitroaromatic Compounds

The reduction of nitroaromatic compounds is a suitable example for a discussion of chemical reductive transformations [2]. The frequently observed very rapid reduction of nitroaromatic compounds in samples of anoxic soil or sediments clearly indicates a non-biological process. Moreover, nitroaromatic compounds are very suitable model compounds for studying redox processes. The transfer of the first electron to the nitroaromatic compound is reversible, allowing measurement of an one-electron reduction potential. This is an indication of how difficult it is to reduce a particular nitroaromatic compound. Measurements in different systems have shown that this parameter – the reduction potential for the transfer of the first electron – does not permit general statements on the reactivity of nitroaromatic compounds in the environment (Fig. 3).

A good correlation between the one-electron reduction potential ($E_h^{1'}(ArNO_2)/0.059V$) and the transformation rate with a slope of 1 was found for a system in which hydrogen sulphide is the reducing agent and natural organic material acted as the catalyst for the reaction. The reaction rate varied over four orders of magnitude, ie., the most reactive compound reacted ten thousand times faster than the least reactive compound. In a system using reduced iron and iron minerals the reaction rate was only one hundred times faster with the most reactive nitroaromatic compound then with the least reactive; in a sediment column the reactivity of the different nitroaromatic compounds was exactly the same.

Although the one-electron reduction potential is not suitable for providing generally valid predictions about the reactivity of nitroaromatic compounds under environmental conditions, the use of this parameter in a given system allows evaluation of the rate-limiting steps. In certain cases it is even possible to deduce information about the redcing agent responsible for the reaction. In natural organic material quinone-like structures can catalyse the reaction and in sediment columns surface-bound reduced iron species are postulated as the primary reducing agents.

In the sediment column, in which all nitroaromatic compounds were equally reactive (Fig. 3), the chemical reductive transformation by reduced iron was very closely coupled to the biological regeneration of the reducing agent. The equal reactivities of all nitroaromatic compounds was a consequence of the slow biological regeneration of the reduced iron (Fig. 4). This iron reduction is an anaerobic respiration process, ie., oxidized iron is used instead of oxygen in the metabolism of certain bacteria. Iron reduction in the sediment column was limited by the presence of easily-degradable organic material. If acetate was added to such a system the transformation rates increased directly. The acetate was immediately used up and a considerably higher amount of nitroaromatic compounds was reduced in the same time period. If the nitroaromatic compound was omitted then only a very small quantity of the acetate was consumed, clearly illustrating the close correlation between the reduction of nitroaromatic compounds and acetate oxidation.

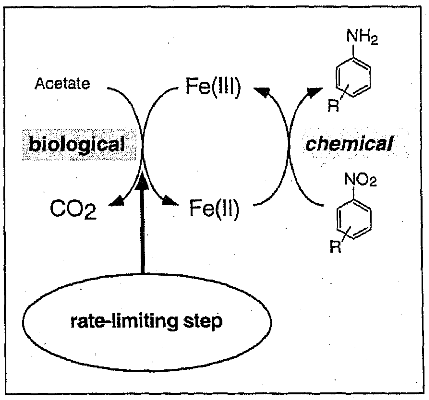

Fig. 4
Direct coupling of biological oxidation of acetate and the chemical reduction of nitroaromatic compounds through reduced iron (Fe(II)).

An Example of a Biological Process: Reductive Dechlorination

In contrast to nitroreductions, many reductive dechlorinations of chlorinated compounds are purely biological processes [3]. Long adaptation periods of months which are necessary before dechlorination can even proceed are one argument for biological processes. Furthermore, reductive dechlorination reactions are often very specific so that only one substituent chlorine atom at a particular position in the molecule is cleaved by a bacterial enrichment culture. If the substituent chlorine atom is in another position then the same bacteria are unable to dechlorinate the compound. Bacteria which catalyse such reductive dechlorinations do so either as a respiration process or as a side reaction (Fig. 5). In the last case the bacteria do not profit from the high energy content of the reaction. A large range of anaerobic bacteria are able to catalyse these reactions. The enzymes in the bacteria which catalyse the dechlorinations are not specifically adapted to the reactions and normally catalyse another reaction. For example, the enzyme in methanogenic bacteria responsible for the reductive dechlorinations normally catalyses the last step of methane production.

The bacteria which use a chlorinated compound in a respiration process exploit the energy of a reductive dechlorination reaction [4]. In these bacteria the oxidation of an electron donor, such as organic matter, and molecular hydrogen is coupled to the reductive dechlorination and not, as in other bacteria, to the reduction of oxygen, nitrate, iron, manganese, sulphate or carbon dioxide. *Dehalobacter restrictus,* a bacterium which dechlorinates perchloroethylene to dichloroethylene, is so specialized that it is still not known which electron acceptor this bacterium used before perchloroethylene entered the environment. The great difference between these bacteria and those which only dechlorinate in a side reaction is that their rate of dechlorination is much higher. *Dehalobacter restrictus* thus dechlorinates perchloroethylene twelve thousand times faster than a methanogenic bacterium. Furthermore, considerably less substrate (electron donor) has to be added to the culture. Approx. 90% of electrons liberated during oxidation of the electron donor are used for the reductive dechlorination – in contrast to only fractions of one per cent for methanogenic bacteria. Bacteria in which dechlorination is part of the respiration process are therefore much more attractive for use in clean-up measures than bacteria in which dechlorination is only a side reaction.

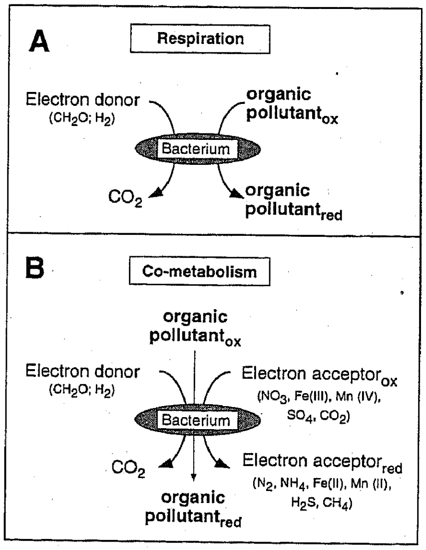

Fig. 5
Reductive dechlorination by anaerobic bacteria. Reductive dechlorination is performed by bacteria in two ways, either in the course of a respiratory process (A) where the chlorinated compound is important for the survival of the organisms or solely in a side reaction (cometabolic reaction (B)). Such bacteria do not require the chlorinated compound for their survival, but also do not profit from the energy-rich reaction.

Conclusions

Organic pollutants such as nitroaromatic and chlorinated compounds which can only be degraded with difficulty, if at all, in the presence of oxygen undergo reductive transformation under anoxic conditions. With nitroaromatic compounds this means that the nitro groups are converted into amino groups; with chlorinated compounds, one chlorine atom is replaced by one hydrogen atom or a double bond is formed. These transformations do not correspond to the processes which are commonly referred to as biodegradation, namely the conversion to mineral components. The products formed by these reductive transformations may be harmless compounds or compounds which under other conditions are mineralized by bacteria. In some cases products may be formed which are considerably more toxic than the parent compounds. Reductive transformations can be chemical or biological processes or a direct coupling of both processes. A good understanding of such processes enables statements to be made about the fate of the above mentioned organic pollutants in the environment. This in turn opens up new avenues and approaches to the technical and biological treatment of polluted areas.

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Markus Boller

The Contribution of Municipal Drainage to the Accumulation of Pollutants in Soil


Yvo Weidmann

Markus Boller

Rainwater flowing off fixed surfaces in urban areas is often highly polluted with heavy metals. Depending on the sewage system, the pollutants accumulate in the hydrosphere or in the pedosphere (soils). In both separate and combined sewer systems, highly diffuse heavy metal deposits gradually accumulate. In runoff water infiltration systems, the heavy metals are contained, but very quickly build up in the soil. Accumulation must be better controlled in the future. In the long term, only measures at the source can prevent environmental pollution by heavy metals.

Rainwater as a Source of Environmental Pollution

Water drained from municipal areas is classified as wastewater, regardless of whether the water entering the sewage system is contaminated or not. Certainly, sewage from domestic and industrial consumers which contains large quantities of dissolved and solid matter is considered contaminated; however, it is more difficult to evaluate runoff water derived from rainfall. Recent studies on the quality of runoff waters have demonstrated that surface water drainage from roads and, to some extent, from roofs and traffic-free zones, contain pollutants. The designation "non-polluted" is most properly applied to extraneous water which is often drained in greater quantities and derived from infiltrated groundwater, street fountains, small bodies of surface water and the like which enter the sewage system.

Substances transported in different wastewaters from urban areas create material flows which ultimately leave traces in the hydrosphere, pedosphere or atmosphere. The historical development of water technology, in terms of the construction measures designed to prevent water pollution, tried to minimize such traces. Since our society decided around 1920 to use water as a means of transporting a part of our domestic wastes, we have always sought to abrogate or reduce the negative effects of sewage disposal in receiving waters and deposition of sewage sludge on agricultural land. Since the start of the post-war era, a series of primarily technical measures, later supported by legislative regulations, were intended to solve the problems caused by residuals contained in treated wastewaters. The ever-increasing number of treatment steps clearly shows the limitations of end-of-pipe measures. One of the last measures has been a switch in municipal drainage policy with the aim of promoting local water cycles through the infiltration of non-polluted wastewater.

The Removal of Wastewater Creates Material Flows

Consider the most widespread drainage system in Switzerland – the combined system – in which contaminated wastewater is mixed with rainwater and extraneous water flows and discharged together. In principle, residual matter from domestic sewage is manifest either in the receiving body or enters

	Rainwater	Roof runoff	Road surface*	Drinking water max. value
TSS µg/l	8.5	70	200	
Cd µg/l	1.4	0.65	1.7–5	5
Cu µg/l	11	200	90	1500
Pb µg/l	35	130	170–500	50
Zn µg/l	85	400	400	5000

*Lower values for residential roads, higher values for motorways

Table 1
Mean concentrations (µg/L) in rainwater and surface water runoff from roof and roads.

the sewage sludge in the course of solids removal, eventually contributing to pollution of the pedosphere. Whether environmental pollution takes the form of water or soil contamination depends to a large extent on the contaminants under consideration; that is, on their physical, chemical and biological properties, the chemical conditions at the interfaces of solid surfaces, and on the drainage and treatment systems for the wastewater.

The behavior of substances in wastewater can be elucidated by monitoring mass balances and mass flow rates in a drainage area. It is important to recognize that there are substances which primarily pollute the hydrosphere and those which mainly pollute the soil. Their diffuse removal in the hydrosphere through wave action and sediment transport is difficult to monitor or control, whereas disposal in soil or in stationary lake sediments results in localized contamination which, in the absence of degradation, will lead to their accumulation at concentrations proportional to the quantity disposed.

Of the substances which enter the pedosphere, heavy metals occupy a special position. They are completely recalcitrant, for the most part bound to particulate phases, relevant in terms of environmental toxicology and yet can be analyzed more easily than many organic substances. They are of particular importance in municipal drainage because they originate from polluted domestic and industrial wastewater. They are also present in significant quantities in wastewaters such as runoff from roofs, squares and roads which, to date, have been regarded as more or less unpolluted.

Of the numerous heavy metals which pose a threat to the environment, cadmium, copper, lead and zinc are the most prevalent when judged by established contamination criteria (e.g., soil contamination standards). In general, heavy metals are strongly bound to the particulate phase, i.e., the sludge. This has long been known and is important in light of alternative municipal drainage systems as discussed below.

Removal processes resulting from adsorption and precipitation lead to an accumulation of heavy metals in the sludge. Since the sludge remains in a waste treatment plant much longer than the wastewater itself, heavy metals accumulate in the sludge with enrichment factors of 1000 or more. Consequently, the question of how they can be prevented from entering wastewater is posed. A large number of steps have been taken in the last 10 years to reduce the heavy metal output from industrial and commercial effluents, resulting in a slow but continuous reduction in the heavy metal content of sewage sludges. In contrast, so-called "diffuse" heavy metal contributions have increased in importance. Analysis of heavy metal input in municipal areas has clearly shown that substantial quantities are derived from "uncontaminated" wastewaters which enter the drainage system via runoff during rainfall events from dry and wet depositions on solid-surface areas.

A Case Study of Heavy Metal Flow

A case study was carried out in the St. Gallen urban area to establish the importance of heavy metal input from runoff wastewater. This same area was the subject of the recent "Metapolis" study conducted by the Resources and Waste Management Department of EAWAG [1], which considered the entire materials flow through the municipal area. The objective was to estimate the heavy metal loads at different points in a domestic drainage system and to quantify the importance of various sources.

Such a mass flow analysis is not easy to establish. Background information is needed to fill in the values at the desired points along the flow chart. Some material flows are not precisely known and must be estimated, while others can be easily measured. The quantification of heavy metal loads entering a system via runoff water is especially difficult. Rainfall intensity and duration, duration of the previous dry period, atmospheric loads on the area under study, characteristics of surfaces, and sampling modality are some of the parameters which result in a large scatter of measurements and make an estimation of average loads difficult. To provide additional data on water runoff from roofs, the EAWAG is currently conducting studies using three different rooftops in Zürich. Preliminary results suggest that the concentrations of various substances fluctuate considerably, with peak concentrations manifested within the first 30 minutes of rainfall, especially from steep roofs. In addition to the shape of the roof, the use of copper and zinc piping is of critical importance in determining the concentration and loads of both heavy metals.

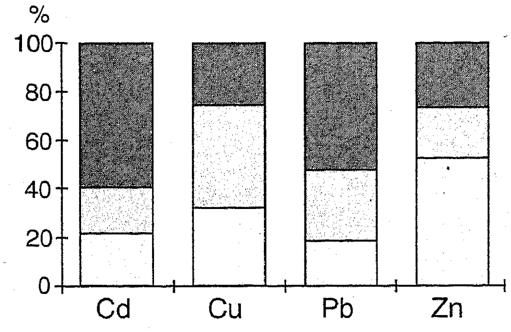
Only such studies considering the dynamic behavior of runoff pollutants allow calculation of so-called equivalent mean concentrations of substances and annual substance loads for mass balance analysis. A study of the literature has so far only yielded characterization of surface water runoff from roads and roofs as shown in Table 1. In general, the importance of concentration in runoff water has not been fully elucidated. The maximum drinking water values are given for comparison purposes only. As may be seen, rainwater contains critical heavy metal concentrations compared to drinking water, while the values for surface water runoff from roofs and roads are unsatisfactory in qualitative terms.

If these concentrations for runoff waters are extrapolated to the case study area of St. Gallen; it is possible to estimate the importance of diffuse components in rainwater compared to municipal and industrial contributions. The results in Fig. 1 show that for all of the heavy metals considered, except Zn, quantities contributed by rainwater runoff are greater than from other potential sources. This neglects the possibly higher number of water-conducting parts of copper and zinc for roof runoffs which lead to initial concentrations of thousands of µg metal per liter of water and mean concentrations of 100–400 µg/L Cu and 1000–5000 µg/L Zn.

Effects of Alternative Drainage Systems

So far only combined drainage systems have been considered in which rainwater and their heavy metal loads are channelled in part via rainwater overflows into receiving waters or into sewage treatment plants and consequently into the sludge. However, supported by new legislation to protect water quality, efforts in the future will focus on other types of municipal drainage systems in which runoff water is drained separately and, if possible, allowed to percolate through the soil as close as possible to the point of precipitation. The construction of infiltration sites is required by law for urban areas. Guidelines on general drainage system design for municipal areas have been recently published by the Swiss Society of Sanitary Engineers (VSA) and by many local water authorities.

Fig. 1
The contribution of runoff water to the total concentration of heavy metals in municipal drainage systems.



▨ *Road runoff*
░ *Roof runoff*
☐ *Domestic wastewater*

There are three basic scenarios which differ, particularly in terms of runoff water drainage: (1) the conventional combined drainage system; (2) the separate sewer system with direct flow of runoff water into the receiving bodies; and (3) decentralized infiltration of rainwater, where possible. These three drainage concepts are visualized below for St. Gallen with estimates of the consequent material flows of heavy metals. In addition, the final locations of the heavy metals and their accumulation rates are assessed.

Combined Drainage System

In practice, the three systems differ considerably with respect to the contribution of rainwater to the total flow. Since with the combined system the highest loads of heavy metals flow via the drainage system into the sewage treatment plant, the accumulation of heavy metals in sludge results from their strong binding to particulate matter. Depending on the nature of sludge disposal, the heavy metals can end up in landfills or on agricultural land. There has been a resurgence in the use of the latter and, in some regions, it accounts for 70% of sewage sludge disposal. Taking this value as a basis, accumulation of heavy metals in addition to the natural precipitation loads accur and result in accumulation rates shown in Table 2. According to agricultural guidelines the maximum permitted sludge spreading rate is 5 t/ha per annum (max. rate); however, realistic rates are in order of 1 t/ha per annum. If the enrichment rates so calculated are extrapolated, and the appreciable present heavy metal content of agricultural soil is taken into account, the heavy metal soil standards of regulating toxic materials in soil (VSBo, 9.6.1986) will be reached within about 100 years. Despite this relatively slow accumulation, toxic material contamination is still problematic, since the

	Rainfall	Spreading of sewage sludge (Top 30 cm)		Total incorporated in soil (Top 30 cm)		VSBo	Background agricultural conc.1)
		Max. Rate	Eff. Rate	Max. Rate	Eff. Rate		
	$g\ ha^{-1}\ a^{-1}$	$g\ ha^{-1}\ a^{-1}$	$g\ ha^{-1}\ a^{-1}$	$g\ ha^{-1}\ a^{-1}$	$g\ ha^{-1}\ a^{-1}$	$g\ ha^{-1}$	$g\ ha^{-1}$
Cd	21	4.4	0.9	25.4	21.9	3600	1080
Cu	143	653	131	798	274	225000	106200
Pb	504	617	123	1121	627	225000	96300
Zn	1047	2856	571	3903	1618	900000	254250

1) Values of the AGW for the Canton of Zürich for the first 20 cm of topsoil [2]

Table 2
Heavy metal accumulation in agricultural soils due to rainfall and spreading of sewage sludge (g ha^{-1} a^{-1}); additional loads from fertilizers not taken into account.

distribution of the heavy metals is both diffuse and irreversible.

Separate Sewage System

With consistent implementation of the separate sewer system concept, the heavy metals would primarily flow into the receiving water via storm sewers. Since most of the heavy metals will be bound to particulate matter, they would mainly accumulate in the sediment. In flowing waters, the contaminated sediments will be removed and deposited without control, while they may be localized in the sediments in still waters. It has been observed that, as in the St. Gallen case study, the least favorable discharge conditions with weak dilution of the wastewater in the receiving body could lead to concentration peaks of heavy metals which at times are considerably above the standards of the regulations for wastewater disposal.

Infiltration of Stormwater Runoff

With the third alternative, in which stormwater is allowed to percolate through the underground, the elevated heavy metal concentrations lead to an enrichment in the soil of the infiltration sites. Instead of a diffuse distribution, there is a strong concentration effect in the finite volume of soil material. If a mean soil permeability coefficient of 10^{-5} m/s is assumed, the infiltration area accounts for approximately 6% of the drainage area taken into consideration. For St. Gallen, this means that a roof surface area of 46 m^2 and a street surface area of 64 m^2 per inhabitant require infiltration areas of 2.8 m^2/inhabitant and 3.8 m^2/inhabitant respectively, on which heavy metal accumulation occurs at higher rates. Depending on the construction of the infiltration site, the runoff water can percolate through permeable troughs into the soil surface (first 30 cm) or into subsurface infiltration shafts (100–200 cm below surface). If the runoff water is percolated into troughs at the soil surface, the already existing heavy metal solution has to be added to the loads caused by stormwater infiltration. Today, this pre-load is considerable and markedly shortens the time until soil standard values for heavy metals are reached. As the data in Table 3 illustrate, the metals Cu and Pb are especially critical. If the analysed soil contamination in urban areas [2] by the AGW Zürich is adopted as a basis in other soils, trough infiltration would be ruled out because of the Pb already accumulated. The soil standards for the other metals would be reached within less than 10 years. With infiltration shafts, the accumulation would be spread over a larger soil volume and, since it is further in the underground, the soil would be free of prior contamination. In that case, the calculated time period until soil standards are reached is 20 to 50 years or more, depending on whether the runoff is from streets or roofs.

The actual course of heavy metal accumulation can be visualized with the help of soil profiles in infiltration installations operated over a number of years. Two different installations were evaluated in Basel city and Basel canton for this purpose. In one case, surface water from the street was channelled into nearby fields; in the other, street runoff was allowed to percolate through shafts into the ground. The results of the studies confirm that the soil standards have long been exceeded for both cases and, as expected, infiltration on the soil surface leads to accumulation in the first 30 cm below surface, whereas in shafts, the metals are enriched over a depth of 150–200 cm.

Comparison of Drainage Systems

As can be seen from the flow chart for copper in Fig. 2, the type of drainage system will determine the final pollution sites in the environment. With combined sewers, Cu will primarily accumulate in agricultural land and in landfills. With separate sewers, it will also accumulate in the sediments of receiving waterbodies. With stormwater infiltration, it will accumulate in the soil beneath the installations. This comparison suggests that in combined and separate sewer systems the heavy metal loads are distributed over the land or into waterbodies in a very diffuse manner. Diffuse loads, in general, result in lower specific accumulation rates; however, their widespread distribution is not desirable in the long term. Depending on the heavy metal and its concentration in runoff waters, sooner or later it will result in unacceptable levels of heavy metals in land used for agriculture and in waterbodies and their sediments. Stormwater infiltration installations, in which the main loads are concentrated in the soil layers

Table 3
Heavy metal concentrations in topsoil (30 cm) and subsoil (100 cm) with trough and shaft/trench seepage.
d.m. = dry matter

Type of seepage		Roof runoff	Road surface water	Municipal background levels	VSBo guide values	Years until VSBo reached, Roof	Years until VSBo reached, Road
		$g\ t^{-1}_{d.m.}\ a^{-1}$	$g\ t^{-1}_{d.m.}\ a^{-1}$	$g\ t^{-1}_{d.m.}$	$g\ t^{-1}_{d.m.}$	a	a
Trough	Cu	11.2	5.2	33	50	1.5	3.3
	Pb	7.4	10.0	48	50	0.3	~0
Shaft	Cu	2.3	1.0	33	50	22	50
	Pb	1.5	2.0	48	50	33	50

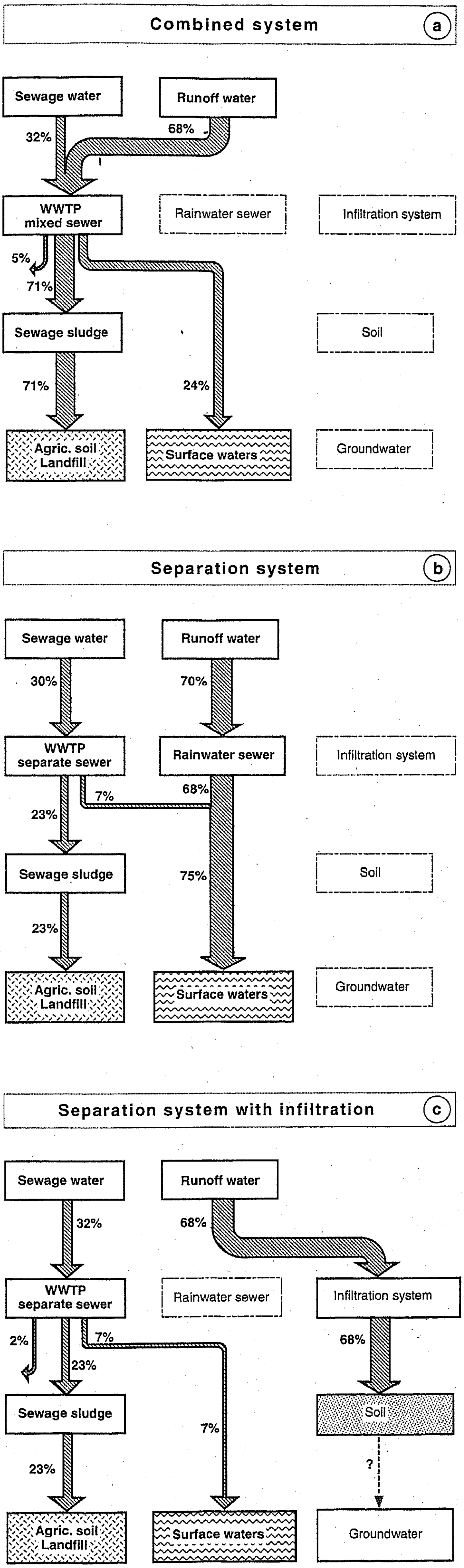


Fig. 2a–c
a) Copper flow in combined sewer system
b) Copper flow in separate sewer system
c) Copper flow in systems with stormwater infiltration facilities

and are present in relatively clearly defined horizons, are preferred in this respect. The danger of diffuse transport and entry into groundwater over a longer period, however, cannot be ruled out.

The Options

The current means by which general contamination of runoff water is dealt must be regarded as irresponsible, since accumulation is diffuse and uncontrolled. Since there is a clearly defined cause-and-effect relationship between heavy metal loads and pollution of the atmosphere, heavy metal emission should be eliminated or reduced at the source where possible. However, due to other pressing problems with air pollution, a reduction in the concentration of heavy metals in the air is only one facet of a much larger problem. Though difficult to quantify, there are additional contributions of copper and zinc, in particular, from roofing and rainwater piping materials. Obviously, the situation would be improved if other types of materials were used. In most cases, action taken to tackle contamination at its source will require many years for implementation with objectives met only infrequently. Efforts to reduce emissions over a timescale of decades, therefore, need to be supported by technical measures in order to eliminate heavy metal contamination of the environment.

In comparison, the new drainage concept employing decentralized stormwater infiltration from roofs and areas with little or no traffic appears to be a sensible approach, allowing the planned accumulation of heavy metals and other well-adsorbable impurities present in rainwater runoff. It is proposed that special adsorbent granular layers be incorporated; their composition and effect are the subjects of additional studies. The technical arrangement should allow access to the adsorbing layers so that they can be easily removed, replaced, and handled.

Acknowledgements

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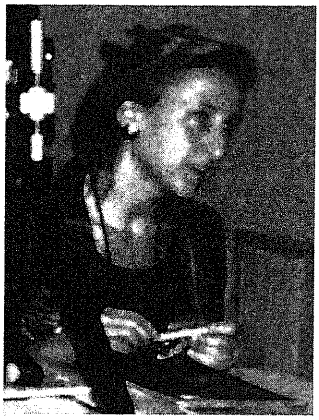
**Annette Johnson, Peter Huggenberger
and Thomas Lichtensteiger**

Long-term Behaviour of Landfills

Implications for Practice


Yva Weidmann

Annette Johnson

The term "final storage site" for waste has been redefined by the Guidelines for Waste Management in Switzerland. Waste should only be stored under conditions in which the chemical and physical properties of air, water and soil are not significantly affected over the long term.

Landfills as Archives

Waste disposal sites which were established in the past now constitute suitable archives for assessing the long-term behaviour of waste material. Such archives are particularly suitable where waste of the same or similar physicochemical nature was stored in the same landfill.

Geogenic deposits (sediments, rocks, soil, ores) are also archives. The processes of dissolution (chemical weathering), transport and precipitation (enrichment) of natural substances are reflected in them. Requirements of landfills in terms of "final storage quality" and site criteria are derived from an understanding of the properties and behaviour of geogenic deposits. Knowledge of the formation of the corresponding deposit or materials therein can be applied to make predictions of the long term behaviour and suitability of a site.

The move away from the direct storage of domestic waste to its pretreatment in waste incineration plants was an important step towards more controlled storage: combustion resi-

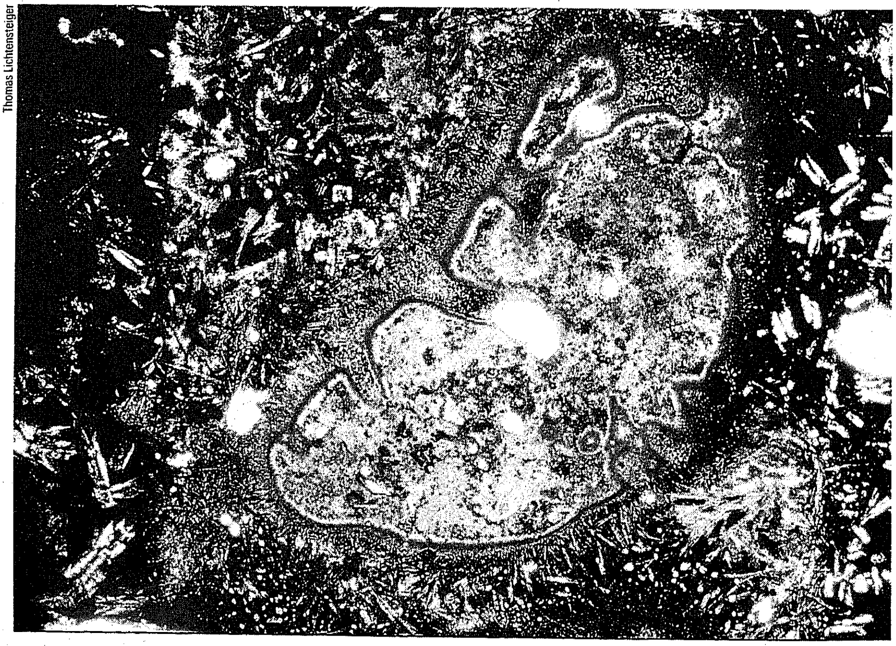

Thomas Lichtensteiger

Fig. 1
Bottom ash viewed through a transmitted-light microscope (thin section).
Melt with an opaque microcrystalline core zone, gel border and spicular crystal growth (silicate), embedded in an iron oxide-rich silicate matrix with spicular to columnar silicate crystals of different types.

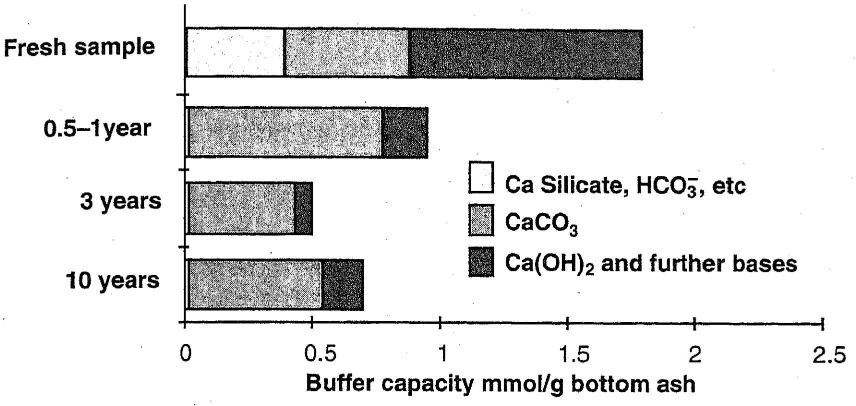


Fig. 2
Buffer capacity of fresh and aged bottom ash. The aged samples were obtained from the Riet landfill in Winterthur.

dues have much more defined properties than untreated domestic waste and require less post-treatment [1].

However, the products of present-day waste treatment plants do not meet the requirements for final storage. Emissions from inorganic residues of incineration mainly consist of salts and in part anions of heavy metals. Although the heavy metal cations are only found in low concentrations in the leachates they can be expected to persist over centuries [2]. By comparison, the life of technical barriers is of the order of decades, so that it would be a false policy to rely solely on such barriers. It is therefore essential to understand the factors governing leachate quality and the role of geological substratum in its role as a geological barrier.

Waste management embraces different technical and economic aspects. This article will concentrate on just two technical aspects, namely the quality of stored waste and the investigation of landfill sites. The aim is to deposit waste in the future so that the chemical and physical properties of water, soil and air in the vicinity of the landfill are not adversely affected and so that the waste stored is available as a resource for subsequent generations.

We will show, taking bottom ash from municipal solid waste incinerators as an example, how long-term behaviour can be inferred from a knowledge of its origin and properties. In the section on "The Landfill Site" the importance of the inhomogeneity of the substratum will be discussed where substances are released from the landfill body.

Municipal Solid Waste Incinerator Bottom Ash

Composition

Bottom ash from grate incinerators comprises ash, melting products and material-specific components. Ash and melts together form the bottom ash matrix.

The ash is a mixture of:

1. Inorganic residues from the combustion of plastics, paper, cardboard and organic waste,
2. Soot particles from incomplete combustion,
3. Non-combustible dust particles which are introduced into the furnace with the waste, and
4. Fine-grain particles of broken glass, ceramics, rock and metal components, or their corrosion products.

Components with a diameter above 2 mm can be recorded as separate components and assigned to a specific material category. These include, in particular, broken glass, ceramics, rock fragments, metal parts and organic residues which have not or only partially been mineralized.

The melts range in size from mm to cm, and are irregularly shaped clumps. They are predominantly of silicate composition and are to a large extent amorphic (vitreous) with numerous crystallized products (silicates and oxides) [3].

Silicon, calcium, iron, aluminium, potassium and magnesium oxides account for approximately 95% of the total weight of bottom ash. Potential environmental pollutants such as salts and heavy metals are present at concentrations 1–2 orders of magnitude higher than in the geogenous reference strata (rocks of the earth crust), namely at g/kg levels. Their leaching behaviour is controlled to varying degrees by the main components. The concentration of soluble salts is predominatly determined by physical processes, which in turn can be influenced by the reactivity of the main components [4]. The main constituents are the primary determinants of the mobility of the heavy metals. They control the leachate composition and the sorption properties of the bottom ash.

A knowledge of the geochemical properties of the bottom ash is necessary for any predictions of leachate composition. Bottom ash composition and behaviour as a function of time are decisive for leachate quality and possible release of heavy metals into the substratum.

Long-term Behaviour of Bottom Ash

To date little is known of the long-term behaviour of bottom ash. Studies have concentrated on leachate composition. Readily soluble salts dominate the leachate composition. Sodium, potassium, hydroxide, chloride and sulphate are the predominant ions in the alkaline leachate. Calcium concentrations are controlled by the precipitation of gypsum. Most heavy metals remain practically immobile.

Processes in the Stored Bottom Ash

The vitreous substances formed in the waste incineration plant are thermodynamically not stable. In the landfill, they begin to react with air and water. Small particles of melt mixed in with bottom ash are the first to react and result in the immobilization of the waste deposits within months. Gel-like shells form around the individual products of melting (Fig. 1). Hydrated calcium silicate phases, known from cement chemistry, then start to crystallize out. Similar processes are also known from the transformation of volcanic glass. Further constituents such as iron and aluminium also contribute to long-term reactivity. Neutralisation reactions accompany recrystallisation processes. A reduction in acid buffering capacity has been observed within weeks of fresh bottom ash being stored [5]. Titrations of bottom ash taken from the Riet landfill have demonstrated that the buffer capacity is much reduced after 10 years compared to fresh bottom ash and is exclusively due to calcium carbonate (Fig. 2).

Since the alkaline characteristics of fresh bottom ash are mainly determined by the calcium compounds, the reactivity of those compounds has a major influence on the development of buffer capacity and thus long-term behaviour. Calcium is present in the form of calcium carbonate (ca. 17%), hydroxide or soluble alkaline calcium silicates (ca. 17%) and less soluble compounds (ca. 66%), probably crystalline calcium silicates [6]. The formation of insoluble calcium compounds proceeds for the first few years after they have been established. It is in direct competition with the production of calcium carbonate.

The reduction in buffer capacity results from internal neutralization reactions, the leaching of bases and the input of acids. The conspicuous drop in buffer capacity over the first years is most probably due to internal neutralization processes and the binding of calcium in insoluble compounds. Acids which are transported into the bottom ash body through wet deposition or which originate in the bottom ash body play a lesser role. Internal acid production through the oxidation of iron sulphides is only likely to reduce buffer capacity by a maximum of approx. 5%. The degradation of organic carbon could possibly have a greater effect on buffer capacity [5]. However, little is known about the kinetics. Calcium carbonate, the solubility of which is governed by carbon dioxide partial pressure, is the dominant buffer in older landfills.

Mobility of Heavy Metals

The reactivity of bottom ash is of importance to the mobility of heavy metals. Heavy metal cations, the mobility of which is limited by poorly-soluble solid phases and adsorption processes, can be released as a consequence of the drop in leachate pH. We can assume that the calcium carbonate content is the predominant factor in buffering leachate pH-values. Assuming an homogenously-reacting block without preferred leaching paths, with a calcium carbonate content of approximately 0.5 mmol/g (5%) and an annual water (pH 4.3) inflow of 400 l/m^2 and at a CO_2 partial pressure of 0.0003 atmospheres, the neutralisation rate (sum of calcium ions transported out and acid input) will be approximately 0.2 $mol \cdot m^{-2} \cdot a^{-1}$. This means that the carbonate buffer in a layer approximately 1 m thick will be exhausted after approximately 4000 years. It must be borne in mind, however, that preferential leaching paths, unknown reactions or kinetics make predictions difficult. External influences play a much greater role in shallow deposits than in deeper deposits of a monofill. In practical terms this means that with the quality of bottom ash today its storage in a landfill is preferred to that in a shallow road layer.

The Landfill Site

The original approach to the selection of landfill sites was generally to use pits after extraction of their raw materials (clay, sand, gravel and limestone) to deposit waste of very variable composition. These landfills are today registered as potentially contaminated sites.

More suitable, and today required by legislation, are sites with a geological substratum of poorly permeable sediments where the leachate from landfills cannot adversely affect groundwater or surface waters.

The aim of the Guidelines on Waste Management in Switzerland [EKA, 1986] and the Technical Regulations governing waste management (TVA) is to convert waste into a unreactive physico-chemical state, thus considerably simplifying the search for suitable landfill sites.

Even so, highly concentrated residues will still be produced in future and will only remain stable over long periods under special conditions (eg., pH or oxidation conditions). The choice of geological site thus remains important. The geogenous rock strata of a landfill act as a further barrier but they also have to guarantee stable storage conditions. Selection of a landfill site requires a knowledge of rock-water interactions and watercourses. In both cases the heterogeneous nature of the substratum plays an important role and can include the spatial arrangement of distinguishable lithologies (rock units), the distribution of hydraulic characteristics and the distribution of surface properties of minerals etc.

Heterogeneous Substratum

Heterogeneity is exemplified here with glacial deposits which are often chosen as landfill sites. Glacial deposits embrace numerous possible elements:

- Basal moraines (dense fine-grain sediments with larger clasts (rock components), often of low permeability
- Frontal moraines (heterogenous composition, in part containing slide sediments, different types of poorly sorted sediments of varying permeability)
- Lake sediments (sand, silt, clay, tend to be of low permeability)
- Fluvial deposits in ice tunnels (often gravels, tend to be of high permeability)
- Meltwater streams (fluvial plains in front of glaciers, with gravels, sand, very high permeability, very heterogenous) etc.

A major characteristic of such complex systems is the short distances within which a change in lithology can occur [7]. This makes predictions about the

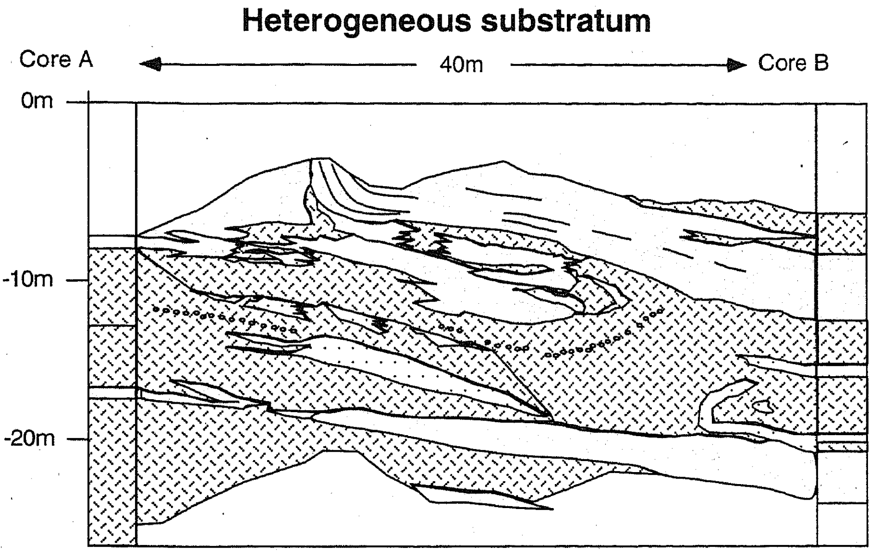


Fig. 3
Jonschwil gravel pit (Thurtal).
Complex distortions of sediment strata point to ice tectonics or slides (slumps) as a possible cause.

▨ *Gravel, sandy gravel*
☐ *Sand, gravelly sand*

geological structures exceptionally difficult. These difficulties are illustrated by the following example. Fig. 3 shows two cores taken from a landfill at a distance of ca. 20–30 m apart. How does the lithology change between them and can the distinguishable horizons between the two bore sites be simply interpolated? The completed picture – a view of a gravel pit in upper Thurtal, gives a clear answer.

Since it is virtually impossible to ever ascertain the full extent of the heterogeneity of the substratum, we have to rely on conceptual models of the formation of a particular deposit (facies models). This is possible because substratum inhomogeneities follow a certain logic which is determined by selective sorting processes during the transport and deposition of sediments. The numerous possibilities and combinations of processes may result in the end product appearing chaotic.

Such facies models provide us with data on the probable arrangement and dimensions of sediment sequences. Considerations on the origin of a particular sediment type and its possible neighbours play a role here. Certain inferences can be drawn about the storage environment and neighbouring environments from sediment structures in drill cores, provided that the integrity of those structures is retained. This is in part possible with fine-grain deposits but remains an unsolved problem with coarse-grained rock types (coarse clasts).

Investigation of inhomogeneities is today based not only on bore-holes but to a large extent on ultra high resolution geophysical methods such as seismic, georadar, electromagnetic and electrical methods [8]. Together, these methods can clarify the apparent chaos. In summary, models or hypotheses about the origin of deposition sequences are simply maps which provide routes for research into relevant aspects, such as the optimization of sampling sites.

Conclusions

An understanding of the origin and properties of landfill content as well as the substratum is an important prerequisite for planning new landfills.

The long-term behaviour of a landfill can be partially predicted on the basis of petrological, geochemical and hydrological data. The function of the substratum as a geological barrier can only be understood with a knowledge of the permeability of rocks and their interactions with the content of leachates.

Further, a knowledge of geological characteristics and the origin of the geogenous environment allow the evaluation of a site in terms of the degree of fluctuation in storage conditions. Such approaches to evaluation also provide an impetus for optimizing waste treatment technology.

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Alexander J.B. Zehnder and Hans R. Wasmer

Soil Contamination:

Clean-Up from the Perspective of Environmental Science and Risk Management


Yvo Weidmann

Alexander J.B. Zehnder

Using cantonal estimates as a starting point, the Swiss Federal Office for the Environment, Forestry and Agriculture (BUWAL) has calculated that there are some 30'000–40'000 contaminated sites in Switzerland. Of these, it is expected that 20% will need to be investigated in depth. Extensive clean-up will be required at approximately 500 locations at a total estimated cost of 4 billion Swiss francs or 30 Swiss francs per resident per year over 20 years. Switzerland is currently embarking on a systematic clean-up of polluted sites, but there are problems to be solved at both scientific and political levels.

The Objectives

The Environmental Protection Act (USG) has formulated objectives for sites already recognized as polluted: "the protection of humans, animals and plants, as well as their communities and biotopes, from harmful or irritating effects and to maintain the fertility of the soil". These objectives are embodied in numerous regulations.

The Problems

An attempt to define objectives through precise scientific formulations generally leads to the following problems:

1. The actual danger or *potential for danger* of the pollutants (type, quantity, properties) are unknown.
2. Physical, chemical, biological and hydrogeological data for the site and its environment are lacking or incomplete. At best, hypotheses may be formulated to decipher the routes by which pollutants may have been dispersed. These routes, in turn, will depend on the geographical location, the structure, chemistry and biology of the soil and substratum, and the properties of the pollutants.
3. The definition of *hazard* implies endangerment to a specific situation or object which is to be protected. The question is not solely one of risk, however, but embodies the definition of protection as well.

Defining protection is not simply a philosophical declaration of principle. It is the basis upon which decisions are made. Is a suspected area contaminated? Should a given site be cleaned up? To what extent are clean-up measures required in a given case? This sounds relatively simple; however, the definition of protection objectives is complicated by two considerations: (1) risk assessment and (2) a rational means of dealing with uncertainties. Politicians generally are reluctant to tackle both the degree of damage and the tolerance of uncertainties. Whether damage to the environment is considered low, marginal, critical or catastrophic, and the degree of uncertainty which is acceptable are political decisions for which the designated authorities must assume responsibility. Without such decisions, or some consensus as to how such decisions are to be reached, the problem of soil pollution in Switzerland cannot be efficiently solved.

A large body of knowledge from the fields of environmental sciences, environmental technology and risk engineering may be judiciously deployed or developed further in making decisions impacting the assessment and remediation of contaminated sites. In the following section, we present some suggestions about how such problems can be tackled and the direction additional work should take in the future.

Potential Danger

Both the historical development and current economic structure of Switzerland make the following contaminants and types of sites most prevalent:

- Mineral oils and fuels (i.e., storage and distribution centers, accidents along transport routes)
- Chlorinated hydrocarbons (i.e., dry cleaners, metal processing, production of electronic components)
- Agrochemicals (i.e., production, storage, and distribution of fertilizers and pesticides)
- Heavy metals (i.e., electroplating, tanneries)
- Toxic substance mixtures from old sites of chemical and gas works
- Landfills (covered, for the uncontrolled storage of wastes of indeterminate nature from domestic, small business and industry sources)

There is little or no information available on contaminated sites from the arms industry (e.g., production facilities, test and disposal sites). Since Switzerland has few raw materials, any large sites polluted by the extraction of ores, fossil fuels, or basic chemicals can be practically ruled out.

The Canton of Aargau's register of polluted sites, for example, lists a total of 3565 suspected sites spread over 232 communities. These sites may be classified as follows: 29% open (= not yet full) pits; 18% municipal waste landfills; 24% landfills containing excavated material, building waste and inert materials; 7% multi-component landfills without building waste; 5% municipal waste landfills with special waste; 1% special waste landfills; 5% landfills of unknown content; 8% contaminated industrial sites; and 3% sites with liquids which endanger water. In Winterthur, an old industrial city, a total of 850 suspected sites have been identified. Of these, 200 are back-fills, 50 are accident sites and 500 are industrial sites.

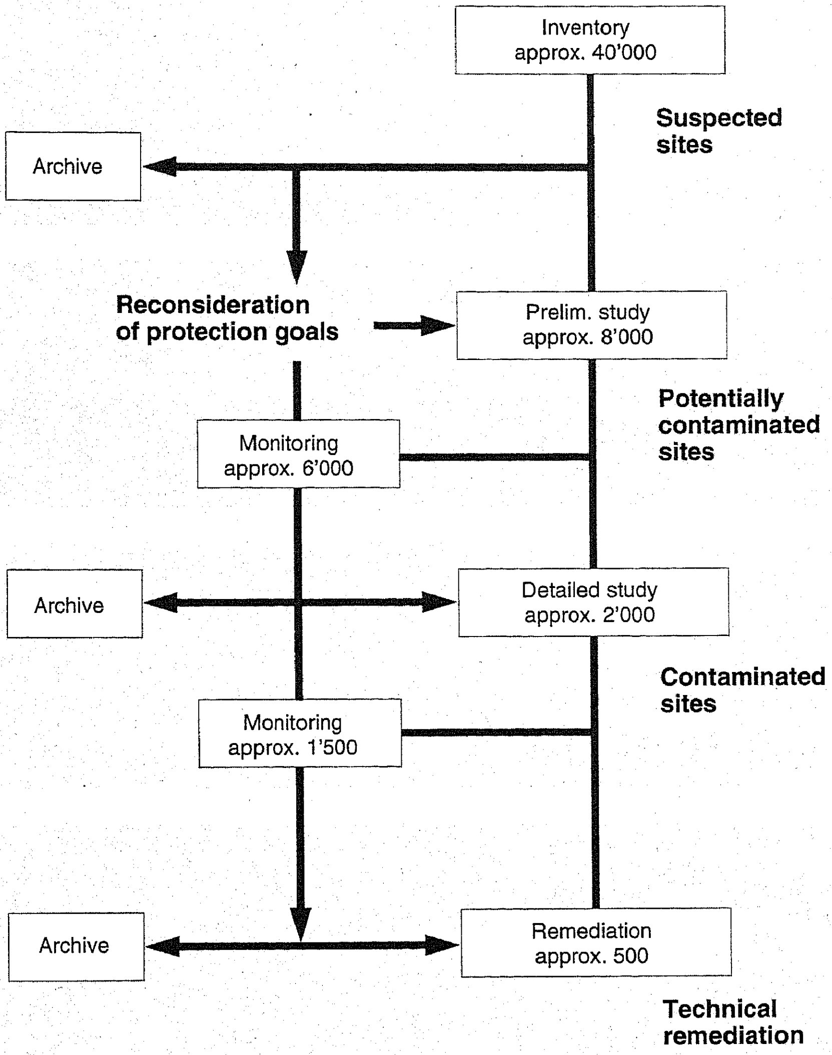

Fig. 1
A concept for the evaluation of polluted sites (from [1]).

These estimates clearly illustrate the range of contaminants and types of sites that have already been identified in Switzerland. Many cantons have identified their suspected sites or are in the process of doing so; others have only started to establish a register. BUWAL has formulated a concept for evaluating polluted sites [1]. The procedure is divided into four phases as illustrated in Fig. 1:

Phase 1: Documentation and initial assessment of suspected sites in a rapid and cost-effective way with the aim of recording a large number of sites where there is risk. Prioritization of sites in terms of the need for further action through qualitative risk assessment.

Phase 2: Preliminary investigation and interim assessment to establish the danger to the environment in each case of high priority.

Phase 3: In-depth investigation and final assessment for the need to clean-up a polluted site.

Phase 4: Design of clean-up project, implementation of clean-up and evaluation of success of remedial action.

The first phase of site assessment has not yet been completed in Switzerland. A hazard evaluation is carried out in each phase to eliminate sites of lower priority. This involves (a) identifying the dangers, (b) knowing the release routes of contaminants within defined system limits, and (c) assessing the likelihood of the danger actually materializing (see Fig. 2). Evaluation becomes increasingly time-consuming and costly with each phase. The chal-

Risk evaluation of contaminated sites

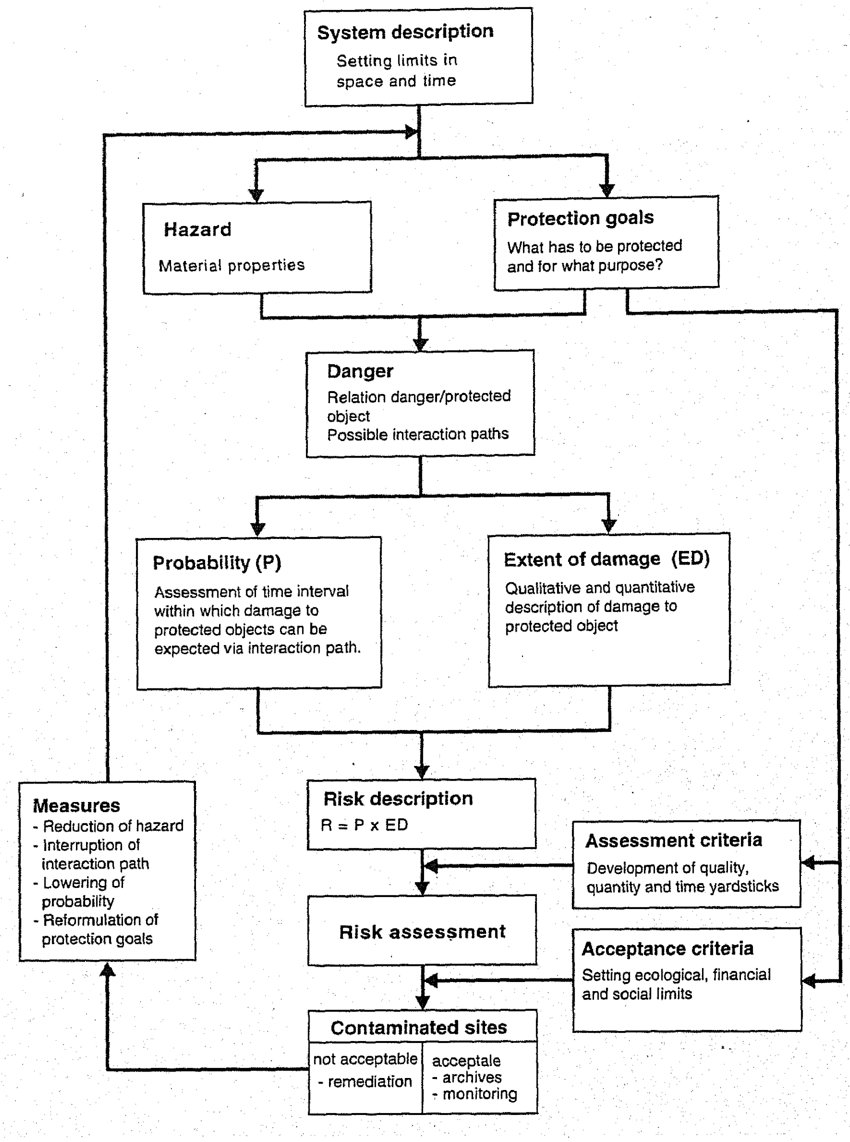

Fig. 2
Risk evaluation of polluted sites.

lenge in Phase 1 lies in reaching a decision about the classification of a given site at a reasonable cost and then determining the need for further action in Phases 2, 3 and 4.

Release Routes for Pollutants

Data about the release of pollutants is based on strict natural science and engineering criteria. The path by which a given contaminant is released is dependent on two factors: (1) the chemical and physical properties of the substance itself and (2) the nature and composition of the substratum or environment of the polluted site.

Environmental contaminants may be divided into six classes:

(i) water-soluble, mobile, volatile and reactive/degradable (i.e., includes components of motor fuel and degradation products of municipal waste landfills)
(ii) water-soluble and mobile (e.g., components of motor fuel and heating oil)
(iii) water-soluble, highly adsorbent, volatile and reactive/degradable (e.g., acetone, toluene, xylene)
(iv) water-soluble, highly adsorbent, non-volatile, possibly reactive and degradable (e.g., nitro compounds, chlorinated phenols)
(v) water-insoluble, less dense than water (e.g., complete motor fuel, other fuels)
(vi) water-insoluble, denser than water (e.g., chlorinated solvents, polyaromatic hydrocarbons)

Classes (v) and (vi) are referred to as "Less dense than water Nonaqueous Phase Liquid" (LNAPL) and "Denser than water Nonaqueous Phase Liquid" (DNAPL), respectively.

The soil and subsoil can be divided into five categories:

(i) homogenous, monolayer
(ii) homogenous, multilayer
(iii) heterogenous, monolayer
(iv) heterogenous, multilayer
(v) fissured

All categories – from homogenous sandy soils to fissured karst – are found in Switzerland. The hydrogeological conditions, therefore, must be determined at every site. This classification of soils and subsoils allows for both the release routes to be postulated and the potential risks to be identified. In addition, it gives some indication of the difficulties inherent in cleaning up contaminated soils (see Table 1).

The Risks of a Polluted Site Versus Its Clean-Up: At What Risk?

The importance of the decisions to be made about contaminated sites becomes apparent if projected costs are assigned to the various phases shown in Fig. 1:

- Recording of 40'000 suspected sites: SFr 50 million
- Preliminary investigations of 8'000 potential polluted sites: ca. SFr 250 million
- In-depth investigation of 2'000 polluted sites: ca. SFr 500 million
- Clean-up of 500 polluted sites: ca. SFr 2'500 million

If in the course of clean-up the "wrong" sites are cleaned up, then assuming an error rate of 10% (50 out of 500 polluted sites) would cost some SFr 250 million.

The experience gained in dealing with uncertainty in classical risk engineering can also be applied to pollution problems. The discussion below relates to the flow chart shown in Fig. 2. The first step is a system description: the polluted site has to be delineated in terms of area, impact on humans and environment, and the time scale to be considered. The chemicals present in the contaminated site represent a danger which could have a negative effect on the protection objectives.

A hazard is said to exist if an object to be protected is exposed to a potential danger. In a stricter sense, a risk R is described by the known formula $R = P \times ED$, where P is the probability, and ED is the extent of damage. Application of this simple formula to polluted sites, however, is fraught with problems. The probability P is a measure of likelihood that toxic substances will be released. To assess this, the possible release routes must be known. It should also be possible to formulate worst case scenarios. The probability P thus does not describe the possible presence of a pollutant, but defines a time interval within which the release route can join cause and effect. From a pragmatic perspective, the time scales for polluted sites can be estimated to lie between ten and one thousand years, corresponding to probabilities of 10^{-1} to 10^{-3}. It is, therefore, not recommended that probabilities of 10^{-4} to 10^{-7} be used.

The degree of damage is directly dependent on the pollutant potential and indirectly a function of the protection objective or the value attributable to the object to be protected. A typical degree of damage could be defined as "a maximum value for the utilization of ground water is exceeded by a factor of 50 in an aquifer over a ten year period".

Since the danger (type and quantity of pollutant) is generally unknown, or there is considerable uncertainty attached to the determination of the polluting potential of a mixture of substances, it is necessary to assume different values (maximum, minimum and range). Thus the extent of damage, ED, does not have a single value but a whole series of values (ED_1, ED_2 … ED_n) or a range from ED_{min} to ED_{max}.

As already pointed out above, it is not appropriate to describe uncertainties of pollutant potential using probabilities. Consequently, the risk associated with a polluted site should not be described by a single function (curve) $R = P \times ED$, but by a group of curves, $R_i = P \times ED_i$ $(1 \leq i \leq n)$. This group of curves can be represented in diagrammatic form (probability vs degree of damage). Acceptance lines can be drawn, but must only be defined for the range of relevant probabilities (10^{-1} to 10^{-3}).

It is anticipated that consensus can be reached for risk acceptance using such an approach. Those affected by the risk are then able to take part in the risk discussion with the individual steps shown in a comprehensible form (despite numerous uncertainties) so that the entire decision-making process is transparent and can be followed. In contrast to the way risks are represented in nuclear power, where the so-called "risk tails" $0 \times \infty$ or $\infty \times 0$ are prominent aspects of discussion, a constructive risk dialogue should be more possible with contaminated sites.

In classic risk management, the aim is to use suitable measures to reduce the risks so far that they lie within the acceptance lines. Costs are always associated with the measures which can be optimized using cost-benefit analyses or cost limits. Whether these traditional methods can be used for polluted sites remains to be seen. There is considerable doubt about the suitability of such approaches, since it is questionable whether statistical methods are at all appropriate in the evaluation of such items as the willingness of a society to pay for environmentally friendly goods.

One point is clear from these considerations: the problem of soil pollution cannot be solved in the longer term by scientists and engineers alone; it will be become increasingly more important to include economists. Judicious political decisions require a reliable quantification of the threat posed, its risk and its associated costs. In the end, the decisive factor will be whether or not experts, affected parties and those bearing responsibility can discuss the problems and agree on satisfactory solutions.

The Situation Outside Switzerland

Switzerland can learn most from the successes and failures in Holland, Germany and the USA. In The Netherlands, for example, contaminated sites for which the pollution values lie above the statutory limits or guideline values are cleaned up without fail. This approach is very unwieldy, however, as only the degree of contami-

	Contaminant Chemistry					
Hydrogeologie	Mobile, Dissolved (degrades/ volatilizes)	Mobile, Dissolved	Strongly Sorbed, Dissolved (degrades/ volatilizes)	Strongly Sorbed, Dissolved	Separate Phase LNAPL	Separate Phase DNAPL
Homogeneous single layer	1*	1–2	2	2–3	2–3	3
Homogeneous multiple layers	1	1–2	2	2–3	2–3	3
Heterogeneous single layer	2	2	3	3	3	4
Heterogeneous multiple layers	2	2	3	3	3	4
Fractured	3	3	3	3	4	4

* Relative ease of cleanup, where 1 is easiest and 4 is most difficult

Table 1
Relative ease of cleaning up of contaminated aquifers as a function of contaminant chemistry and hydrogeology.

nation is established; strict procedures for clean-up are then followed. Every contaminated area that is discovered is cleaned up, and there is no freedom to allow clean-up to be tailored to the degree of danger posed by the polluted site or its later use. The Dutch are presently revising relevant laws and regulations. In The Netherlands, some 200 million guilders (approximately SFr 154 million) are being spent by the state each year for clean-up measures. In addition, between 1986 and 1994, a 60 million guilder research program into soil clean-up was carried out.

In Germany, procedures have been developed which set priorities on the basis of the objects under threat and, to some extent, on the basis of usage. This ensures that each polluted site is considered individually. Those sites of high risk are cleaned up first. Over the last 12 years, the Federal Office of Research and Technology (BMFT) in Germany has invested DM 200 million in clean-up and technology development.

To date, 10 million cubic meters of soil have been cleaned under the auspices of the Superfund Program in the USA. This is close to the quantity of material which would have to be excavated for the new NEAT Gotthard line (14 million m^3). The USA has also made considerable progress in the conceptual area. The latest developments of the Environmental Protection Agency (EPA) (e.g., the Superfund Accelerated Cleanup Model (SACM) [3] and guidelines for defining clean-up objectives [data quality objectives = DQO]) [4], show considerable promise for risk assessment of contaminated sites. The SACM was primarily conceived for use by the regulatory authorities and optimizes their approach. The DQO define ground rules which allow the various affected parties to rapidly agree on clean-up aims for polluted sites. The four key elements of the DQO are:

1. A strict delineation of political "risk aims" and the technical discussion of alternatives.
2. The transformation of political requirements, inclusive of the difficult definition of tolerance of uncertainties, into specific, concrete and measurable clean-up criteria.
3. The definition of the critical requirements and objectives of clean-up agreed by all affected parties.
4. The deployment of the entire arsenal of technical measures available to make the clean-up as efficient as possible.

Consideration should be given to the use of DQO in modified form in Switzerland to solve certain difficulties in risk assessment.

An internal EAWAG study carried out within the framework of the FoSP "Sustainable Resource Management, exemplified by Water and Anthropogenic Sediments" was completed in August 1994:

Michael Nay (1994): Literature search – polluted sites, EAWAG, Dübendorf

Contents: The approach to clean-up of polluted sites, above all in Switzerland and Germany; data collection and evaluation; sampling and analysis; research projects relevant to polluted sites; an overview of clean-up and protective measures.

This internal study runs to 400 pages and is thus available only on disc direct from the author (Tel. 01-823 51 55) at the price of SFr. 50.–, including VAT.

Conclusions

An estimation of the potential hazard of a polluted site must be based on a qualitative and quantitative knowledge of physical, chemical and biological processes in terms of area and time scale and the hydrogeological conditions of the site.

The problem lies in determining the level of knowledge needed and calls for a pragmatic approach. The experience will teach us what information suffices for assessment and how much uncertainty is allowable. In the words of Immanuel Kant, the need to decide is always greater than the body of knowledge. ChemRisk® [5], which is routinely used by the U.S. EPA, was developed in an effort to estimate chemical risk. It is based on a natural science/technical approach in which a model of human exposure is elaborated on the basis of the contaminant(s) present. The model takes into account the behavior of the pollutant in the environment, its toxicology and all possible routes of dispersal.

The objectives of protection are to be formulated according to the site conditions on the basis of risk assessment.

Such an approach allows each contaminated site to be assessed individually and clean-up to be tailored to future use. For instance, it is not necessary for former industrial sites to meet the requirements suitable for a childrens' playground. Individual treatment of sites allows available resources to be used more optimally where they are most needed.

Clean-up measures must be sound and ecologically expedient (e.g., be lasting), be feasible in terms of financing and technology, and be acceptable to society.

The stumbling blocks here are ecological expediency and the acceptability to society. The provisions of the Environmental Protection Act govern the ecological aspect, although a level of pragmatism is needed here as well. Acceptance by society certainly depends on how informed the public is and on how well-balanced the whole clean-up package appears. This balance must be based on comprehensible criteria. A modified DQO could be useful here.

The limiting factors for the clean-up of polluted sites in Switzerland are: (a) a knowledge of the potential hazard in terms of scope and time, (b) the time required before measures take effect, and (c) the financial resources.

Our limited knowledge of the potential hazard, the effectiveness of clean-up measures and the limited financial resources mean that concerted action is needed. The federal government must take a clear lead, involving the cantons and private sector and exploiting existing technology to its fullest extent. Clean-up technology is already very advanced internationally and has been used successfully by numerous companies. State-supported clean-up programs should not concentrate on technology development; however, a certain degree of freedom for innovation must be guaranteed for each clean-up operation.

Polluted sites are a national problem

The identification and clean-up of polluted sites in many cases overstretches the resources of cantons, communities and private companies. Contamination is not just a local problem, since leached chemicals can contaminate ground water which is used regionally or nationally as a source of drinking water. The development of evaluation criteria and the creation of the conditions needed for prospective risk assessment are beyond the means of most cantons and require a coordinated approach on the part of all parties, as well as input from university scientists and engineers and the research and development facilities of industry.

Where Do We Go from Here?

The federal government must take the lead. Priorities and time frames must be established for clean-up measures. To define the basic concepts and criteria for reaching decisions, it will be necessary, inter alia, to allocate finances. The corresponding financial instruments are envisaged in the revision of the Environmental Protection Act.

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[1] Bundesamt für Umwelt, Wald und Landschaft (BUWAL). 1994. Altlasten-Konzept für die Schweiz: Ziele und Massnahmen. Schriftenreihe Umwelt Nr. 220. Herausgegeben vom BUWAL, Bern.

[2] National Research Council (NRC). 1994. Alternatives for Ground Water Cleanup. National Academy Press, Washington, D.C.

[3] Environmental Protection Agency (EPA). 1992. Guidance on Implementation of the Superfund Accelerated Cleanup Model under CERCLA and the NCP. OSWER Directive No. 9302.1–03. US EPA, Washington, D.C.

[4] Environmental Protection Agency (EPA). 1993. Guidance for Planning for Data Collection in Support of Environmental Decision Making – Using the Data Quality Objectives Process (DQO). EPA QA/G-4. US EPA, Washington, D.C.

[5] Bachmann, A. 1995. Crucial Needs for Environmental Risk Assessment (ChemRisk®). Proc. SCOPE/UNEP Workshop on Soil and Groundwater Pollution, *in press.*

Ecomorphological Evaluation and Development of Streams and Stream Systems

Between 1991 and 1994, EAWAG scientists worked jointly with the Canton of Zürich's Department of Water Conservation and Hydraulic Engineering to develop plans for monitoring and assessing streams and stream systems and to establish principles for their ecologically based development. A final report was published in October 1994 [1].

A key feature of the program is the use of a new method for evaluating the ecomorphological status of stream systems. In addition to monitoring water depth, water-level width, variability in depths and widths, it considers channel form, bed substrates, bed and bank obstructions, bank vegetation, and the use of surrounding land. The status of the stream is then compared with a reference status (i.e., "the natural condition of the waters in the existing cultivated landscape"). Any shortcomings are noted with special attention paid to obstructions which might hinder the longitudinal migration of organisms (e.g., weirs, sills and culverts). Additional data on various biological indicators (aquatic plants, small animals, fish), water chemistry, conservation of nature and species, and other features specific to the locale are also collected.

The end result of these monitoring efforts is to define the principles that will be used to design an ecologically based water development program. Such a program is already in operation in the Austrian Tyrol. The program developed for the Canton of Zürich is currently serving as a basis for a national system of monitoring and evaluating the ecomorphological status of Swiss streams and stream systems. This project is managed jointly by EAWAG and the Federal Office for the Environment, Forestry and the Countryside (BUWAL).

This project and its implementation will be described in the EAWAG news 39 E.

Michael Hütte

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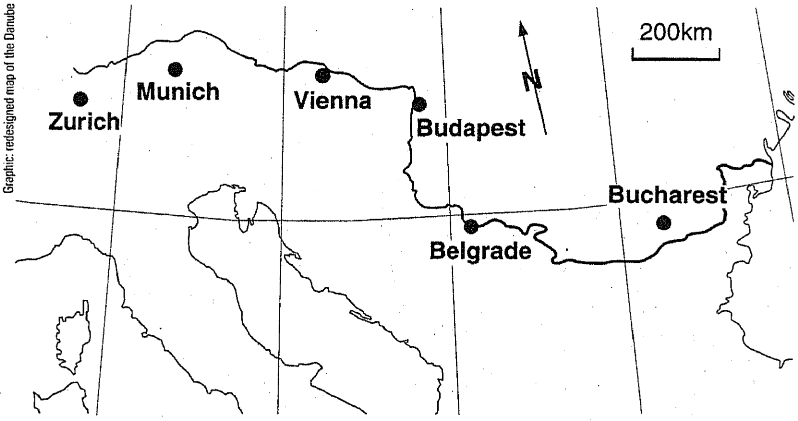
[1] M. Hütte, U. Bundi and A. Peter: *Konzept für die Bewertung und Entwicklung von Bächen und Bachsystemen im Kanton Zürich,* ISBN 3-906484-10-6

Conference of the International Working Group for Danube Research (IAD), 29 Aug–2 Sept 1994 in Zuoz

Danube Research



Graphic: redesigned map of the Danube

The Danube from the Spring to the Black Sea.

The IAD* is a loosely-structured umbrella organization that coordinates scientific research and development operations currently taking place in 14 Danube countries (from Germany to the Black Sea, Romania and the Ukraine). From its founding in 1956, with Swiss involvement by Prof. Otto Jaag (EAWAG's first director), until the reorganization of Eastern Europe in the 1980s, the IAD has been one of the few organizations to promote regular personal contact among its members. Conferences are generally held each year, timed to coincide with the SIL** World Congress. Organized by the member countries on a rotational basis, Switzerland was responsible for the conference in 1994. Overall direction fell to the national representative *Prof. Heinz Ambühl.* Assisted by *Dr. Hans Rudolf Bürgi,* an experienced conference organizer, and his expert team consisting of *Christa Jolidon* and *Heinz Bachmann,* Prof. Ambühl hosted the conference in the Lyceum Alpinum in Zuoz in the Engadine region, the only Swiss catchment area of the Danube.

It is noteworthy that the IAD does not use formats normally employed by international specialist conferences of this size (around 100 participants). For example, the scientific papers, which are 2–5 pages in length, are printed before the meeting and issued to the delegates. They are, however, not formally presented. Instead, they are then developed into "review papers" by the heads of the specialist groups and presented in plenary sessions. In practical terms, the conference consists (apart from specialist group meetings and excursions) of plenary sessions exclusively. The review presentations are subsequently published in book form. By assisting with the organizing and editing of these papers, EAWAG provides welcome development aid, especially to those Danube countries still experiencing serious financial difficulties.

At the invitation of the power generation company "Engadiner Kraftwerke AG", a full-day excursion was arranged to visit the power generation plants "Punt dal Gall"/Livigno – Ova Spin (on the Spöl) and Pradella and Martina (on the Inn). During a second excursion, delegates traveled by train over the Bernina Pass to Poschiavo where, in the midst of the spectacular scenery, the technique of plankton sample collection was demonstrated and samples were examined under the microscope.

The overriding factor affecting the research problems of the Danube and its tributaries is the enormous ecological upheaval currently taking place as a result of the construction of numerous barrages and hydropower stations. In just a few decades, the Austrian stretch of the Danube has been turned into an almost unbroken chain of artificial lakes with a hydropower station at Gabčikovo and two huge installations in the "Iron Gate" *(Eisernes Tor).* The Danube is also being used in many areas for sewage disposal to an extent that we in Switzerland have never experienced, even at the height of river pollution in the 1970s. The fishing industry, so vital to the Eastern countries, is suffering considerably. Work undertaken by the IAD has highlighted this deplorable state of affairs, and we are now doing everything within our power to encourage water conservation (even becoming politically active!). It is not surprising then that the concept of "water quality" *(Gewässergüte),* a factor that we have failed to appreciate in the past, has now gained such significance for the central and lower sections of the Danube and currently forms the focus for a large part of limnological research.

More information can be obtained from the "Limnological Reports Danube 1994" (Vol. 1: Scientific seminar papers, 442 pp.; Vol. II: Comprehensive reviews, 321 pp.; Vienna/Dübendorf 1995 [edited by EAWAG]).

Heinz Ambühl

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* IAD = "International Working Group for Danube Research" of the International Association of Theoretical and Applied Limnology

** SIL = Societas internationalis limnologiae

An Update on the Priority Research Program

EAWAG is involved in the development of a high priority research program that is based on the available evidence that active management of natural resources is essential to the long-term preservation of global ecosystems. EAWAG has initiated an interdisciplinary research program entitled the "Sustainable Management of Resources: Water and Anthropogenic Sediments", the goal of which is to develop practical approaches for the sustainable use of regional resources. The background and objectives of this work have been detailed in a previous issue of *EAWAG news* (Vol. 35). The following provides an update on progress made to date.

Selecting a Study Region

In the initial phases of the research program, we first needed to define the principal questions related to regional sustainability: What are the central environmental problems that conflict with regional sustainability? What key processes are responsible for these problems? We also needed to find a region that would be specifically suited to the investigation of these problems. We eventually settled on the region defined by the watershed of the river Töss and its tributaries (Töss region) whose economic and industrial life centers around the town of Winterthur. The reasons for selecting this region are outlined in the box below.

Definition of "Sustainability" according to the World Commission on Environment and Development (WCED)

A development or activity is considered to be sustainable if it meets the needs of the present generation without compromising the needs of future generations.

Reasons for Selecting the "Töss" Watershed as an Investigation Area

- Typical structure for the region of central Switzerland
- Sufficiently large to allow valid conclusions (ca. 430 km^2)
- Widely differing types and intensities of land use in the subregions
- Industrial and political center located in middle of watershed (Winterthur)
- Closed water cycle within the Töss watershed
- Availability of a large amount of basic data

An analysis of the environmental status and use of resources in the Töss region revealed a number of ways in which resources are not used in a sustainable fashion:

- increasing overuse, in quantitative terms, of the ground water
- increasing contamination of the ground water by pollutants (e.g., nitrates)
- continuing deterioration of the variety of the landscape with significant consequences for natural ecosystems and biodiversity
- increasing concentrations of pollutants in the air and soil, primarily caused by consumption of fossil fuels and industrial activities
- threats to groundwater quality from numerous contaminated waste sites

Research Objectives

An additional goal in the planning phase was to identify the linkage between important human activities (e.g., water and land use, waste disposal) and environmental changes. To a certain extent, this could be achieved through specific scientific investigations. But since human activities are also affected by economic and sociocultural factors, our research will attempt to obtain a better understanding of the key relationships in these areas as well. We then plan to use these findings to develop strategies for sustainable development and for the environmentally-acceptable future use of resources at the regional level.

Specifically, our work should help us develop environmentally-based concepts and strategies for:

- providing a reliable long-term supply of clean drinking water from regional aquifers
- restoring ecologically functioning structures in the regional water network in order to facilitate self-supporting natural communities of organisms
- limiting contamination in environmental compartments

Research Areas

In order to achieve these objectives, the key areas of research have been subdivided into three subtopical and one integrational area. Approximately 20 projects are currently underway.

Projects within the subtopic "Anthropogenic Sediments" are investigating the potential threat to the environment posed by a former household waste dump. Objectives for the work include identification of substances originating from these anthropogenic sediments and a determination of their fate and transport in subsoils and ground water.

Research interests in the "Ground Water" area will focus on changes in groundwater quality due to infiltration of substances originating from human activities, especially heavy metals and organic compounds from stormwater systems. Pollutant conversion and transport occurring in the subsoil and in subsurface aquifers are of primary interest. An additional area of concern involves the effects of increased stormwater infiltra-

continued p. 34

tion on the quantity of usable ground water.

The primary aim of projects within the subtopic "Water Systems" is to investigate the importance of structure and connectivity in the regional water network. This research will also consider transitions with terrestrial surroundings and ground water in preserving the diversity of biotopes and the role they play as linking elements in the natural environment.

Finally, the "Integrational Studies" will investigate the relationships between human activities and the regional environment. This research will attempt to identify the social and economic behaviors that have led to unsustainable resource use.

As this overview of the current research areas suggests, EAWAG is focusing primarily on its collective expertise in the water quality field; however, the following is needed for a comprehensive understanding of resource sustainability on a global scale:

- concepts for the sustainable use of energy and its social and economic consequences
- a better understanding of the significance of terrestrial biodiversity, especially on a regional ecosystem level
- data on the significance of agriculture, urban structures and traffic on soil and groundwater quality

The involvement of other institutions, including universities, research institutes, government agencies and the private sector, will help us expand our understanding in these critical areas. To this end, contacts with the canton of Zürich, the town of Winterthur, the Federal Institute of Technology (ETH Zürich) and private consulting engineers have already been made and will be expanded in the future.

Walter Wagner

Report of the first CLEAR Conference 4–9 September 1994
Centro Stefano Franscini, Monte Verità, Ascona

Climate Change and Alpine Regions

Climate change research to date has tended to focus on the global environmental risk. Little is known about the regional aspects of climate change. The first CLEAR Conference attempted to close this gap by investigating Alpine regions that are particularly sensitive to climate change.

The Alps as a Sensitive Climate Zone

The Alps represent a special challenge to climate researchers, as evidenced by the following two examples. First, because of the specific location and shape of the Alps (otherwise known as the "croissant in the west wind"), air currents flow both over and around them. The air flowing over the Alps produces precipitation, while the air flowing around them manages to retain its moisture. The modelling of these effects and any possible changes are of crucial importance in estimating future precipitation trends.

The following diagrams (see figure 1) illustrate this behavior by means of air currents flowing over and around an idealized mountain. The air flows from left to right. The diagrams show the actual current lines from the side (two upper figures) and from above (two lower figures), with the currents flowing over (two left-hand figures) and around (two right-hand figures) the mountains. Note the slight vertical displacement of the air currents in the top "flow around" figure.

The second example of the challenge posed by regionally-based climate research relates to the field

continued p. 36

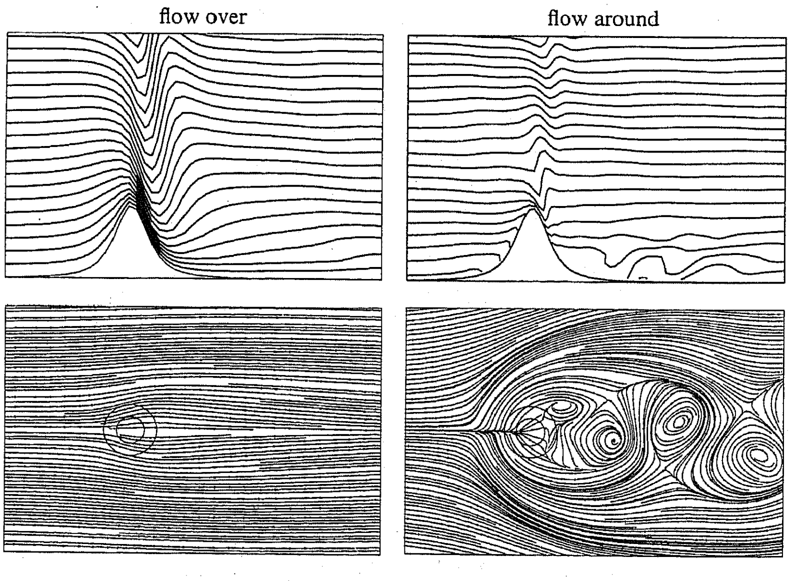

Fig. 1
The Alps as a simplified model from the side (two upper figures) and from above (two lower figures), showing the pressure distribution for currents flowing over (two left-hand figures) and around (two right-hand figures) the mountains. Printed by kind permission of Christoph Schär, Institute for Atmospheric Physics, ETH Zürich.

CLEAR = Climate and Environment in Alpine Regions

CLEAR is a project within the Priority Program Environment, sponsored by the Swiss National Science Foundation (SNF). It is designed to investigate the physical, biological and social aspects of climate change in nine separate projects. The CLEAR process incorporates an additional 12 projects in Module 1 of the Priority Program Environment. The speaker for CLEAR is Huw Davies, Institute for Atmospheric Physics, ETH Zürich. The 21 projects are coordinated by Carlo Jaeger and Urs Dahinden of the Human Ecology Group at EAWAG. The planned publications will be supervised by Peter Cebon, a postdoctoral researcher in the Human Ecology Group. Three of the projects listed below (Dürrenberger, Lotter, Pahl) are under the direction of EAWAG scientists. The Pahl [2] and Dürrenberger [3] projects have previously been described in EAWAG news. Results of the Lotter project are presented in this issue (see Sturm und Lotter).

CLEAR PROJECTS

Climate and Environment in Alpine Regions

Speaker: Huw C. Davies

Brassel, Kurt E., Geographisches Institut, Universität Zürich: Integration von Umweltdaten mit heterogenem Raum- und Zeitbezug.

Dürrenberger, Gregor, Humanökologie EAWAG, Dübendorf: Innovative responses to anticipated climate change

Fischlin, Andreas, Institut für terrestrische Ökologie ETH, Schlieren: Alpine forest ecosystems in a changing climate – paleoclimatic model validation and sensitivity analysis.

Gyalistras, Dimitrios, Institut für terrestrische Ökologie ETH, Schlieren: Case studies in bioclimatic scenarios derivation.

Ohmura, Atsumu, Geographisches Institut ETH Zürich: Numerical model studies of the influence of the Alps on climate.

Pahl-Wostl, Claudia, Umweltphysik EAWAG, Dübendorf: Reconstruction and modelling of the longterm dynamics of ecosystems.

Ratti, Remigio, Istituto di Ricerche Economiche IRE Bellinzona: Mobility economics – climate change – agents (MECCA).

Schär, Christoph, Institut für Atmosphärenphysik ETH Zürich: Alpine climate and climate change: a study of some key atmospheric processes.

Tschannen, Olivier, Institut de sociologie et de science politique, Université de Neuchâtel: Social and cognitive processes in regional milieus in response to global environmental problems.

Environmental Changes and Modifications in the Subalpine/ Alpine Ecocline: Establishment of a Plant and Soil-Based Evaluation Model

Speaker: Jean-Paul Theurillat

Geisler, Patricia, Conservatoire et Jardin Botaniques, Chambésy-Genève: Changements environnementaux dans l'écocline des étages subalpin-alpin: réaction et bioindication des bryophytes.

Gobat, Jean-Michel, Laboratoire d'écologie végétale, Université de Neuchâtel: Modification de l'écocline subalpin/alpin: réaction du sol, notamment de sa fraction organique.

Küpfer, Philippe, Institut de botanique, Université de Neuchâtel: Le polymorphisme génétique intraspécifique dans l'écocline subalpin/alpin: un indice révélateur des potentialités d'adaptation aux changements environnementaux.

Spichiger, Rodolphe, Conservatoire et Jardin Botaniques, Chambésy-Genève: Case studies in bioclimatic scenarios derivation and sensitivity of plant distribution.

Theurillat, Jean-Paul, Conservatoire et Jardin Botaniques, Chambésy-Genève: Changements environnementaux et modifications de l'écocline subalpin/alpin: réaction de la couverture végétale.

Environmental Dynamics: Past and Present

Speaker: André F. Lotter

Ammann-Moser, Brigitta, Systematisch-Geobotanisches Institut, Universität Bern: Fire-history in central and southern Alps.

McKenzie, Judith, Geologisches Institut, ETH Zürich: Lakustrische Ablagerungen als Monitoren von Dynamik im Grenzbereich Atmosphäre–Erdoberfläche: Kalibration chemisch-physikalischer Tracer, Teiltestgebietsstudien (LAMODATE).

Lotter, André F.H., EAWAG/ETH Umweltphysik und Systematisch-Geobotanisches Institut, Universität Bern: Lake sediments as proxy-archives for the reconstruction of environmental dynamics in space and time: calibration.

Pfister, Christian, Forschungsstelle Regional- und Umweltgeschichte, Universität Bern: Regionale Klimaveränderungen im südöstlichen Schweizer Alpenraum zwischen 1400 und 1900 im Lichte historischer Proxy-Daten.

Stauffer, Bernhard, Physikalisches Institut, Universität Bern: Rekonstruktion von Klimaschwankungen durch die Analyse von Eisbohrkernen

Individual CLEAR Project:

Fröhlich, Claus, Physikalisch-Meteorologisches Observatorium, Davos: Klimatologie der Ultraviolett-Strahlung und ihre langfristigen Veränderungen.

of biology. Increased average temperatures force plants to migrate to higher altitudes. But just how fast can alpine plants migrate? The answer may be found in historical data on the fauna of various alpine summits. At least one plant species has managed to keep pace with climate changes observed to date by migrating upwards [1].

Interdisciplinary Work

Most scientists agree that a variety of scientific and social disciplines must be involved in order to understand climate change. It is not clear, however, how multidisciplinary expertise should be integrated. For example, should the integration primarily involve the collection of data that are then evaluated in a common computer model? A number of problems would arise from using this approach, since both the quality of the data and its validity will differ considerably from one field to the next.

The CLEAR process (see box) has adopted a different approach in which integration is achieved via the investigation of interdisciplinary topics; for example, regional perspectives or the uncertainty of future developments in natural and social systems. To date, interaction among the various projects has been good. Even the foreign delegates attending the CLEAR Conference were impressed by the spirit of interdisciplinary tolerance and openness which prevailed.

Delegates and Conference Structure

Over 80 individuals participated in the first CLEAR Conference. The first day was organized jointly with ProClim, the Global Change Forum of the Swiss Academy for Natural Sciences, and was aimed at the general public. Participation on the following four days was restricted to some 50 scientists involved in the CLEAR process who worked together on a joint publication. The writing and discussion process was supported by foreign specialists who gave presentations on selected subjects.

Planned Publications

Results from both the CLEAR research and the first CLEAR Conference will be published in two English-language volumes. The first volume will be written in form of a discussion for politicians and the general public. The second and more comprehensive volume will be aimed at a scientific readership as well as policy analysts, journalists, teachers, and students.

Urs Dahinden

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[1] Grabherr, G.,Gottfried, M. and Pauli, H. (1994): Climate effects on mountain plants. Nature, Vol. 369, p. 448.

[2] Pahl W., Claudia, J., and Carlo C. (1994): Risk Communication: The Example of Climate Change. *EAWAG news*, 36E, Ocotober 1994. p. 6–8.

[3] Truffer, B., Dürrenberger, G. und Rothen, S.: Will the "Car of the Future" be Developed in Switzerland? Comments on the Supercar-EAWAG Workshop of 20/21 September 1993. *EAWAG news*, 36E, October 1994. p. 36–37.

Heads of Research Units of EAWAG

July 1995

EAWAG

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Deputy Director	**Wasmer Hans**
Vice-Director	**Bundi Ueli**

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Finance	Joss Ulrich Martin
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Apprentices	Reutlinger Max
Personnel	Cajochen Verena
Experimental Station/ Workshop	Burkhalter Hans

* *rotating management*

Professor Jürg Hoigné Retires

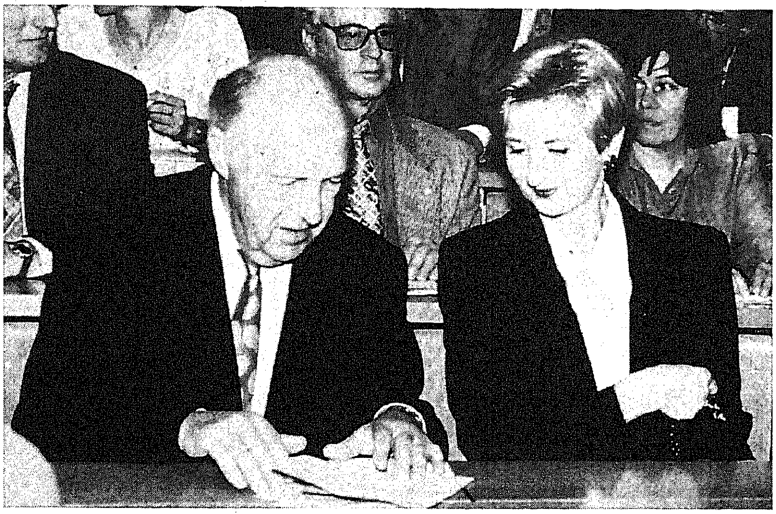
After a long and successful career as a scientist and teacher, Professor Jürg Hoigné retired on 1 June 1995.

After receiving his Ph.D. in the Institute for Physical Chemistry at the Swiss Federal Institute of Technology (ETH) in Zürich, Jürg Hoigné left Switzerland for a postdoctoral fellowship at the Brookhaven National Laboratory (USA) where he focused on problems in the field of radiation chemistry. Two years later, in 1960, he returned to the ETH-Zürich as a research associate for radiation chemistry and lecturer in photochemistry and radical chemistry.

In 1965, Jürg Hoigné received the *venia legendi* for radiation chemistry and radical chemistry at the ETH-Zürich. In 1975, this venia legendi was extended to include environmental aqueous chemistry.

After eight years with INRESCOR AG (International Contract Research Co.) in Schwerzenbach, where he was head of the Department for Applied Radiation Chemistry, Jürg Hoigné joined EAWAG in 1973. Since then he has led the research group in oxidation kinetics in the Chemistry Department and acted as the deputy head of the department from 1973 to 1989. In 1986, he was appointed head of the Institute for Aquatic Sciences and Water Pollution Control (IGW) of the ETH-Zürich, and from 1989 to 1990, served as chair of EAWAG's Chemistry Department.

Since 1975, Professor Hoigné has been docent at the ETH-Zürich for the chemistry of drinking water and wastewater treatment and participated for the lecture on unit operations for water treatment. Since 1977, he also taught environmental chemistry in the Department of Chemistry.


Max Reutlinger

Professor Jürg Hoigné and his wife in the EAWAG auditorium at the symposium given in his honor on 16 June 1995.

Professor Hoigné has worked in and influenced many fields of research. He has been able to combine areas as different as cloud chemistry and drinking water treatment by applying the same concepts to understanding the reactions involved. In the field of ozonation, his research has led to the introduction and application of processes which today are routine in the treatment of drinking water.

But his professional activities included much more than his obligations at the EAWAG and ETH-Zürich. From 1973 to 1980 he was a member of the International Rhine commission. He was also on the editorial board of the Journal of Ozone Science and Engineering, served on the Steering Commitee of the EUROTRAC HALIPP group, and participated in the workshop "Oxidation Processes for Drinking Water Treatment" hosted by the German Association for Gas and Water (DVGW).

Jürg Hoigné received numerous academic honors for his efforts in both research and teaching. He is Titular Professor at the ETH-Zürich (Department of Chemistry) and honorary member of the International Ozone Association, an honor given in recognition of his outstanding contributions towards furthering the objectives of the association. His engagement in research guided by precise questions resulted in numerous widely recognized publications. In the field of environmental sciences, he is one of the most cited scientists.

On the occasion of Prof. Hoigné's retirement, a symposium was organized by Dr. Urs von Gunten at the EAWAG in his honor. All of the presentations were given by former collaborators and colleagues, who not only referred to him as an outstanding scientist, but also expressed their relationship to him in personal ways. Their presentations in the fields of photochemistry, radiation chemistry, atmospheric chemistry, and drinking water treatment, reflected the wide variety of Professor Hoigné's scientific interests and the contributions he has made to both the fields of research and teaching.

We offer Professor Hoigné our best wishes for the future. Although we hope that he now has the time to realize all of his private plans, we are looking forward to welcoming him to EAWAG as an esteemed colleague on many occasions in the future. *js*

His most recent work has focused on the following areas:

- Aqueous ozone and hydroxyl radical chemistry, reaction kinetics and application for wastewater, drinking water and cloud chemistry
- Experimental methods for aqueous ozone chemistry including analytical methods
- Kinetic aspects of chlorine dioxide reactions and photochemistry of aqueous chlorine
- Reaction kinetics of photochemical reactions in surface water and clouds, including the role of singlet oxygen, superoxide ions, peroxy radicals, solvated electrons, hydroxyl radicals and transition metals
- Modelling of photochemical reactions and formation of disinfecting by-products

Münster Appointment

Dr. Elisabeth I. Meyer was recently appointed Professor of Limnology at the University of Münster, Westphalia (Germany), and took up her new post on 1 November 1994. The university's new Department of Limnology has been set up by Dr. Meyer and is part of the Biology Faculty. The department will be offering basic limnology lectures supplemented by additional special lectures, practical courses and seminars.

Prof. Meyer joined EAWAG's Department of Hydrobiology/Limnology in January 1991 as a lecturer (subsequently becoming a senior lecturer) in the ETH Department of Environmental Sciences. In addition to her teaching and lecturing duties, Dr. Meyer, together with colleagues at EAWAG, has been involved in surface water research, studying the structure and dynamics of benthos organisms in streams and their relationship to other components of the ecosystem. She has also been studying the effects of disturbances, in particular, extreme flow situations (e.g., floods, droughts) in a pre-alpine river (Necker, Canton of St. Gallen) and a river in Central Switzerland (Töss).

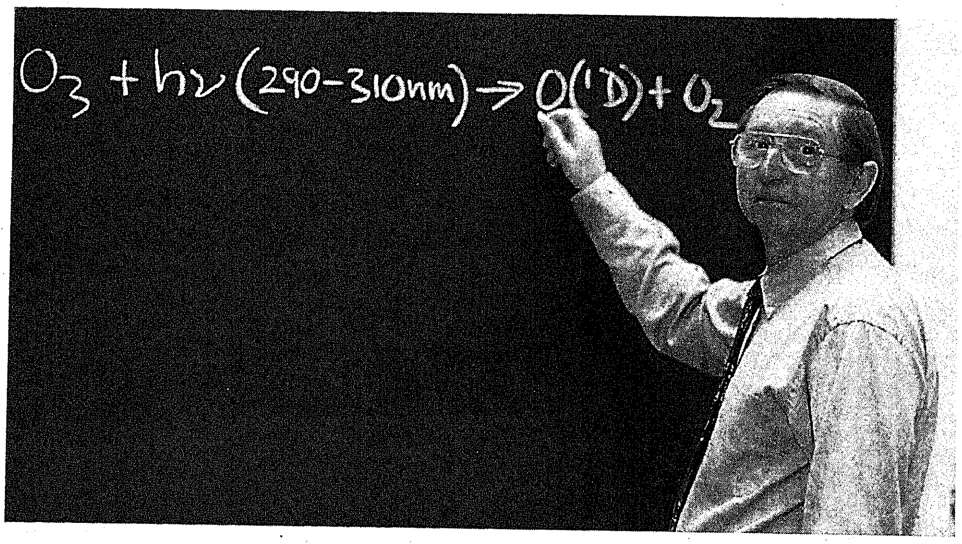
Stefan Wey

New address:
Prof. Dr. Elisabeth. I. Meyer
University of Muenster
Zoological Institute
Department of Limnology
Huefferstrasse 1
D-48149 Muenster
Tel: 0049 251 83 3881
Fax: 0049 251 83 4668

Dr. Meyer received her habilitation from the ETH Zürich in 1993 for her thesis entitled "Benthic Invertebrates in Small Running Waters, as illustrated by a Black Forest Stream: Biocenotic Structure, Population Dynamics, Production, and Food Web Structure". In April 1993 she was granted the *venia legendi* by the ETH Zürich, allowing her to give lectures on aquatic biology and ecology. Upon the retirement of Prof. Ambühl in April 1994, she was appointed acting Head of EAWAG's Department of Hydrobiology/Limnology.

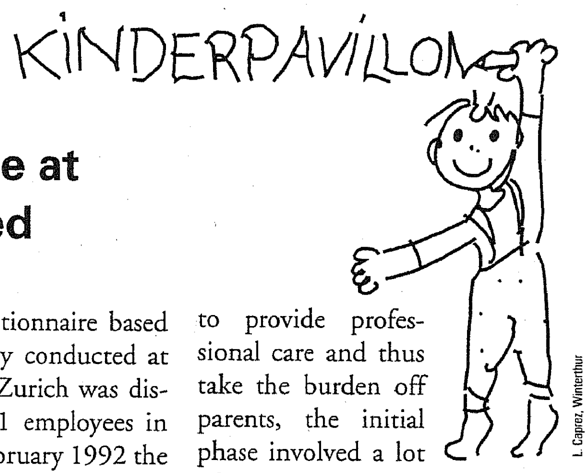
Professor Meyer will be maintaining her scientific and personal contacts with the ETH Zürich and EAWAG. Together with her assistants Eva Tania Schellenberg and Rainer Zah, she will be working on a project to investigate the "Effects of Low Water Droughts on the Ecosystem of the River Töss" as part of the current EAWAG Research Program. She will continue to work with EAWAG colleagues on multidisciplinary research projects investigating quantitative interactions in the food webs of running waters. One contribution will be a dissertation on the ecological function of protozoa in the hyporheic interstitial waters of a pre-alpine river. During the 1995 winter semester, she will be participating in a series of lectures at the ETH Zürich on "Systematics of Aquatic Invertebrates", which she inaugurated two years ago. Dr. Meyer's research in Germany will be extended to include lowland waters. She plans to continue her field and laboratory investigations on the structure and function of benthos in aquatic ecosystems.

Professor Meyer's successor as Head of EAWAG's Department of Hydrobiology/Limnology is the former Deputy Head Dr. Peter Bossard who assumed his new position last November.



Stefan Wey

At the end of 1994, the Board of the Swiss Institutes of Technoloy appointed Alistair Kerr professor at the ETH Zurich. Kerr, a British citizen born in 1934, heads the research group for atmospheric chemistry at EAWAG and teaches in the Department of Environmental Sciences.



L. Caprez, Winterthur

Children Day-care Centre at EAWAG/EMPA Opened

Since Tuesday 1 November EMPA and EAWAG employees have been able to leave their children in the new day-care centre. Daily from 07.30 to 17.30 hr two part-time carers (each 60%), both trained pediatric nurses with practical nursery experience, and one full-time trainee take turns to look after children aged between 2 months and 4 years. The day care centre was set up by a group of interested employees and originally comprised 2 rooms, to which a third was added at the end of 1994. A kitchen is also available for the preparation of snacks and drinks. At lunchtime children's portions can be obtained from the nearby staff restaurant.

But just how did this facility – so highly prized by the parents concerned – come into being? As a result of questions raised at a women's meeting in June 1991, a questionnaire based on a similar survey conducted at the University of Zurich was distributed to all 291 employees in October 91. In February 1992 the evaluation working group headed by Ilse-Dore Quednau (EAWAG) established that 10 women and 19 men were keen on at least one type of child-care.

R. Niederöst, EMPA

A few incorrigible optimists attempted to find solutions across a wide range of levels. In the end the parents involved had to act on their own initiative. Accordingly the "Day-care Centre Association" was formed on 8 June 1993. Membership is open to any EMPA or EAWAG employee wishing to support the day nursery, or obliged to do so if they make use of its facilities. The Association committee currently comprises 3 EAWAG and 3 EMPA employees.

Although the object of the day-care centre is to provide professional care and thus take the burden off parents, the initial phase involved a lot of work for the committee members. Fortunately, the personnel department of EAWAG assumed responsibility for the direct payment of wages, billing the Association each month. A deficit guarantee by both EMPA and EAWAG was promised.

In selecting the carers the committee placed great emphasis on their willingness to cover for other staff during holidays or periods of illness, thus exposing the children to the minimum number of staff changes. Following a fairly relaxed induction period for the carers, with relatively few children, several more children are now sought so as to relieve the financial strain on the currently involved parents. Parents are responsible for the bulk of the day-care centre's costs. The fairly steep contributions of Sfr. 63.– per child per day have already scared off a number of potential users.

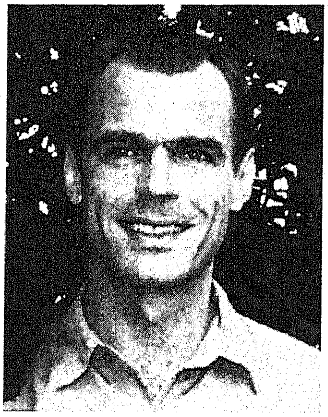
The search for premises finally came to an end when EMPA offered the use of space in their staff restaurant building following refurbishment of some guest rooms. Following completion of this work at the end of October the Association moved in with numerous gratefully received donations and newly purchased beds, and the day-care centre finally opened for business with 7 children in the ground floor rooms. Since two rooms open directly onto fields some weather-resistant toys and safety fences to stop children running onto the road were added in Summer.

Diana Hornung,
Member of the Day Care Association

Otto Jaag Prize for Water Pollution Control 1991 and 1994

for Peter Krebs

The "Otto Jaag Prize" winner in 1991 was *Peter Krebs*, whose dissertation was entitled *"Modelling and Improving Currents in Secondary Settling Tanks"*.


Paul Schlup

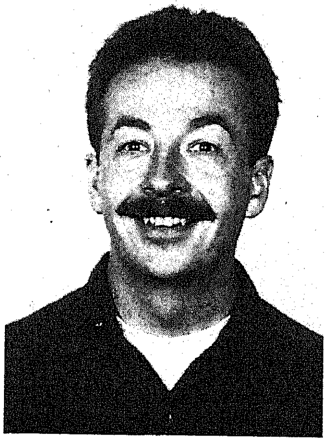
Working under Professor Willi Gujer, EAWAG, and Professor D. Vischer, ETH Zurich, Krebs successfully developed simple, effective and highly practical improvements to the design and dimensions of secondary settling tanks. Existing and projected secondary settling tanks can now be optimized as a result of his work. In the experiment, sludge was simulated with a clay suspension, thus allowing the density effects of the settling phase to be taken into account. He was able to demonstrate that the sludge content in the inflow was the main reason for the rolling motion occurring in secondary settling tanks. The following approaches can be adopted to improve the situation:

- a low inlet position to reduce the potential energy surplus
- an energy dissipation device located transversely across the inlet to produce turbulence in the bed current, and
- several transverse walls with holes to even out the vertical velocity profiles in order to improve utilization of the tank volume and to stimulate flocculation.

From 1991, Krebs worked at the Institute of Hydromechanics at the Technical University of Karlsruhe under Professor Rodi on a research project on turbulent mixing and sedimentation processes. Since 1994, he has worked at the EAWAG in the Urban Hydrology Group (see article in EAWAG news 37E).

for Reto von Schulthess

The "Otto Jaag Prize for Water Pollution Control" is not awarded annually. But in 1994, it was given to *Reto von Schulthess* for his doctoral thesis on *"The Emission of Nitrous Oxide (N_2O) in Denitrifying Activated Sludge Systems"* (ETH thesis 10790, Publ. 1990).



Reto von Schulthess can be contacted at the following address: Künzler und Partner, Kellerstr. 36, 6005 Lucerne.

After studying biotechnology at the ETH Zurich, von Schulthess started his postgraduate research at EAWAG in urban hydrology and water pollution control. Under the supervision of Professor Willi Gujer of the Department of Engineering Sciences, his dissertation research focused on the emission of nitrous oxide (N_2O) from waste water treatment plants.

Nowadays, nitrogen elimination is of primary concern in the design of waste water treatment plants; however, it has not been known whether or not N_2O is released during nitrogen elimination processes in waste water treatment. Using a combination of laboratory testing, mathematical modelling and investigations in an actual treatment plant, von Schulthess convincingly demonstrated that, under ideal process conditions, N_2O emissions from waste water treatment plants are negligible, equivalent to 0.1–0.4% of the denitrified nitrogen. In order to obtain ideal conditions in the nitrification-denitrification process, nitrite concentrations above 2 g Nm^{-3} should be avoided.

Key-word: nitrous oxide

Since 1950, nitrous oxide levels worldwide have been increasing at a rate of 0.2–0.3% per year. As a result of the increase since 1980 of an additional 15 ppb (to 300 ppb), it has now become the third most important greenhouse gas after CO_2 and methane or, in an industrial country like Switzerland, after CO_2 and CFCs. The higher the levels of nitrous oxide reaching the stratosphere, the greater the amount of NO formed, resulting in a more rapid depletion of the ozone layer. The following are important sources of nitrous oxide emissions in Switzerland: loss of nitrogen from soil (60–80%); from incineration processes (10–20%); and emissions from ground water and stagnant bodies of water.

EAWAG Evaluated by an International Team of Experts

For the first time ever, an entire ETH institution – in this case EAWAG – has been evaluated by an international group of experts. The evaluation team was composed of internationally renowned academic scientists and field specialists: two members each from the USA and Germany and one member each from Central America, The Netherlands and Switzerland. The President of the ETH Council issued the team a list of questions to consider in their evaluation, including areas of strategy, scientific quality, contributions to science and environmental protection and future plans. The evaluation took place between 17 and 22 July 1994.

In its report, the evaluation team commented very positively on EAWAG's achievements in research, teaching and consulting. Strong support was voiced for EAWAG's long term plans, which include a gradual change in emphasis to the sustained management of natural resources. According to the evaluation team, this change in direction – moving away from the tenet of environmental conservation – will require a high degree of commitment. They cited the immediate need to increase awareness of this new emphasis among EAWAG staff.

The team believes EAWAG should continue to be involved in research, teaching and consulting, but stressed that links with the scientific and financial communities as well as government agencies should be extended. European contacts also need to be strengthened. In response to the evaluation team's proposals, in the coming months EAWAG will be addressing a number of issues, including the development of stronger ties between EAWAG and ETH, consideration of the internal consequences of focusing on resource management issues, integration of a strong economic component, and how to better deal with interdisciplinary questions.

The EAWAG Advisory Committee has studied the evaluation report in detail and agrees with all of its main conclusions. As a result of experience already gained in multidisciplinary work, the Committee believes that EAWAG is particularly well positioned to develop a research program that focuses on the interactions between human behavior and natural systems; however, the Committee stresses the need to develop new approaches to environmental protection and urges EAWAG to take a leading scientific role in this emerging field.

Ueli Bundi

Book Review

On the Nature of Man, Quantitative Growth and Sustainable Development in the Third World


International Studies in Global Change: 5

Transforming Economic Institutions in the Face of Global Change

Taming the Dragon

Carlo C. Jaeger

Gordon and Breach

A cruise down the River Saône to escape for a few days and I'm only allowed to pack *one* scientific book! But which one? I eventually choose Carlo Jaeger's *Taming the Dragon* – pretty much cheating on my quota since in its 300 or so pages, the author weaves an intelligent web of ideas that would normally be found in *several* books – ideas that are essential to an understanding of current environmental problems as well as their satisfactory resolution.

As early as the Preface, the reader is both alerted to the need to cross disciplinary boundaries and warned about the associated risks of doing so. We have heard such warnings before; more often than not, they prove to be rather trivial and superficial. In this case, however, they are valid because the author dares to venture into the difficult terrain of sociology, economics, philosophy, psychology, natural science and other disciplines, exposing himself to the scorn of the discipline-bound Pharisee. The book sails under the flag of human ecology, an area of science that is far from being well-defined. One point is not in doubt, however: provided the field of human ecology does not develop out of the simple addition of facts from different disciplines, it certainly should last the course – a conclusion that applies to the environmental sciences generally.

Jaeger's book makes a serious attempt to conduct an interdisciplinary analysis of the transformation of economic instruments against a background of global change. Rather than formally reviewing the book, I would prefer to encourage potential readers to take their own cruise down a French river. I will, therefore, confine myself to those sections of the book whose messages I found personally moving. Accordingly, I will skip over the first four chapters in which Jaeger primarily addresses sociological issues. It is not that these discussions are dry – in fact, quite the opposite!. We physicists all too often fail to think about the social and cultural environment in which we parade our theories and hardly ever consider the human as an *Accountable Animal* (Chapter 2). Likewise, we rarely ask how it is that our society has rated this physical way of thinking, this often very abstract approach to nature, as the most important of scientific disciplines (at least until very recently) and how this ranking is related to the current environmental crisis.

Carlo Jaeger must have realized very early on that functioning at the level of specific action is primarily determined by economic processes, since he made economics his second career after sociology. The thread of two main ideas run through these two chapters. First, Jaeger the economist believes in the potential of the mechanisms of the free market economy. Jaeger, the sociologist is aware of the motives behind human behavior and knows that they cannot be suppressed but must be turned to positive use. Jaeger shows how the elements of the market economy could be exploited both to avoid ecological damage and to manage limited resources (land, energy, water, minerals, etc.) effectively. This process might ultimately cause money to take on a new significance, resulting in what would be the equivalent today of a rather utopian cultural revolution. Secondly, qualitative development in today's industrially developed countries, in terms of a decoupling of economic growth from physical growth, is a vital prerequisite for sustainable development in Third World countries. According to Jaeger, the development policies pursued by First World countries should serve to curb their own "physical turnover" (e.g., the turnover of energy and raw materials), while simultaneously reducing the difference in economic potential between First and Third World countries.

Economic models for analysing these ideas are included, and the mathematically inclined reader can familiarize himself with the corresponding theoretical approaches in Chapter 5 *(Transforming the Economy)*. Like all such theories, economic or not, they may prove the *existence* of solutions – and even then only when making some very specific assumptions – but they supply no information on the practical feasibility of implementing such solutions. Jaeger is aware of this. *Jürg Minsch* of the University of St. Gall urgently warns against the calculated optimism of private industry, confidently propagating the belief that an increase in efficiency will allow the gap between economic and physical growth to be increased without limit. Achieving economic growth without necessarily having to renounce physical growth: is this not the latest (rather deceptive) message of the Western economic system? Among Third World countries, the suspicion appears to be growing that they are merely being written off. For example, the editorial of 15 October 1994 in the Indian environmental journal "Down To Earth", in its critical appraisal of the Cairo Conference on Population and Development, states: "*...whatever the world's population, one American child will continue to consume as much as 33 Indian children or 422 Ethiopians. ... Cunningly, the rich avoided any discussion on the issue and worked on the warped assumption that population, and not consumption, leads to environmental degradation.*"

In this context, Jaeger's message risks being viewed as just another simplified strategy for future development. Illustrations in Chapter 5 might suggest, at least to selected sectors of industry, that the consumption of energy and resources may be curbed without adversely affecting the standard of living. Despite this shortcoming, it is to the author's credit that an economist would have concluded his work with a theory for a new balanced economy – however theoretical or realistic. As a human ecologist, he adds a final chapter *(Managing the Environmental Crisis)*, outlining his thoughts in a bold and innovative way. Jaeger reflects on the human and political prerequisites for this new economics. He does not believe that the theories or actions of a single individual (e.g., some new Karl Marx) can help us out of this current crisis. The problems have become much too complex. If it is to succeed, this cultural regeneration must be instigated by a large number of individuals and nations.

After reading the book I would personally add that, since humans as individuals cannot fundamentally change, this regeneration can only be achieved by humans acting as *community*, both in terms of the internal structure of nations and the relationships among them. Ultimately, throughout the course of history, the same *Accountable*

Animal lives in very different cultural settings as far as ethical principles are concerned. In addition to his messages on economics and political development, Jaeger implicitly calls for us to think about the regeneration of our political structures. From this standpoint, the simultaneous occurrence of environmental crisis and political malaise, both of which are causing particular concern in Switzerland today, may be viewed as an opportunity for integral reform.

Dieter Imboden

Carlo C. Jaeger: *Taming the Dragon* (Gordon and Breach, 1994)

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

EAWAG-Publications

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