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EAWAG news

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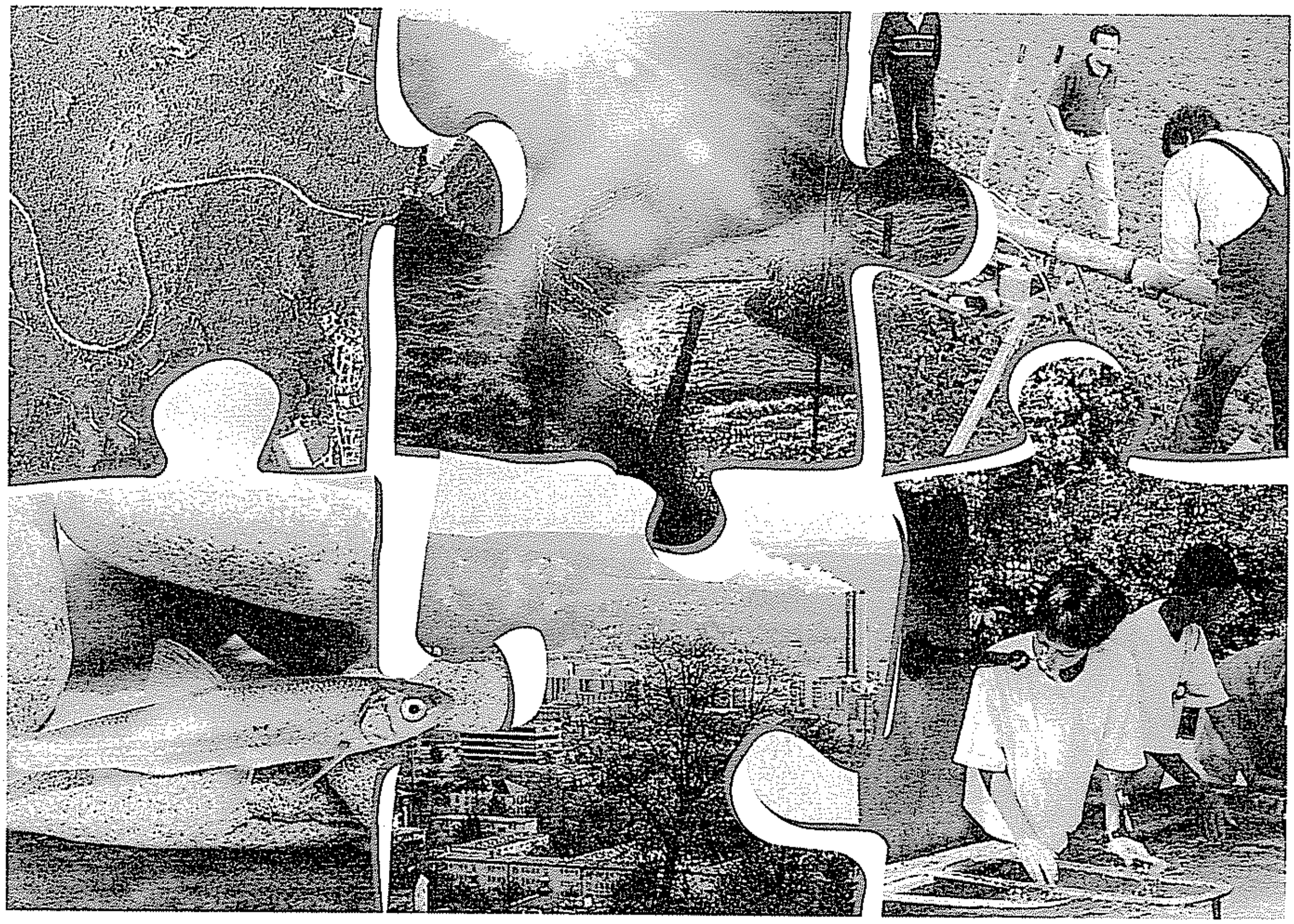
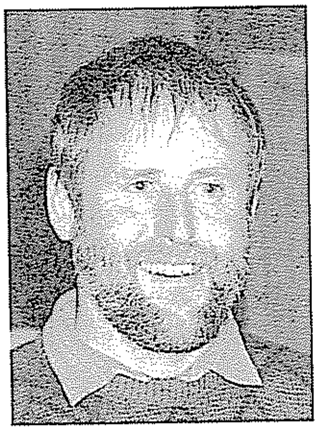


EAWAG
and Sustainable Water Protection



Over the last several decades, the trend of massive contamination and deterioration of water quality has been reversed, which should be considered an enormous success; however, other problems remain unresolved, and new ones have emerged. A few such concerns include the destruction of many streams by putting them into culverts; the conversion of many aquatic habitats into desolate channels; the discharge of chemicals into the environment; the increased throughput in natural cycles due to agriculture, urbanization and transportation; the high cost and resource intensity of today's urban water management; and the conflict between the use of streams for hydroelectric power and their ecological function.

It is impossible to attribute these problems to a readily definable set of causes. To a great extent, they are simply a consequence of our lifestyle and management practices. In addition, they have grown out of historical shortcomings, in particular, the compartmentalization of environmental legislation and enforcement and the lack of preventative measures.

In order to move water and environmental protection towards sustainability, it will be essential to:

- coordinate the various demands of water and environmental protection at the levels of politics, legislation and enforcement, and to better integrate them into human activities (living spaces, transportation, agriculture, etc.);
- align actions simultaneously at all levels with the participation of both the general populace and special interest groups; and
- maximize the efficiency of measures and the ways in which they are implemented.

Science must continue to explore and understand processes in the natural environment and the effects of human activities on them. The greatest challenge, however, will be to implement new forms of interdisciplinary research and to integrate science into the processes of society as a whole towards sustainable development. The relationship between humankind and the environment has to be considered in all its ecological, sanitary, economic, social and cultural aspects. Ecologically efficient and socially acceptable technologies and management practices need to be developed as a cooperative effort between scientists and those involved it their practical application. Science also must dramatically improve its dialogue with the general public in order to determine the direction of future research and to influence ongoing social change.

The primary goal of the research emphasis "Sustainable Regional Resource Management" was to start developing integrated approaches to understanding and managing surface and ground waters as well as waste sites. Such an undertaking necessarily leads to a multitude of difficulties – scientific, structural, methodical and human. In some areas, the original goals had to be modified significantly; in others, new cooperations and alliances were formed giving results a much broader basis. This, in turn, has initiated an irreversible process which is leading to new approaches and changing attitudes towards scientific activities at the EAWAG.

Ueli Bundi,
Vice President

EAWAG

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Cover
Sustainable Regional Development
Components with very different characters must be integrated: the Töss region was chosen to bring together a variety of disciplines, using the available tools and various players. From upper left, in clockwise direction: Linsen Valley above Winterthur; upper reaches of the Töss near Fischenthal; sampling of the Töss groundwater (see Johnson and Höhn); fountain in Pfungen; the soufie, a protected species (see Peter and Gonser).

Walter Wagner

Natural Waters – A Mirror of Regional Development

Walter Wagner

The Töss region has experienced a strong development over the last several decades. Population has increased over 60% since 1950. The development of the region has led to a multitude of changes in the structure and quality of natural water systems. As a consequence, the ability of these water systems to serve as a drinking water resource and as aquatic habitats is severely reduced from its original state, a sustainable use of resources is at risk.

The Töss watershed covers 430 km² and receives 540 million m³ of water per year in the form of precipitation. Of this volume, roughly two-fifths evaporates; the balance flows through the region and is used in numerous ways along its way, until it leaves the watershed at its confluence with the Rhine near Tössegg.

For many plants and animals, water is their required habitat. But it is also used in many ways by humans, e.g., as a source of drinking water, in energy production, as a transport vehicle for waste products, etc. The various uses by nature and civilization put different demands on the water itself; namely, in terms of quality, quantity and seasonal distribution. Civilization also has demands on its own protection. Flood damage is to be avoided when possible using reasonable means. Often the different demands are diametrically opposed, which inevitably leads to conflicts between the various uses and interests.

The regional population is not only dependent on the many uses of the water, but it also shapes and changes the natural fluxes and water quality through a variety of activities. Water sources are, therefore, an important factor to be considered in the future development of the region, but are also a reflection of previous development strategies. EAWAG has used the Töss region (Fig. 1) as an exemplary demonstration of how sustainable management of water resources can be achieved on a regional scale.

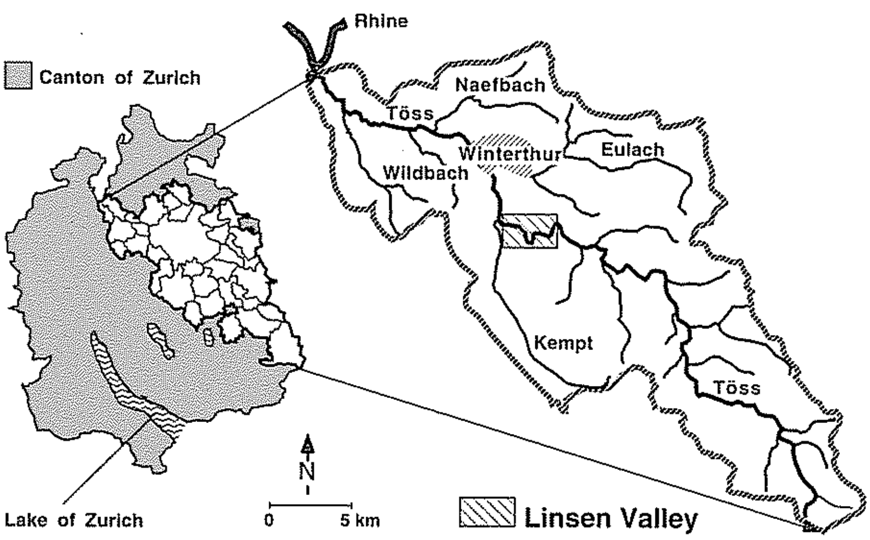

Fig. 1
The area of the Töss watershed is 430 km² with a population of 180,000. The majority of the population lives in relatively small communities; there are very few cities. The Töss region is typical of Central Switzerland.

Factors in Regional Development

A crucial element in the sustainable use of water resources is the understanding of interactions and interdependencies between human activites and water quality. The Töss region has experienced significant growth over the last 50 years (Tab. 1), which has left its mark on its water systems.

An ever increasing population needing more and more space for settlements, roads, agriculture and improvements in flood protection has resulted in nearly complete straightening and canalization of all the major rivers and streams in the region. Along three quarters of its course, the Töss itself has lost lateral variability entirely in its stream bed. Its bed has been stabilized by 568 artificially induced rock and

Development since 1950	
Population	1,6 x
Drinking water consumption	1,8 x
Settled area	2,6 x
Settled area per person	1,6 x
Energy consumption	4,9 x
Energy consumption per person	3,1 x
Agricultural productivity	1,8 x
Grain yield per ha	1,6 x
Motorized traffic	14,5 x
Domestic waste of the City of Winterthur	4,2 x
Domestic waste per person	2,6 x

Tab. 1
Factors in Regional Development in the Töss Watershed from 1950 to 1993.

land slides. In heavily populated areas, such as Oberwinterthur, over 60% of the streams have disappeared into underground culverts [1].

The effects of urban development on natural water budgets are illustrated in Fig. 2, using the community of Embrach as an example. As a consequence of population growth and increased per capita spatial demands, the amount of settled land has increased five-fold since 1952, largely accounted for by a loss of agricultural land. In parallel with the population growth, the demand for drinking water has dramatically increased. Wastewater and collected runoff from precipitation, together totalling almost 1.3 million m³, are directly fed to the wastewater treatment plant at Rorbas which reduces the natural above- and below-ground runoff in the area by almost 20%.

Because of an increase in emissions of atmospheric pollutants, expanded use of fertilizers and chemicals in agriculture, and the significant volumes and degrees of contamination of wastewater and waste materials, especially during the 1970s and 1980s, the quality of lakes and streams in the region has deteriorated. Since then, water quality has rebounded in many locations, mostly due to well targeted measures. Still at a criticial level, however, are contributions of nitrogen compounds from non-point sources as well as potential ecotoxicological effects of chemicals reaching surface and groundwaters.

The percentage of land used for agricultural purposes in the Töss region has decreased slightly over the last few decades; however, agricultural yields have steadily risen since 1955 because of changing uses and land management practices [2]. A higher percentage of land is planted in crops, especially corn, while the amount of land used for natural pastures has declined (Fig. 3). This change in land use alone has caused the nitrate loss to increase by approximately 15% between 1965 and 1985 [3]. In addition, more intense agricultural methods have caused an increased use of fertilizers and pesticides.

The Condition of Regional Water Resources: Significant Shortcomings

The current condition of the regional water resources, the result of past development and present day use, is unsatisfactory in many respects, implying that some demands on the resource will not be met in the future. A number of indicators reveal current and future problems which could seriously curtail future use of the water both by humans and by nature (Tab. 2).

Overuse of Groundwater

Natural groundwater reservoirs in the region have been severely impacted. Groundwater is being continuously withdrawn for drinking water purposes, while natural recharge has been dramatically reduced by an increase in hard top surfaces. As a consequence, some local groundwater reservoirs are no longer able to maintain a balance between discharge and recharge, a trend that is contradictory to sustainable use. On the one hand, the water volume available for the drinking water supply may be inadequate in the long term. On the other hand, changes in the natural water balance have direct ecological consequences such as more frequent episodes of streams going dry [4].

Groundwater in the Töss watershed has and is being overused. The groundwater associated with the Eulach was documented to be steadily dropping as early as the first half of this century. In order to compensate for increased groundwater use and reduced infiltration rates, water is currently being

Water budget of a community (precipitation minus evaporation) in million m³ per year

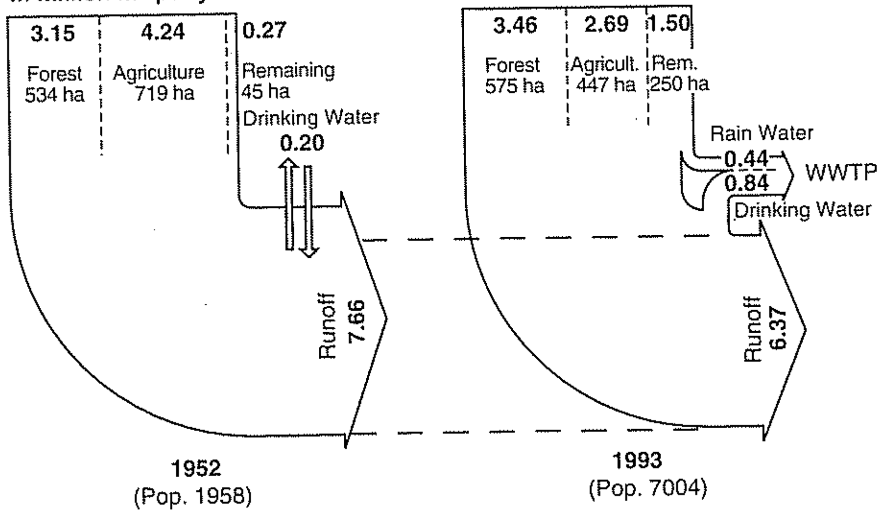

Fig. 2
Changes in the water budget for the community of Embrach over the last four decades.
The settled area ("remaining") increases by more than a factor of five. Increased urban drainage reduces natural runoff in the area by almost 17%.

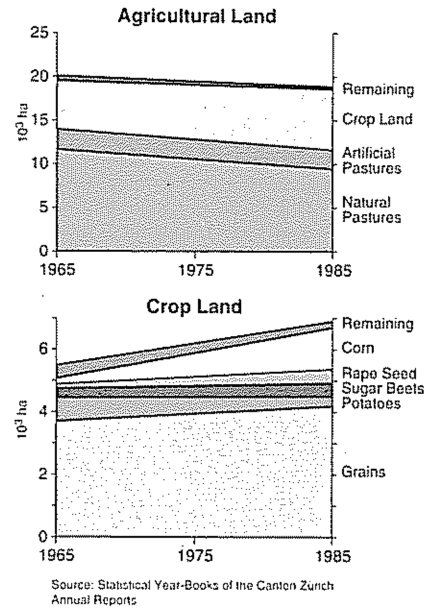

Fig. 3
Agricultural land use in the Töss region. While the overall land area used for agriculture decreases, the share used for crops increases.

pumped from the Töss valley to the drainage of the Eulach and allowed to recharge the groundwater in an infiltration well. This has lead to a stabilization of groundwater levels; however, even the more sparsely populated areas along the upper reaches of the Kempt, in the vicinity of the community of Fehraltorf, are experiencing dropping groundwater levels [4].

Problems of Water Quality

Water quality, as evaluated by conventional indicators such as nitrate or organic carbon loads (DOC), presents a more optimistic picture: contaminant concentrations have leveled off and, in a few cases, even begun to drop, although absolute nitrate and DOC concentrations are still near or above water quality goals in most areas.

In addition, many streams are starting to show water quality problems that are due to the ecotoxicological effects of trace organics (see EAWAG News 40, pp. 8). So far, no such cases have been documented in the watershed of the Töss, but the future use of water in the area is uncertain even from a qualitative point of view.

Problem Area	Indicators
Groundwater quantity	Locally dropping groundwater levels
Groundwater quality	Rising nitrate and chloride concentrations
Quality of surface waters	Nitrate and DOC concentrations often near or above quality goals
Quality of aquatic habitats	Diminishing diversity

Tab. 2
Assessment of Condition of Regional Water Resources.

Effects on Biodiversity

The quality of aquatic habitats in the region has been significantly changed by human activities. Canton-wide surveys indicate that many plant and animal species are already extinct or are near extinction [5]. The situation is most dramatic in the aquatic habitats which naturally show high diversity. Many species are no longer able to maintain viable and self-sustaining populations. In the Töss, for example, only a few of the indigenous fish species can be found above the first major obstacle for upstream migration (see article by A. Peter in this issue).

Conditions for Sustainable Water Management

All the problems discussed above cannot be blamed on a single cause, but are the consequence of a variety of regional developments and activities. In order to secure the future use of water in the region, it is not sufficient to solve individual problems with *"end-of-pipe"* solutions. In many cases, such solutions can bring local improvements, but more often than not also yield unwanted side effects in other areas. Moreover, such technical fixes are usually very expensive and energy intensive, which hardly makes them an option in a sustainable management scenario. A very illustrative example of just how complex these problems can become is the study on how to deal with roof runoff, which can be heavily loaded with contaminants (see article by M. Boller in this issue).

In order to achieve sustainable regional water use, measures have to address the sources of the problems. To this end, it is necessary to understand the driving forces of social development which determine the way water is used. Historically, the most important stimuli in this region were population growth, rising industrial productivity, mobility, and demands on space and resources.

The overriding priority is to bring whole activity areas (e.g., agriculture, transportation, energy production) into a sustainable mode of operation. This requires scientific-technical approaches and the incorporation of social, economic and political aspects into the problem-solving process. Science, government agencies, industry and the general population have to enter into an intensive dialogue. In the study of the Töss region, EAWAG has attempted to do just this. Andrea Rüede discusses methodologies and experiences that have emerged from this study in a separate article in this issue.

Decisions and action have to take into account social value systems as well as scientific facts. With this dramatically widened view, EAWAG has started to follow a new and unknown path. Exchanges across disciplines and between the various regional players have initiated numerous learning processes; the process may at times be painful, but is a necessary one in trying to reach the goal of sustainable water management on a local, regional, or even global scale.

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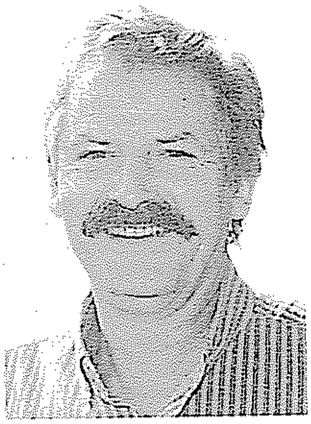
Markus Boller*

New Pathways for Rainwater

In order to move towards truly sustainable water use, urban water management practices will simply have to settle for "smaller" water cycles. For example, runoff from permanent surfaces should not be channelled into sewer systems, but allowed to percolate into the soil wherever possible. (This is actually a requirement already contained in the Swiss Water Protection Act).



Markus Boller

* *in collaboration with Adrian Ammann, Irene Brunner, Thomas Bucheli, Jack Eugster, Stefan Haderlein, Martin Häfliger, Edi Hoehn, David Kistler, Daniel Kobler, Sabine Koch, Yael Mason, Werner Meier, Peter Steen Mikkelsen, Vincent Mottier, Michael Ochs, Stephan Müller, Andrea Rüede, Laura Sigg, Christian Singeisen, Michele Steiner, Andreas Voegelin and Jürg Zobrist.*

The introduction of new strategies for handling water drainage is expected to yield several benefits, including increased recharge to groundwater aquifers, a decrease in the hydraulic load to sewers and wastewater treatment plants and reduced storm overflow volumes and peak flows.

The watershed of the river Töss is an example of where allowing meteoric water to infiltrate into the soil has allowed us to refine qualitative descriptions of the infiltration of runoff from roofs and streets into a more quantitative formulation. Various EAWAG projects have studied the water quality of runoff as well as the impact of alternative water drainage on the transport and fate of some critical chemical constituents. Despite the fact that infiltration of runoff can be quantitatively documented to have positive effects, until recently, it has not been proven to be a sustainable solution; on the other hand, neither have any of the other options proposed for the treatment of runoff.

How much Rainwater can be Artificially Infiltrated into Soil?

With an annual average rainfall of 1400 mm, the watershed of the River Töss receives a total of 540 x 10^6 m^3 of water per year. Approximately 200 x 10^6 m^3 exits the watershed as surface runoff, while only about 34 x 10^6 m^3 (6.3%) comes from permanent surfaces. Some 20 x 10^6 m^3 are contributed by streets, 10 x 10^6 m^3 from roof tops, and the balance from parking lots, ramps courtyards and the like. At present, 14 million m^3 of runoff flows into wastewater treatment plants via combined sewers or, during very heavy rains, directly into streams and rivers through special structures. In the future, as large a proportion as possible of these 14 million m^3 as well as of the uncontrolled runoff of 20 million m^3 is planned to be diverted, eventually reaching the groundwater via special infiltration systems.

The amount of surface runoff that can be drained depends on such factors as soil permeability, slope of the ground and the location of areas of groundwater protection. In a grid with units of 100 m x 100 m, these parameters were measured using geographic information systems (GIS). The information maps were superimposed on one another and resulted in a drainage map of the Töss valley on which the appropriate areas for infiltration could be identified. Only 10% of the surface area could be classified as good with an additional 18% as moderately appropriate. Often good areas for soil drainage are congruent with built-over areas at the bottom of the valley, thereby increasing their infiltration potential.

The amount of surface runoff that can be drained into the ground depends on the degree to which it can be connected to drainage installations. For this reason, various scenarios with increasing degrees of drainage connection were used in making our calculations. Table 1 shows the assumptions used in the calculations together with the corresponding annual drainable amounts of runoff.

The importance of the drainable amounts of water for water manage-

Scenario	connected surfaces	drainable amounts 10^5 m^3/year
1	50% roof surfaces 20% driveways, parking	1,8
2	100% roof surfaces 50% driveways, parking	4,2
3	100% roof surfaces 80% driveways, parking 50% streets	9,1
4	100% roof surfaces 100% driveways, parking 100% streets	15,0

Table 1
Rainwater runoff from permanent surfaces that can be infiltrated into soil.

ment in the area becomes obvious when compared to the relevant turnover of water in the Töss valley. Even in scenario 3, the drainable amount of runoff from urban areas and roads remains very modest at 3% of the total. Only when compared to water flows within urban areas (e.g., the consumption of drinking water and the production of wastewater) does the drainable amount of runoff contribute significantly to the urban water cycle. Figure 1 represents scenarios 1 to 3 with the amounts of drainable runoff estimated from fixed surfaces for individual sections of the area as well as for the entire Töss valley expressed as a percentage of the consumption in drinking water. Scenario 4 is regarded as impractical and is not discussed. The results suggest that at most only about half of the groundwater extracted for drinking water in the Töss watershed can be replenished by the artificial drainage of runoff. It should be emphasized that this contribution to groundwater recharge, viewed from the vantage point of a water manager, can only be attained by implementing all of the technically feasible possibilities for drainage management.

As the drainage of runoff can only be effected in new construction or through renovations, diverting the water into such drainage installations may take decades to realize. Disconnecting the precipitation runoff from public sewers will hydraulically relieve the sewage system by up to 60% of its present load and lead to a corresponding decrease in overflows from sewers with subsequent improvements

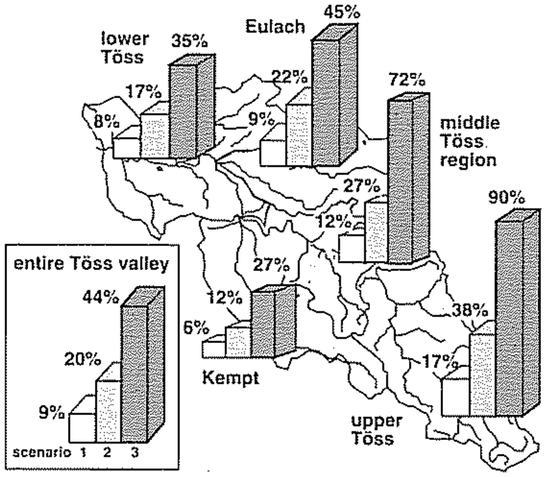


Fig. 1
The amount of infiltrable precipitation runoff in comparison to the consumption of drinking water in the Töss valley (light block = scenario 1).

in the treatment of wastewater. But the money saved by these types of projects will only be realized when reconstruction of the existing sewer system and wastewater treatment plants has been completed.

Contamination of Surface Runoff

With regard to the issue of water drainage, it is often assumed that precipitation is only slightly polluted (even clean) and that any potential contaminants are retained by the soil. Consequently, the potential pollution of groundwater has usually been assumed to be very low. Detailed investigations of runoff from roofs and roads have shown, however, that substances contained in these types of surface runoff are subject to strong dynamics: when it starts to rain, much higher concentrations of various contaminants can be measured at the beginning of the event as compared with concentrations in the rainwater later on; this is called the "first-flush effect". EAWAG has carried out investigations of this effect on various roof types and has documented first-flush for various substances. During a series of seasonally varied rainfall events in the city of Zürich, samples were taken proportional to the runoff from a tiled roof, a sloping glass fiber roof and a gravel-covered flat roof, each with an area of approximately 100 m^2. Figure 2 shows the three types of roofs that were studied. Additional investigations were conducted on the runoff from a combination of various flat roofs totalling 5000 m^2 in the town of Winterthur. The results suggest that the substances contained in the runoff from roofs are typically influenced by the following parameters:

- substances accumulated in dry and wet deposition,
- construction materials in contact with rainwater,
- the type of roof construction.

Dry and Wet Deposition in Runoff

Estimates of the annual load of the investigated parameters of water qual-

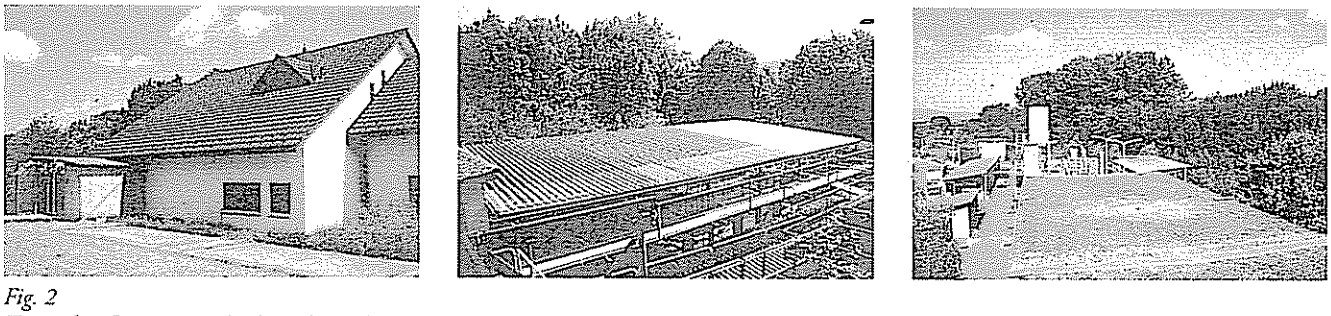


Fig. 2
Types of roofs investigated: tile roof (Werdinsel), glass fiber roof (Tüffenwies), gravel flat roof (Tüffenwies).

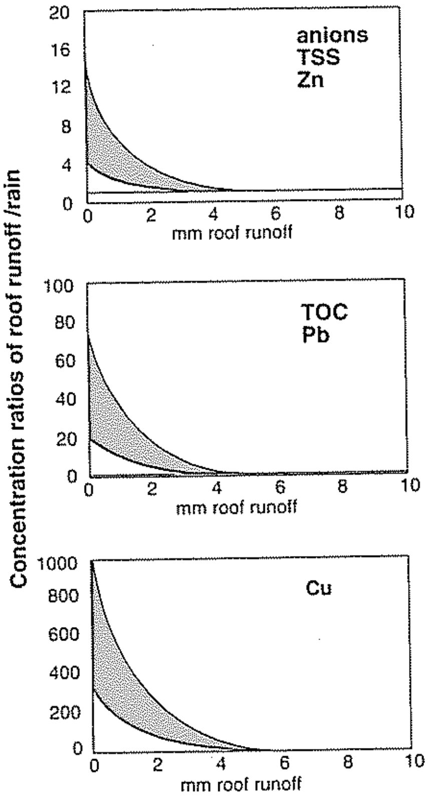


Fig. 3
Classification of first-flush effects of various substances in runoff from roofs.

ity show that the degree of wet deposition is only slightly higher than that of dry deposition. For this reason, dry periods before a rain contribute significantly to the concentration of substances in a roof gutter. Recording the concentrations of the substances in relation to the amount of runoff (1 mm runoff = 1 l/m^2) permits a generalization of their properties. Figure 3 shows typical first-flush effects with approximate concentration increases of 10x compared to the concentrations in rainwater typical for various anions (Cl^-, SO_4^{2-}, NO_3^-), suspended matter, zinc and Atrazine. TOC and lead represent a second class of substances with up to 100-fold increases; these include the wash out of particulate and colloidal matter apart from the dissolved share. Copper is the only substance whose concentrations at the beginning are already up to 1000 times higher than the amount in rainwater which illustrates the influence of the construction materials used.

The Influence of Construction Materials

The enormously increased levels of copper are obviously a consequence of using copper gutters. Figure 4 shows the copper levels in runoff from roofs during increasing amounts of runoff; the difference between the tiled and polyester roofs with gutters made of copper and the gravel roofs without copper gutters are very obvious. The high rates of copper corrosion made further studies relevant on the amount of copper in current use on the outsides of buildings and on the potential copper flux to the environment through precipitation. Amounting to an average of 5.3% of copper surfaces on roofs and in roof gutters, the total area of copper surfaces in contact with rainwater amounts to about 410,000 m^2 in the Tösstal area. Based on the rates of corrosion described in the literature, between 0.5 and 4 µm/year, copper loads between 2000 and 4000 kg Cu/year were calculated. The copper load from roof gutters amounts to at least 40% of the total load in domestic wastewater due to the present use of combined sewers. Part of the copper flows directly into receiving waters; another fraction is bound in sewage sludge, 50% of which is used in agriculture. It must be emphasized in this context that current soil management practices contribute many times more copper than the distribution of sewage sludge. Copper loads similar to those from roof runoff originate from street runoff, which also lead to the diffuse pollution of soil and natural waters. When the new drainage systems are introduced, copper and other heavy metals from roofs and street runoff will probably accumulate relatively rapidly in the upper layers of soil.

Another important contribution of construction materials to the composition of roof runoff originates from bitumen surfaces used on flat roofs. The herbicide R and S Mecoprop, released during the hydrolysis of Preventol, which prevents the growth of plants on roofs, runs such roofs in concentrations approximately 100x higher than that of other pesticides like Atrazine. Figure 5 shows the course of Atrazine and Mecoprop concentrations in relation to the amount of runoff from flat roofs in Winterthur. Differences in concentrations and the wash out behaviors are obvious. Previous estimates of the significance of

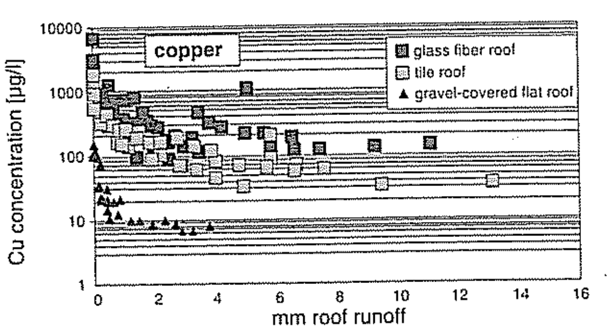


Fig. 4
Concentrations of copper in the runoff from roofs with copper gutters (glass fiber and tiled roofs) and those without copper installations (gravel roofs).

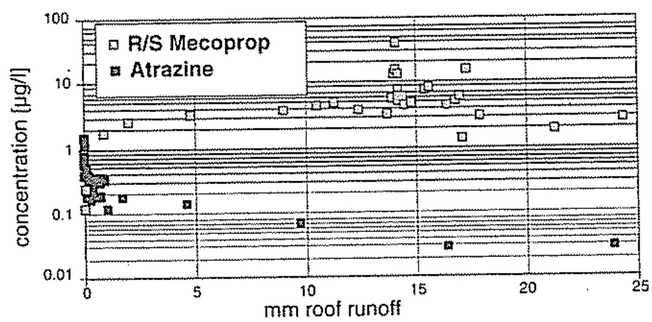


Fig. 5
Atrazine and Mecoprop in the runoff from a flat roof.

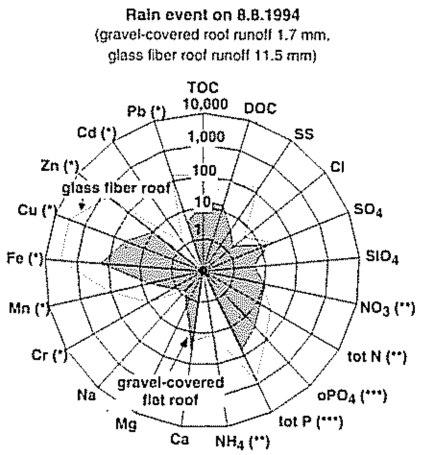


Fig. 6
Concentrations of pollutants in the runoff from a sloping glass fiber roof and a gravel flat roof (mg/l, (*) µg/l, (**) mgN/l, (***) mgP/l.

Mecoprop washed from flat roofs resulted in diffuse loads similar to those from Mecoprop applications in agriculture.

The Influence of the Type of Roof Construction

There are significant differences between sloping roofs and flat roofs with respect to their quantitative and qualitative water runoff behavior. The significantly increased capacity of flat roofs for accumulating material, combined with a filter-like roof construction, makes this type of roof both a "deposit" and often a "sink" for many substances. Diminished first-flush effects, filtration, adsorption and biodegradation are all processes which lead to an improved quality of the runoff water from flat roofs, depending on the substances involved. Figure 6 shows a comparison between the concentrations in runoff from a polyester roof and a gravel-covered flat roof for a series of investigated parameters. In the long term, flat roofs or flat roofs covered with greenery can be expected to capture and accumulate pollutants effectively.

Qualitative Comparison between Runoff from Roofs and Streets

Runoff from streets contains significantly higher concentrations of pollutants than runoff from roofs. Particulate-bound pollution and the substances released through the use of vehicles and burning fuel show especially high levels. A comparison of the total loads expected from the degree of pollution and the amount of roof and street surfaces in the Töss valley results in higher shares for roads and roofs of all of the measured water quality parameters including copper. Nitrate, cadmium, lead and polyaromatic hydrocarbons are released into the environment from streets at levels that are over five times higher than from roof runoff. Runoff from roads should be treated with special precautions if it is allowed to drain into the ground. Various possibilities such as using pits filled with humus have already proven their value in practice where the concentration of the pollutants occurs in a contained space. The often practiced and encouraged diversion of runoff over the sides of roads is problematic because a relatively uncontrolled and very diffuse accumulation of contaminants may result.

What is the Fate of Pollutants?

The present day drainage systems cause the release of substances from runoff either directly into the environment or into the combined sewer systems. Substances which adsorb well, such as heavy metals, and polyaromatic hydrocarbons (PAH), adsorbable halogenated organic substances, are bound to particulate phases which result in their accumulation in aquatic sediments, in farmland soils, in the soil of urban areas and along roadsides. Mobile substances, including several pesticides, are either degraded in wastewater treatment plants or enter the groundwater. As the pollutants become distributed over large areas, these processes become extremely slow. Their consequences (e.g., the progressive contamination of fertile soils), is considered unacceptable in the long term. If precipitation runoff is to be drained off into the ground, in the future there will be several locally contained sites for the accumulation of the substances of high rates; for the more mobile substances, there usually is facilitated access to the groundwater. Investigations of the soil in infiltration systems for road runoff suggest that the accumulation of pollutants mainly occurs either in the layers of soil near the surface with a higher content of fine material or in colmation horizons. Figure 7 illustrates the depth profiles of the heavy metals cadmium, copper,

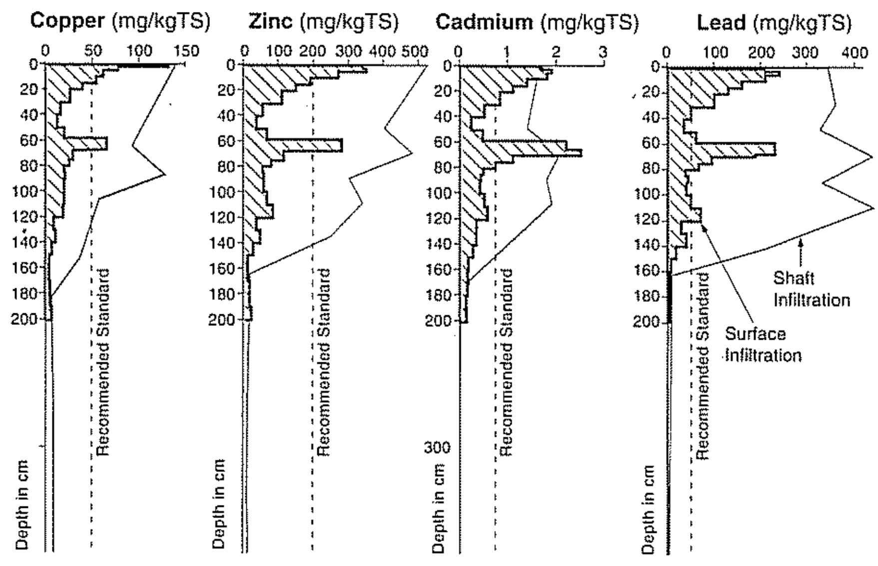


Fig. 7
Accumulation of heavy metals in the ground under infiltration systems for road runoff in Canton Basel.

lead and zinc for pits or shafts which are about 30 years old and located in the Canton of Basel. The detection of significant levels of accumulation of pollutants in the ground under drainage installations would be documentation of *soil* contamination, but which would give us little information about the transport of substances in the *porewater.*

Within the framework of constructing a new drainage installation pit for the above mentioned flat roofs in Winterthur, EAWAG installed an experimental shaft in the pit from which samples of porewater could be extracted, and the vertical transport of substances could be monitored. The pit, professionally constructed according to technical rules, proved to be more permeable than expected according to observations documented during several rain events. Although lead and zinc remained in the upper soil layer, copper, cadmium, Atrazine and Mecoprop effected quick and practically complete breakthrough into the neighboring gravel, giving rise to the suspicion that they could penetrate to the groundwater aquifer.

Figure 8 illustrates the behavior of Atrazine: rapid, undiluted and biochemically uninfluenced transport to depths of 1.6 m under the surface of the pit. This example shows that coarse-grained drainage sediments and fluviatile gravel are not secure barriers for the penetration of pollutants into groundwater, even if they contain a layer of relatively new humus without significant signs of colmation. The construction of installations for drainage beg improvements which can retain such substances and faciltitate more efficient biodegradation.

Deficits in Sustainability

Apart from the drainage concept which is being developed, nondegradable substances that accumulate (e.g., heavy metals) are deposited in the environment by the application of sewage sludge on agricultural soils, in the sediments of natural waters and in the

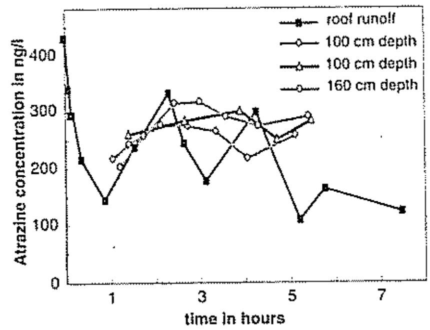


Fig. 8
Breakthrough of Atrazine in a pit drainage installation.

ground beneath drainage installations. Table 2 shows an overview of the expected environmental impacts through combined sewers, separate drainage systems and infiltration scenarios. The accumulation in soils and aquatic sediments will be irreparably damaging to soil fertility, result in serious ecotoxicological concerns in the aquatic food chain, change ecological balances and decrease biodiversity. Small organisms (mainly invertebrates), algae, fish and plants may already exhibit detrimental effects or damage at low levels or dosages. The only possibility which can be judged as posing a lower danger is if the substances are bound to artificial landfills – as long as they create no potentially hazardous conditions in the future. Accumulation in drainage installations is also a possible solution, but implies a potential danger of saturation of the soil and breakthrough to the groundwater.

The problem of diffuse accumulation of heavy metals in the environment is mainly one of no acute pressure (to date or in the near future) to decelerate or stop the processes of accumulation through legal regulations. As the processes involved are long term, problems may only be detected after several decades, depending on the rates of accumulation. Producers of such substances, as well as the authorities, tend to judge the risks involved as low.

As the dependencies (the amount of substances being used, their turnover and their accumulation) shown in Fig. 9 suggest, action should be taken immediately. The point is not to take advantage of the scope of accumulation permitted up to its exact legal limits or standard levels, but to initiate those long term practices that will reduce, replace and prevent the use of these

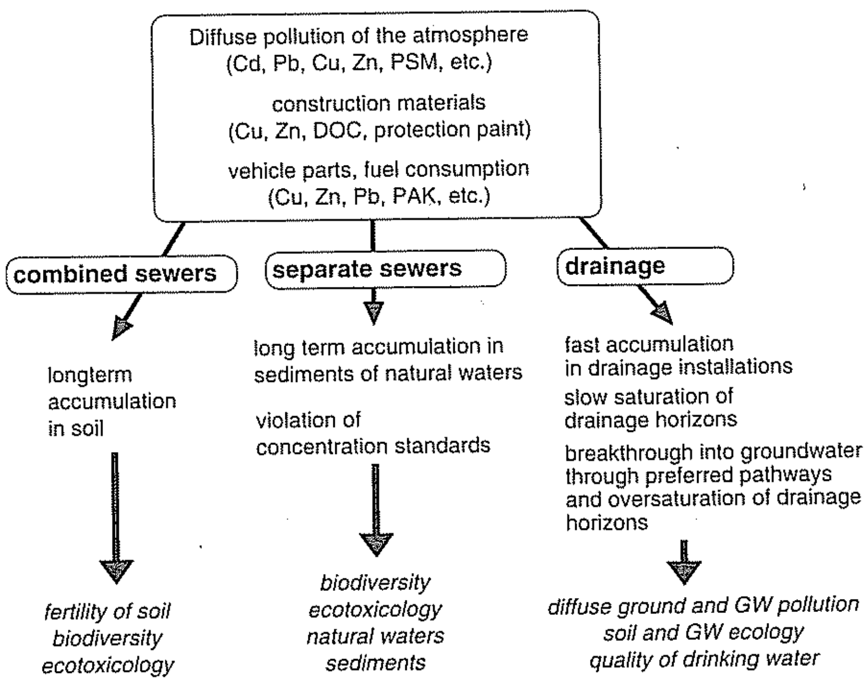


Table 2
Deficits in sustainability by the disposal of urban precipitation runoff.

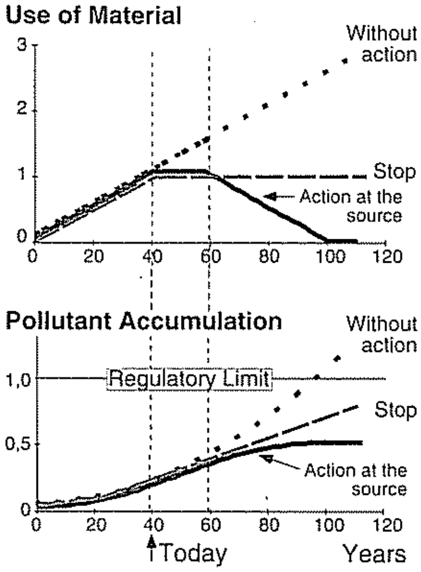


Fig. 9
Schematic representation of trends in the use of pollutants and the concomitant accumulation of substances in the environment.

substances. The graphs illustrate that even if a pollutant contained in construction materials is immediately taken out of circulation, its accumulation will continue due to the amounts already in use; even if replaced completely, the accumulated amounts of contaminants will remain constant in the condition they were deposited in the environment, a problem of concern for future generations.

Development towards Sustainability

Even though new regulations on the accumulation of pollutants from runoff have little chance of being ratified at present, measures remain in place which depend on the responsible action of those involved which, in turn, are based on understanding and far-sightedness. An effective approach to the issue requires new partnerships which reach beyond the traditional sphere of urban water management engineers. Figure 10 represents the partnerships recently formed on the issue of construction materials where measures taken at both the source and end-of-pipe are being discussed and options for their realization are being explored. Similar groups will become necessary for the fields of traffic and agriculture in order to develop a comprehensively sustainable urban water management.

Among the general measures to be taken at the source, reduction in use and in turnover of polluting materials and their replacement or banning should be mentioned; effects of such measures, however, will only become noticeable in the long term. For this reason, supporting end-of-pipe measures will also be propagated which will effect improved localization and control of the current accumulations of pollutants. In the case of the infiltration precipitation, it has been suggested that the installations should also be constructed as cleansing stations, not just hydraulically efficient constructions. Current studies being carried out at EAWAG will show which porous materials that possess good hydraulic conductivities and special adsorbant properties would be the most appropriate for the localized fixing of pollutants and the control of their transport. In order to gain a better overview of the sites of accumulation, communities are urged to keep an updated registry of drainage installations.

Summary and Conclusions

The introduction of drainage installations for handling precipitation is a sensible measure in urban water management if it is applied to as many urban areas as possible, including roads. This leads us to the question of the quality of the runoff from permanent surfaces. The current quality of roof and road wastewaters suggests that a flow of unwanted materials is entering the environment leading to the diffuse pollution of soils and natural waters. Here one has to differentiate between classes of substances which accumulate in drainage installations beyond the lifetime of such installations and other substances whose behavior is very mobile and which enter the groundwater without special measures. Among the first group are the heavy metals found in higher levels in precipitation runoff (e.g., copper, cadmium, lead and zinc and organic substances such as PAHs). The second group includes various pesticides. The problems of accumulation do not appear suddenly or acutely, but are involved in a slow process whose control should start now. In the long term, it becomes obvious that environmentally friendly solutions can only lead to the goal of obtaining sustainable small-scale water cycles by taking measures at the source. Knowing the originators of the pollutants in precipitation runoff, a list of requirements for improving air quality and for the restriction, ban or replacement of certain construction materials and vehicle parts as well as materials used in the maintenance of roads and vehicles should be set up. Measures taken at the source of pollution can often take a long time to come into effect, even if the individuals and groups involved are willing – especially in the case of construction materials. It may require the life span of a building for a change to take place. In order to effect better control of the diffuse pollution from precipitation runoff, supporting technical measures such as infiltration installations (end-of-pipe) are a possibility for locally fixing organic pollutants and possibly even for their biodegradation. For this purpose, new types of drainage installations have to be built which prevent hydraulic short cuts into the groundwater and which foresee the use of chemically and biochemically active filter media. The sooner such measures are put into effect, the quicker the disposal of precipitation water can be integrated into a new concept of urban water management.

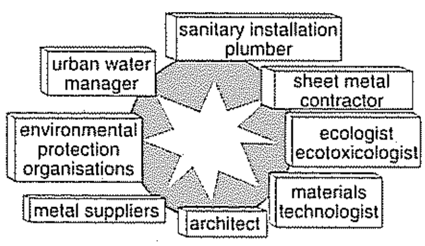


Fig. 10
New partners in urban water management.

Annette Johnson and Eduard Hoehn

The Influence of Old Municipal Solid Waste Landfills on Groundwater Quality

C. Annette Johnson [1] *Eduard Hoehn* [1]

During the past decades, the number of contaminated sites that are potentially hazardous for both the hydrosphere and biosphere has increased dramatically, in Switzerland, as in other industrialized countries. They are estimated to number about 50,000, 5–10% of which may have to be remediated. The costs of site assessment and remediation will amount to billions of Sfr. This situation demands the development of guidelines for efficient site evaluations.

Objectives

About half of the potentially contaminated sites in the Swiss prealpine plateau consist of mixed deposits of domestic and industrial waste. These old landfill sites, which may contain potentially hazardous substances, are often situated in old gravel pits. In the same gravel layers, one can often locate groundwater aquifers that are currently in use. In Switzerland, over 80% of the drinking water is drawn from the subsurface. Sites polluted by wastes lying directly above exploitable groundwater can threaten this resource [1]. For this reason, the effects of old landfill sites on the groundwater quality must be assessed.

In the town of Winterthur, some 700 potentially contaminated sites have been registered, about 200 of which are landfills. The total area of the sites covers about 3% of the total area of the town. These figures indicate a probable pollution of groundwater in the area of Winterthur whose extent has not been assessed to date [2]. Within the framework of the priority research program of EAWAG, the goal of the investigation has been to assess the long-term hazard of old landfill sites in Winterthur using the Riet site as an example. Our aim has been to determine the

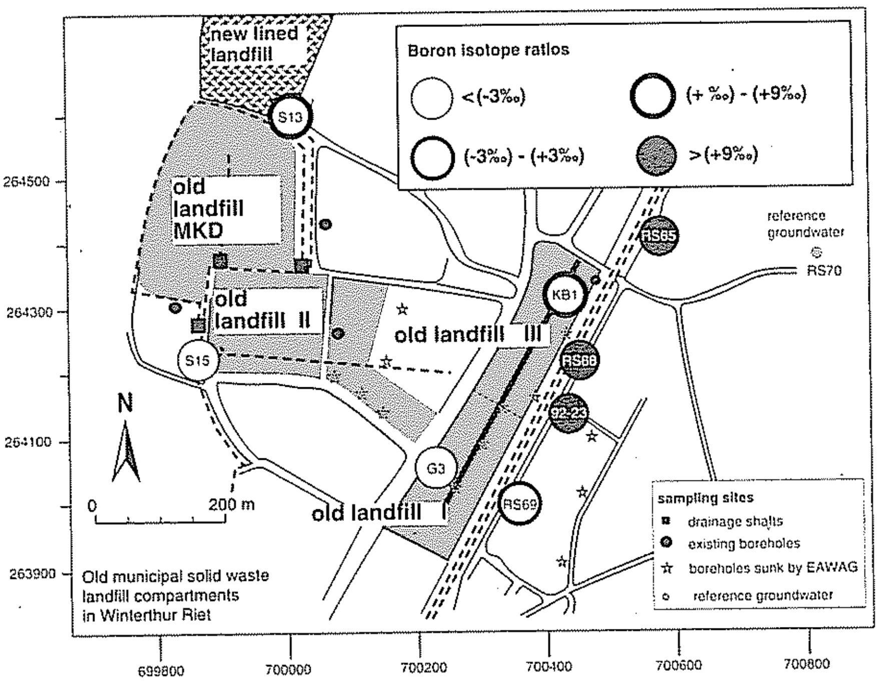


Fig. 1
Sketch of the location of old landfill compartments and the sampling sites at the Riet in Winterthur. Sampling sites for the determination of boron isotope ratios are indicated as large circles. Figures in ‰ indicate the water sample's deviation from a standard water and enables the determination of the origins of the various water components.
Dashed line = leachate drainages ; line from KB1 to G3 = location of the geological profile in Fig. 2.

* *in collaboration with Karim Abbaspour* [3], *Aria Amirbahman, Adrian Ammann, Peter Huggenberger* [2], *Vijay Matta, Michael Nay, Anita Peter, Sonja Riediker, René Schoenenberger, Laura Sigg, Mario Snozzi, Andrea Ulrich* [4], *Jürg Zobrist and Hans-Rudolf Zweifel*

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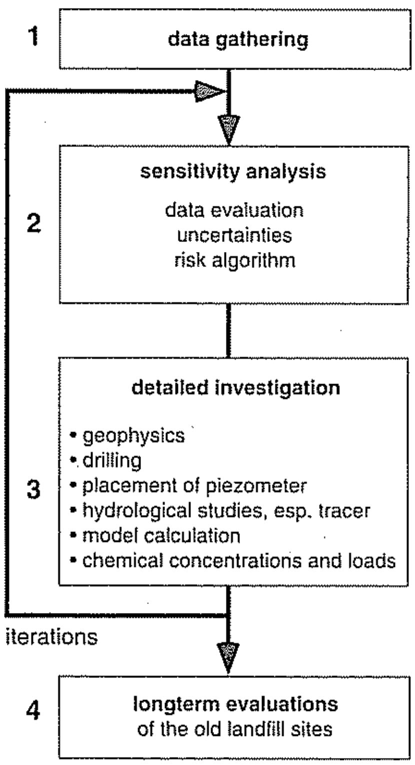
long-term risk of pollutant release to the aquifer and to assess the need for remediation according to the guidelines of the recently proposed contaminated site ordinance [3]. With this study, we have aimed to create a conceptual basis for the assessment of old landfill sites in general and to apply our knowledge to assess the movement of contaminants from Winterthur's former landfill sites into the subsurface in particular.

Our objective has been met by a "detailed investigation", which, in comparison to a "preliminary investigation" proposed in the aformentioned ordinance, is based on an investigation on a much finer spatial- and process-oriented resolution. The extent of the investigation must be weighed against the expense and urgency of the remediation. The more efficient the investigation, the better the financial investment. A detailed investigation consists of several stages for the purpose of acquiring data:



A sensitivity analysis for estimating parameter values and the uncertainty of data can be carried out according to the method of Abbaspour et al. [4]; using a mathematical algorithm, the quality of the collected data can be evaluated. Under certain circumstances, the results of the sensitivity analysis may mean that more data must be acquired.

The Riet site in the northeast of Winterthur was of special interest to us because the town of Winterthur has disposed a significant proportion of its wastes in this location for over 70 years. We wanted to find answers to the following questions:

- Do the old landfill sites pose a threat to the groundwater, and if so, by which substances? How quickly and to what extent can contaminants move in the groundwater aquifer and reach the adjacent Wiesendanger Feld?
- Is it sufficient to monitor the sites or must they be actively remediated?
- What criteria can be used to assess the long-term behavior of these former landfill sites? How should old landfill sites containing largely untreated domestic waste assessed in general?

The Site

In addition to the contemporary lined landfill compartments at the Riet site, there are four compartments with old unlined deposits (see Fig. 1, Site I: 1918–1925; Site II: 1925–1935; Site III: 1950–1960 and the multicomponent landfill compartment, MKD: 1960–1990). The old landfill sites I–III consist of domestic waste filled into old peat pits up to 3 m deep. East of the old landfill III at a depth of 5–10 m, the subsoil consists of very permeable gravel-sand deposits increasing in thickness towards the east; this section is located at the edge of a utilized groundwater aquifer in the Wiesendanger Feld. Preliminary technical and historical investigations have shown that the old landfill sites release contaminants into the groundwater. Because of these results, the Cantonal Department for Wastes, Water, Energy and Air (previously AGW, now AWEL) ordered the monitoring of the leachate and groundwater in the vicinity of the site in 1994.

Procedure

Our detailed investigation of the former landfills required two years and encompassed a detailed survey of the site as well as extensive chemical analyses including the following:

- Electromagnetic measurements provide an overview, are inexpensive and nonintrusive (EM31).
- Drilling cores for the detailed investigation of the subsoil and for material sampling. Practically undisturbed airtight core samples were taken of material from the noncohesive gravel-sand layers using an inner plastic liner. These were subsequently analyzed in the laboratory ([5]; see top right photo on the title page of this journal).
- Groundwater observation well liners were placed into the boreholes for the purpose of sampling leachate and groundwater from various depths.
- Chemical analyses of material and water samples for the estimation of the behavior and transport of substances.
- A water balance, a groundwater model and tracer studies were carried out in order to estimate the transport and for estimating loads of potential groundwater contaminants.

Results of the Preliminary Investigation

Using the geophysical method EM31, the boundaries of the old landfill sites were more precisely delineated than on existing maps. The heterogeneity of the landfilled material could be discerned by areas with higher electrical conductivity in the old landfill III [6]. We expected that in such areas the data would correlate with the composition of the old deposits. Our new wells enabled a much finer resolution of the geological and hydrogeological situation of the subsoil than had previously been possible (see, e.g., Fig. 2). The water balance showed that only a small fraction of the rainwater reaches the groundwater; most of it is drained off by old drainage systems placed under the old landfill compartments [7]. A new tracer method using boron

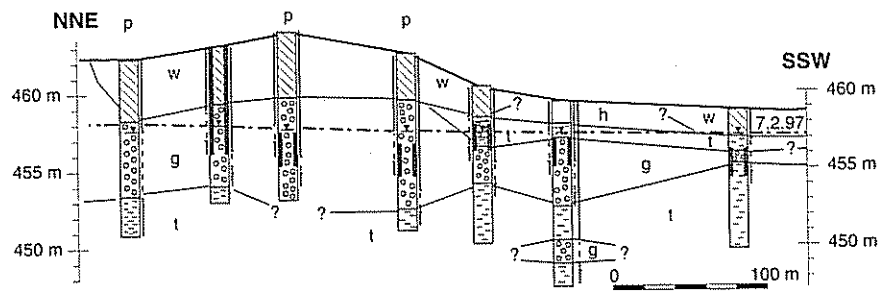


Fig. 2
Geological profile of Compartments III and I indicated in Fig. 1 (geological succession: w = artificial fill; h = humus; g = gravel-sand; t = moraine; p = boreholes; fine lines next to the borehole profile = groundwater observation pipes, dashed section = screened section; thick lines on both sides of the borehole profiles = practically undisturbed samples extracted with a «liner»; question marks = further course uncertain; dash-dot line = groundwater table.

isotopes allowed the identification of water of different origins in the groundwater (most likely leachates of different compartments of the old landfill). Leachates from the old landfill II (shaft S15), leachates from the old landfill III (well KB1) and groundwater from upstream areas (e.g., well RS65) flow in the groundwater in the direction of well RS69, where they are detected as a mixture of all three water bodies (Fig. 1; [8]). In the area of old landfill III, the results of the groundwater flow model [9] showed a deviation of about 30° towards the southwest compared to the flow directions of the groundwater estimated in preliminary investigations. A small amount of groundwater originating from the old landfill II probably mixes with the groundwater aquifer of Wiesendangen when the groundwater table is high. This result supports our interpretation of the boron isotope ratios.

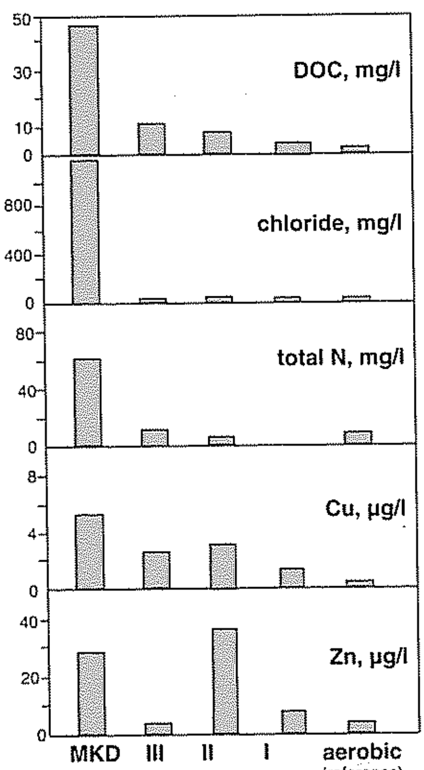


Fig. 3
Concentrations of DOC, chloride, Tot-N, Cu, and Zn in leachates of Compartments I, II, III and MKD, site as compared to the groundwater from the Wiesendanger Feld (RS70).

Results of the Geochemical Investigation

Geochemical composition of the groundwaters: In Wiesendanger Feld, east of the Riet area (sampling site RS70), the groundwater was not affected by the old landfill sites. Its composition (oxygenated, hard waters) served as a reference for the evaluation of the contaminated leachates and groundwaters.

The contamination of the leachates in the old landfill sites I–III and the groundwaters in their vicinity (concentrations and loads) with pollutants such as salts, inorganic compounds and heavy metals, was significantly lower than that of leachates from the MKD compartment and from the compartments of the landfill site currently in use. The main source of groundwater contamination originates from the microbial oxidation of organic material as well as from the naturally occurring remains of peat pits. In the absence of oxygen, microbes make use of other electron acceptors for the degradation of organic matter, resulting in the reduction of nitrate, manganese, iron and sulfate. Figure 3 shows the differing concentrations of a selection of inorganic parameters in the leachate of the old landfill compartments. With the exception of Zn and As (not shown), concentrations are highest in leachates from the MKD compartment. There is a clear enrichment of zinc (Zn) in the leachates of the old landfill II and arsenic in the old landfill III (60 µg/l in comparison to 27 µg/l in MKD leachate and 2 µg/l in leachate from Site II). In order to determine the reason for these differences in concentrations, it would be necessary to conduct analyses on the solid phases in the landfill.

The contamination of the groundwater can also be estimated as loads, measured in kg/day, i.e., as flow rate in m^3/day times the concentration in kg/m^3. The groundwater flow through the Wiesendanger Feld («reference» in Fig. 3) at approx. 20,000 m^3/day is about 100 times higher than the flow of groundwater through the area of the MKD and old landfill II. If the concentrations of dissolved organic carbon (DOC), as shown in Fig. 3, are 5–10 times higher in old landfill II than in the area of the groundwater reference, this would mean an increase in the load of 10–20%. For this reason, we assume that the extent of the reduced groundwater plume is limited to a relatively small reactive margin downstream of old landfill I. Outside this region, the contaminated groundwater mixes with oxygenated groundwater which does not flow under the old landfills. This behavior was demonstrated clearly in the boreholes which had been sunk out from the old landfill II diagonally along the originally assumed flow direction in the preliminary survey [10]; the concentrations of chloride or sulfate, for example, decreased sharply outside old landfill site III.

Long-term Behavior

The decision to take remedial action depends, among other things, on the evaluation of the temporal development of concentrations and loads of potential contaminants leaching into the environment. In order to estimate the long-term behavior of deposits in a former landfill, information on the composition and reactivity of the deposited materials is required. These two factors determine how quickly the concentration of a pollutant decreases or whether changing biogeochemical conditions might lead to an increase in the contaminant load. A decrease in both concentrations and loads can be expected for most compounds as a function of time and leaching rate; however, where geochemical conditions change (e.g., redox reactions), there is a possibility that organic substances are no longer degraded or that heavy metals are more mobile.

Composition of Deposits in an Old Landfill Site

The determination of the composition of old waste deposits is difficult because of heterogeneity and the usual lack of historic documentation. In most cases, only random samples are taken for financial and operational reasons. In the old landfill III at the Riet site, for example, six composite core samples (0.3 to 2.0 m) have Zn concentrations varying between 0.07 to 1.2 g/kg. There is no direct correlation to electrical conductivity measurements (EM31), no correlation to dissolved concentrations and no way other than sampling and analysis to determine the overall Zn content of Site III. The confidence in data can be improved by soil statistical methods, but this means taking hundreds of samples because the composition of the old deposit must be characterized as a function of area and depth [4]. Even then one can assume that some substances remain undetected.

An historical literature survey can be used to understand of the contents of old municipal solid waste landfill sites [11]. In this century, the amount of waste has greatly increased, and its composition has changed dramatically [12]. At the beginning of the century, 50% of the domestic waste still consisted of ashes; the rest was mostly compostable material (see Fig. 4). In time, the amount of ash and compostable material decreased, and the complexity of the wastes increased. Not only were different categories of wastes, such as plastics, landfilled, but the diversity of chemical components increased as well. Since the 1960s and 1970s, municipal solid waste is incinerated and deposited as ash.

The concentration of compounds in leachates from inorganic wastes like ash mainly depends on the type of waste and the rates of the leaching processes. Leachate from wastes containing organic material can be expected to be reducing and to contain a palette of organic compounds (mainly in deposits since 1950). The leaching processes depend on the redox conditions. With this basic information alone, it is already possible to assess the content and the likely influence on groundwater quality of the various compartments at the Riet site.

Reactivity

Reactivity can be understood as those processes occurring within a landfill body that control long-term emissions. On the one hand, it depends on the composition of the waste; on the other, on the biogeochemical properties of the leachable substances. The reactivity of the older compartments at the Riet site could be determined by the redox state of the leachates and groundwater. Analyses of redox species (see Fig. 5) have shown that in and downgradient from Site III, the concentrations of DOC and especially of reduced iron, Fe(II), and sulfide, S(-II) are clearly greater than that of the aerobic groundwater of the Wiesendanger Feld. In this area, methane is also detected, indicating that methanogenic conditions exist at least locally. Within the area of old landfill site I, neither oxygen nor dissolved Fe(II) or S(-II) could be detected. Suboxic conditions can be found here as a consequence of the mixing of leachate waters from the old landfill sites I and III with the groundwater of the Wiesendanger Feld.

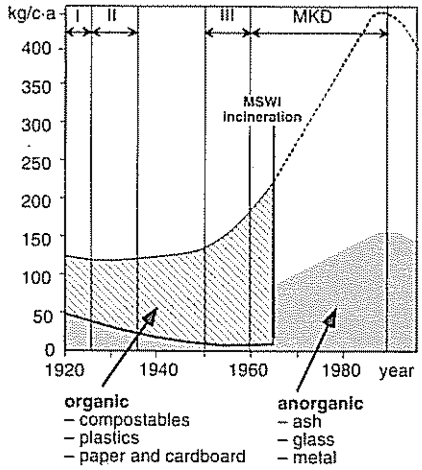


Fig. 4
Sketch of the amounts and probable composition of wastes landfilled at Riet as a function of time.

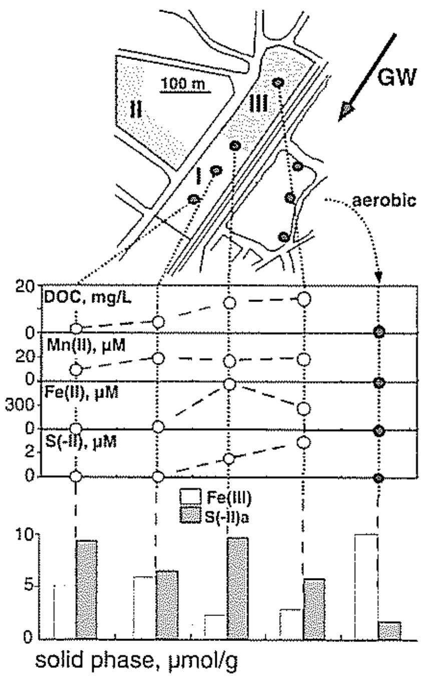


Fig. 5
Selected redox parameters of the groundwater and of the solid phase in samples taken from Compartments I and III.
GW = groundwater flow direction.

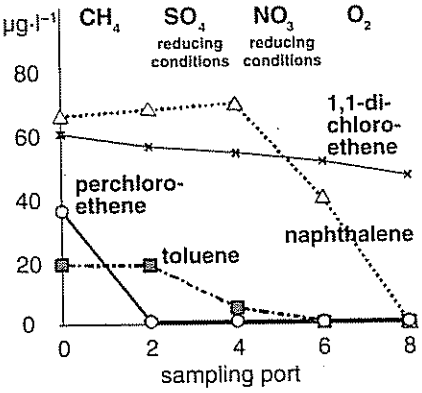


Fig. 6
Transformation of compounds in a laboratory model of a landfill redox plume. Compounds are run through four columns (left to right) simulating methanogenic, SO_4 reducing, NO_3 reducing and oxygenated groundwaters. Changes in concentrations indicate transformation processes.

Analysis of the solid phase at Sites I and III indicates that Fe oxides are present in lower concentrations and that sulfide (probably FeS) concentrations are enhanced in comparison with the aquifer material from the Wiesendanger Feld. Since suboxic conditions today prevail at Site I, the conditions must have been more strongly reducing in the past [10]. Thus, the analysis of the solid phase of material from old landfill sites provides an indication of changes in geochemical conditions of an old landfill in the past.

The degradability of many organic compounds depends on redox potential. Nay et al. [11] have shown in their recent study how tetrachloroethene is degradable under methanogenic conditions (Fig. 6), while aerobic conditions were necessary in order to degrade naphthalene. Compounds such as 1,1-dichloroethene were shown to be only minimally degraded under either condition according to their study. These compounds could not, however, be detected anywhere or at any time at the Riet site.

Emissions and Long-term Evaluation

Figure 7 qualitatively illustrates the development of leachate concentrations from a municipal solid waste landfill [13, 14] with time. Methanogenic conditions, accompanied by the emission of methane, carbon dioxide and other gases, are rapidly established and lasts for the first several decades. At the same time, emissions of different compounds are expected via leachates. Leachates from fresh municipal solid waste landfills are characterized by high concentrations of organic carbon, ammonium and salts, a lack of dissolved oxygen as well as an almost unlimited supply of organic compounds. Concentrations of heavy metals, such as Cu or Zn, usually remain low due to the formation of insoluble metal sulfides. Under oxic conditions and at favorable pH values, heavy metals may be released; however, as long as $CaCO_3$ is present as a buffer, the mobility of heavy metals is low. The waste material at Site III has such high $CaCO_3$ concentrations (between 10 and 40 weight %), that it would take several thousands of years to be leached out.

The situation at Riet is summarized in Fig. 7. There is a definitive correlation between age and leachate concentrations in most components. The redox parameters also indicate that compartments I and II are not very reactive, while biodegradation processes are still active in Sites III and MKD. Thus, the emissions at Sites I and II are close to environmentally acceptable levels, while the temporal development of compartments III and MKD requires monitoring. It should be noted that the temporal development of each compartment depends on the waste composition and cannot necessarily be compared directly.

Costs

The BUWAL (Federal Office for Environmental Protection) estimates the costs for the detailed investigation of a former landfill to be about SFr. 250,000. [1]. Our detailed investigation, lasting two years, amounted to total expenses of about SFr. 400,000, including both field and laboratory work. The town of Winterthur contributed SFr. 79,000 towards the study, for which we would like to express our thanks. The relatively high expenditures can be explained by the interests of a research-oriented investigation.

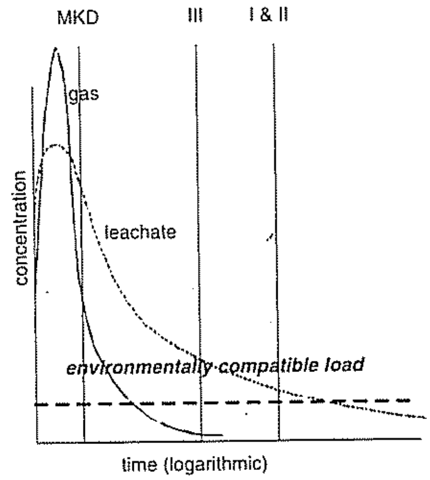


Fig. 7
Representation of the long-term emissions from municipal solid waste landfills acc. to [12, 14] and a qualitative assessment of Compartments I, II, III and MKD.

Conclusions

What is the risk of contamination of the groundwater through the unsealed old landfill sites I, II and III? With the exception of zinc and arsenic, we found no levels of pollutants in the leachate and groundwater that would warrant intervention by the authorities. For this reason, we can also guarantee the long-term utilization of the groundwater from the present catchment installations (not drinking water) in the Wiesendanger Feld. The projected costs of several hundred thousand SFr., which a remediation of the old landfill sites I–III would entail, are disproportionately high in our opinion.

We regard old landfill sites containing mainly domestic waste from the 1950s and before as presenting, in general, a smaller problem for groundwater than more recent landfills. An historical investigation may prove useful in such cases (acc. to [3]).

The monitoring concept for the protected groundwater resource of the town of Winterthur has the potential for widespread application. In our evaluation of the former landfill sites I–III, we assume that groundwater monitoring by the authorities is being modified to both obtain greater resolution and in consideration of our results concerning the compounds involved. As to the metals mentioned above, an investigation of material from the corresponding old landfill sites would be appropriate. The multicomponent landfill, however, should be monitored more closely than the old landfill sites I–III due to the increased potential of contamination of its wastes. If future monitoring results should, contrary to our expectations, indicate a deterioration of the current state, the situation in the multicomponent landfill should be especially examined.

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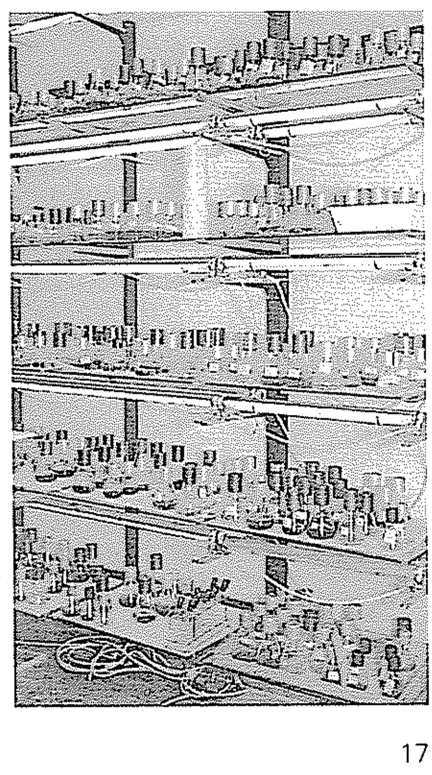
EAWAG Loses a Show Piece

Maintenance of the algae collection at EAWAG, consisting of approximately 300 pure cultures, has recently been discontinued for budgetary reasons. The collection was initiated by former EAWAG director Prof. Otto Jaag and later expanded by Dr. Alfons Zehnder, a high school teacher. For years, Dr. Zehnder donated his time to isolate and maintain algae and cyanobacteria from all over the world. He brought back a number of specimens from his travels abroad (e.g., Nepal) and then developed nutrient media appropriate for each. The pure cultures had to be continously transferred to new flasks in order to be kept alive. The collection was small by international standards, but treasured because it contained a number of rare and special species with well-documented isolation histories. Each year, 50–100 cultures were used in teaching and research, for practical demonstrations and in scientific experiments.

Dr. Marianne Bosli-Pavoni, a former collaborator of Prof. Jaag, graciously took over culture maintenance following the untimely death of Alfons Zehnder. She familiarized herself very quickly with the culturing techniques and kept the cultures alive with much love and dedication. Since her appointment at 20% time was insufficient to accomplish the work needed for maintenance, she generously donated her time. She even agreed to continue working after her retirement. One of her last tasks before leaving her position was to dissolve the collection and find new homes for as many cultures as possible. The majority of taxa were sent to Kaiserslautern, Germany. We take this opportunity to thank Dr. Bosli-Pavoni for her many years of hard work and dedication.

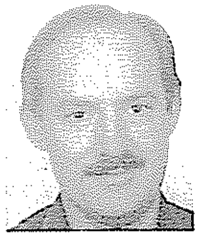
While an archive for biodiversity had to be abandoned here, scientific interest in algae is as strong as ever, for both medical and toxicological research. Algae produce compounds of interest to pharmacologists, or can be used in molecular and physiological experiments because of their unusual metabolic capabilities. This work often requires the use of a number of pure cultures as one would find in an algae collection. *Hans-Rudolf Bürgi*



Armin Peter and Tom Gonser

The Töss as Habitat

Armin Peter



Tom Gonser

* *with René Gächter, Matthias Brunke, Ivana Jancarkova, Tania Schellenberg[1], Flavio Tunesi[2], Peter Ulmann and Rainer Zah*
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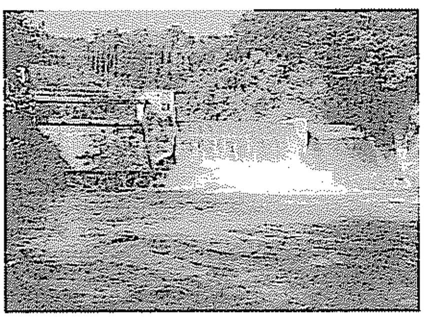
[2] *Forchstr. 143, 8032 Zürich*

The ecological condition of the Töss was analyzed from its mouth at the Rhine to its source with an emphasis on habitat and the composition of fish species. Special attention was paid to the connectivity of the habitat and its condition. The ecological situation in the Linsental near Winterthur was studied in more detail.

Above the weir at Freienstein (12 species of fish):

Chub, brown trout, minnow, Prussian carp (Carassius auratus gibelio), bullhead, gudgeon, pike, roach, tench, stone loach, *spirlin*, three-spined stickleback.



Below the weir at Freienstein (23 species of fish):

Eel (Anguilla anguilla), chub (Leuciscus cephalus), *grayling* (Thymallus thymallus), brown trout (Salmo trutta fario), barbel (Barbus barbus), minnow (Phoxinus phoxinus), perch (Perca fluviatilis), bullhead (Cottus gobio), gudgeon (Gobio gobio), dace (Leuciscus leuciscus), pike (Esox lucius), bleak (Alburnus alburnus), *nase* (Chondrostoma nasus, left), rainbow trout (Oncorhynchus mykiss), roach (Rutilus rutilus), tench (Tinca tinca), stone loach (Barbatula barbatula), *spirlin* (Alburnoides bipunctatus), pumpkinseed sunfish (Lepomis gibbosus), three-spined stickleback (Gasterosteus aculeatus), *soufie* (Leuciscus souffia, right), burbot (Lota lota), catfish (Silurus glanis).

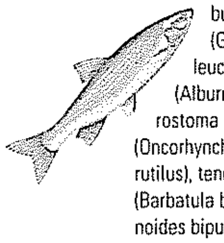


Fig. 1
Species of fish present below and above the weir at Freienstein. The species in italics are protected under the Convention of Bern.

Systems Analysis

An analysis of the river system in an area is necessary in order to assess its potential for restoration. The following analysis is based on ecomorphologic studies along the entire length of the Töss including several tributaries [1], supplemented by biological investigations of the fish. The most important ecomorphologic parameter, the connectivity of the habitats, is discussed below.

In order to assess the current condition of a lotic system, its ecological integrity must be evaluated [2]. This includes:

- its chemical integrity (water quality),
- its physical integrity (habitat structure, discharge dynamics),
- its biological integrity (genes, populations, communities, landscape).

Analyzing Longitudinal Connectivity

In the Töss, a total of 568 artificial constructions may be counted along its total length of 59.7 km, in comparison to only 35 natural barriers. The average free-flowing reach of river is only 99 m in length. In Fig. 2, the existing barriers to migration ≥2 m are shown. The species of fish living in the Töss have been analyzed with respect to these impassable barriers. Their effects on fish fauna have been illustrated using the example of the first 6.5 m high weir near Freienstein (Fig. 1). In the 4.6 km long, mostly natural stretch between the river's mouth into the Rhine and the weir, there are 23 species of fish. These were probably also present above the weir before it was built (a near-natural stretch of 3.3 km). To date, only 11 of these species can still be found above the weir (along with one new species, the Prussian carp). Five of the next seven high obstructions contain fish ladders; however, all of these ladders were built for fish which could leap well and do not function for small fish species.

Condition of the Habitat and Occurrence of Fish Species

The Töss can be divided into four sections:

- *1st section*

mouth of the Töss into the Rhine to reach no. 7 (below Pfungen), 7.9 km in length.
Characteristics: habitat mostly near-natural, 24 species of fish present (12 species above Freienstein)

- *2nd section*

below Pfungen to reach no. 17 (the beginning of the Linsental), 10.1 km in length.
Characteristics: monotonous habitat, land-water interactions lacking, seven species of fish present. Several species are missing as a consequence of the homogeneous habitat.

- *3rd section*

reaches 18 and 19, Linsental (5.75 km long)
Characteristics: habitats monotonous, lacking land-water interactions, four species of fish present (high abundance: bullhead; average abundance: brown trout; low abundance: minnow and stone loach). The low abundance of minnows and stone loach is a consequence of the monotonous constructions in the river. The 143 artificial obstructions (maximum height 50 cm) are barriers to the migration of these small fish species.

- *4th section*

above Linsental to the river's source (38.8 km long)

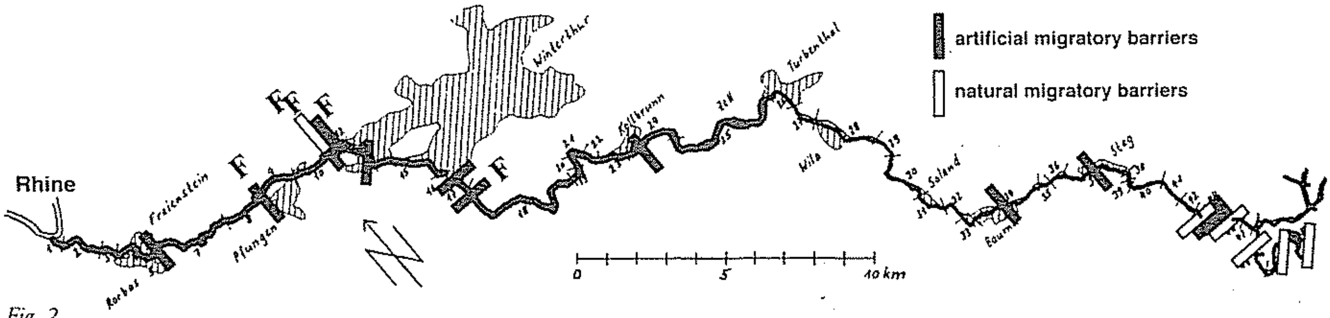


Fig. 2
Catchment area of the Töss, acc. to [1]; migratory barriers ≥2 m have been added. F indicates that a fish ladder has been built by the corresponding migratory barrier. The numbers 1–50 designate the reaches of the ecomorphology study.

Characteristics (without the source region): extremely uniform reach of river, monotonous habitats, lacking land-water interactions. The four species of fish present (brown trout, minnow, bullhead, stone loach) only occur in low densities. This is mainly due to the monotonous obstructions and the use of the river for hydroelectric power, but is also due to naturally occurring dry spells. The connectivity for fish is not indicated, as there are 332 artificial transverse obstructions (the reach of free flow being 117 m).

Lateral Connectivity

Special habitats (such as side channels or oxbows connected to the Töss only during flooding) are very different compared to the Töss itself, e.g., in flow, temperature, chemistry and diversity. These very valuable fish habitats (i.e., habitat for young fish, overwintering zones) possess a high density of biomass and are colonized by specialists which contribute to a relatively high level of biodiversity.

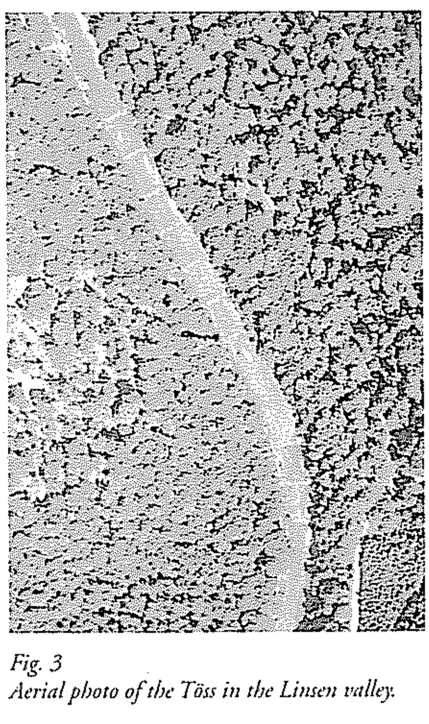


Fig. 3
Aerial photo of the Töss in the Linsen valley.

The Lack of Tributary Connectivity

The tributaries of the Töss usually flow abruptly over a bed drop down into the Töss; connectivity is lacking. There are no opportunities for the immigration of small-sized fish species (the bullhead being the dominant species). In the upper reaches of the Töss valley, eight tributaries have been analyzed [3]. Six tributaries are already impassable by small-sized fish species where they flow into the Töss; one stream is only passable along the first 100 m; another stream for only the first 200 m.

Summary of the Deficit Analysis

- The longitudinal connectivity is strongly inhibited in the Töss (568 artificial transverse constructions).
- The tributaries are extremely disconnected.
- The Töss is being heavily used for hydroelectric power; 17.5 km (30% of the entire length) are reaches of residual water; in 11 of 15 locations, no minimum flow is guaranteed.
- Only a few nearly-natural reaches of river still exist (a maximum of 13% of the entire length).
- Except for the nearly-natural reaches, the fish habitat in the Töss is extremely monotonous (lacking variability in both depth and structure).
- Lateral connectivity is practically absent.
- The fish fauna is strongly impaired (species diversity, density).
- Biofilms, which effect the self-purification process in the river, are swept away even by small floodwaters in massively engineered reaches of the Töss.

In short, the intense use of the river and the constructions on the Töss are not without consequences to its ecological status. The management of the Töss region cannot be regarded as sustainable, and its future ecological integrity cannot be guaranteed.

A comprehensive improvement of the habitats of the Töss should be initiated. The best way to achieve this goal is to re-establish links (increase longitudinal connectivity) and by guaranteeing minimum flows.

Ecological Deficits in the Linsental

At first glance, the Linsental seems to be in a nearly natural condition; a closer look, however, reveals the Töss' heavily obstructed nature (Fig. 3). The shores are reinforced and force the river into a 20 m wide channel. Due to the resulting accelerated flow and a general lack of debris input from its catchment area, the Töss has downcut the stream bed. In order to prevent a further sinking of the river bed, transverse bed steps have been inserted every 30–40 m. As the entire river at the present time flows in a fixed sunken channel – even during flood conditions – its interaction with the surrounding land is missing, and there are no dynamics of fluvial morphology.

The disconnection of the river with the surrounding land has far reaching consequences for the riparian vegetation. The latter is monotonous in structure (Fig. 4) because it is not periodically disturbed by floods and renewed. This means that there is no successional diversity of pioneer communities nor periodically flooded woods of various ages. The vegetation is also unexposed to periods of inundation through flooding or high groundwater levels.

The surrounding land has a negligible effect on the morphology of the river which, in turn, has negative consequences for the development of aquatic habitats. Exposed gravel beds, hollowed-out shore lines and levees, a river bed of variable width, woody debris structuring the river bed and meandering side channels are all lacking. Most notably, there are no small bodies of water separated from the river on the flood plain such as oxbows, disconnected branches of the river or spring brooks of varying connectedness to the river and groundwater. Such bodies of water possess a thermal regime different than that of the main branch of the river and usually flow much more slowly. They provide habitat for a very different spectrum of organisms and are very important for the biodiversity of the fluvial landscape. For example, natural springs possess a fauna adapted to relatively stable conditions. In a river's side channel, many animals can be found which prefer calm waters; opportunistic species which fly in from the outside can also find appropriate habitat (e.g., species of many insects). The ponds in such flood plains are also essential habitat for amphibians which are one of the most endangered groups of animals in the region.

The Early Töss

Old maps drawn before the obstructions on the Töss were built clearly show that the river used to be richly branched, that it possessed a high variability in width and that there were natural springs, side channels, oxbow ponds and vegetated accretion islands on a broad alluvial plain. The heterogeneity of such a fluvial system (shown in Fig. 5) with its various aquatic habitats and plant communities at various stages of successional development can only develop through dynamic interaction between the river and the surrounding land. As the Töss kept changing its course, over time, it occupied the entire width of the Linsental.

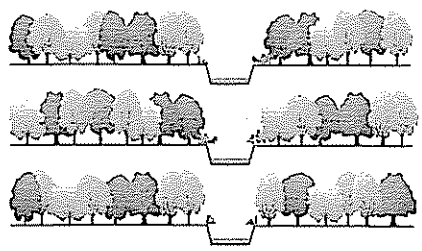


Fig. 4
Schematic transverse profiles along the Töss in the Linsental today.

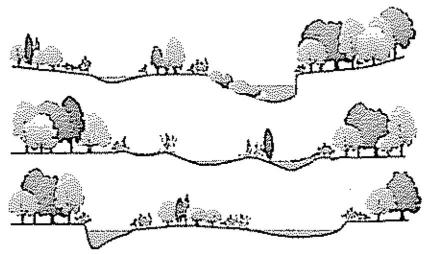


Fig. 5
Diagram of transverse profiles along the Töss in the Linsental around 1816.

Ecological Importance and Implementing Restoration

The Linsental, a wooded area without houses or agricultural land, seems to be ideal for letting the Töss flow more freely again. Permitting it to restructure itself naturally would help many small invertebrates, amphibians and birds to find appropriate habitat, which at present are nonexistent or practically so. This would be very valuable for the biodiversity of the entire Töss area and its landscape. This local measure would, however, be of no importance to many species of fish as long as their migration is hindered by high bed steps.

How much space are we willing to allow the restored Töss? Enough space should be given for the development of naturally occurring habitats. A return to a near-natural state should be directed towards allowing the natural structuring processes to take place again; i.e., the river "does the work". This entails the first step of removing reinforcements from the shores so that floods can sculpture the fluvial area in diverse ways; however, this procedure demands a long term perspective. Only during the course of many years will the various habitats and diverse stages of ecological succession be able to develop by themselves. The static, constrained river should be able to develop into a dynamic river in control of itself.

Purposeful Restoration Brings Knowledge

The restoration of the Töss would result in far more than an increase in ecological value. It would also be a project from which we could learn with implications reaching far beyond the region. In combination with other interests (e.g., flood control, drinking water supply, recreational value), measures can be formulated which implicitly contain predictions or hypotheses. These predictions as well as the time frame (i.e., the time by which certain successes are expected) should be clearly stated. After an appropriate time span, the degree of success should be evaluated as a direct function of the measures that were undertaken. If the conditions that the project was striving for did not manifest themselves, then the measures should either be strengthened or new ones should be formulated and implemented. If the expected results occur, the project can be regarded as a success, and the knowledge gained can be transferred to the restoration of other natural systems.

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Eduard Hoehn

The Linsen Valley – Both Drinking Water Resource and Natural Habitat

Eduard Hoehn

In the Linsen Valley (Linsental) near Winterthur, the authorities are planning to revitalize the canalized Töss to itsa near natural state. In this section of the valley, groundwater is withdrawn for drinking water by the city of Winterthur. These two very different uses ultimately lead to conflicts in land-use conflicts. EAWAG is contributing to thea solution of such problems by carrying out investigations at an experimental site in the valley.

The Linsental south of Winterthur is about 3 km long and is a completely wooded section of the Töss Valley. Photographs from the last century show a branched river system of the Töss in this part of the valley (see EAWAG news 39, title page). At present, the river Töss flows in channels with dams and is cut off from the surrounding land. The water of the river Töss is clean. The valley is about 100–200 m wide. The sediments of this section of the Töss consist of sand and gravel. At a depth of about 5 m, a groundwater stream 10–20 m thick flows through a very permeable sand and gravel aquifer. The river loses water in several locations to the subsurface and recharges the groundwater. The groundwater is of good quality and is withdrawn in a sustainable way from wells. It is used by Winterthur (StWW) without treatment and supplies a considerable portion of the city's drinking water.

The Questions

The Cantonal Department for Water Pollution Control and Construction (AWEL) plans to revitalize the canalized river to its near natural state in certain reaches of the Linsental. But how will the river bottom change when the river Töss flows unhindered? In what ways could drinking water wells become contaminated in the process? To answer such questions, particularly those concerned with the potential for infiltration of pathogenic bacteria, changes in water quality need to be predicted. For this reason, an experimental site has been selected with the goal of estimating residence times of both the groundwater and infiltrated water as well as better understanding mixing phenomena. A hydrogeological investigation of this experimental area included

a) geophysical studies (geo-radar) at two sites, one with observed exfiltration of the groundwater to the river, and one with assumed infiltration of the river to the groundwater; and

b) the construction of groundwater observation wells oriented along flow lines, as well as pipes driven in the river bed

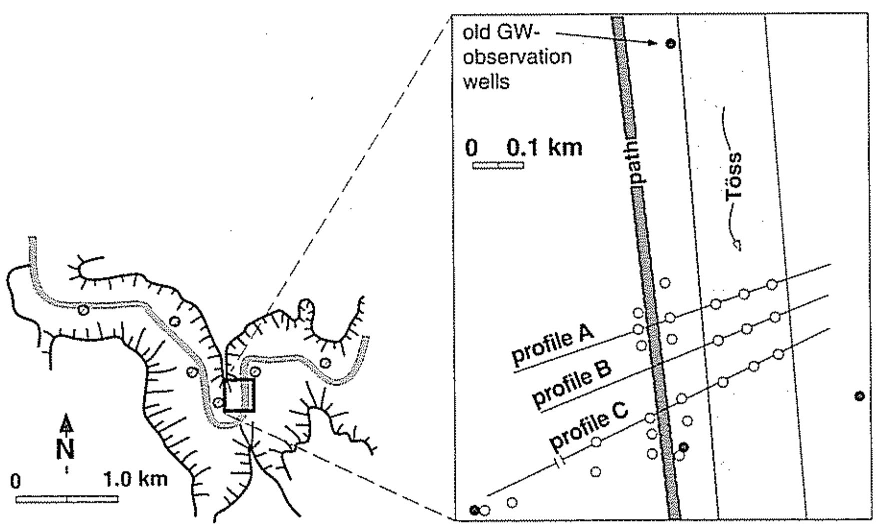

Fig. 1
The experimental site in the Linsental (circles in the left picture = groundwater wells).

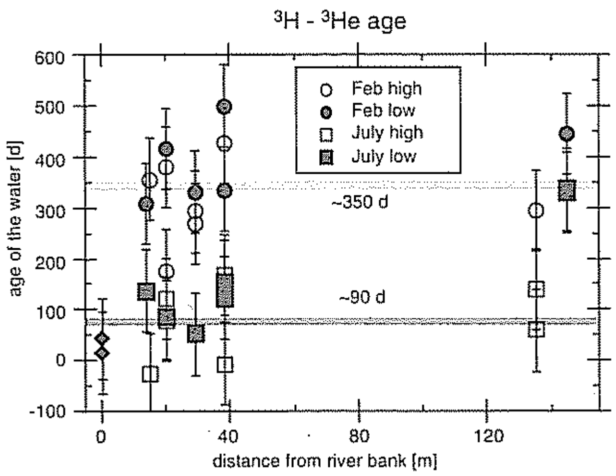

Fig. 2
Residence times of the water infiltrating from the river Töss along an assumed groundwater stream line; in winter, the groundwater residence times are longer than in summer (for details, see [2]).

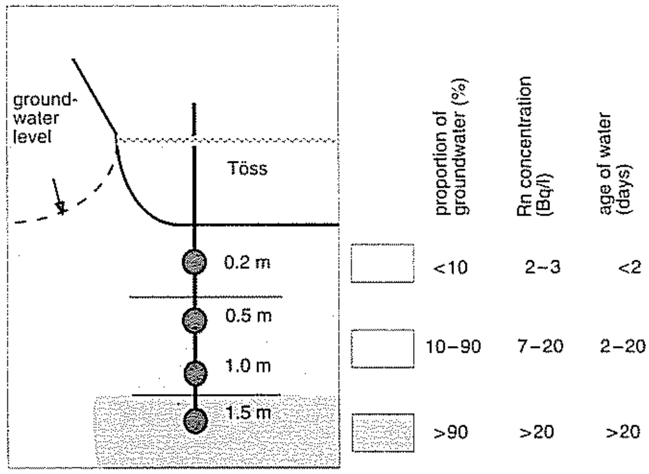

Fig. 3
Residence times of the water in the infiltration area of the Töss River bed: Radon concentrations at various depths in pipes driven into the bed of the Töss River.

of the Töss (screened sections at various depths).

The hydrological study included the use of naturally occurring isotopes of inert gases (^{3}He, ^{22}Ne and ^{222}Rn) and numerical modeling of groundwater flow. In close cooperation with the City's Water supply (StWW) and AWEL, the results of this study should form the basis for the decision-making process regarding revitalization of the Töss.

An interpretation of the radar signals together with geological data showed structures in the subsurface of the experimental site which allowed us to assume that the river's behavior was very "wild" in earlier times, depositing huge layers of gravel and sand during flood events [1]. Core inspections from the drillings corroborated data from the georadar survey and permitted the identification of a few less permeable layers located at greater depths. Further downstream, the groundwater gradient suggests possible infiltration, but only to a limited extent.

Groundwater Residence Times

Measurements showed that there were significantly fewer fluctuations of groundwater temperature than of the water of the river itself. "Older" groundwater has an almost constant temperature. A simple water balance model of the Linsental allowed us to estimate the average residence time of the groundwater to be about 200 days. Using concentrations of helium and neon in samples of the ground and surface waters from downstream borehole sites, the groundwater age was calculated to be in a similar range (Fig. 1; [2, 3]); radon concentrations of 25±2 Bq/l (n = 18) in the wells suggested a residence time for the groundwater of at least 20 days. In the pipes driven into the river bed, the radon concentrations at a depth of 0.5–1.0 m ranged between 2 and 20 Bq/l, suggesting a narrow zone of mixing between river water and "older" groundwater (Fig. 3; [2]). Using hydrogeologic data from this and previous studies in our groundwater flow model produced groundwater residence times which are comparable to both those estimated from the water balance and those calculated using the inert gas tracers [5].

Limits to Revitalization of the River Töss

Efforts to revitalize the River Töss means that the river should be allowed to recreate its bed through erosion and redeposition. But how high will the risk of groundwater contamination be for the water supply agency? In a study carried out by StWW, sections of the river were identified in which river water infiltrates to the groundwater at residence times of probably less than 10 days. In such areas, revitalization must be avoided due to the risk of a breakthrough of bacteria and dissolved contaminants from the river Töss to the groundwater wells; this is because the flow distance from the river bank to the wells could decrease, and the share of infiltrate in the extracted groundwater would increase. For this reason, only short reaches of the river can be revitalized, i.e. a few hundred meters in length. In addition, the residence times, mixing ratios and potential for breakthrough of dissolved substances in the groundwater must be monitored both near the river and near the extraction wells. This monitoring must be carried out more intensively than ever before and especially after flood events. The results of our investigations suggest that this project can begin.

Many thanks to colleagues in the working group of this project: Dr. Peter Huggenberger (to date geologist of the Canton of Basel-Stadt/University of Basel), Dr. Rolf Kipfer, Urs Beyerle, Martin Hirt and Norbert Mattle.

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Andrea Rüede

Participatory Processes

A Challenge for Science?

Andrea Rüede

The demand for environmental sciences to take into account political and practical considerations is growing ever stronger, although research is struggling to deliver. The project "Use of Copper as a Building Material in Exterior Applications" serves as an example of how participatory processes can be beneficial in many ways.

The current use of copper in exterior building applications is predicted to have detrimental long-term effects on soil and water. Markus Boller presents the situation from a scientific and engineering standpoint in another article in this issue. Here we would like to address a different aspect of the "copper problem":

How is the Long-term Danger of Copper Contamination of Soil and Water Assessed by the Political Arena and by Individuals Dealing with the Problem on a Day-to-day Basis?

Near the end of 1997, the Swiss Institute for Architectural Biology and Architectural Ecology (SIB) and the WWF Lucerne held a press conference discussing the planned culture and congress center in Lucerne, which was supposed to receive a roof consisting of a copper skin. The SIB and the WWF Lucerne argued, based mostly on EAWAG publications, that this common practice essentially results in a creeping contamination of soil and water and that it is time to take preventive action: architects, contractors, engineers and scientists are called upon to find alternatives [1]. The Swiss Sheet Metal Contractors and Plumbing Installation Union (SSIV), on the other hand, proposes in its information brochure "Copper as a Building Material for Roofs and Facades" that the use of copper in exterior applications is entirely unproblematic, even from an environmental standpoint [2]. The Swiss Agency for the Environment, Forests and Landscape (BUWAL) did not see any acute problems arising from the use of copper and, therefore, saw no reason to act. In EAWAG's opinion, however, the introduction of copper into soil and water is indeed a long-term problem. Increased efforts should be made to search for ecologically, economically and technically acceptable substitution materials and innovative solutions. Infiltration basins with adsorbing filter layers should only be viewed as a temporary stop-gap measure.

In light of hardening positions between the two interest groups (including EAWAG) on a *national* scale, EAWAG decided to initiate a participatory process on a *regional* level. The primary goal was to facilitate and stimulate a dialogue between the various national interest groups. Intense discussions among affected groups are expected to lead to a document assessing the severity of the long-term problem, possible options and alternatives to copper, and concrete measures which can be taken in the short-term. This was an opportunity to test the political and practical relevance of research conducted at EAWAG and to develop potential research questions. The example of "Copper as a Building Material in Exterior Applications" proved to be fortunate in two ways: first, the release of copper from roofing and siding applications into the environment is smaller than the contribu-

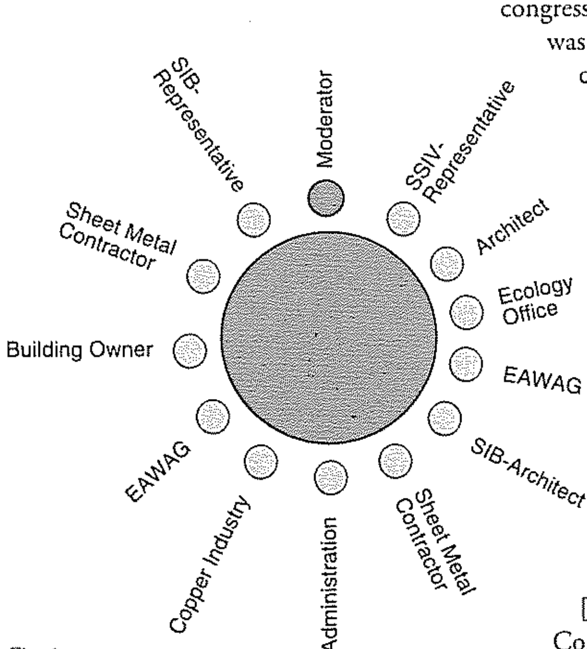


Fig. 1
Participating parties in the focus groups on copper.

tion from agriculture, but the social implications are more easily defined and assessed and, from a scientific point of view, can be analyzed more easily and with more immediate gain. Secondly, the need for action is not immediate, which increases the chance for an objective discussion and makes it more likely that alternatives will be developed which meet ecological, economical and social criteria.

The Use of Focus Groups

Participatory processes *in science* have a long-standing tradition in the political sciences. On a number of occasions, they were and are being used at EAWAG. By involving affected parties and decision-making entities, the practical and political relevance of research can be tested and improved. Results from participatory processes are typically recommendations or advisory opinions. Their intent is to aid on-going political processes or initiate new processes. An important tool in participatory processes are focus groups.

Focus groups are well organized group discussions among 6–12 participants. The primary goal is to bring together experience from a variety of fields and apply it to a concrete problem. Discussions are typically led by a moderator. Participants interact and react to one another, creating new ideas in the process. Focus groups are particularly useful in collecting qualitative information and in establishing evaluation criteria.

The following criteria can be used in deciding whether a focus group would be an appropriate tool in a given situation. These criteria are a prerequisite, but not necessarily sufficient to warrant the use of a focus group; a lot depends on the particular problem at hand:

- Assessing the possible range of options
- Evaluation of acceptance level for expert opinions
- Finding potential areas of consensus in acute conflicts
- Representing the different perceptions of a problem by various affected parties
- Uncovering latent conflicts
- Feedback from research to practical relevance
- Generation of new research questions [3–8].

A Concrete Example

As part of our project, twelve representatives from the Swiss Midlands met in three sessions of three hours each, debating the "Use of Copper as a Building Material in Exterior Applications". We succeeded in bringing together a very broad spectrum of participants from architecture, research, industry, interest groups and administration.

Each meeting was focused on one topic. To inform and to stimulate discussion, each participant was given a three-page document on the topic of copper use in building applications, where the opposing positions of the SSIV, the SIB/WWF Lucerne and of EAWAG were explained.

At the first meeting, the discussion was "jump-started" by 15-minute opening statements from each of the three groups. The second meeting was dedicated to finding evaluation criteria for judging various options and alternatives. The third meeting was devoted to formulating concrete measures and to agreeing on written recommendations. EAWAG contributed significantly to the research aspects of the recommendations, e.g., suggesting a research emphasis on investigating copper fluxes and budgets in the Töss region.

What have the Focus Groups Achieved?

The two-page document created by the focus group was subsequently discussed with *national interest groups,* which cleared up several important misunderstandings and led to a common understanding of the problem. As a result, the interest groups formulated their own document stating their new common position. The need and the benefits of this cooperative process among research, industry and interest groups was most noticeable in the formulation of research projects to evaluate the various alternatives.

Benefits of the focus group discussions for *research* were most obvious in the following areas: additional aspects of the problem were incorporated into the research, incorrect assumptions were corrected, methodical experience relating to the use of focus groups was gained, and new cooperations were initiated. In addition, a number of new research topics were formulated.

Participation in the focus groups "forced" the scientists to pay far more attention to preparation, presentation and justification of research results than is common practice. The crucial experience was for scientists to perceive themselves as only one of many involved parties and to include political and social considerations in addition to their purely scientific arguments. Focus groups not only expanded the network of contacts between disciplines and groups, but also created research demands which were created "at the desk".

Focus Groups: A Challenge for Science?

Focus groups challenged scientists and other participants alike. The most important characteristic for the scientists was not their professional qualifications so much as their personal abilities and aptitudes. It was most important to put the purely scientific view into perspective and to keep an eye on the bigger picture. This does not mean that scientific results were irrelevant, but that their meaning was put into context and that their weight and value had to be delineated.

A second challenge was the presentation of research findings. For focus groups, it is essential that scientific material be presented in a clear and understandable form. This does not mean that statements can be oversimplified or be presented without proper basis or reference, but there is a heightened need for reducing results to their essence.

At the same time, we would like to underscore the importance of the learning process by participants in focus groups. as mentioned above; focus groups are particularly useful in situations where scientific results suggest several possible solutions. Participants of focus groups have to come to realize that these uncertainties cannot necessarily be eliminated by more research. They must learn to accept these uncertainties and find ways to responsibly and constructively deal with them.

EAWAG participants were: Markus Boller, Gregor Dürrenberger, Tove Larsen, Walter Meier, Christoph Meyer, Claudia Pahl-Wostl and Christian Singeisen.

[1] SIB/WWF (1997): Medienunterlagen «Kupfer – ein unterschätzter Schadstoff» (zu beziehen bei: U. Brütsch, Postfach, 6023 Rothenburg).

[2] Schweiz. Spenglermeister- und Installateurverband (1997): Dokumentation «Kupfer als Baustoff für Dächer und Fassaden» und «Kupfer als Baustoff» (Bezug: SSIV, Auf der Mauer 11, 8001 Zürich).

[3] Dürrenberger, G. et al. (1997): Focus Groups in Integrated Assessment. A Manual for a participatory tool, Zürich.

[4] Greenbaum, T.L. (1993): The Handbook for Focus Group Research, Lexington Books.

[5] Kitzinger, J. (1994): The Methodology of Focus Groups: The Importance of Interaction between Research Participants; Sociology of Health and Illness, *1*, 103–121.

[6] Krueger, R.A. (1988): Focus Groups: A practical guide for applied research, Sage, Beverly Hills.

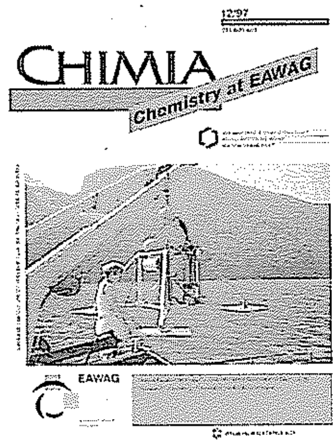
[7] Merton, R.K., Kendall, P.L. (1946): The focused interview; American Journal of Sociology, 541–557.

[8] Morgan, D.L., Spanish, M.T. (1984): Focus Groups: A New Tool for Qualitative Research, Qualitative Sociology, *3*, 253–270.

Special Issue of CHIMIA

"Chemistry at EAWAG"

This professional journal for science, technology and industry in the area of chemistry is the official publication of the new Swiss Chemical Society. In 14 review articles, EAWAG scientists discuss their research and highlight results. The entire December 1997 issue is dedicated to research activities at EAWAG. *Walter Giger*



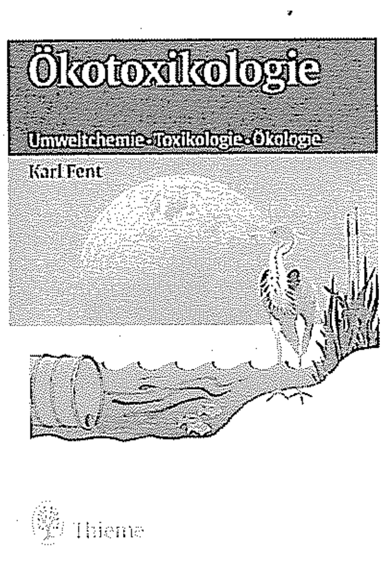
The cover page features the lander used by biogeochemists in Kastanienbaum.

Karl Fent

Ecotoxicology

The field of ecotoxicology examines effects of anthropogenic chemicals on plants and organisms in nature. Ecotoxicology is a multidisciplinary science, connecting environmental chemistry, toxicology and ecology. One of the most important aspects of ecotoxicology is the long-term goal of avoiding adverse environmental impacts before they occur and to protect the environment.

Until now, ecotoxicology has often been limited to merely studying the effects of certain chemicals on selected laboratory organisms, partly because a clear definition of the field was lacking.



This new book defines ecotoxicology as a modern environmental science and gives students and scientists in a number of disciplines as well as professionals working in the environmental field an in-depth look at this important new science.

The first two chapters introduce the basics of environmental chemistry and toxicology. Subsequent chapters introduce concepts used in modern ecotoxicology. Rather than discussing all the possible negative effects observed in ecotoxicology, a few relevant effects on organisms (e.g., on reproduction) are discussed in depth, and key processes are examined on all biological levels from single organism to the whole ecosystem. All chapters stand alone, but include numerous cross-references to other chapters, reflecting the interrelated nature of ecotoxicology itself. Each chapter begins with an overview, summarizes the most important conclusions in bullet form and is largely illustrated by 168 figures and 63 tables. The bibliography is an extensive collection of recent publications in the field of ecotoxicology.

Karl Fent (1998): Ökotoxikologie, G. Thieme Verlag, Stuttgart, ISBN 3-13-109991-7, (Fr. 71.–).

Tove A. Larsen

Sustainable Management of Resources on a Regional Level

The preceeding articles illustrate efforts in managing regional resources in the Töss region in a sustainable way. Can this aim be met using the traditional methods of environmental research? Are new research strategies needed?

Tove A. Larsen

Central to the idea of sustainable development is the concept of resources. Fig. 1 shows various types of resources each of which represents a different aspect of the sustainability puzzle. The listed themes represent examples within each of the groups. Natural resources are listed on the left; anthropogenic resources on the right. At the top are those resources that hold a special position at EAWAG; at the bottom are more conventional conceptions of resources. The illustration suggests that the sustainable management of resources may be viewed as being the best way to manage all different resource types. A similar concept of resources was presented with respect to urban water management in a previous edition of EAWAG News [1].

The projects in this high-priority research program mainly concern the themes in the upper part of the Fig. 1, with the conventional resource types only marginally included. This is a conscious choice: the traditional fields of competence at the EAWAG shall be retained in the future, but new aspects of sustainable resource management should be increasingly integrated.[1]

What new aspects have been included in this high-priority research program? We have mainly worked with a spatio-temporal resolution which should do justice to the regional level. In Fig. 2, the time and spatial scales of sustainable development are compared to those of typical research. The message is that the work of a large part of current – especially top-notch – research is carried out on a very small spatial and temporal scale, whereas globally sustainable development, as it is envisioned for the 21st Century, has to take place in completely different dimensions. The concerns of globally sustainable development in our field include international water rights and the conflicts involved [2] as well as clean drinking water for everyone [3]. One of the major challenges for current research is building the bridges between research carried out on a small scale and attaining goals for the entire planet in the new century.

We can also aim for a more modest goal and start working on the sustainable management of resources on a regional level. The idea behind this is that the sum of all sustainably managed regions will bring us closer to global sustainability. On the regional level, we have the possibility to carry out concrete research. In the projects of this high-priority research program, we have attempted to move towards the regional level and to combine the individual results from research with the development of the region.

A key thesis to this effort can be stated as follows: at the regional level society plays a major role. When investigating a river or stream the processes of society are hardly of much importance. If, however, we aspire to investigate the potential regional development of this river, then we must combine the research problems of the natural scientists and engineers with the decision making processes of the

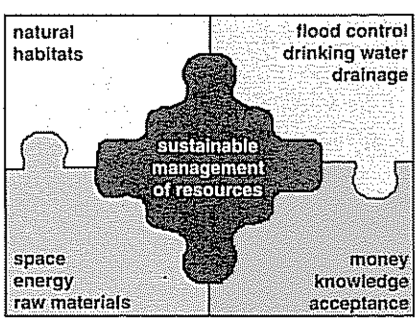


Fig. 1
The natural and athropogenically induced resources seen from the standpoint of EAWAG.

[1] This concerns in particular the researchers participating in the high-priority research program. For some time, the Department of Resources and Waste Management (Stoffhaushalt und Entsorgungstechnik) at EAWAG has oriented itself to the common definition of resources (lower half of the diagram).

society. Whether this results in a good research assignment is open to discussion. But if we accept the challenge, the social component cannot be ignored. Using a few examples from the high-priority research program, we shall discuss this statement below.

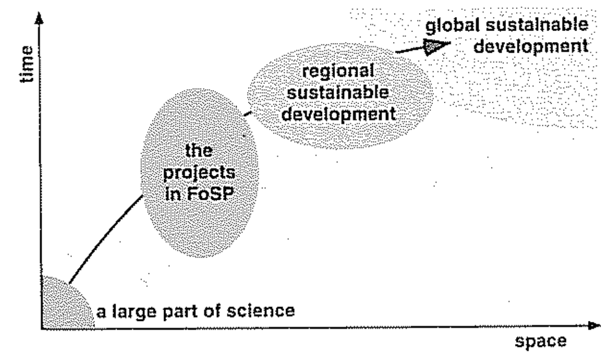


Fig. 2
The space and time scales of sustainable development integrated.

Drainage of Precipitation Runoff

The Problems of Nondegradable Substances are Put Off

To date, nondegradable pollutants from precipitation can be found in sewage sludge, in lakes, rivers and spread diffusely in the landscape. Precipitation, which may also be contaminated, can penetrate into the ground where it is not sealed. The diffuse distribution occurs so slowly that it may take a long time to detect any damage. We can quantify the pollutants in sewage sludge; if the sludge is distributed as fertilizer onto fields, we can estimate when the pollution standards for soil will be exceeded. From the problems concerning sewage sludge, we can also conclude that combined sewer overflows and the direct discharge of stormwater contribute to the pollution of lakes and rivers.

Under the new water protection act, which calls for the infiltration of stormwater, the pollution pressure on sewage sludge is decreased, and the compounds are redistributed according to the chosen system of infiltration. Basically, the more diffuse the distribution, the longer it takes to reach a critical situation – and the more difficult it becomes to carry out a remediation should the need arise. To date, the lesser of the evils seems to be the concentration of nondegradable compounds in the infiltration basins. We have to consider, though, that we are creating new potentially hazardous sites using this methods. Genuinely sustainable solutions can only mean dealing with the problem at the source. Such solutions can, for example, be developed using so-called participative procedures. A small pilot scheme on the theme of copper was carried out in the high-priority research program. It is described in Andrea Rüede's article in this issue.

The Ecology of Running Waters

A New Definition of Technology is Needed

Similarly, when creating the resource habitat or "living space", we enter a new field of work if regional objectives are included. "Back to nature" has become almost impossible in all parts of Switzerland: flood control, water supply, energy production and anthropogenic demands for living space force us to make concessions when attempting to revitalize natural bodies of water. This means that ecologists cannot simply apply their basic knowledge of naturally functioning ecosystems; they have to commit themselves to new types of "habitats" or living spaces which do not exist anywhere yet but which should function nevertheless.

Revitalizing lotic systems is an example of the need to understand the word "technology" in a broader sense. The technology of revitalization encompasses not only the types of construction used. It also includes the ecological questions: how long must the stretch of river be, e.g., how much space does a body of water need for the revitalization to make sense? This means that the phases of development as well as of progress control are requisite for environmental issues – as they are for any new technology: not solely the so-called "hard" technologies can claim them.

Included in this new definition of technology is the active participation of the population in creating the goals of the revitalization apart from the experts. In addition, the large investments that a revitalization entail would probably be impossible to ratify without broad consensus.

On What Level are Concrete Problems being Solved?

Not all problems of regional sustainable development can be solved on the same level. There are problems which are expressed regionally, but which have to be resolved supra-regionally.

Problems encountered with running waters can be easily approached regionally. This is not surprising because for us a region is defined by its aquatic system, its watershed, and not according to administrative boundaries. The revitalization itself can occur locally. But apart from this, there are many issues that only let themselves be solved satisfactorily on a regional level. It is interesting that several of the regional issues such as water supply, recreation and to a certain extent also flood control can be described by the "city-to-land" relationship.

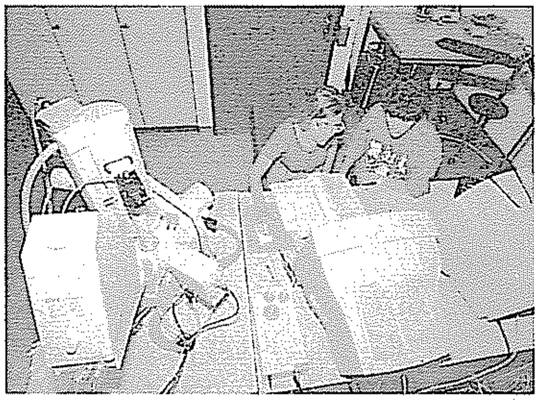
In contrast, the degree of pollution of stormwater is a supraregional problem. The organization of the entire municipal infiltration of stormwater runoff takes place on a local, community level. Technologies, however, which can reduce pollution significantly can in practice only be developed within a national or even international context.

Environmental Problems are Symptoms of Lifestyle

As citizens, we all want drinking water, energy, mobility and nice rain gutters on the roofs. This is true today, and this will not change. What new research strategies are needed in this case?

New Scanning Electron Microscope Goes into Service

A new scanning electron microscope (SEM) was installed in the spring of 1997, replacing an older instrument that has been in service for some 20 years. The new instrument is a conventional SEM with enhanced analytical capabilities, including image processing and archiving, an x-ray detector for energy-dispersive spectroscopy, and a semiconductor detector for backscattered electrons. It can handle a wide variety of samples, including crystals, cinders from incinerators, mineral surfaces, suspended particles in streams, aquatic fauna, lake sediments, biofilms, and microorganisms. The variety of samples puts high demands on the instrument, but even more so on the users and operators of the SEM lab.



Department of Environmental Physics and Scanning Electron Microscopy

We will have to make concessions when weighing the various interests against one another: as discussed in the section on the revitalization of running waters, a total "back to nature" approach is not possible in Switzerland; however, we have to encourage innovations which enable us to manage our resources in a sustainable way. The environmental sciences alone cannot contribute the necessary innovations. Cooperation efforts with implementation and practice are needed – as seen in the water conservation effort of the past 30 years. In the future, new professions as well as the public as a whole must be included in the research process. If we want to approach the problems at the source, the issue in many cases concerns the production of and demand for environmentally compatible products. Participatory discussion encourages and supports finding solutions and is part of a new research strategy. A first modest yet concrete example is the search for roofing materials that will not create a potential environmental hazard for future generations.

From Reactive to Active Environmental Protection

Why do wastewater experts now have to deal with household products and roofing materials? Does this not extend beyond their professional realm? We don't think so. Wastewater and rainwater act as indicators which can detect unsustainable patterns in the chain of production and consumption in the same way that wastes do. It is important that the experts in those fields call attention to these connections and contribute to solutions from their point of view.

Seen from a practical point of view, wastewater experts cannot ignore the problems. The unsustainable elements in the line of production and consumption manifest themselves on the disposal end, often in a very disagreeable way by rendering otherwise sensible solutions unnecessarily difficult. A well known example is sewage sludge which poses one of the largest problems for wastewater experts because of its contaminant load. Without such pollutants, the sludge could be made available for agriculture in an economical and sensible way; in this way, at least part of the nutrients would be returned for reuse.

Similar problems are encountered in the infiltration of stormwater. The installations should not only divert the water but also fulfill the functions of cleaning and retention; both construction and operation become correspondingly expensive and demanding. In addition, uncertainty exists whether this procedure is appropriate; after all, we are knowingly creating new potentially hazardous concentrations of pollutants.

Looking back in history, the experts working on environmental problems have mostly acted reactively. They have tried to deal with problems as they arose. One exception has been the successful efforts to remediate industrial plants and processes to a point where the pollution of sewage sludge with heavy metals is minimized. Today we see, however, that this approach is not enough; a source-oriented approach in industry has brought success. But consumption is just as important as production. In the case of stormwater infiltration, this "consumption" mainly consists of corrosion and erosion of surfaces (such as roofing materials made of copper) and various surface treatments. Not only are these direct effects on the lakes and rivers important but also air quality plays a role: traffic, energy production, consumption of pesticides, etc. influence the final quality of the rainwater via the air and deposition.

A proactive instead of reactive environmental policy would deal with these problems wherever they appear. The large time spans discussed above have the advantage of giving us enough time: we do not have to act here and now. We can and should think about the right approach. Quick and cheap solutions today may become expensive ones tomorrow. But the longer we wait, the more acute the problems will become, and the less time we will have.

[1] Larsen, T.A. and Gujer, W. (1997): Sustainable Urban Water Management – Technological Implications. EAWAG news, 43E, p. 12–14.

[2] Zehnder, A.J.B. (1997): Water, a Commodity in Short Supply? EAWAG news, 43E, p. 3–4.

[3] Wegelin, M. and Schertenleib, R. (1997): Appropriate Water Treatment – a benefit for all. EAWAG news, 43E, p. 5–7.

From the Engineering Department

How Urine is Transformed into Anthropogenic Nutrient Solution (ANS)

Since the middle of July of last year, EAWAG has been operating a *No-Mix* toilet where urine is collected and stored in a separate tank. The new toilet was installed in the laboratory building and is accessible to both men and women.

Why separate urine? A large portion of nutrients is removed from human metabolism via the urine; for example, 85% of the nitrogen and 50–80% of the phosphorus. This is why urine is referred to as an *A*nthropogenic *N*utrient *S*olution (ANS).

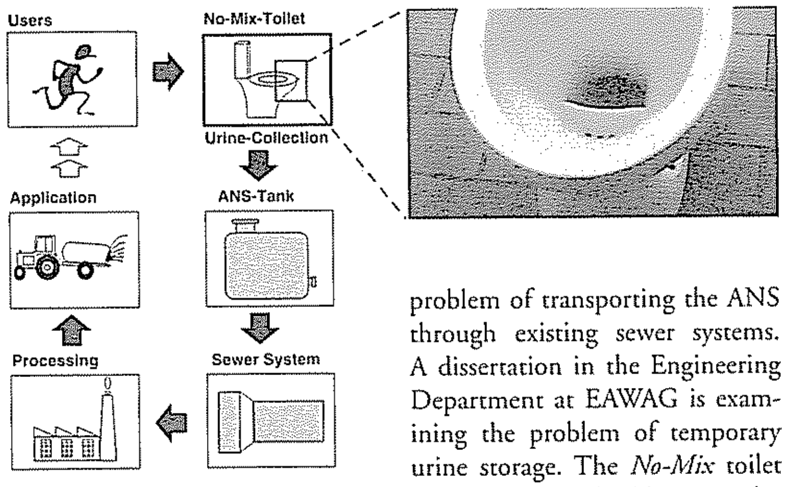
Nowadays, nutrients are often classified as waste products which have to be fed to a wastewater treatment plant as quickly as possible, where nitrogen and phosphorus are removed from the waste stream at a high energy cost. Separation of ANS from wastewater would significantly reduce the load on wastewater treatment plants.

At the same time, agriculture uses large quantities of artificial nitrogen and phosphorus fertilizers. The production of these fertilizers is very resource intensive; nitrogen is produced in the energy intensive Haber-Bosch process, while phosphorus is extracted in the form of minerals. It seems reasonable to collect nutrients which are excreted and directly feed them back to agriculture in the form of ANS.

But recycling ANS only makes sense under certain circumstances:

- the consumption of primary resources has to drop dramatically,
- the collected nutrients have to be useable as agricultural fertilizers without extensive processing, and
- the transport of ANS from the toilet to the farm or processing plant should not require excessive new infrastructure or expenditure.

Storage and transport of ANS in urban areas is a problem for which a solution has been proposed. Urine collected in *No-Mix* toilets is temporarily stored in small holding tanks in the house. At night and during dry weather, the tanks are opened on a staggered time schedule. The existing sewer system transports the ANS to the processing plant where it is processed into fertilizer [1]. Such a processing plant should, of course, be located near the wastewater treatment plant.



Various undergraduate and diploma research projects in the group for Urban Water Management at ETHZ have dealt with the problem of transporting the ANS through existing sewer systems. A dissertation in the Engineering Department at EAWAG is examining the problem of temporary urine storage. The *No-Mix* toilet in the laboratory building is a pilot project and allows for the collection of urine under realistic conditions.

Kai Udert

[1] Larsen T.A. and Gujer W. (1996) Separate Management of Anthropogenic Nutrient Solutions (Humane Urine). *Water Science and Technology, 34*, 87–94.

A New Project at EAWAG in the Spirit of Changing Paradigms

Ecoelectricity

The project "Ökostrom" is aimed at promoting green power and involves a new scientific approach combining basic scientific research; economics and sustainable development of alpine regions. We will develop criteria for an ecolabeling of electricity generated by hydro power plants, based on green pricing experience in California and on the Zürich Electricity Stock Exchange. The customer can reward environmental efforts

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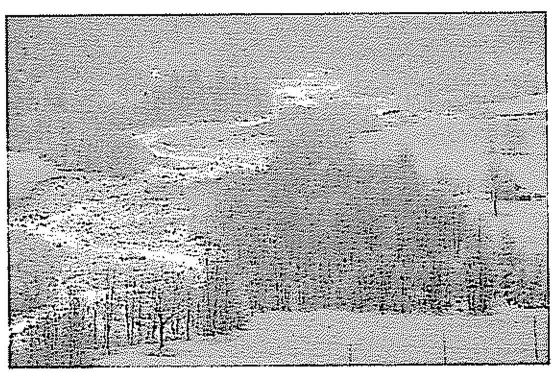

The floodplain near Ponto Valentino in the middle stretch of the River Brenno del Lucomagno (Blenio Valley, Ticino) is of national importance, but endangered by water diversion.

Bernhard Wehrli Promoted to Associate Professor

The ETH Council has chosen Bernhard Wehrli to become associate professor for Aquatic Chemistry effective 1 October 1997. Professor Wehrli will continue to lecture in the Department of Environmental Sciences at the ETH-Zürich where he had been an assistant professor. His group is working at EAWAG's research center for limnology in Kastanienbaum. Over the past several years, the team has specialized in quantifying exchange processes at the sediment/water interface in lakes, wetlands, in coastal systems and in rivers.

Bernhard Wehrli exhibited a keen interest in environmental issues even during his undergraduate studies in chemistry at ETH. He has obtained first-hand knowledge about environmental and water protection policies in the context of hydroelectric developments in the Swiss alps (power station Ilanz, Greina). These experiences motivated him to obtain his Ph.D. with Prof. W. Stumm and to also participate in the postgraduate course in "Urban Water Management and Water Protection". After obtaining his doctorate, he spent one year in the USA where he broadened his knowledge in Earth Sciences and numerical modelling at the California Institute of Technology.

After his postdoc, he worked as scientific associate in the "Multidisciplinary Limnological Research (MLF)" group at EAWAG, where he developed his own research interests. Together with physicist Alfred Wüest and limnologist René Gächter, he focused on the evaluation of lake restoration measures. This gave his research on processes at the sediment/water interface an important link to practical applications. Collaborative projects also allowed him to develop new methods for investigating and quantifying processes in lakes and at lake bottoms. Alain Manceau in Paris used x-ray spectroscopy (EXAFS) to shed more light on mineral formation processes in dark, anoxic zones of deep lakes. Arthur Schweiger (ETH) used pulsed ESR-spectroscopy to investigate interactions between carbonates and metal ions on a molecular level. Beat Müller and Christian Dinkel developed a profiling probe equipped with chemical sensors which can be deployed to the sediment surface and record processes at the sediment/water interface on a scale of millimeters.

After a short research period in Paris, Bernhard Wehrli became assistant professor for Aquatic Chemistry in 1991. His young research group showed commendable enthusiasm and tackled many questions, such as:

- How much of the nitrate in our lakes is transformed to harmless nitrogen?
- How are calcium carbonate precipitates formed? Can they be prevented with "magnetic water treatments"?
- Can trace metals in lake sediments give us a clue about the lake's oxygen budget in the past?

Experiences from lake research in Switzerland were also transferred to other lake systems, such as Lake Baikal and the Black Sea.

In his courses for students in environmental sciences, chemistry and environmental engineering, Bernhard Wehrli attempts to build a bridge between the understanding of chemical processes on a molecular level and the macroscopic observations in environmental sciences. In the future, crucial challenges for environmental scientists will be to work in interdisciplinary teams, find answers in short periods of time, and produce practical results. Bernhard Wehrli is immersing himself in this experience in the interdisciplinary project "Ecoelectricity" at EAWAG.

Rene Schwarzenbach,
Head of the Institute for Water Protection and Water Technology (IGW) at ETHZ

SGHL-Prize for O. Heiri

At the 11th Annual Meeting of the Swiss Society for Hydrology and Limnology (SGHL) last October, Oliver Heiri was awarded a prize for his outstanding diploma dissertation on "The Spring Emergence of non-biting midges (Diptera: Chironomidae) along a Minimum Flow Stretch of the Engelberg Aa (OW/NW)". This research was conducted in Section XA of ETHZ at EAWAG during summer 1996. *Jürg Bloesch*

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provided by the power companies through paying higher prices for renewable energy.

The marketing potential for the product "green power" is being studied in several social sciences projects at EAWAG. The ecological damage caused by hydro power plants will be assessed in a case study of the power station Luzzone using water from the Brenno River system in Val Blenio, Ticino.

The project "ecoelectricity" involves all affected parties through a co-operative process in differentiating between various electricity products. The case study has started in April 1998, is being accompanied by a group of external supervisors, and will be extended, in a second phase, to whole Switzerland and possibly Europe.

Jürg Bloesch

Bernhard Truffer, Jürg Bloesch, Christine Bratrich, and Bernhard Wehrli (1998): "Ökostrom": Transdisziplinarität auf der Werkbank. GAIA 7, No. 1, 26–35.

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

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