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Sustainable Water Usage and Innovations



an important role in this process, but are not positive *per se*. It is becoming ever more important to work with a broader basis of understanding of what is meant by "technology and innovation". On the one hand, social boundary conditions and alternative ways to use a resource have to feed into the process of finding new solutions; dialogue with the social sciences can be very fruitful in this endeavor. On the other hand, the effort must be broadly supported by research in the natural sciences; in particular, proposed alternatives for products and usage should be evaluated on the basis of how "energy intensive" they are with respect to production and consumption.

An innovation-oriented strategy for the management of water contains a number of new challenges for the EAWAG. A sound scientific understanding of the fundamental processes and their interdependencies will continue to be crucial. In order to deliver relevant advice and practical answers, however, research has to be increasingly guided by the logic of the innovation process. One vehicle to assist in reaching this goal is increased cooperation between representatives from industry, government and the general public. Putting a "real face" on this rather abstract strategy for innovation will be one of the most interesting tasks the EAWAG will face in the near future.

Dr. Bernhard Truffer

Head of working group "Ecological Innovations", EAWAG Department of Human Ecology

EAWAG



Realization of "sustainable development" must face the difficult issue of *water usage*. Supplying the world's ecosystems with water is fast becoming one of the most urgent of global problems.

Without any deeper analysis, it would appear that there is a water shortage, both in quality and quantity. To a large extent, however, any real shortages are due to inefficient use of the resource "water". Various studies have demonstrated that there is an enormous potential for conserving water in nearly all areas of application. Several articles in this issue outline ways in which our water resources could be managed in a more sustainable way.

There is another aspect of water which relates to the realization of "sustainability". Globally, hydroelectric power is the most important renewable source of energy and should perhaps be promoted. On a local level, however, forceful development of hydroelectric power can lead to negative ecological impacts. It would make sense then to develop new designs for power plants and evolve new ways of operating them which can mitigate the apparent contradiction between "global" and "local" sustainability. The EAWAG is in the process of developing a cross-disciplinary project called "Ecopower" whose primary objective is to address some of these issues.

Problems at both the local and global levels have to be solved if the use of water is to become truly sustainable. Ecologically motivated innovations play

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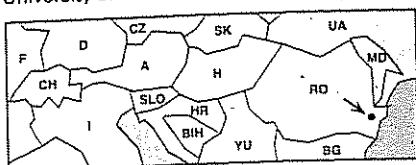
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Cover
Flooded forest on Fundu Mare Island on the Danube Delta of Rumania (see arrow on map below). Please see related article by Paul Brunner and Christian Lampert on the Danube watershed (photo: Virgil Iordache; used with permission of the Department of Ecology, University of Bucharest).



Alexander J.B. Zehnder

Water – A Commodity in Short Supply



Alexander J.B. Zehnder

Fresh water is the first resource that will be in short supply on a global scale. If demographic predictions are correct, it will take only 20–40 years before humankind will consume more water than is replenished by rainfall. Strict and careful reuse of fresh water could, however, boost available supplies by as much as 70%.

Global Water Balance

Approximately 2.5% of the earth's total water is present as fresh water. About 95% of that is bound in polar ice caps, glaciers, permanent snowfields and in groundwater aquifers deeper than 1 km below the earth's surface. Only about 5% is directly usable by humans and other organisms [1].

Sustainable management of fresh-water must be based on the only renewable source of fresh water; namely, rainfall. Rain is produced exclusively by solar energy and thus meets the criterion of sustainability. When more water is withdrawn from ground water and surface waters than is replaced by rainfall, the sources of fresh water are depleted in the long term. Examples include Lake Aral, which has lost 80% of its volume since 1950, and ground water aquifers in the Sahara beneath Libya which are thousands of years old, but will be depleted within the next few years.

Annually, the earth's continents and islands receive between 90,000 and 120,000 km³ of rainfall, the average being 113,000 km³. Of this total volume, 65% evaporates and another 25% reaches the oceans without ever being available as fresh water. Roughly 14,000 km³ are actually usable. A significant portion of this remaining volume falls in scarcely populated areas (e. g., Siberia) and is, therefore, difficult to access. In reality, 9,000 to 12,000 km³ of fresh water are available for use in agriculture,

for drinking water and in industrial processes [2].

Water for Food Production

The current annual worldwide consumption of fresh water is about 5,500 km³. Approximately two-thirds of this amount is used by agriculture; that is, it is used in food production. As a rule of thumb it can be stated that: 2 kg of wheat (dry weight of the whole plant) yields 1 kg of bread. In order to produce this amount of plant material, 1 m³ water is needed. The plant absorbs this amount of water, but loses a large portion of it to the atmosphere through evapotranspiration. This loss is difficult to reduce, although selection of smaller plants and genetic engineering could possibly reduce the loss by 25%. American farmers typically use about 4 m³ water per kg of wheat, while farmers in tropical areas use about 5 m³ of water to grow 1 kg of rice [3].

One kg of wheat flour provides approximately 3,500 kcal [4], which means that supplying a vegetarian diet of 1,000 kcal per person per day requires an annual water consumption of 100 m³. This is a very optimistic estimate which ignores losses that occur during harvest and processing or due to pests and spoilage, all of which increase water demand accordingly. Typically, losses are between 20 and 50%, with 40% being the current average value.

To produce 1 kcal of meat, 4.5 to 16 kcal of plant material is needed, with 10 kcal being the average. A daily diet of 2,500 kcal requires an annual water consumption of 350 m³ if the

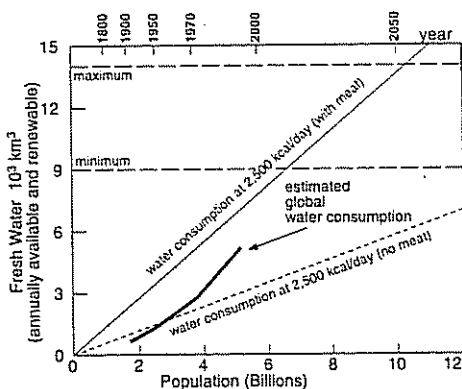


Fig. 1

Annual water consumption for an increasing global population at a diet of 2,500 kcal per person per day. The solid line represents an 80% vegetarian/20% meat diet, while the dotted line represents a completely vegetarian diet. Both lines include an extra 250 m³ of water for households, the service sector and industry. The dashed lines at 9,000 and 14,000 km³ indicate the minimum and the maximum annual value for the globally available volume of renewable fresh water. The heavy solid line represents the estimated actual global water consumption.

Country	Rainfall	River Input	Total
Egypt	35	1075	1110
Algeria	735	35	770
Germany	1235	965	2200
The Netherlands	670	5350	6020
Israel	370	100	470
Morocco	1200	-	1200
Switzerland	6430	1130	7560
Spain	2815	25	2840
USA	9940	-	9940

Table 1
Renewable fresh water volume in m^3 per person per year.

River Input = input from rivers originating outside the country. Numbers are calculated based on data from [5] and [8].

diet is completely vegetarian. If the diet is only 80% vegetarian and 20% of the diet is supplied by meat, the water consumption increases to $980 m^3$. These numbers include a 40% overall loss in production and processing of the plant material for both humans and animals.

Water in Households and Industry

Western European countries use an additional $250 m^3$ of water per person per year. $140 m^3$ are used for industrial production, while the balance goes into drinking water production or other domestic and related uses (e.g., service industry, hotels, restaurants, hospitals). In North America, the same activities require $380 m^3$, while the number for Africa is around $30 m^3$. The higher consumption levels for North America are primarily due to higher consumption in private households and in the service industry [5].

How Much Water Does One Need?

The total annual water consumption per person is somewhere between 800 and $1,200 m^3$, with outliers both on the high and low ends. According to [6], countries with less than $1,700 m^3$ of renewable water per person per year can no longer afford to allow unrestricted use of fresh water. Below $1,000 m^3$, there are some first signs of shortage; below $500 m^3$, there is a

severe deficiency. Switzerland has water in abundance. If Germany were dependent on rainfall alone, it would have to economize the use of fresh water to avoid shortages, while The Netherlands would have to worry about some serious shortages. Rivers originating outside these countries tend to equalize the national water budgets (Table 1).

For How Long Will We Have Water?

Based on existing data and the nutritional habits of the industrialized world, the annual water consumption in the year 2020 is projected to be nearly $9,000 m^3$ and approaching $12,000 m^3$ by the year 2040 (Fig. 1). Depending on the assumptions used in the projections, the renewable portion of our water resources could be globally in short supply as soon as 20–40 years from now. Regionally, many countries are already dealing with shortages in freshwater supplies.

Where Do We Go From Here?

Water is the first resource in which a shortage will challenge humanity as a whole. Most of us will be confronted with the problem of fresh water in one form or another within the next 20–30 years. Water plays an essential role in most aspects of our lives. Without political, legal and social measures, water shortages will hinder economic development, increase the potential of conflicts and amplify the negative effects of population growth. As long as women and children continue to spend a large portion of their day securing the necessary supply of fresh water, they will not contribute to the economic development of a region. This is exacerbated by the fact that poorer and less educated families often have more children [7]. Possible consequences of water shortages (and subsequent food shortages), poverty and population pressures include economic and political conflicts as well as migratory tendencies with effects that will be felt

far outside the immediately impacted regions.

Through strict and careful re-use of water, the volume of available water in areas with immediate shortages could be increased by as much as 70%. In order to reach this goal, economic tools are needed. Water must be viewed as a precious commodity instead of being freely available. Unfortunately, at this point in time, we do not have a clear strategy for inducing such an attitudinal transition. Even developed countries like Switzerland struggle when trying to legislate and implement complex changes (e. g. CO_2 legislation).

The public, scientists and decision-making bodies, all must become sensitized to the challenge of supplying fresh water. Only in this way will we be become aware of the problem and contribute to its solution. Adequate water supplies will continue to be a fundamental requirement for the survival of humankind. Since the regeneration of fresh water through rainfall is directly linked to solar energy, the water budget is an excellent example for both, the development of criteria for sustainable use and the responsible management of a resource.

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Martin Wegelin and Roland Schertenleib

Appropriate Water Treatment – A Benefit for All



Roland Schertenleib and Martin Wegelin

Water is becoming a commodity in short supply, notably in many developing countries, and its multiple use calls for treatment. The scarcity of resources promotes an appropriate use of simple and ecologically sustainable water treatment methods. This is a challenge, both for developing and developed countries.

Poor Quality Water for an Increasing Population

From a global and particularly from a regional viewpoint, water is becoming a quantitatively and qualitatively endangered resource. Countries with renewable and usable water resources (precipitation) below 1000 m³ per capita per year can be qualified as "short of water" according to current knowledge and use of conventional technologies and practices. In other words, water is becoming a limiting factor in the production of food, sanitation and economic development. Twenty-six countries with a global population of over 320 million already belong in this category. Over half of the population in the Middle East and North Africa already live in countries where water is in short supply.

Increasing populations and relentless industrial development will lead to more acute water scarcity problems in the next few years and decades unless the global population can be stabilized and, above all, a more economic use of the resource "water" is attained. From a quantitative viewpoint, agriculture, which consumes some 70% of the water resources, constitutes the sector with the greatest potential for savings. Large quantities of water may be conserved with relatively little effort through the use of more efficient irrigation methods and an increased reliance on wastewater. Significant quantities of water can also be saved by systematic water recycling in the industrial sector whose consumption of water resources amounts to roughly 20%. A mere 10%

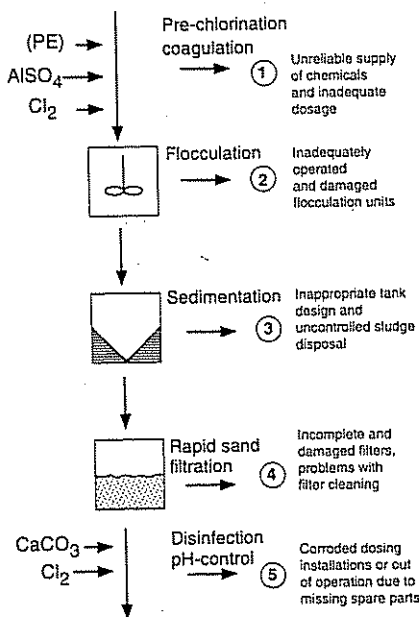
of water resources is used for drinking water. The highest quality standards are, however, imposed on this quantitatively negligible percentage of water. Increasing populations and industrial development contribute not only to enhancing the conflicts between the different types of usage mentioned, but also to deteriorating the quality of available water resources, thereby placing increased importance on water treatment.

EAWAG's research department "Water and Sanitation in Developing Countries" (SANDEC) focuses on the development of appropriate water treatment processes. Following a brief survey of the drinking water treatment problems in developing countries, two processes which were developed at the EAWAG are described.

Drinking Water Treatment Problems

Conventional drinking water technology often uses three treatment stages to treat solids in surface water: flocculation/sedimentation, rapid sand filtration and disinfection. Various chemicals are added, including coagulation agents, pH adjusters, oxidants and disinfectants. This type of treatment requires close monitoring of the water quality, adequate dosage of the chemical products and proper technical maintenance. Such operationally complicated and technically sophisticated installations have also been built in developing countries.

The experience gained in these countries reveals, however, that such



*Fig. 1
These are the most frequently encountered problems in many developing countries with conventional drinking water treatment technologies.*

Too much water in Cameroon...

In the Northwest Province, the rainy season, with an abundant precipitation of 4,000 mm, lasts from May to October. Helvetas has been installing water supplies for the past 30 years in this mountainous region once covered by tropical forests. The sand filters treating the clear river water worked perfectly well at first. But their continued operation has become increasingly difficult, and some filter installations have had to be shut down over the past 15 years. What are the causes of such problems?

The originally well-protected catchment areas could not withstand the demographic pressure and greediness of some middlemen. Fire clearings transformed the land into agricultural areas, and the precious tropical wood was felled for export. This led to soil erosion and clogging of the sand filters. To complement the sand filters, gravel filters have recently been installed under EAWAG's guidance. Clear and perfectly safe water again flows to the villages. Since a sustainable water supply starts with protection of the resource, the inhabitants have had to commit themselves to the future protection of the catchment by employing judicious agricultural practices and a reforestation program.

... and too little in Bolivia

It rarely rains in the Andes at 3,500 m. Since the annual precipitation only totals 400 mm, vegetation is consequently sparse. The inhabitants in their dispersed settlements live off their modest agriculture and small cattle breeding operations. The limited amount of water originates from contaminated rivulets. There is hardly any firewood, and animal dung is often used as fuel. The population suffers from diarrheal diseases, and cholera keeps flaring up.

Bottles, which have recently made their appearance on the local market, are filled with water and exposed to the sun. The inhabitants also take these bottles to the field to quench their thirst at work. The sun plays a key role in their culture; it symbolizes strength and health which is also transmitted to the water. Should the experiment succeed, the process could soon spread over the entire Andes where the inhabitants of the valleys still suffer from dreaded cholera epidemics.

facilities are often inadequately operated, insufficiently maintained and frequently out of operation. Some of the most frequently encountered problems are presented in Fig. 1. Chemical usage faces problems of unreliable supply and inadequate dosage. The systems are damaged by the tropical climates and the timely supply of spare parts is not ensured. Consequently, conventional drinking water treatment technologies often fail in rural water supply systems. Alternative treatment processes are, therefore, needed.

Gravel and Sand Filters

Chlorination and slow sand filtration are the two processes most successfully used in improving the water quality. In

most rural water supplies in developing countries, reliable and efficient chlorination of drinking water is unlikely for the aforementioned operational reasons; thus, an increasing number of slow sand filters are currently being installed. To attain an adequately hygienic level of water quality, however, both processes require raw water of relatively low turbidity.

Due to soil erosion, the turbidity levels of tropical surface waters are very high during the rainy season and frequently at other times during the year. An example of solids separation in a sedimentation tank operating under laminar flow is illustrated in Fig. 2. During flow through the system, the solids settle at the bottom of the ca. 2–3 m deep sedimentation

tank. The finer suspended particles of minor settling velocity are, however, only partially separated.

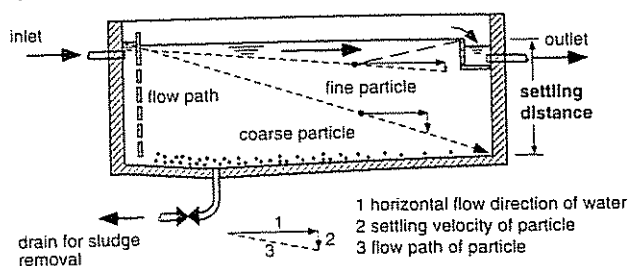
Installation of coarse gravel significantly enhances the treatment efficiency of sedimentation tanks. The settling surface of a tank filled with gravel is thus enlarged a hundred times, and the solids in the pore system of the filter require only a few millimeters to reach the gravel surface. In contrast to sedimentation by flocculation, the gravel filters (roughing filters) do not require the addition of chemicals and are characterized by their high process stability and operational security, thus making them particularly suitable for solid matter separation in rural drinking water treatment plants in developing countries.

Intensive laboratory research at the EAWAG [1] and field tests with SANDEC's partners in Third World Countries have led to the development of gravel filter technology [2]. Extensive studies in the gravel and sand filtration field were conducted by SANDEC's partner CINARA in Cali, Colombia [3]. Installation of gravel pre-filters enabled the use of slow sand filters with highly turbid surface water. The fecal coliform concentration may be reduced by 4–5 logs with this process combination (total treatment efficiency of over 99,99%).

Solar Water Disinfection

The inhabitants of developing countries have to fend for themselves and

Sedimentation Tank



Roughing Filter

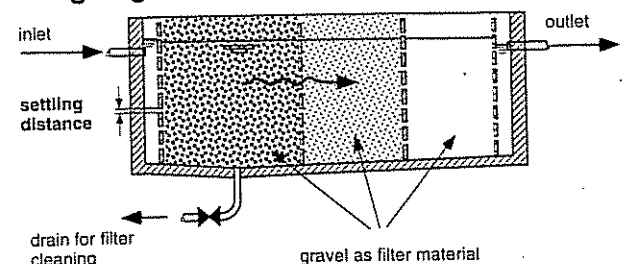


Fig. 2 Functioning of a sedimentation tank operating under laminar flow and gravel filters (roughing filters).

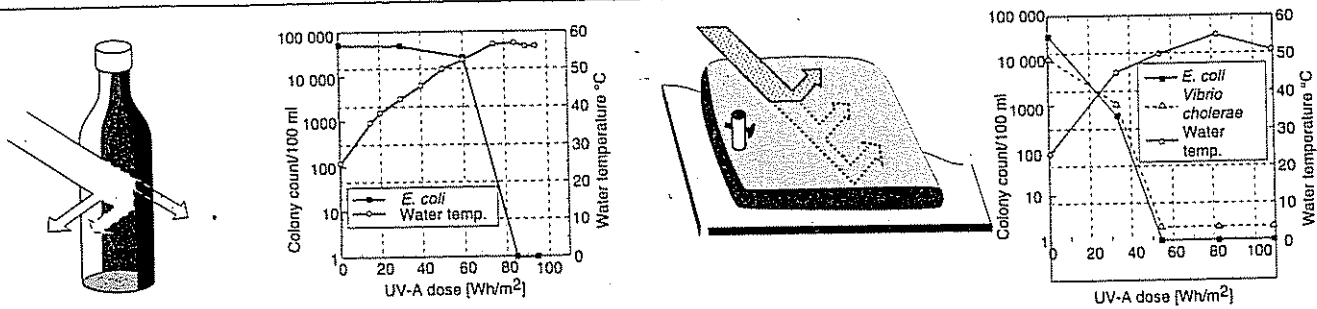


Fig. 3
Inactivation of fecal coliforms (*E. coli*) and *Vibrio cholerae* through solar water disinfection in bottles and plastic bags.

deal with problems such as nonexistent public water supplies or distributed water of poor quality. Treatment is mainly restricted to water directly reserved for drinking. The boiling of water is generally recommended, but sometimes not possible as the limited supply of firewood or kerosene is primarily used for cooking. Consequently, new and individual treatment methods, applicable under very poor conditions, are of prime importance. Solar water disinfection is a potential treatment process in these situations. To date, either sunlight (treatment by irradiation) or heat (treatment by pasteurization) have been used for drinking water disinfection.

The bactericidal effect of sunlight is well-known, and its application in treating drinking water has been field tested on various occasions [4, 5], although often with contradictory results [6]. In 1991, laboratory and field tests were conducted by the EAWAG to examine the disinfection potential of sunlight on drinking water and in an effort to develop appropriate treatment processes. Bacterial cultures (*E. coli*, fecal streptococci and enterococci), viral cultures (enteroviruses and rotaviruses) as well as bacteriophages were used in the irradiation tests.

Laboratory tests [7] indicate that a combination of irradiation and pasteurization may produce synergistic effects that drastically improve the potential for solar water disinfection. Field tests carried out with a natural bacterial mixture in Colombia, Jordan and Thailand confirm the EAWAG results. Furthermore, efficient inactivation of the cholera pathogen (*Vibrio cholera*) through solar disinfection was also demonstrated [8].

Exposure of water-filled transparent and half-blackened bottles (to increase the heat absorption capacity) is the simplest method of solar water disinfection. Temperature development and fecal coliform reduction in such exposed and blackened Coca-Cola bottles are illustrated in Fig. 3; however, preference is given to the use of plastic bags, as water exposure to sunlight is more intense through a small water depth and a large exposure surface. These examples provide impressive evidence of the potential of solar water disinfection.

The production capacity of solar disinfection installations can be increased considerably by continuous flow systems conveying the water by gravity from the elevated raw water tank over the exposure container to the clean water tank. The treated warm water heats the cooler raw water by means of a heat exchanger. The solar energy absorbed is recirculated in the system, and the treated water is simultaneously cooled to a desired temperature. The daily capacity totals about 100 liters/m² collector surface.

A market research study identified user interest and applicability of solar water disinfection. Demonstration projects are currently underway in nine different developing countries to assess the sociocultural acceptance and affordability of these simple treatment methods.

Local Commitment for Global Welfare

Why should anyone having to fight for survival each day be concerned with ecological, even global, interdependence, especially since greater aware-

ness of a problem seldom leads to a change in behavior.

Necessity compels us to act and seek appropriate and ecologically sound solutions. Solar water disinfection is, for instance, a simple, inexpensive and appropriate technology which also contributes to reducing worldwide deforestation; i.e., use of firewood for fuel purposes. Changes in attitude and behavior are needed to reach an environmentally more sustainable use of our natural resources. By promoting energy-saving technologies, which mainly use renewable resources, we invest in sustainable development that is ultimately vital for our survival as well.

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Saul Arlosoroff

Israel – A Case Study of Water Resources Management



Saul Arlosoroff

Development and water experts who have an interest in the Middle East and in the economic development of semi-arid countries, often pose the question: how does Israel prosper with less than 300 m³ of water per capita per year? International organizations define countries with less than 1000 m³ as highly stressed.

This paper will try to clarify some of the policies, their legislative basis and selected economic issues that have enabled Israel to reach an annual GDP of \$ 16,000 per person, meet many of her agricultural needs (except grains), export agricultural products and maintain a high standard of living — all with very limited freshwater resources. I will focus on demand management (also termed water conservation, water saving strategies or the program for increased efficiency of water use) [1–7].

The policy of Israel to meet the growing demand for water focuses on supply and demand activities and investments, while the long range solution lies with desalination of sea water. Present activities are aimed at delaying the large investment and associated costs involved in the development of this expensive, albeit unlimited, source of water. The three main instruments are:

- Re-use of sewage effluent: Recent regulations have increased the level of sewage treatment in order to maximize its re-use potential, minimize health and environmental risks and enhance the trading instruments for the exchange of freshwater allocations with treated effluents, mainly for water conservation/irrigation.

- Water conservation and improved efficiency of water use: Policies and achievements concentrate on mixed tools including:

- (a) allocations, norms and progressive block rates for each sector; and
- (b) research, development and implementation of agronomic techniques as well as technological means of improv-

ing water use efficiency, while reducing water consumption in the domestic, commercial, industrial and irrigation sectors which includes urban parks, gardens, and agriculture.

- Sectoral water allocations: Recently, major changes in the approach to the system have been initiated, including elimination of urban allocations, imposition of sanctions if unaccounted water use rises above approved levels, and the possible introduction of water market trading with allocations on an economic basis made between members of a sector, between sectors or between Israel and her neighbors.

Israel and her Neighbors

The present population of Israel is about 5.7 million and is increasing at a rate of 2.2–2.5% per year. Best estimates for the year 2020 indicate a population of 10–13 million (see Table 1).

The present average water consumption — including the domestic, commercial, industrial ones (DCI) — is 110 m³/year/capita, taking into account past efforts that have resulted in about a 30% savings. Present industrial forecasts, coupled with projections for water consumption, converge at an estimate of 110–120 m³/y/capita by 2020. These figures assume a much higher standard of living coupled with very rigid, wide-scale implementation of water demand management policies. The level of urban water demand will, therefore, amount to 1.0–1.3·10⁹ m³/y of fresh water for the projected population.

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Water use 1989 → 2040	Population	Domestic Use		Total Industrial Use	Irrigation area	Total Irrigation Use	Irrigation Water application rate	Grand Total Water Use
	10 ⁵	10 ⁹ m ³ /a	m ³ /a	10 ⁹ m ³ /a	ha	10 ⁹ m ³ /a	m ³ /ha/a	10 ⁹ m ³ /a
Israel	5.0 → 12.8	495 → 1280	100 → 100	115 → 260	200'000 → ND	1100 → 1900	5500 → ND	1710 → 3440
West Bank	1.0 → 3.8	35 → 380	35 → 100	5 → 40	10'000 → ND	100 → 350	10'000 → ND	140 → 770
Gaza	0.7 → 2.6	20 → 260	25 → 100	-	5000 → ND	60 → 100	11'000 → ND	80 → 360
Jordan	3.6 → 16.9	170 → 1700	50 → 100	40 → 180	70'000 → ND	760 → 550	10'850 → ND	970 → 2430
Total	10.3 → 36.1	720 → 3620		160 → 480		2020 → 2900		2900 → 7000

Table 1
Water use: actual and projected (ND= not determined).

Inelastic agricultural demand for water to supply basic fresh food (e.g., dairy products, eggs, and vegetables) is estimated to be 25–30 m³ per capita; this adds an additional 0.22–0.33·10⁹ m³/y. Urban and agricultural consumption of freshwater resources will amount, therefore, to approximately 1.20–1.65·10⁹ m³/y in 2020 for Israel alone, which has a maximum supply of 1.70·10⁹ m³ of fresh water.

Re-use of treated effluent in Israel will reach 70–75% of the total DCI use which amounts to almost 100% of the total sewer flow (the entire population will be sewerred by 2020). The estimated treated effluent flow by 2020 will be 0.7–1·10⁹ m³/y.

Supply and Demand

There are a number of major policy options which could significantly change supply and demand pressures in the region. Reduction of government water subsidies affect water prices, demand and public funding for water projects. Israel's large-scale demand management policy of the 1970s led to a significant increase in the product value per unit of water or land. Industrial production per unit of water has also increased substantially in this period to over 80% (see Figs. 2–4).

Israel has already used a host of management tools, including water rate adjustments, government incentives and penalties, investment credits to increase water use efficiency, enhanced research and development, soil conservation and extension service, as well as local manufacture of high-quality technological systems, which have all promoted a decreased demand for water and enabled authorities to reduce water allocations without diminishing the net income of the

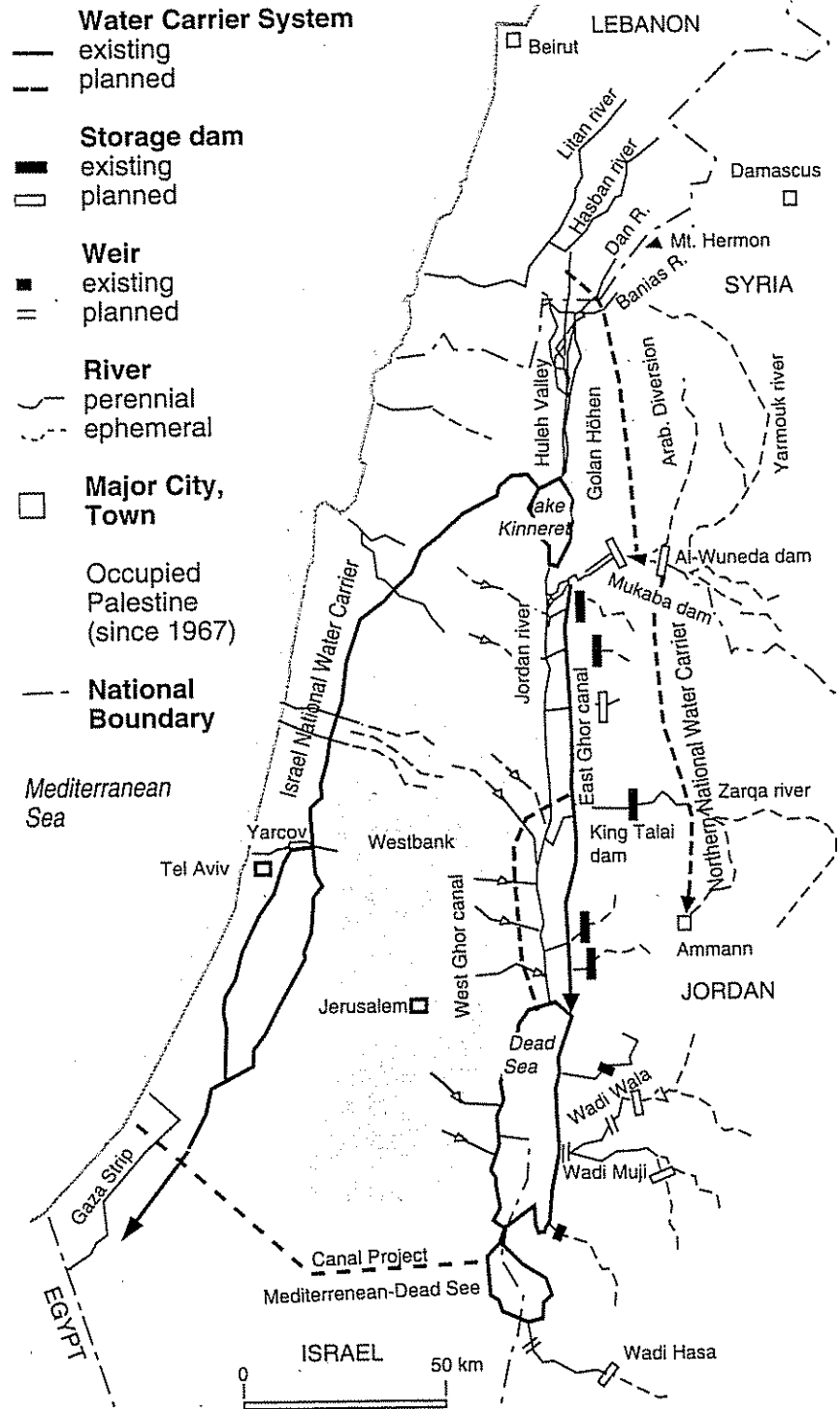


Fig. 1
Surface waters of the Jordan/Yarmouk catchments showing existing and previously planned diversions.

production sectors (see Fig. 2 for the basic parameters of Israel's strategy).

Demand Management in Agriculture and Industry

This endeavor includes continued efforts, both technological and economic, to reduce water use in the future and improve the efficiency of water use in agriculture. Incremental costs of water saved in Israel range from 0.04 to 0.05 US-\$/m³. The figures for irrigation assume increased production per unit water in real terms. They reflect some change in the basic production cycle; that is, adapting to more economical cropping patterns and changing industrial processes. The levels of direct and indirect water production through savings and improved efficiency of water use are very important as they represent a permanent reduction in demand.

Urban Water Conservation

Unaccounted-for water (UFW) causes significant water and financial losses to urban utilities and municipalities and ranges from 0.15 to 0.35 US-\$/m³, which would be better invested for additional conservation and maintenance efforts. Unaccounted-for water has been substantially reduced in Israel, but remains a serious problem in other Middle Eastern countries, where UFW rates in some cities are greater than 50% (of which leakage accounts for

estimated 50% of UFW, or up to 30 m³/y and capita).

Re-use of Human Waste Effluents

Israel has completed most of its efforts at establishing and adopting water demand management plans for existing industries, while new industries are currently installing efficient cooling systems and pre-designed "cascading" facilities. The pricing mechanism as well as effluent charges are gradually being enforced and are contributing their share.

Re-use of water effluent should be analyzed in the context of industrial and urban water conservation. When effluent charges are enforced and subsidies are removed, market forces typically produce optimum results. It is reasonable to assume that local re-use for irrigation purposes will be the most cost-effective solution, especially in areas where aquifer pollution is not expected. Drip irrigation of horticultural tree crops is preferred under these conditions when the fields surround most, if not all, the towns and cities. It is essential that the design and implementation of adequate sewage systems are given top priority when external funding becomes available to the Palestinians. Vegetable irrigation should be avoided, and high-level monitoring must be established.

Effluent re-use is a valuable method of reducing demand for fresh water

and is, therefore, used in conjunction with water conservation. Industrial effluent charges and demand management, for example, should be integrated in a common program. When effluent charges are correctly imposed and enforced, the public sector will, in many cases, not need to monitor industrial (and perhaps urban) water conservation. Minimizing effluent flows will lessen costs to industry and reduce consumers' water bills, thus internalizing the decision-making process (see Fig. 5).

Water Market: Temporary or Permanent Solution?

Water in Israel is used within a system of allocations (annual or multi-annual), while in most countries it is user rights that determine use. In many regions, a person who owns land (or cultivates it) has the right to the water flowing beside and under the plot. In other regions, various quota systems allocate the amounts of water on an annual, monthly, weekly, daily or even hourly basis. Veteran users usually have the rights to continue to use the resource; however, the efficiency of water resource allocation and use can be substantially improved through the increased use of pricing mechanisms. For example, trading water on the margin or using a system in which urban/industrial demand is met by supply from farmers could reduce inefficiency. Irrigation water in Israel

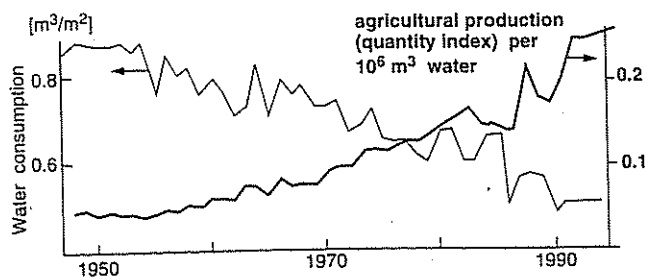


Fig. 2
The agricultural sector (Israel):
a) Water use per dunam 1948-1992.
b) Water use efficiency - returns to water.

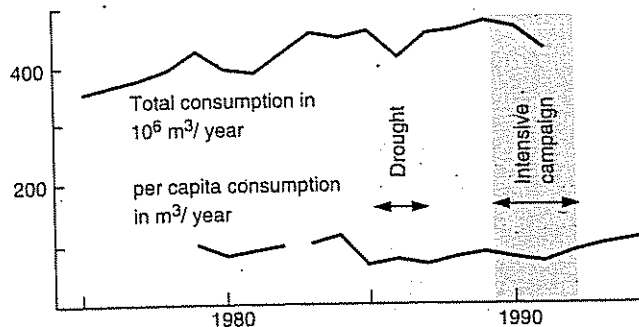


Fig. 3
Total urban per capita consumption.

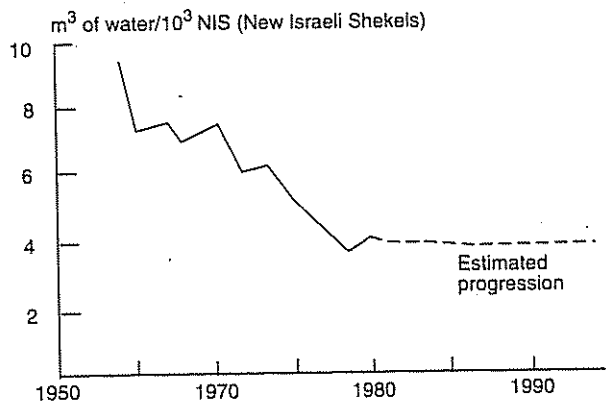


Fig. 4
Average industrial water consumption in m³ per NIS of production (at fixed prices).

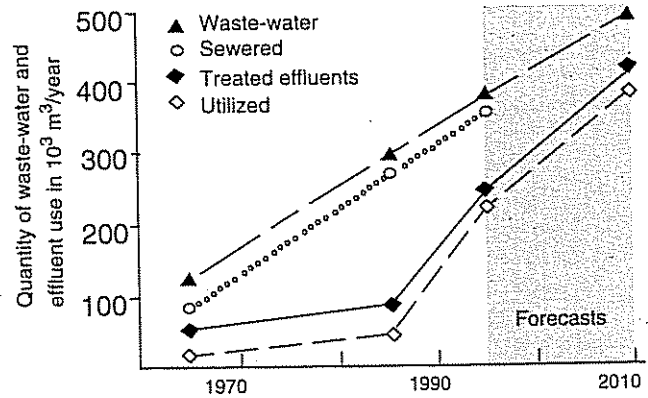


Fig. 5
Wastewater availability and re-use.

was, and continues to be, partially subsidized when supplied by the National Water Company. This administrative allocation system creates a "rent seeking" operation for the development of new resources so that higher demand could lead to over-use of underground sources. A water market where increased urban demand could be sold (indirectly) by farmers could substantially improve sector management and efficiency of use.

The water market may facilitate short- and medium-term solutions for Israel. It could also serve to improve the nation's water relations with the Palestinian Authority and Jordan. The proposal is based on classic economic principles that would help Israel, the PPA and Jordan to meet growing demands for water in the urban sector and, at the same time, encourage farmers to increase their water use efficiency. The parties would voluntarily trade water under the supervision of an agency such as the Water Commission.

Conclusions

Of approximately $0.6 \cdot 10^9 \text{ m}^3/\text{y}$ being supplied to the urban and industrial sectors in Israel, it is feasible to reduce the water demand by 15–20%. It is assumed that if the proper program is implemented, $0.080\text{--}0.120 \cdot 10^9 \text{ m}^3/\text{y}$ of water can be saved. It can delay a future seawater desalination plant (at an estimated investment cost of approximately 400 million US-\$) and will save present running costs (energy,

chemicals, etc.) of approximately $0.15\text{--}0.20 \text{ US-}\$/\text{m}^3$ plus the savings of annual costs of a desalination program.

As most of the incremental growth in water demand will be concentrated in the urban/industrial sector, a comprehensive management policy should become a major component of the regional water policy. In the year 2020, when the population west of the River Jordan will increase to over 12 million, the potential savings would amount to approximately $0.2 \cdot 10^9 \text{ m}^3/\text{y}$. If multiplied by present seawater desalination costs, it may amount to annual savings of 200 million US-\$. This huge sum of money could be used for indefinite coverage of water conservation and effluent re-use projects throughout the region.

Increasing efficiency of water use in agriculture could by itself generate substantial increases in production per unit of water (or effluent) and/or absolute savings. It is estimated that the cost per cubic meter of water saved (or its comparable value in production) will be, based on Israel's experience, $0.10\text{--}0.15 \text{ US-}\$$, which is much lower than the forecasted marginal cost of additional water resources in Israel.

In order to sustain Israel's economic demand for water (fresh plus effluent), policies must be based on major investments, aggressive public education, government incentives and penalties, implementation of a "water market" as well as appropriate changes in water rates. It calls for an elaborate social and

political campaign. Cost per cubic meter, to treat and transfer water and the investments needed to facilitate exchange of freshwater sources for secondary or tertiary treated effluent, could rise to close to seawater desalination costs. In any event, Israel may be forced to desalinate seawater before the year 2020 unless large-scale regional transfers are achieved. Desalination of brackish water has already been integrated into the system. In the Central Negev, desalination of an existing brackish aquifer may be a major source of water, possibly as soon as 2000–2010. All of these programs cannot be implemented unless large-scale investments are made, including the use of international funding and private-sector involvement.

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Tove A. Larsen and Willi Gujer

Sustainable Urban Water Management – Technological Implications



Tove A. Larsen and Willi Gujer

Sustainable development creates new demands on urban water management, not only on material comfort and protection of surface and ground water, but also on the efficient use of resources. Recycling nutrients, new concepts of "slim" construction, new partnerships and a broader understanding of technology will significantly determine the development of urban water management in the next century.

Urban water management permeates our urban society. Many things are taken for granted in daily life – flowing water from the tap, toilets and dry cellars. Technological developments of more than a century have led to this everyday luxury, which has created a largely invisible but expensive infrastructure in cities in the form of a water supply agency, sewers, drainage, household connections and various installations.

Sustainable development means providing this service in a form that is also ecologically, socially and financially viable into the future. In doing so, we should neither overuse resources, overstrain the urban society nor stretch the financial limits.

Our approach in the following analysis is the system depicted in Fig. 1. In this example, the households are examined. All other anthropogenic

activities, however, also fit into such a framework. In order to assess urban water management, one has to realize that water and matter are unequivocally connected. The possibility and effort of reintegrating the water back into the cycle after use are determined by the substances and pathogenic organisms in the water. We have to differentiate between naturally occurring substances from agriculture and the many synthetic substances entering the urban water cycle.

The Resources of Urban Water Management

Resources fuel our activities: ores, energy, democracy, money, etc. and make our everyday life possible. Nature itself is also a resource; if we destroy the environment, we destroy the basis of our own lives, albeit via complex and sometimes very delayed connections. Analyzing the utilization of resources in urban water management, we obtain the four types of resources depicted in Fig. 2 [1].

Sustainable development necessitates taking into account all four resource sectors simultaneously. What does this mean concretely? Will urban water management become even more expensive because of the new conditions? Do we have to accept losses in the field of water pollution control in order to conserve secondary resources?

We have learned from industry that this does not have to be true: e.g., telephones can currently be produced

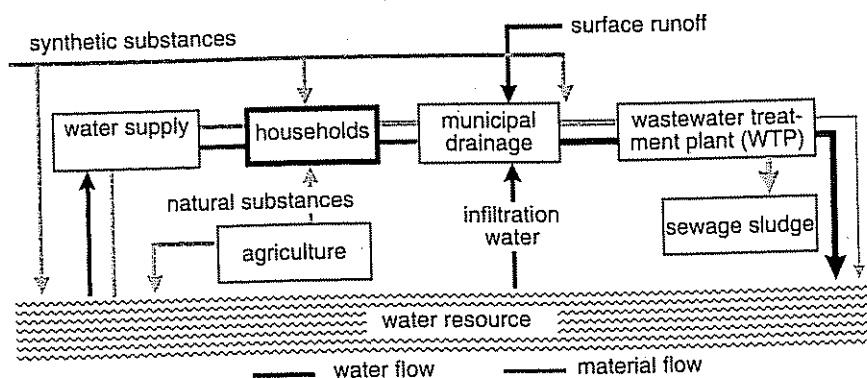


Fig. 1
Flows of water and substances in urban water management. Both are strongly connected and cannot be regarded separately.

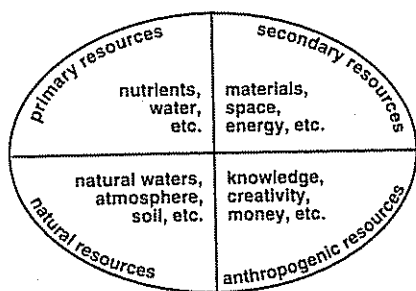


Fig. 2
Resources in urban water management. The primary resources are being managed in urban water management, secondary resources are being used for carrying out the former. Urban water management of today is directed towards optimizing the natural resources and the anthropogenic resource "money".

cheaper because they are already designed to be recycled. We can hope for similar developments from a new approach to urban water management.

In the following sections of this paper important issues will be discussed, each concentrating on one of the four resources.

Primary Resources: Nutrients

Should nutrients (nitrogen and phosphorus) be removed in the sewage treatment plants or should they be brought back into agriculture as part of the natural cycle? This question is being asked ever more often.

Phosphorus as a limited resource is of primary importance. It is not clear how long the reserves will last (100–1000 years, depending on the type of source and the effort involved in obtaining it). Unquestionable remain the inherent dangers from pollution with heavy metals in the use of phosphate fertilizers. The high price of phosphate leads to its disuse in the regions of the world in which it is urgently needed – a blatant example of global injustice [2].

The current trend in ecologically oriented agriculture is easily understood, where the use of synthetic fertilizer is prohibited. This type of agriculture will become difficult without eventually reintroducing nutrients from urban areas.

But how can the nutrients be replaced which were lost by urban water management? What is the fate of the

nutrients in the urban areas? Quantitatively seen, the most significant nutrients from households accumulate mainly in the form of urine: i.e., 65% of the phosphorus, 85% of the nitrogen and potassium, 95% of the total sulfur. These nutrients are, therefore, only available in concentrated form if the urine is not mixed with the other wastewater. Strict separation would also make the expensive removal of nutrients in the sewage treatment plants superfluous [3].

The technical implementation of the separate drainage of urine is currently being investigated in a dissertation. In this new concept, the urine which accumulates in houses flows to the sewage treatment plants at night (Fig. 3). First simulations and experiments suggest that the time of low flow in the sewers is sufficient for this purpose – at least in small drainage areas. Some yet unsolved problems concern the stability of the urine solution such as undesirable shifts in pH leading to ammonia problems (e.g., corrosion) and precipitation.

Secondary Resources: Energy and Construction Materials

The amount of secondary resources utilized by urban water management today is not known – it has never been of any interest. First estimates for Switzerland are shown in Table 1.

Can this expenditure, measured by its achievement, be justified? Globally set goals prescribe reducing the use of resources in our part of the world by a factor of 3–10. The trend is towards massive savings. Such goals are only possible if the economy becomes less

electric power	1–2% (without warm water)
concrete	5–10%
gravel	10–20%

Table 1
Estimates for the relative amount of resources consumed by urban water management compared to the total consumption of the resources in Switzerland.

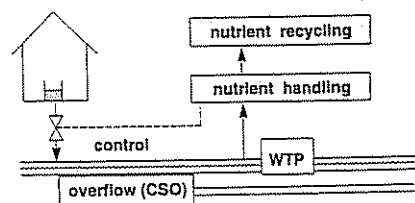


Fig. 3
A system for the separate transport of urine. The less dilute urine can be directed to the sewage treatment plant during the night when the sewers contain almost no wastewater. It is then treated in a separate process for further use.

materialized as a whole. This means that it has to subsist on much less material and energy in future.

The pace of introducing energy saving measures in sewage treatment plants is being increased. As part of the RAVEL program, it has been demonstrated that the economic potential of saving energy amounts to about 60% in most of the sewage treatment plants [4]. The assessment of construction materials used in urban water management is more difficult because it needs to also account for the environmental degradation caused by the acquisition, processing, use and disposal of these materials. Materials as different as cement, steel, copper, etc. first have to be compared adequately in order to find viable alternatives. Many institutions have begun work in this area, including the EAWAG, using the method of *life cycle assessments*.

Natural Resources: Measures Applied at the Source

Much has been invested in water pollution control in Switzerland over the past 20 years. The problems were acute and local at the beginning (massive development of algae, bacteria and fungi, lack of oxygen, etc.), whereas today the more subtle problems in the form of diffusely occurring contamination with substances both foreign and natural (e.g., nitrates) are of primary importance. In contrast to the previous "big" issues in water pollution control, today we are dealing with a multitude

of substances and sources. Copper, for example, has recently been recognized as a potentially hazardous construction material [5]. Studies carried out at the EAWAG [6] have also identified zinc and other metals as being potentially hazardous. In our future activities, it will be important not to focus on a single material but rather to take an integrated approach to the problem. Copper can be replaced by zinc in many cases but, when the latter also turns out to be hazardous, it has to be replaced by yet another material.

An analysis of the probable diffuse sources of contamination in households suggests that measures for the protection of surfaces are of prime importance, i.e., water mains, roofs, façades, etc. On the other hand, we have to deal with an enormous amount of chemicals in households; there is a large demand for such substances (e.g., we want to wash our modern textiles in a careful yet efficient way). The available alternatives can only be judged by the experts. Who does not have trouble choosing the right detergent according to ecological criteria? The example of the household demonstrates how the traditional strategies in environmental protection are no longer adequate. New alliances must be created whose goal is to search for sustainable solutions rather than testing every new material for its potentially hazardous qualities.

Anthropogenic Resources: Least Cost Planning

Rising consumer costs for water and wastewater treatment and the maintenance of expensive but invisible infrastructure are gaining in importance today.

Examples from energy management and waste disposal can be used for illustrating both the possibilities and the risks inherent in urban water management. *Least cost planning* is being applied in energy management; that is, instead of selling electricity, the final product (e.g., light) is being offered in various areas. In this way,

	recycling of nutrients	life cycle assessment	measures applied at the source	least cost planning (LCP)
primary resources		saving water and recycling of nutrients: not at any price	often saves primary resources (water, metals, etc.)	reduced consumption of water can be a result of LCP
secondary resources	results in smaller water treatment plants; new processes needed for recycling of nutrients		often reduces the amount of investment needed	slim construction can reduce need for investment
natural resources	relieves waters during rainy weather	no jeopardizing of water protection efforts!		direct utilization of self purification in streams
anthropogenic resources	supports ecologically-oriented agriculture	technological leap possible for industry	reduces surprises and new potentially hazardous sites	

Table 2

A matrix for a resource-oriented integrated research strategy. Each column refers to one of the themes, while each line pertains to one of the four types of resources discussed in the article.

an incentive for avoiding an expensive expansion of the infrastructure is created by offering energy saving light bulbs, a strategy which in the end becomes cheaper for all involved. A tax on garbage bags has led to a reduction in the amount of garbage generated. The resulting poor degree of utilization of existing infrastructure, however, has led to higher specific consumer costs.

How can urban water management profit from such experiences? Analogous to the example from energy management, measures for saving water could be promoted instead of finding expensive new water resources. There are as yet few incentives today for such approaches to these problems. The picture is the same in sewage treatment plants. It is politically easier to justify construction costs than to receive financial support for creative efforts to analyze and optimize existing installations.

Technological Implications

What technological implications are involved in sustainable urban water management? We have briefly presented several new issues, each of which concentrates on different resources. In order to emphasize the comprehensive approach, we depicted these issues in Table 2 together with the four types of resources in the form of a matrix. The gray diagonal boxes represent the "basic projects" described in greater

depth above. The rest of the boxes are filled with other examples. The reader is invited to participate in thinking further in this way.

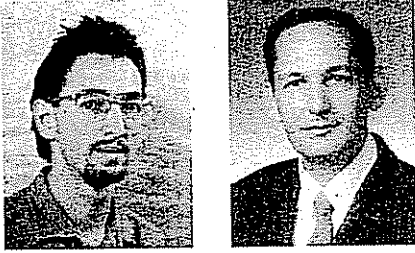
The typical tasks of civil engineers, such as optimizing and extending existing sewage treatment plants or the development of resource saving construction processes, have been combined with new tasks such as least cost planning or the development of new strategies for avoiding diffuse contaminations. A new understanding of technology is needed; we must define "technology" as a comprehensive process in problem solving, not simply as the development of apparatus and processes. Hardware alone is no longer sufficient for doing justice to a less materialized economy.

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Paul H. Brunner* and Christoph Lampert*

The Flow of Nutrients in the Danube River Basin

Sources and Final Sinks



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The increasing eutrophication of the Danube delta and the Black Sea can only be stopped by drastically reducing nutrient emissions. In order to effectively control nutrient inputs to surface and ground water, sources, pathways and sinks of the nutrients must be known. In collaboration with eight Eastern European countries, the nutrient flows and stocks in the Danube catchment area have been assessed using a standardized methodology; measures for reducing the input of nutrients into surface and groundwater have been developed.

The Danube, Lifeline for 70 Million People

After the Volga, the Danube is the largest river in Europe. Its catchment area extends from the Alps to the Black Sea. It encompasses 17 countries and includes about one tenth of the area of Europe. Approximately 70% of the water reaching the Black Sea originates from the Danube. The river serves as a source of drinking and irrigation water and is used as a fishery, for tourism and shipping and to produce hydroelectric power. It is also a "conveyor belt" for geogenic and anthropogenic substances.

Even though the Danube of old songs rarely shows itself in its classical blue robe, it has a high recreational value. Examples of the impressive beauty of the river are the fluvial landscapes of the "Donauauen" near Vienna and the Danube delta on the Black Sea with its extraordinary diversity of plant and animal species, an area protected by the United Nations.

By the last century, the bed of the

Danube had been massively influenced in order to provide protection from floods, for shipping and for bridge construction; its flow behavior and sedimentation dynamics have changed drastically. Today, geologic materials are no longer deposited in the alluvial plains of the River Danube. The material which does not sediment in the dammed sections of the river bed is directly transported to the Danube delta and the Black Sea. The majority of the riparian countries of the Danube Basin have only recently transformed to higher productivity economies and introduced higher environmental standards.

The contamination of the Danube and its tributaries with nutrients and pollutants is high. In order to reach the objectives of water protection (which are not congruent for all riparian countries), anthropogenic inputs must be systematically reduced over the next few decades. This is especially true for nitrogen and phosphorus, reaching the Danube by way of agricultural runoff, sewage treatment plants and as direct inputs from industry and private households in large amounts.

A European Project to Protect Water Quality in the Danube Basin

In order to develop the basis for an efficient strategy to protect the surface and ground waters of the Danube Basin, the European Community com-

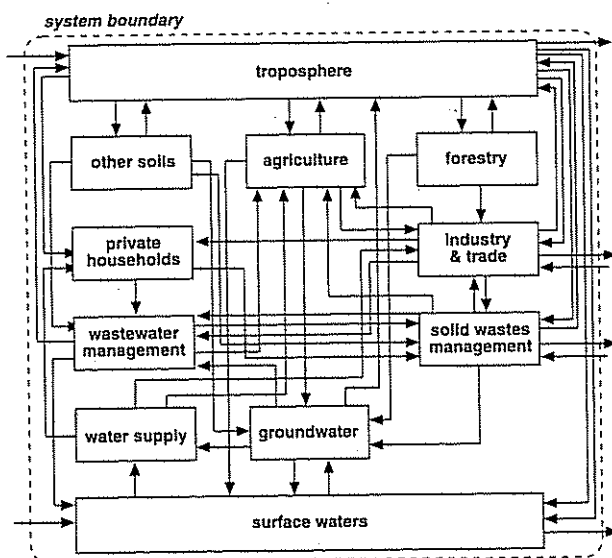


Fig. 1
Definition of the system investigated: The catchment area of the Danube with the most important processes and material flows investigated in the project. Processes include transport, transformation and storage. Annual inputs, outputs and changes in storage were determined for every process. The balances were determined for the two periods of 1988/89 and 1992.

Pathways [in %]	Sources [in %]					1992 in kt
	Agriculture	Households	Industry	Others	Total	Total N
Nitrogen						
Erosion/runoff	17	0	0	4	31	173
Direct discharges	12	4	6	2	24	198
Base flow	17	4	0	13	35	289
STP*	6	10	5	0	20	165
Total	51	19	10	19	100	825
Phosphorus						
Erosion/runoff	28	0	0	3	31	33
Direct discharges	18	6	6	3	33	35
Base flow	2	2	0	2	6	6
STP*	9	14	7	0	30	31
Total	57	22	13	8	100	105

*STP = Sewage treatment plant

Table 1

The most important sources and conveyor belts for nutrients in the catchment area of the Danube for 1992 in % of the total flows of 825 kst/a of N and 105 kst/a of P. The nutrient input has dropped by 15% since 1988/89.

missioned a consortium consisting of the Universities of Technology in both Vienna and Budapest to carry out a study within the framework of the PHARE-program ("Poland and Hungary: Assistance to the Reconstruction of the Economy"). The investigation was launched to develop scenarios for nutrient management with the goal of improving water quality in the Danube Basin [1]. The present paper will mainly present the nutrient balances. Investigations of water quality and wastewater management, led by H. Kroiss (TU Vienna) and L. Somlyódy (TU Budapest), are described in the final report of the project.

The following objectives and tasks were investigated by research teams from Germany, the Czech Republic, Slovakia, Hungary, Austria, Slovenia, Moldavia, Bulgaria, Rumania and Ukraine, all bordering countries:

1. Nutrient balances: materials accounting for nutrients and, in part, for total organic carbon (TOC), for all participating countries and for some selected study regions.
2. Problem identification: assessing the main problems caused by nutrient flows in the Danube Basin today and in the future.
3. Scenarios for solution: investigating strategies for solving the expected problems efficiently. Measures for managing wastewater should receive most emphasis.

The investigations covered the two periods 1988/1989 and 1992, because

the economic situation in the countries of the former Eastern Bloc changed significantly after 1989/1990. In addition, the turnover of materials in agriculture and industry decreased markedly in some areas during this period. Scenarios for nutrient balances in both agriculture and industry as well as in wastewater management were elaborated for the year 2005. The results of the project show that perceptible differences exist before and after the economic changes.

Determining Nutrient Balances: New Methods and Missing Data

As a first step, the partners adapted a standardized method for determining nutrient balances [2]. During a workshop to introduce the methodology, the state-of-the-art and the European goals of water quality and wastewater management were discussed. The partners then applied the uniform balancing methods to their respective countries and to selected case study areas. The more detailed results of the case studies helped to improve the knowledge and data from the national balances. In the next step, the current state of wastewater and water quality management in each country was investigated and related to nutrient flows. The various national and European goals for water protection were compared to the current water quality situation. During a third step, the team developed scenarios for wastewater

management in an effort to identify efficient strategies to reach the desired water quality objectives.

It turned out that the goals of the project had been set very high. There were difficulties in even *establishing nutrient balances*. In order to be able to compare the results from the various countries, a common standardized method of balancing was a prerequisite. This meant that every team had to define and investigate the same system, consisting of identical temporal and spatial system boundaries and the same processes and flows of materials (Fig. 1).

As this holistic approach involving a defined system was both new and rigid for the partners (e.g., the mass balance approach allows the crosschecking of data for each process by " $\Sigma \text{input} = \Sigma \text{output} + \text{change of stock}$ "), a relatively large effort was needed to accomplish this goal. In addition, still unresolved methodological problems appeared in the course of determining the balances (e.g., how to determine the load of nutrients eroded and/or leached from land used for agriculture and forestry, how to estimate the intermediate or final deposition of nutrients along the pathway from erosion to the surface water, etc.).

A further difficulty appeared in the *acquisition of data* for establishing nutrient balances and for water and wastewater management. Whereas in the centrally planned economies, a large amount of data was gathered from all economic sectors (agriculture, forestry, industry, the local economy including water and wastewater management), less information is available since the transformation to a market economy. One reason for this is that the centralized structures have been replaced by new institutions collecting less data. Another reason is that the value of data has been acknowledged and, therefore, information has become expensive to obtain. For these reasons, it was difficult to obtain comprehensive data in several of the countries on nutrient flows and emissions from major industries.

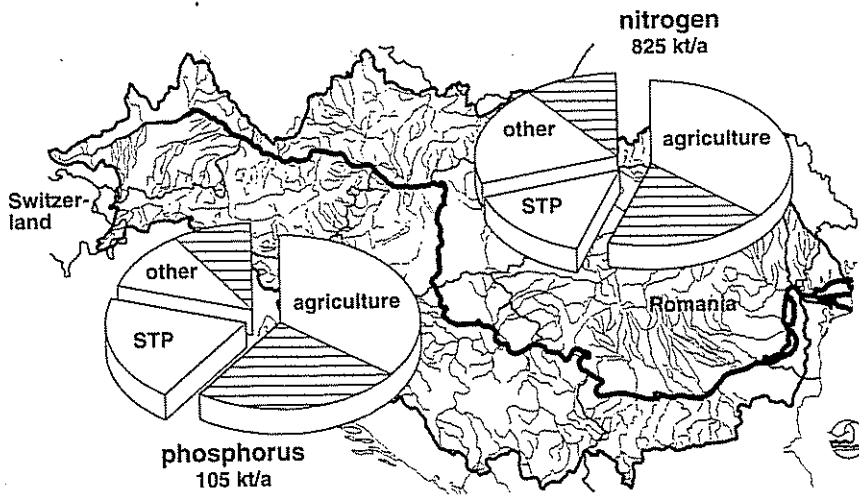


Fig. 2
Sources of nutrients in the catchment area of the Danube in 1992.
(STP = sewage treatment plant; other = diffuse inputs from forestry (white), and direct inflow from private households and industry (hatched), agriculture: the hatched areas represent direct and indirect inputs (i.e., via treatment plants) of animal waste products, the white areas represent erosion and leaching of nutrients).

Agriculture: the Key to Efficient Nutrient Management in the Danube Basin

The results obtained by the various teams allowed us to draw a common picture of the basin-wide nutrient flows and stocks. These results served to establish various scenarios for future water protection measures. To date, the project is in its final phase; the results will be published by PHARE in the fall of 1997 [1]. The results on nutrient balances are summarized in Table 1.

Agriculture is the main source of nutrient input. Erosion is the main pathway to surface waters for both P and N. The direct inputs of liquid manure from agriculture are high (about 12% of the N load and about 20% of the total P load). The second largest source of nutrients is private households (about 20% of the total N and P load). The fraction originating from industry amounts to approximately 10% each for N and P.

Regarding the pathways of the nutrient inputs, the main nitrogen load (35%) originates from the exfiltration of ground water into surface waters. Erosion, direct input and the outflows of municipal sewage treatment plants each contribute 20–25% of the total load. Almost half of the nutrient input originates from Romania, while Germany, Austria and Hungary contribute

about one-third of the nutrient load to surface waters of the Danube's catchment area.

The results suggest that nutrient input into the Danube dropped by about 15% between 1988/89 and 1992 for nitrogen as well as for phosphorus. Retention (sedimentation, denitrification) in the surface waters of the catchment area amounted in both years to around 20% of the total load for N; for P, about 35% of the total load in 1988/89 and 50% in 1992 were retained (Fig. 2).

Material Flow Analysis – an Appropriate Instrument for Environmental Monitoring

An important result of this project is the dissemination of the technique of material flow analysis (MFA) among the partners. This instrument permits early recognition of future loads and/or depletions of nutrients. It serves as an important base on which to set priorities for nutrient management and water quality as well as for the general conservation of resources environmental protection. Material flow analysis is especially effective in helping to set priorities in countries with limited means but with a large a number of problems. To remain in contact with the project partners beyond the scope of this study could ensure future appli-

cation of MFA for strategic decisions in environmental protection.

A further result of this project is that eight countries came together to share their nutrient balances and strategies in water protection, showing great interest and understanding for one another's country-specific efforts in protecting their surface and ground waters. It is obvious that the River Danube is an important pathway for disposing of the wastes of people living upstream, including their economies. The future question is: How will the increasing population, the growing living standard as well as the increasing per capita turnover in the Eastern European countries affect water quality in the Danube River Basin? Crucial for the turn of events will be the consumption behavior, the type of agriculture used and whether the emission standards issued for industry, households and urban wastewater can be met in the future.

A Personal Post Scriptum

This project is not only of scientific value (which was primarily born at the EAWAG); it is undeniably interesting because of its approach and because of the collaboration with eight countries in Eastern Europe. It was a new experience to personally ensure that the research funds reached their destination – to literally hand out money to some partners. It was unusual and unforgettable that it can take as much as 18 hours to meet a European partner by the fastest route. Three days of a workshop on a research vessel of the Romanian partner in the middle of the Danube delta, the final sink of so many nutrients, lets one physically experience the pathway of wastes produced by the upstream population!

- [1] PHARE (1997): Nutrient Balances for Danube Countries; EU/AR/102A/91. The final report of this project may be ordered from the Danube Programme Coordination Unit (PCU), PHARE Commission in Vienna.
[2] Baccini P. and Brunner P.H. (1991) *Metabolism of the Anthroposphere*, Springer Verlag, New York und Heidelberg.

The Ozonation of Drinking Water

Oxidation of Trace Compounds



Urs von Gunten

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The utilization of lake water for drinking water requires multistage treatment. According to the new food law and the emphasis on good treatment practices, public water works are expected to assess the various treatment stages in order to estimate their effectiveness in the event of contamination. By investigating the ozonation stage of water treatment, we determined to what degree its oxidation efficiency may be estimated using conservative and reactive tracers in the ozonation reactor.

Introduction

Due to comprehensively implemented water protection laws in Switzerland, the quality of natural water is so good in some cases that a large amount of drinking water can be distributed either without any purification (38%) or after a one-stage treatment (33%). These exceptionally clean water sources are principally ground water and spring water [1]. In contrast to these low level treatment systems, sophisticated multistage purification processes also exist in Switzerland, mostly in large urban areas where drinking water is taken from lakes (ca. 20%) [1]. Such lakes, which are principally open reservoirs, have a high risk of contamination both from sewage and from chemical contamination.

An accident involving phenol in Lake Zurich in 1967 illustrates how sensitive a lakewater supply is to such contamination. Chlorination of the phenols that entered one of the waterworks for the city of Zurich resulted in the formation of chlorophenols which strongly affected its taste and odor; the water was not potable for

some 80,000 inhabitants [2]. As a consequence of this accident, the lakewater works of Zurich and other communities were expanded to include additional treatment with ozone.

Water Purification with Ozone

Criteria for good drinking water (no turbidity or color, good in taste and smell, absolutely hygienic, low content of substances according regulations in the Swiss Ordinance for the content of foreign and other constituents and according to the reference book on foodstuffs, the "Lebensmittelbuch" (Chapter 27A on "Drinking Water") can also be achieved for highly polluted waters (e.g., surface waters, karst springs) using a multistage treatment scheme like that shown in Fig. 1. The raw water (RW) is first subjected to preliminary ozonation in order to oxidize certain constituents. In a second treatment stage, the physical elimination of particles involves flocculation, sedimentation and filtration. The intermediate ozonation stage, operated under clearly defined conditions, disinfects and oxidizes the water once

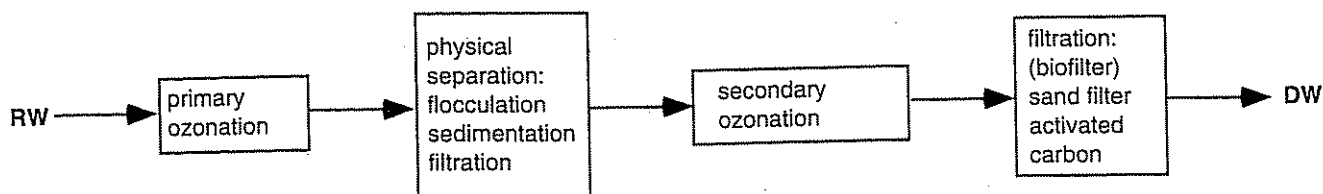
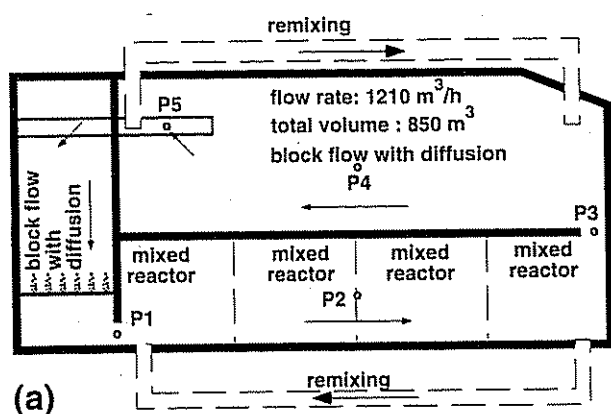
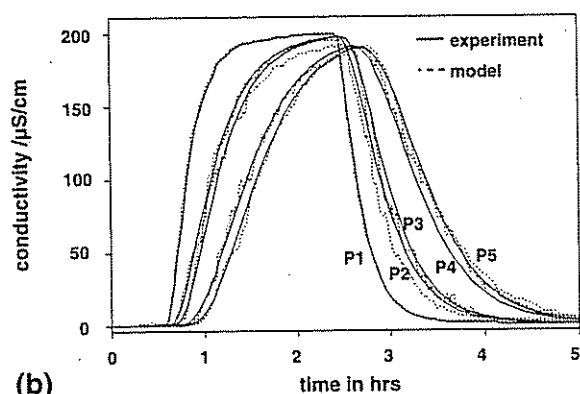


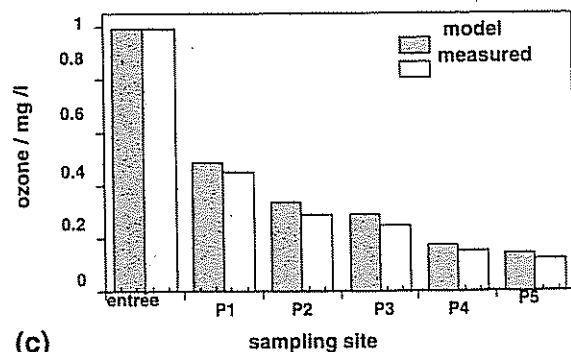
Fig. 1 Chain of process reactions for the purification of surface waters (also some karst water). RW: raw water, DW: drinking water.



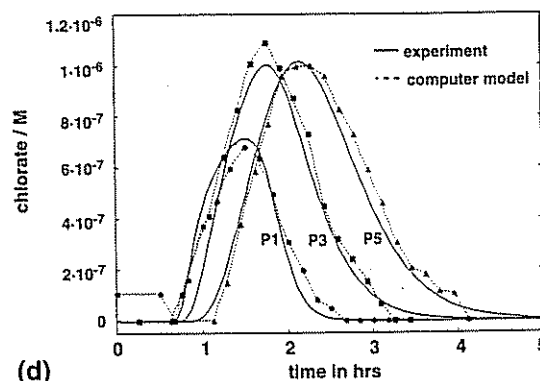
(a)



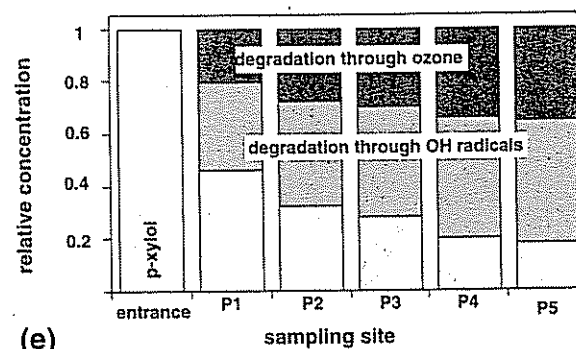
(b)



(c)



(d)



(e)

Fig. 2
 a) Ozonation reactor in the lake waterworks Leng. Subdivision of the reactor as it has been used for hydraulic modeling.
 b) Breakthrough curves for a conservative tracer (NaCl): experiment and model for the sampling sites P1–P5
 c) Measured and modeled ozone profile in the reactor
 d) Chlorate as reactive tracer: experiment and model
 e) Estimating the oxidation of *p*-xylene by ozone and OH-radicals.

more. After that, activated carbon filtration facilitates the adsorption of hydrophobic substances and degrades any residual ozone. Activated carbon filtration also enhances the microbial degradation of organic reaction products (e.g., acids, aldehydes, ketones) which may form during ozone treatment of natural organic matter (NOM). In this way, some of the nutrients that enhance bacterial growth in the distribution system are eliminated in the waterworks. This elimination may be even better with subsequent slow sand filtration. Before distribution, a final disinfection agent (chlorine and/or chlorine dioxide) is usually added to the drinking water in order to guarantee its hygienic quality until it reaches the consumer's tap.

Apart from the desired treatment effects, a number of byproducts are also formed during the ozonation of

drinking water [3]. Bromate, resulting from the ozonation of waters containing bromide [4], is considered to be the most significant. Because of its potentially carcinogenic effects, new regulatory limits on bromate were imposed in the early 1990s [5]. The maximum concentrations of bromate allowed are comparable in importance to those set for trihalomethanes which form during chlorination. In Switzerland, however, bromate plays a subordinate role since bromide levels in natural waters are usually low.

Characterization of an Ozonation Reactor

In many water treatment systems in Europe and the USA, the application of ozone must be optimized to achieve both disinfection and oxidation with minimization of byproduct formation;

however, this objective can only be met if the hydraulic conditions and concentrations of oxidation products in the ozone reactor are known.

In the ozonation reactors of many waterworks, neither the hydraulics nor the oxidant concentrations are well known. The new food law of 1 July 1995 mandates good treatment practices; that is, internal control has high priority [6]. To meet this goal, the operators of waterworks must assess the purification stages to be able to estimate the effectiveness of the processes in critical situations. In this article, such an assessment is demonstrated using the example of how an ozonation stage can be characterized.

Based on experiments using a conservative tracer, the hydraulics of the reactor can be described. Using computer models (AQUASIM [7]), the hydraulics can be linked to chemical

processes. Reactive tracers aid in validation of the model in two stages: (1) the degradation of ozone, and (2) the reactions of ozone with hypochlorite.

Tracer Test

Five sampling sites (P1–P5) were installed in the pre-ozonation reactor of one of Zurich's lakewater works (Fig. 2a). In the first chamber, ozone is added to the water; two chambers follow in which the disinfection and the oxidation processes take place. Although originally conceived as a plug flow reactor, a strongly non-ideal flow (dead zones, short circuiting) takes place in the reactor. Strong mixing is obvious when comparing sampling sites 1, 2 and 3. Although these sites are situated at equal distance from one another, breakthrough curves for the tracer at points 2 and 3 are almost identical. The same behavior can be observed in sampling sites 4 and 5. The good agreement between the tracer experiment and the computer model (shown in Fig. 2b) was achieved by dividing the reactor into subunits and adding sufficient recirculation to simulate back mixing as shown in Fig. 2a.

Ozone Decay

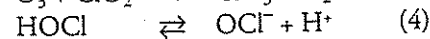
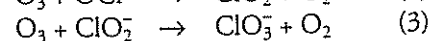
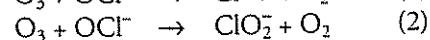
Ozone has a relatively short half-life in water and decays to secondary oxidation products, mostly OH radicals. The kinetics of ozone decomposition in lake water can be measured in the laboratory and its rate constant used for modeling. A comparison of the ozone concentrations measured in the reactor with those simulated by modeling ozone decomposition and the hydraulics are in good agreement (Fig. 2c).

Reactions of Ozone with Hypochlorite

In order to prevent the raw water intake pipe located in the lake from being colonized by zebra mussels, it is cleaned once a month by shock chlorination. To accomplish this, the water

pipe is filled with a solution of 10 mg Cl₂/l. After 8 h, the pumps are turned on, and the chlorine solution with approximately 5 mg Cl₂/l is pumped through the preliminary ozonation reactor. This routine cleaning operation can be used for testing the model with a reactive tracer.

The following reactions take place between ozone (O₃) and hypochlorite (OCl⁻); their kinetics are already well known [8]:



Ozone reacts with hypochlorite but not with hypochlorous acid (HOCl); therefore, the protonation equilibrium (4) has to be taken into consideration. As the amount of hypochlorite being oxidized to chlorate (ClO₃⁻) is known from the above reaction sequence, the model can be validated using the formation of chlorate.

In Fig. 2d, the amount of chlorate formed is compared to that calculated by the model in the shock chlorination experiment. The agreement between both sets of data suggests that certain reaction kinetics, which were determined in the laboratory, can be transferred directly to a large installation, taking the hydraulics into account.

Oxidation of Trace Organic Compounds

As already mentioned, ozone decays in water forming OH radicals, which usually readily react with most dissolved substances in water. The most important sinks for OH radicals in drinking water are carbonate/bicarbonate and naturally occurring organic material (NOM). As these substances occur in relatively high concentrations, the resulting concentration of OH radicals is so low that they cannot be measured using direct methods (e.g., electrodes, spectrophotometry, etc.). For this reason, the concentration of OH radicals ([[•]OH]) must be measured indirectly (e.g., via the decrease of a trace organic compound). Such laboratory measure-

ments result in the ratio [[•]OH]/[O₃], which remains constant for the water during a large part of its ozonation [9]. In this way, the concentration of OH radicals can be determined using routine measurements of ozone concentrations during the treatment of drinking water. The decrease in trace organic compounds may be calculated from these results (e.g., pesticides, chlorinated hydrocarbons, methylbenzene, etc.). A computer simulation for the decrease in *p*-xylene in water is shown in Fig. 2e; 35% is degraded by ozone directly and 47% by OH radicals.

This study demonstrates that it is possible to comprehensively describe the oxidation (including the ratio [[•]OH]/[O₃]) taking place in an ozonation reactor by determining the hydraulics and by measuring ozone decay. This allows waterworks to predict the rate at which a given trace compound of concern is degraded during a specified treatment stage and to take specific steps in case of massive contamination.

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Achim Albrecht, Gerrit Goudsmit, Jin Qian, Laura Sigg, HanBin Xue, Daniel Kobler, Alfred Lück and Yvo Weidmann

The Transport of Cobalt in Lake Biel

In the Footsteps of the Aare River



Achim Albrecht, Gerrit Goudsmit, Jin Qian, Laura Sigg, HanBin Xue, Daniel Kobler, Alfred Lück and Yvo Weidmann

Interest in the behavior of metals in natural systems has grown due to new knowledge of metal mobility during transport of metals from waste disposal sites. Using the element cobalt, adsorption, sedimentation and transport were observed and quantified in Lake Biel. The presence of particles and speciation of dissolved metals were found to play an important role in these processes.

The behavior of metals in aquatic systems can be roughly divided into two categories (Fig. 1). If the metal remains dissolved, its behavior is the same as that of its medium of transport, water (in fig. 1: {1}). If the metals react with particles, colloids or dissolved organic substances, their fate is coupled to that of their carrier. Apart from being transported further, sedimentation or direct sorption to immobile substances can also occur (2). Every reaction can take place in both directions and depends on local chemical conditions. This is true for processes occurring near the surface as well as for those below ground, the former characterized by a simpler hydrology and better accessibility.

The investigated area of the Aare River and Lake Biel (Fig. 2) is unique in that radioactive ^{60}Co originates in known amounts exclusively from the nuclear power plant Mühleberg, although ^{60}Co levels are well below regulatory limits. As the lake is strongly influenced by the Aare River, balances for water, particles and metals can be easily calculated.

Particle Composition

The grain size of particles plays a key role in the adsorption of metals because smaller particles can bind more metals due to their larger surface/mass ratio. A comparison of the particle size distribution in samples collected in sediment traps in the deepest part of the NE basin of Lake Biel (Site B in Fig. 2) and in the delta of the Aare River (Site A) in July of 1996 shows clear differences between the two sites (Table 1; Fig. 3). The median particle size from the delta is $>25\ \mu\text{m}$, while particles from the deepest lake site are less than $15\ \mu\text{m}$ in size.

The mineralogical composition of the particles is also important (Table 1). Clay minerals sorb metal ions much more efficiently than tectosilicates (quartz or feldspar) or carbonates (calcite) due to their layered silicate structure. In addition, the quantitative presence of particles from the Aare at a sample site can be estimated from the fraction of silicate minerals (clays, quartz and feldspar) in the sample, as these are exclusively erosion products

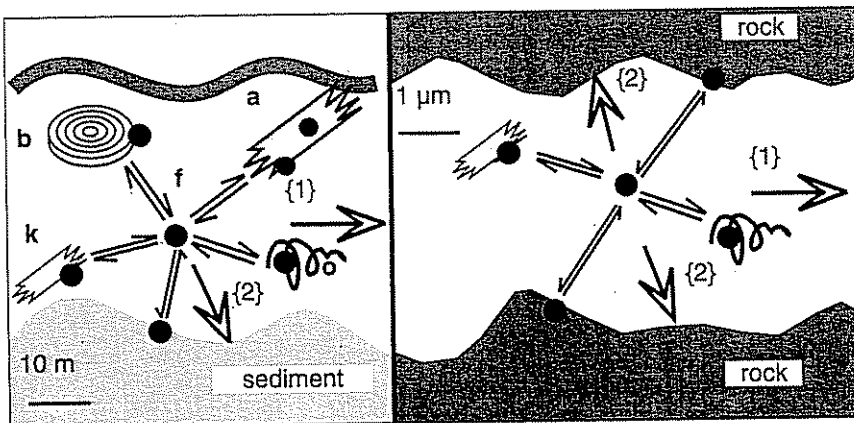


Fig. 1 Schematic illustration of the behavior of metals (dark circles) in lakes and rivers (left) and below ground (right). In both systems, the metals are either transported further (1) or are retained by sediments/rocks (2) to which they become bound. Abbreviations: f = free metal, b = biological, a = inorganic particle, k = colloid, o = dissolved organic substance.

from the catchment area and do not come from the lake. This is not the case for carbonates. For example, the relative amounts of quartz and feldspar decrease from 30% to 10% with increasing distance from the Aare delta.

The third key role is played by particles of biological origin, known to be efficient adsorbents of metals. Information on the relative amounts of organic matter in the samples can be obtained from the amount of nitrogen bound to particles (Table 1).

A fourth role is played by manganese and iron hydroxides. As these are very often found as coatings on other particles and cannot easily be analyzed on their own, we shall exclude discussing them for the moment. The decrease in particle size, the increase in the organic fraction and the decrease in the quartz and feldspar proportions, all reflect the changing particle influence of the Aare (Table 1).

⁶⁰Co Activity and Balance in Lake Biel

Characterization of particles and ⁶⁰Co activity measured in the sediments helps to establish a cobalt balance for the lake. In order to convert the measured activities [Bq/kg; Fig. 4] into flux rates [Bq m⁻² day⁻¹], a relationship has to be found between the sample mass and the deposition period. The latter can be determined for a sediment core using ¹³⁷Cs dating (Fig. 4). The maximum levels in ¹³⁷Cs activity are related to the increased deposition as a

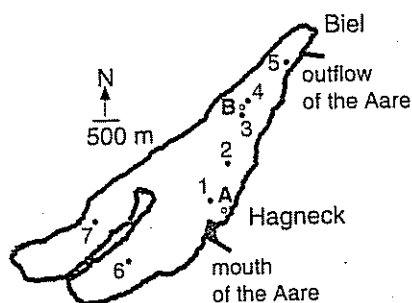


Fig. 2
Map of Lake Biel with locations of the sediment cores (1–7) and sediment traps (A and B).

location	⁶⁰ Co flux [Bq m ⁻² d ⁻¹]	sedimentation rate [cm/year]	particle size [median in μm]	fractions [%] nitrogen	quartz [%]	feldspar [%]
cores						
1	0.29	3.7	23.6	0.17	18	14
2	0.44	1.4	8.8	0.23	21	7
3	0.97	2.0	7.5	0.34	12	2
4	0.38	1.7	8.9	0.47	–	–
5	0.48	2.0	14.5	0.5	–	–
6	0.65	1.5	11.6	0.39	9	1
7	0.43	1.4	8.5	0.33	14	2
traps						
A	–	–	27.1	0.2	19	3
B	0.41	–	14.9	0.33	8	1

Table 1
Flux of Co and information on particles.

result of atmospheric atomic tests (maximum in 1963), fallout from the Chernobyl accident (1986) and emissions from the nuclear power plant Mühleberg (1976–78). ⁶⁰Co reflects the release from Mühleberg, with a maximum in August of 1982. The depth distribution of these radionuclides can be used to date the sediments of each core from Lake Biel and to assign a specific deposition period. The ⁶⁰Co activity can thereby be corrected for radioactive decay according to its time of deposition. In this way average flux rates for ⁶⁰Co could be calculated for every core after 1986 (Table 1).

It is remarkable that the maximum flux (0.97 Bq m⁻² day⁻¹; core 3) and a relative minimum (0.38 Bq m⁻² day⁻¹, core 4) originate from cores which were taken in close proximity to one another. Local sedimentological variations seem to play as significant a role as the spatial distribution of the radionuclides in the lake. For this reason, the data from each sediment core was weighted the same for calculating the total deposited amount. By multiplying the sedimentation area of Lake Biel, 3 × 10⁷ m², with the average flux of 0.52 Bq m⁻² day⁻¹, an average daily deposition of 1.6 × 10⁷ Bq day⁻¹ is obtained. Based on this information, the ⁶⁰Co deposited in the lake amounts to 52%, taking into consideration the average daily release of 3.0 × 10⁷ Bq day⁻¹ from the nuclear power plant (for the period of 1986–October 1996). These results were corroborated by data from the sediment traps from the

deepest part of the lake. From the beginning of July 1996 to the beginning of September 1996, an average deposition rate of 1.2 × 10⁷ Bq day⁻¹ of ⁶⁰Co could be measured in all three

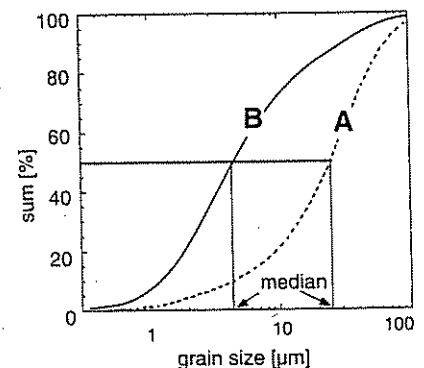
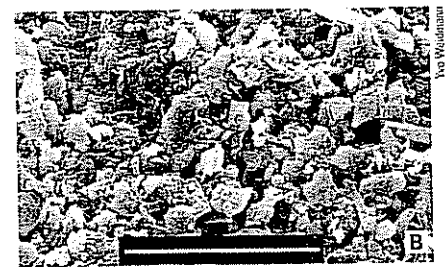


Fig. 3
Characterization of particles from the delta of the Aare River (A) and the deepest part of the lake (B) using grain size distribution (graph) and the scanning electron microscope. Reference length: 30 μm.

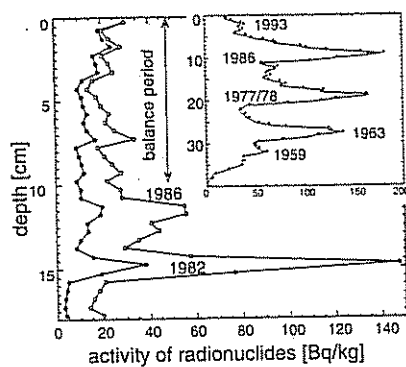


Fig. 4 Depth profile of the radionuclide ^{60}Co (larger graph from 0–20 cm depth) and ^{137}Cs (insert 0–40 cm depth) in core 2 from Lake Biel. Using the ^{137}Cs distribution, the core and each individual sample can be dated. The measured activity of the ^{60}Co (filled circles) were corrected for radioactive decay to the time of deposition (open circles) (see also [1]).

traps. Compared to the average release of $1.9 \times 10^7 \text{ Bq day}^{-1}$ by the nuclear power plant Mühleberg, the deposition of cobalt amounts to 66%.

The Fate of the Aare after Entering the Lake

The intrusion of the Aare into Lake Biel is an important process to consider in understanding the dynamics of metal ions. It determines their average residence time in the lake and, therefore, the time available for adsorption to particles or colloids. The intrusion depth depends on the difference in density of the two waters. The density is determined by the temperature, the salt concentration and the amount of suspended matter.

In the summer months, there is a distinct temperature and density stratification in Lake Biel. The surface waters of the lake are usually warmer and carry less dissolved salts than the water of the Aare. The water of the Aare intrudes directly below this layer, in the thermocline (Fig. 5). For this reason, and because of the high inflow rate of the Aare compared to the size of Lake Biel, the calculated residence time of the water of the Aare amounts to only one week in summer.

In the winter months, Lake Biel is only weakly stratified (Fig. 5), and the temperature varies by only a few tenths of a degree. As the temperature for both waters is about 4°C at that time,

the salt content becomes important for the density and for the intrusion depth. A typical salinity profile shows that the Aare, carrying more dissolved salts than the water of Lake Biel, sinks down to a deep layer in winter. The average residence time of the Aare water is, therefore, distinctly higher (> 60 days) than in summer.

Lake Traverse

As the water of the Aare mixes in the upper layers during the warm season, its freedom of movement is correspondingly restricted which makes it easy to trace in the lake. In order to definitively determine its location, the dye uranine was added to the regular inflowing wastewater of the nuclear power plant Mühleberg during an on-site experiment. The experiment began on 19 August 1996 in the evening and ended on the 27 August 1996 at Lake Biel near the outflow (Fig. 6). Break-through of the dye could be measured near Hagneck and was used to determine the sampling period for cobalt and particle analyses. Further sampling took place in the lake on 20, 21, 22 and 27 August 1996. Location and depth of the uranine could be determined using probes and so helped in tracing the water of the Aare. The concentration of dye as a function of depth at different locations was indicative of the increasing dilution of the Aare in Lake Biel. Because of the low activity of ^{60}Co in the wastewater of the nuclear power plant, radioactivity could only be measured in Hagneck. It amounted to 1.1 Bq m^{-3} ($4.4 \times 10^{-7} \text{ nM}$) with a particulate fraction of 58% (particles $> 0.45 \mu\text{m}$). In the lake itself, the ^{60}Co activity was below the detection limit.

The stable, naturally occurring isotope, ^{59}Co , could be quantitatively determined at Hagneck and in the lake (Fig. 6). At Hagneck, the concentration was 2.7 nM ; in the lake, it decreased with increasing distance to the inflowing Aare and reached a minimum of 1.2 nM near Biel. The particulate fraction suggests a similar trend for ^{59}Co as for ^{60}Co . At Hagneck, it

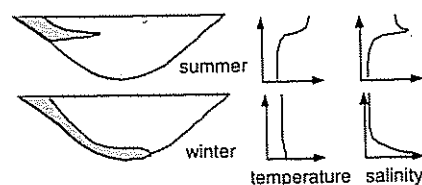


Fig. 5 Schematic representation of the intrusion of Aare water in Lake Biel. In the summer months, the water of the Aare intrudes directly beneath the mixed warm surface layer (above). In winter the high salt content causes it to sink to greater depths (below). The salt content can be used as an indicator for the water of the Aare River in Lake Biel (right).

amounted to 55%, after which it continuously dropped to 16%. The reduction in the concentration of stable cobalt during the sampling traverse of the lake was calculated to be 55%, which agrees well with the calculated decrease in ^{60}Co based on data from sediments (52%) and sediment traps (66%).

An agreement between the results based on the two cobalt isotopes is

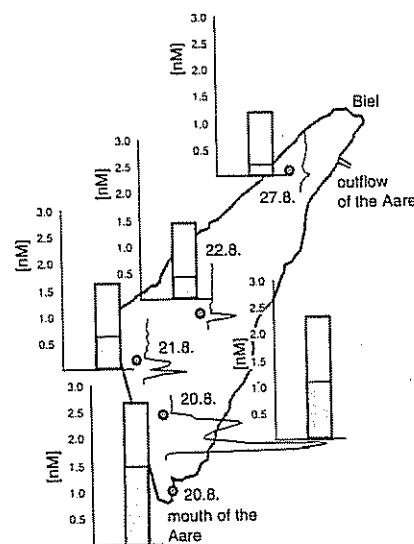


Fig. 6 Using a dye and the measurements of depth profiles, it was possible to trace the water of the Aare in Lake Biel. Apart from finding its location, the profiles could be used for estimating the relative mixing of the Aare waters with lake water. Among the measurements carried out at every site, the total concentrations of cobalt and the particulate fraction (gray) are graphically presented. Using the reduction in concentration from 2.7 to 1.2 nM , the fraction of cobalt retained in the lake can be estimated to be about 50%. The significance of particles can be seen in the reduction of the particle-bound fraction from 55 to 16%.

certainly not trivial, particularly when taking into account the wide variation in chemical species, the coexistence of two oxidation levels and the different origins of the two cobalt isotopes [2]. This allows us to take the next step: drawing on biogeochemical data of stable cobalt in order to interpret the data of radioactive ^{60}Co . For stable cobalt, the chemical form can be determined using polarographic methods. It is possible to differentiate between free, positively charged cations and organic, usually negatively charged, complexes. This is only possible above a concentration of 0.06 nM, which is far above the concentration of ^{60}Co . Preliminary results suggest that the organically complexed fraction in all samples amounts to over 75%, whereby there is a perceptible trend towards increasing organic complexing of the cobalt from the Aare (77%) into the lake (93%). This data on the speciation of cobalt brings us an important step closer towards understanding metal transport. The tendency of cobalt to bind dissolved organic substances

increases the number of players in the competition for metal ions, which usually causes a decrease in its particle-bound fraction. The complexed fraction of the cobalt remains in the dissolved form and, in our case, leaves Lake Biel.

The particles which were sampled during the study exhibit trends similar to those measured in sediment samples. For example, the fraction of nitrogen in suspended particles in the lake increased from 0.78% on 20 August to 1.3% on 21 August and 1.6% on 22 August. In spite of these heterogeneities, the distribution of ^{60}Co in the lake is rather homogeneous. As a consequence, the particles responsible for the transport of cobalt must be very fine and distributed fairly evenly by current flow throughout the lake. This regulation of the distribution of the metals through fine particles and the concomitant reaction of dissolved organic substances with the metals allows a direct comparison between the processes taking place in the lake and below the ground (Fig. 1).

Acknowledgements

We would like to thank the nuclear power plant Mühleberg, the power plant group of Seeland and the Laboratory for Water and Soil Protection of the Canton of Bern for their logistic support. X-ray diffraction measurements were carried out at the Université de Neuchâtel (Geology Department). This research is financially supported by the Swiss Federal Nuclear Safety Inspectorate (HSK).

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Markus Boller Promoted to Professor

The ETH Council has promoted Markus Boller to Professor at the Swiss Federal Institute of Technology because of his outstanding performance in research and teaching. Markus Boller began his career at the EAWAG in 1973 after completing degrees in Civil Engineering at ETH and in Sanitary Engineering at the Technical University in Delft. He initially worked on the flocculation process during wastewater treatment, which was the focus of his dissertation research. Over a twenty year period, he gradually widened his focus to include all aspects of sanitary engineering, with an emphasis on urban water management.

Since 1983, he has been actively involved in teaching at ETH and in

developing special courses for professional associations. He has helped shape the course content in drinking water and wastewater technology, given as part of the EAWAG's continuing education program. Markus Boller is also a favorite speaker at the yearly informational seminar series EAWAG holds for the public.

Apart from his excellent technical and personal qualities, Markus Boller has also made himself a name as "EAWAG's poet". He has enriched many of the EAWAG festivities (year-end celebrations, birthdays, retirements, anniversaries) with his humorous contributions in verse form. A few short verses at the end of this Laudatio may give an idea of his talents. He wrote these the verses on



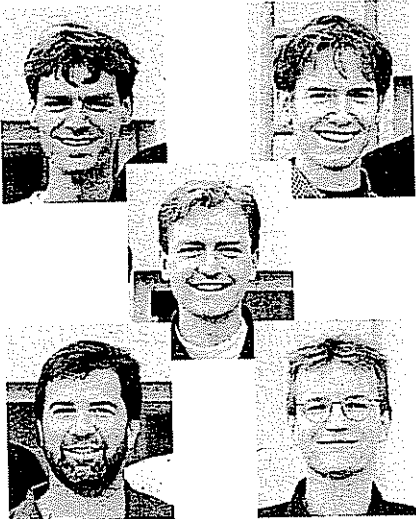
the occasion of stepping down as head of the Department of Environmental Engineering Sciences. (Walter Giger)

Nun ist der Boller bei den Professoren und hält auch künftig steife Ohren. Er hat jetzt einen noch schärferen Blick für Trinkwasser und EAWAG-Politik.

Now that Boller is with the professors and will continue to keep his ears stiff. He has now an even keener eye for drinking water and EAWAG-politics.

Jan Roelof van der Meer, Marco Jaspers, Patrick Sticher, Ronen Tchelet and Hauke Harms

Bacteria which Report the Bioavailable Concentration of Environmental Pollutants



Jan Roelof van der Meer, Marco Jaspers, Patrick Sticher, Ronen Tchelet and Hauke Harms

The enormous sensitivity and specificity of receptor proteins for their target compounds is something we experience continuously, although we are usually not aware of it. For example, our sense of smell is based on the interaction between receptor proteins and natural or synthetic chemicals. Even bacteria are capable of sensing their environment, mostly by a kind of "smelling". This bacterial sense of smell may be used to report the bioavailable concentrations of various environmental pollutants.

What is Bioavailability?

Many pollutants, even though in principle degradable by bacteria, persist in the environment. It is not because bacteria don't like to chew them up, but mostly because they cannot get sufficient access to them. The compounds are not available to the bacteria in a form that is optimally suitable for microbial uptake and digestion. This occurs very often when a chemical is poorly water-soluble and sorbed to particulates or to the soil matrix. Unfortunately, many compounds were

designed to be poorly water-soluble, intended for use as hydraulic oils and fuels or as solvents for dry cleaning and degreasing. When present as pollutants in the soil, such chemicals are present as droplets or adsorb very strongly to soil particles (Fig. 1). Bacteria can degrade only those molecules which dissolve in the water phase and which diffuse through the very small pores present in the soil. Because bacteria tend to stick to the soil particles as well, they cannot move to their food (in this case, the pollutants) easily. Biodegradation does not occur or proceeds very slowly and inefficiently.

How can one determine whether biodegradation is really limited due to insufficient availability of the pollutants to the bacteria? Chemical analyses are not sufficient. Such methods were developed to characterize the total amount of pollutants present – which they do very successfully. By estimating total amounts, however, one would perhaps conclude too soon that sufficient food for the bacteria would still be around. One could also determine if bacteria were present that are able to degrade the polluting substances, but this does not tell us whether the bacteria are actually active *in situ*. For better prediction of biodegradability, it would be nice to have an additional method which would measure exactly those concentrations of the pollutants which can be taken up by the bacteria and lead to active biodegradation.

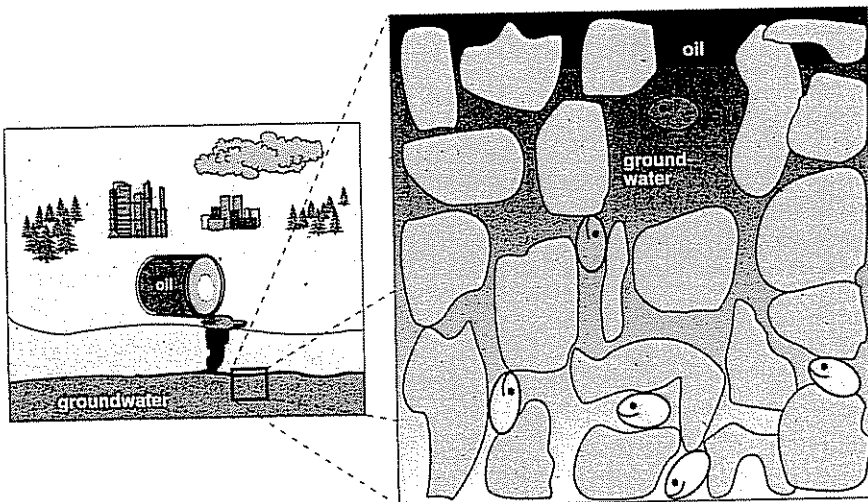


Fig. 1
Gasoline spilled in the subsurface will, because of its lower relative density, float on the surface of the groundwater. The poor water solubility of many individual compounds in gasoline can lead to poor biodegradation rates. Farther away from the oil phase, and especially within soil aggregates, the concentrations may become too low for biodegradation to occur.

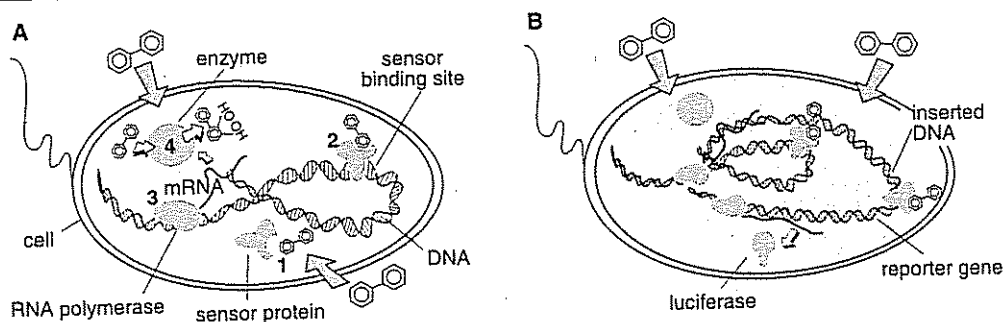


Fig. 2
The process of bacterial sensing in a natural bacterium (A) and in a reporter bacterium (B).

(A) A sensor/regulator protein recognizes a molecule which enters the cell as potential food (1) and binds to the DNA at a specific site (2). This results in reading of the information of a gene by the enzyme RNA polymerase (3) and synthesis of a new protein. In this case, this would be an enzyme needed for breakdown of the food molecule (4).

(B) In the reporter bacterium, a second DNA binding site for the sensor/regulator protein is introduced, which is coupled to a DNA fragment with the information for the luciferase enzyme. A recognized food molecule will now lead to the synthesis of the light-emitting luciferase as well.

Biosensors for the Bioavailability of Environmental Pollutants

If we would like to have information about which fraction of the pollutants present in an environment is directly encountered by microorganisms, we should look to the organisms themselves. Pollutant concentrations toxic to algae should be sensed by the algae themselves, and those concentrations available for microbial degradation can best be reported by the bacteria actively degrading the pollutants. Biological systems capable of doing this are called *biosensors* [2]. Biosensors generally contain two components, one which can sense its environment and the other a signalling component. General characteristics which biosensors should have are listed in the box below. In our research group, we decided to develop biosensors for a series of environmental pollutants (here we call them "reporter bacteria"). To do so, we made use of bacteria capable of using these pollutants as their food source.

Bacterial Sensing

To develop reporter bacteria, one uses the biological sensing systems of the organisms themselves. Bacteria are capable of sensing changes and stimuli in their environment, upon which they will react with a meaningful response. With the help of molecular genetic techniques, these reactions can be artificially directed to yield easily mea-

surable signals, such as light emission (bioluminescence) [1], fluorescence or coloring. Such bacteria will now "report" a change or stimulus in their environment by emitting light or by fluorescing (hence the name "reporter bacteria").

It is necessary to understand some more details of bacterial sensing, because it will clarify the specific advantages of reporter bacteria and the problems arising in interpretation of the measured signals. On a molecular level, one can best envision bacterial sensing as a sequential process of molecular interactions between chemical compounds, specific proteins and DNA (Fig. 2A). The first interaction, the actual sensing, is that of a particular stimulus with a specific sensor protein in the cell. For example, this can be a chemical compound which enters the cell and is recognized as food. It could also be the sudden absence of oxygen to which the cell must react. Upon interaction, the sensor protein will become slightly modified.

The modification of this protein now triggers the response of the cell. Hereto, the modified protein can interact with other cellular proteins, which in turn become modified. Finally, such modified proteins will interact with the DNA. They will bind to specific regions on the DNA, which are located in front of genes (genes are the regions on the DNA which code for the synthesis of proteins). By binding to the DNA at these positions, they

can regulate whether or not genes are being "read" (expressed). For example, they can stimulate gene expression, which will lead to the formation of a new protein (encoded by the gene). In other cases, they may repress gene expression, which results in the inhibition of synthesis of that specific protein. The cell has now reacted to the stimulus by synthesizing new proteins or by inhibiting synthesis of others.

Cells have a large set of proteins which perform such sensing jobs, become modified, and bind to the DNA. They are called *sensor* or *regulatory* proteins. (Some are called sensor/regulatory proteins, when they perform both functions of sensing and DNA binding). Cells need such a large set, because numerous changes in the environment have to be monitored (e.g., temperature, light, presence of food or nutrients, interaction with other bacteria, interaction with surfaces). Interestingly, although all these sensor and regulatory proteins do comparable jobs, they interact rather specifically. This is very important for the cell because it must avoid those particular environmental stimuli that will result

Requirements for Biosensors

- The biosensor should be sufficiently sensitive. For its application in soil bioremediation, this means that it should be able to detect pollutants below the concentrations indicated for a clean soil under environmental regulations.
- The biosensor should be sufficiently specific. This means it should detect only those compounds it was designed for and ignore all others.
- The biosensor should give an easily measurable signal. For application in soil systems, where one does not want to disturb the local structure, a light or fluorescent signal, which can be determined from a distance, seems most appropriate.
- The biosensor should be robust, not be disturbed too easily by the presence of other toxic compounds in the environment, and have a reasonable life time.

in the wrong response. One way of dealing with this problem is to have very specific binding sites on the DNA for the sensor and regulatory proteins. On the other hand, the molecular interaction of signals with the sensor proteins can be less specific. For example, more than one compound of similar chemical structure will be recognized as food, which actually makes sense from the bacterium's viewpoint.

Construction of Reporter Bacteria

For the construction of a reporter bacterium, one couples a DNA molecule containing the binding region of a specific regulatory protein with the DNA coding for a reporter protein which has to have easily measurable activity or properties. Such a fusion of two DNA pieces is a relatively simple process and can be accomplished in the laboratory. In our experiments, we first isolated several DNA binding regions, all from different bacteria that are able to degrade specific environmental pollutants. For example, from a bacterium named *Pseudomonas oleovorans*, which can utilize alkanes with a chain length between 6 and 12 carbon atoms, we took the DNA binding site for the alkane sensor/regulatory protein (AlkS) [3]. From a *Pseudomonas putida* capable of utilizing toluene, we isolated the DNA binding site for the toluene sensor/regulator, and, similarly, from a *Pseudomonas azelaica* that for the 2-hydroxybiphenyl sensor/regulator.

All these DNA pieces were then individually fused with a piece of DNA containing the gene for bacterial luciferase (Fig. 2B). Bacterial luciferase is an enzyme capable of emitting light in a biochemical process called bioluminescence [1]. These combined DNA pieces (the actual "gene reporter"), were then brought back into the bacteria from which the DNA binding sites were originally isolated. The bacteria carrying the gene reporter do not see a difference between their "own" DNA and the reporter DNA. As soon as they now sense the presence

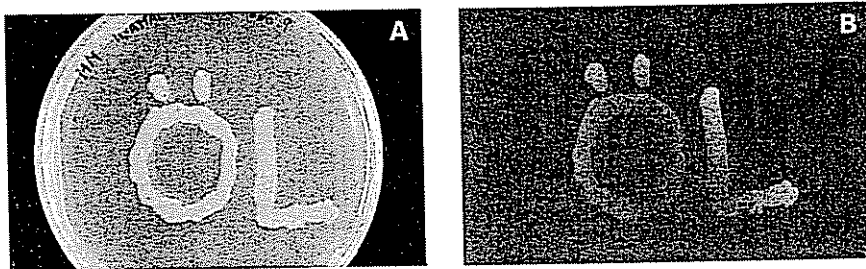


Fig. 3 The alkane reporter bacterium when grown in large numbers on agar plates (here forming together the word "oil", (A), will emit blueish light when incubated with octane vapor (B).

of alkanes, or toluene, or hydroxybiphenyl, they will not only react by synthesizing the enzymes necessary for degradation of these compounds, but will make the reporter protein as well. The sensor/regulator proteins will recognize both their "original" DNA binding site, and the same one in front of the reporter gene. The response of the bacteria to their food sources is now measurable as bioluminescence. In one case, we used a bacterium which cannot use the alkanes as food, but which can only "sense" them. The bioluminescence of this bacterium to varying concentrations of octane (with 8 carbon atoms), is shown in Figures 3 and 4 [3].

Outlook for the Future

The results obtained so far (see also EAWAG Jahresbericht 1996) encourage us in our idea that reporter bacteria can give useful and meaningful infor-

mation about the actual concentration of environmental pollutants available to them. This approach allows us to study more complex questions dealing with the microbial degradation of poorly soluble and strongly sorbed compounds. It is clear to us that we will still have to tackle many biological and technical problems before reporter bacteria will be used routinely. For example, how specific are they in distinguishing chemicals of related structure, and how sensitive are they to toxic compounds? In addition, reporter bacteria are genetically modified microorganisms which must be treated as such. This means that we cannot use them outside the laboratory, because they have to be kept in a contained environment and precautions be taken to prevent their survival. Perhaps one approach would be to immobilize them on the tips of optical fibers from which they cannot escape. Pollutants would have to be able to diffuse freely to the bacteria, and the emitted light signal could be detected remotely in a luminometer. If successful, the development of a mobile system for measuring bioavailable pollutant concentrations would no longer be utopic.

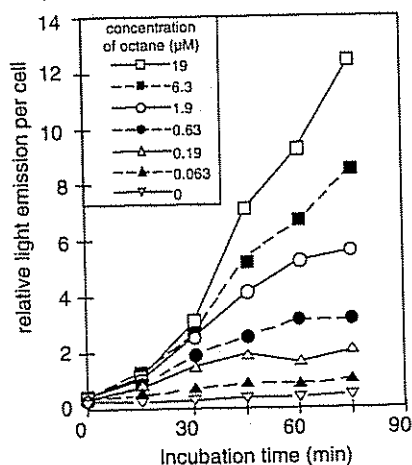


Fig. 4 Concentration-dependent light emission by the alkane reporter bacteria, after incubation with octane.

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James V. Ward

New Research Directions in Limnology



James V. Ward

The Limnology Department is expanding its horizons by strengthening its expertise in running water ecology, by incorporating research on ground water and riparian/wetland systems and adding ecological genetics to its repertoire. The recent addition of new scientists to the department has enabled it to pursue new research initiatives and to conduct truly holistic studies of complex systems.

Introduction

Limnology is a multidisciplinary endeavor that integrates aspects of the physics, chemistry, geology, and biology of inland waters (Fig. 1). Limnological investigations on all of these aspects are conducted by researchers in various EAWAG departments. In the Limnology Department, we also deal with physical, chemical and geological phenomena, though our primary research mission is biological limnology. Originally developed as the study of lakes, the field of limnology now also includes running waters, ground waters, and floodplain/wetland systems [2].

The primary purpose of this article is to present the new research foci of the Limnology Department and to introduce new colleagues who are involved in implementing these research initiatives. Progress in limnology requires a collaborative approach. There exist few places better suited to transdisciplinary research in limnology than the EAWAG. The Limnology Department seems to be an ideal organizational unit for integrating the knowledge base and expertise present in various departments.

Portrait of the Department

The Limnology Department consists of 15 academic staff, 9 technical staff, and 9 doctoral students. Some of these are part-time positions and three of the academic

staff members, their technicians and doctoral students, are based in Kastanienbaum. Our research focuses on *whole organisms*, their ecology, genetics, biogeography and evolution. Because we integrate the study of whole organisms into environmental research, many of the investigations conducted by the Limnology Department are truly "ecological" in nature. This is critical because it enables us to effectively study complex topics such as *biodiversity, population dynamics, community structure, succession, food webs, competitive and behavioral interactions and trophic cascading* and to contribute to comprehensive multidisciplinary studies on environmental problems such as *endangered species, habitat fragmentation, ecotoxicology, acidification, climate change, and lake and stream restoration*.

The Department of Limnology has a long history of investigating pelagic patterns and processes in the large Swiss lakes. This research, conducted in collaboration with members of other EAWAG departments, has brought Switzerland international recognition in the sphere of lake eutrophication/restoration. It also has resulted in an extremely valuable long-term data base that serves as a source for ongoing and future projects which investigate ecological interactions in pelagic food webs and plankton communities, carbon and phosphorus cycling, and the influence of solar radiation on primary productivity.

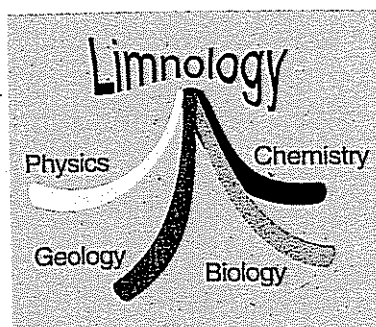


Fig. 1
The multidisciplinary nature of limnology.
Modified from [1].

New Research Goals

The new colleagues in the Limnology Department strengthen and expand our existing research areas, add new scientific disciplines and expertise and provide the department with new perspectives. We anticipate an exciting future as new research goals are implemented and new research initiatives are realized. With the addition of new scientists, the Limnology Department now has expertise in the following research areas:

- lake/pond ecology
- stream/river ecology
- groundwater ecology
- littoral, wetland and riparian ecology
- ecological genetics
- evolution
- modeling, and
- ecotoxicology.

The ultimate goal of the department is to conduct basic and applied research with strong conceptual foundations and a holistic perspective, that encompasses a range of spatio-temporal scales and leads to a greater understanding of patterns and processes (Table 1).

New Research Initiatives

Let me briefly describe four research initiatives that are in the early stages. These are intended only as examples from a diverse array of projects being planned and conducted by department members.

Val Roseg – a Glacial Flood Plain

Val Roseg, at the headwaters of the River Inn near St. Moritz, is a braided alluvial floodplain system formed in glacial outwash (Fig. 2). Habitat diversity in the various braided channel segments is enhanced by divergent water sources (glacier, ground water, valley wall tributaries). Alpine flood plains are extremely sensitive to climate

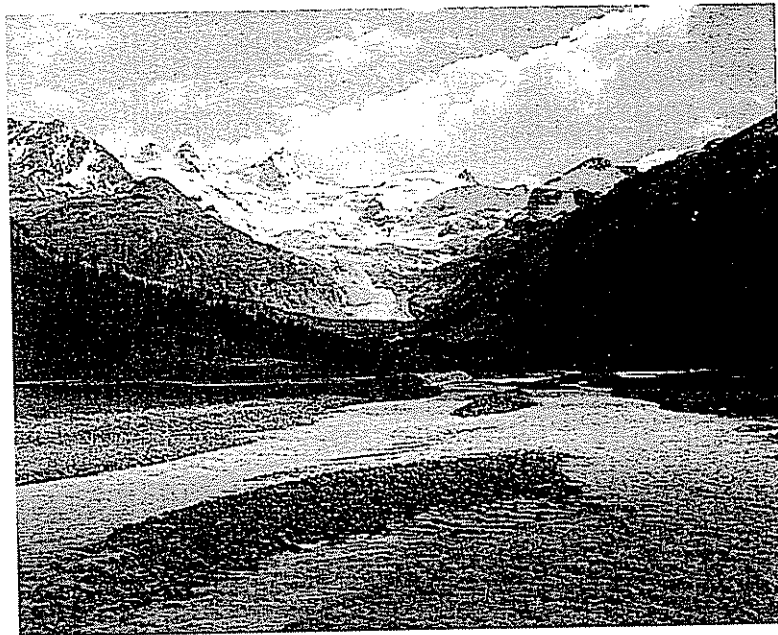


Fig. 2
Val Roseg, a glacial flood plain in the Engadin.

change, yet virtually nothing is known of their ecology. Research focuses on the roles of disturbance, environmental gradients, connectivity and spatio-temporal heterogeneity on (1) biodiversity of zoobenthos, groundwater fauna and periphyton, and (2) ecosystem processes such as primary productivity and decomposition. Project Coordinator: U. Uehlinger.

Fiume Tagliamento – a Model Riverine Landscape for the Alps

This is the only river in the Alps with a natural flood regime and the

resulting spatio-temporal dynamics which sustain the ecological integrity of lotic ecosystems [3]. In collaboration with Professor Peter Edwards (Geobotanic Institute, ETH) and Professor B. Rossaro (University of Milan), we intend to investigate patterns and processes associated with aquatic fauna, riparian vegetation, and organic matter dynamics in an attempt to test general ecological models developed for river systems. This is an ideal system to evaluate landscape-based biodiversity patterns (alpha, beta, & gamma diversity)

Themes	Topics
Organismic Approach	Alpine Limnology
Strong Conceptual Foundation	Biodiversity
Hierarchical/Scalar Approach	Role of Disturbance
Spatio-Temporal Perspective	Pattern & Process Along Environmental Gradients
Disturbance as a Structuring Agent	Metapopulations
Connectivity & Ecotones	Organic Matter Dynamics
Field Approach-Supplemented by Experimentation & Modeling	River & Lake Restoration
Ecosystem Management	Stream Assessment
Recovery Trajectories of Biocenoses	Behavioral Ecology
	Food Web Interactions
	Ecosystem Resiliency
	Biologically Mediated Fluxes

Table 1
Future research themes and topics in the Limnology Department.

New Colleagues



Mark O. Gessner

came to us from the Center for Ecosystem Research at the University of Kiel. His Ph.D. degree (1991) is from the University of Freiburg, Germany. He is well known for his research on organic matter dynamics in aquatic systems and for quantitative investigations on the role of aquatic hyphomycetes in decomposition processes. Dr.

Gessner recently completed his Habilitation at the University of Kiel.

Example of a recent publication: Gessner, M.O. et al. (1996): A partial budget of primary organic carbon flows in the littoral zone of a hardwater lake. Aquatic Botany 55: 93-105.



Tom Gonser

is not new to the EAWAG, but he is a recent addition to the Limnology Department (from Fisheries Science). His doctoral work, conducted through the University of Freiburg (1990), dealt with the biology and ecology of Chilean mayflies (Ephemeroptera). This was followed by a postdoctoral position at the Flathead Lake Biological

Station in Montana, where he developed expertise in ground-water ecology.

Brunke, M. & T. Gonser (1996): The ecological significance of exchange processes between rivers and groundwater. Freshwater Biology (in press).



Florian Malard

is a Postdoctoral Associate in the Limnology Department. His Ph.D. research at the University of Lyon (1995) dealt with the biology of karstic waters. Dr. Malard has already published extensively on various aspects of groundwater ecology.

Malard, F. et al. (1996): Developments in sampling the fauna of deep aquifers. Arch. Hydrobiol. (in press).



Piet Spaak

is an ecological geneticist/evolutionary biologist who came to us from a postdoctoral position at the Max-Planck-Institute of Limnology in Plön. His Ph.D. dissertation at the University of Utrecht (1994) investigated hybridization in *Daphnia*. Dr. Spaak will be teaching a new ETH course on Ecological Genetics of Aquatic Organisms.

*Spaak, P. & J.R. Hoekstra (1995): Life history variation and the coexistence of a *Daphnia* hybrid with its parental species. Ecology 76: 553-564.*



Christopher T. Robinson

is a broadly trained stream ecologist who completed doctoral studies at Idaho State University (1992). He has worked with macroinvertebrates, periphyton and fish in the contexts of disturbance ecology, community structure, colonization dynamics, bioassessment, and population genetics. Dr. Robinson has participated in projects in Russia and Latvia.

Minshall, G.W., C.T. Robinson & D.E. Lawrence (1997): Immediate and mid-term responses of lotic ecosystems in Yellowstone National Park, USA, to wildfire. Can. J. Fish. Aquat. Sci. (in press).



Klement Tockner

came to us from a postdoctoral position at the University of Vienna where he was Coordinator of the Floodplain Restoration Project on the Danube. His Ph.D. dissertation (1993) dealt with the community ecology of zoobenthos in the shore zone of the Danube. Dr. Tockner is interested in connectivity between lotic and wetland habitats, especially in relation to biodiversity and organic matter transformation during passage through floodplains. He will be teaching a new ETH course on Wetland Ecology.

Tockner, K. (1996): Colonization experiments for biomonitoring riparian communities of a large regulated river, the Danube (Austria). Arch. Hydrobiol. Suppl. 113: 433-442.

and to investigate the factors that structure biodiversity. Project Coordinator: K. Tockner.

Role of Wood Debris in European Streams

Wood debris is routinely removed from streams and rivers throughout Europe, with far-reaching consequences for water quality, channel morphology, aquatic and riparian habitats and ultimately on the ecological integrity of lotic

ecosystems [4]. A collaborative proposal between several European countries with coniferous and temperate mixed forest settings has been developed, with the following goals:

- 1) to assess the value of wood debris as a water resources management tool and
- 2) to evaluate the extent to which results of research conducted in North America are applicable to Europe.

The proposal originated with Professors A. Gurnell and G. Pets (University of Birmingham, UK). The Department of Limnology (EAWAG) and the Geobotanic Institute (ETH) are the Swiss partners. Project Coordinator (Switzerland): C. Robinson.

Fragmentation of Alpine Stream Networks

Headwater streams are under increasing threats from habitat

Vladimir Krejci and Hans Rudolf Wasmer

Collaboration with Eastern Europe

Experiences and Goals for the Future

fragmentation [5; 6], with largely unknown implications for aquatic biodiversity. Mountain peaks are ecological islands; as altitude increases, habitat area decreases concomitant with increasing insularity [7]. We are developing a research project to

- 1) examine habitat fragmentation of stream networks in high elevation catchments of the Swiss Alps,
- 2) relate patterns of biodiversity to habitat fragmentation,
- 3) relate genetic structure (meta-population patterns) to habitat fragmentation in an attempt to
- 4) determine conservation measures to minimize threats to biodiversity in alpine catchments.

Project Coordinators: C. Robinson and P. Spaak.

I thank my colleagues P. Bossard, R. Gächter, M. Gessner, T. Gonser, F. Malard, C. Robinson, P. Spaak, K. Tockner and U. Uehlinger for suggestions on this article.

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- [2] Margalef, R.(ed.), (1994): *Limnology Now*. Elsevier, Amsterdam. 553 p.
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- [4] Gurnell, A.M., K.J. Gregory & G.E. Petts, (1995): The role of coarse woody debris in forest aquatic habitats: implications for management. *Aquatic Conservation* 5: 143-166
- [5] Zwick, P., (1992): Stream habitat fragmentation - a threat to biodiversity. *Biodiversity and Conservation* 1: 80-97.
- [6] Dynesius, M. and C. Nilsson, (1994). Fragmentation and flow regulation of river systems in the northern third of the world. *Science* 266: 753-762.
- [7] Ward, J.V., (1994): Ecology of alpine streams. *Freshwater Biology* 32: 277-294.

Changes in the political scene in Eastern Europe in 1989 have, among other things, led to increased technical exchanges between the "East" and "West". One example is the partnership between EAWAG and the Czech Technical University in Prague (Ceske Vysoke Ucení Technické Praha, referred to in the following text as "TUP"), which originated in 1993 with discussions on some systematic cooperation.

The purpose of the cooperation was to form a working group within the civil engineering faculty at TUP which would be able to bring a modern approach to research and education in the field of "water resource systems in urbanized areas" and become nationally and internationally recognized.

The primary reasons for the cooperative approach were:

- a common interest in problems related to sustainable development in urban water management (UWM),
- a strong need for investments in the Czech Republic (first investments and renewal) as well as in Switzerland (mostly renewal),

- a limited number of experts (in both countries) who are working on new concepts in urban water management,

- the internationally important role EAWAG is playing in this field,

- already existing scientific contacts between the two institutions,
- readiness of the Swiss Government to support cooperative efforts with East European countries.

The collaboration is anticipated to last over a period of 7-9 years, having been initiated in 1995.

The financial contribution made by Switzerland (i.e., salary of the project leader, cost of mate-

Urban Water Management in the Czech Republic

Over 85% of the population in the Czech Republic are connected to a public water supplies. Between 1990 and 1994, the average water consumption in households dropped from 174 l/person to 129 l/person per day, which was mostly the consequence of a massive increase in water prices from 0.6 Kč/m³ to over 10 Kč/m³. Water consumption in industry and agriculture showed a similar drop. The drop in water consumption by industry was not only due to price politics, but also to a drop in production levels as well as improved water management and conservation.

Approximately 73% of the wastewater is currently collected by public sewer systems (in most cases, leading to a mechanical-biological waste water treatment plant). The degree of wastewater collection is increasing steadily and wastewater treatment plants are being expanded and updated continuously, especially within the watershed of the River Elbe in a joint effort between Germany and the Czech Republic.

The structural condition of drinking water pipes, sewer systems and older drinking water and wastewater treatment plants is very poor. For example, losses in the drinking water supply system for the year 1994 amounted to 280 Million m³/year, or 29% of the total drinking water production. The cost for improvements and renovations is beyond the means of the State or the communities, and other sources (banks, etc.) have to be found to finance these projects.

Inside EAWAG

rials, expenses for undergraduate and graduate student exchange programs) for the first three years was estimated at Sfr 850,000.-. The TUP covered salaries for Czech personnel, provided the infrastructure and contributed to the operating costs. Additional support for a regional study was obtained from the Czech Ministry for the Environment.

Higher Education Activities in the Czech Republic in the Field of UWM

UWM has a long tradition in the Czech Republic. As early as 1897, TUP established a chair for "Rural Engineering, Water Supply and Urban Drainage". Today, a degree in water management is offered at several universities. Approximately 200 students graduate per year, with one third of these graduates specializing in UWM. Many of the graduates, however, are not taking positions in the field. Banks and information technology companies offer higher salaries and better career opportunities such that UWM is not able to recruit the youngest and the brightest.

The faculty at TUP is primarily involved in teaching. Occasionally,

there is consulting activity or participation in small research projects. Administrative duties are often a burden and demand much time. There is very little room left for systematic research activities and, in many cases, there is no up-to-date infrastructure. The primary reason for this situation is the 50-year old separation of teaching and research. The management at TUP is trying to overcome this outdated tradition and to promote research to a higher priority, but is encountering numerous difficulties as well as significant resistance. For this reason, the management at TUP strongly favors cooperation between the EAWAG and the TUP institutes involved in water management.

EAWAG Support for Research at TUP

The collaboration with EAWAG allows Czech personnel to become more active in research. The regional study, which is the main focus of the collaboration, sponsors a number of diploma and doctoral dissertations. The concentration of the research activity in the same geographical region facilitates the gathering of back-

ground information, insures its efficient and repeated use and strengthens the communication between project participants. The "integrated" and "interdisciplinary" nature of the project is particularly important. Initially, the emphasis has been on the development of new strategies for urban drainage systems; the focus will gradually be broadened to include drinking water as well as surface and ground water protection.

Setting up a Working Group

The formation and development of a working group "water resource systems in urbanized areas" had a promising start. A number of younger assistants showed an interest which translated into several diploma research projects and the acceptance of graduate students into water management programs. At the same time, the working group tried to form international ties. Eventually, a UWM group called "Urban Hydrology" has been able to establish itself within the Institute. The group did not have official status, but was functioning as a team; unfortunately, the younger and enthusiastic members of the group have not succeeded in bringing their more established colleagues within the Institute on board. Increasing tensions and attractive offers from the private sector have led to the recent resignation of several younger faculty members. The group is nearly obsolete and functionally no longer part of the Institute for UWM. The remaining members of the group were transferred to other Institutes within TUP, where they receive continued support and encouragement for research activity from the EAWAG. At the beginning of 1997, the EAWAG supported a proposal for a "Laboratory of ecological risks of urban drainage" (LERMO) to TUP's administra-

Phase of Collaboration	Time	Tasks
Feasibility Study	1994	<ul style="list-style-type: none"> • Examination of conditions for realization of a medium- to long-term cooperative effort • Preparations for a research project in the field of integrated urban water management.
Stage I	1995-1997	<ul style="list-style-type: none"> • Formation and consolidation of a working group. • Work on a research project (regional study) • Involvement of undergraduate and graduate students in the research • Transfer of findings from research to teaching • Transfer of findings from research to practice
Stage II	after 1997	will be determined in December 1997

Table 1
Phases of the collaboration.

tion. The proposal was based on a program of the Czech Education Ministry which targets young faculty members and attempts to support their research activities within the universities. The proposal has virtually identical goals and emphasizes cooperation with the EAWAG. The scientific advisory board of TUP has passed along a recommendation for funding to the Education Ministry. The LERMO has been officially established starting January 1998 for a period of three years.

Transfer of Results from Research to Teaching

Initially, the knowledge transfer from research to teaching was simple and successful. Since the "Urban Hydrology" group has been cut from the Institute for Urban Water Management, contact with students has become more difficult. Despite this obstacle, cooperation with the EAWAG is ongoing and ambitious diploma and doctoral research projects are still being undertaken.

Transfer of Research into Practice

The transfer of results coming out of basic research to every day practice is being accomplished very successfully. Major contributions have been made in the application of modern calculation methods, elaboration of Master Plan for Urban Drainage, wastewater treatment in rural areas, and optimization of energy consumption in wastewater treatment, to name a few.

The immediate translation of research results to practical applications is very instructive and motivating for younger scientists, although it can be rather time consuming and could potentially detract from their primary academic goals. On the other hand,

contacts with government and industry should help bolster the reputation of academic institutions which is very important at this point in time.

Exchange of Students, Graduate Students and Post-Docs

The exchange of students between EAWAG and TUP is rather limited:

- During 1995 and 1996, several students from TUP were able to come to the EAWAG to gain some practical experience, some even to perform their diploma research projects. The experience was a benefit both professionally and in terms of language skills.

- So far, no doctoral students from TUP have taken advantage of the option to conduct part of their research at the EAWAG, even though offers were made in several cases. This disappointing response may be due to the small number of students in the program; reasons for declining were personal (family situations or loss of jobs), worries about possible embarrassment, language barriers, and sometimes simply "laziness". The high technical demands, the intensity of the work schedule and the emphasis on scientifically relevant research at the EAWAG have not helped to motivate TUP students (at least not so far) to take on dissertation research in Switzerland when they have the option of a relatively fast, technically less demanding and strongly practice-oriented dissertation at home.

What Have We Learned?

Things we have learned from our cooperative effort can be summarized as follows:

- Collaboration has to be carefully planned and knowledge of local circumstances is extremely valuable.

- EAWAG's activities in research, teaching and consulting and the way it is structured is unusual for partners in middle- and eastern European countries and makes it difficult for them to accurately assess the EAWAG.

- Work on a concrete project (e.g., a case study) is the best way to gauge the potential for cooperation of a partner institute and it's individual coworkers.

- Stabilization of the political and economic situation in the Czech Republic has a positive effect on cooperative projects like this one. Successful companies (in the private sector) gradually begin to feel deficiencies in the education of their personnel and, therefore, are beginning to show more interest in academic institutions.

- Today there are a few successful private companies working in the field of Urban Water Management who are able to offer young professionals competitive salaries and career opportunities. At the same time, however, these companies draw the best people away from academic careers which hinders the development of new faculty.

- At the beginning of the cooperative effort, funding appeared to be the biggest problem. While the financial support of the Czech Republic is insufficient for the current research program, the attitude of the "old guard" of professors towards modern demands on academia appears to be at least as serious a problem. The current level of the science, the readiness to learn, accepting responsibility and assuming reasonable risks, as well as professional attitudes (to only perform and accept high quality work) are at least as important as adequate funding.

Future Goals

The contract for the first phase of the cooperation expires in 1997. After evaluation of the project by

the the EAWAG directorate and representatives of the ETH Council and after negotiations with representatives from TUP, private industry and government research and political representatives in January 1997, the following preliminary conclusions were drawn:

- The collaboration between the EAWAG and TUP has a significant impact on the future development of urban water management in the Czech Republic. The positive influence cannot only be felt at the University, but also outside. This has been recognized and publicly

stated by renowned figures in politics, economics and science outside the University.

- The collaboration should continue on after 1997, although the form and the organization of the collaboration has to be examined and newly defined during 1997.

Alistair Kerr

Chemical Reactions in the Atmosphere

A Look Back and a Glance at the Future



Alistair Kerr

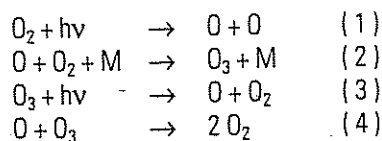
A native Scotsman, Prof. Kerr appeared at his farewell party in the summer of 1996 in a kilt, a dress habit which he intends to cultivate more frequently at festivities back in his homeland. He is shown here with his retirement present, a large-scale thermometer.

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It is now widely appreciated that the earth's atmosphere has a layered structure with the troposphere extending from the earth's surface up to about 10–15 km. Above that the stratosphere reaches an altitude of 50 km. Although the chemistry of these two lowest regions of the atmosphere is connected via the slow transport of trace chemicals from one region to the other, traditionally, the chemical reactions taking place in the troposphere and stratosphere have been considered separately.

Stratospheric Chemistry

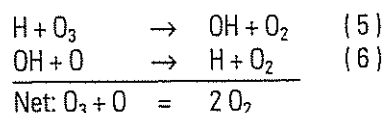
Serious interest in chemical reactions in the earth's atmosphere was initially focused on the stratosphere, and the first International Ozone Conference was held in Paris in May 1929. At that conference, Dobson presented the first results from his extended ozone monitoring network. Chapman attended the meeting, and the following year published the original photochemical theory of stratospheric ozone formation [1, 2] involving four oxygen-only reactions:



Rate constant measurements in the 1950s showed that reaction (4) was, in fact, much slower than

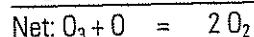
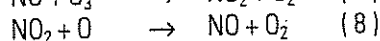
was believed at the time of Chapman's theory, which resulted in the amount of ozone calculated from this reaction scheme being greater than that observed in the atmosphere. This led to the postulation by Hunt [3] that cyclical or catalytic reactions of HO_x radicals (H, OH, HO₂), originally proposed by Bates and Nicolet [4], were responsible for some of the "missing" ozone, its removal arising from the slow rate of reaction (4).

For example

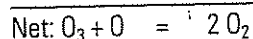
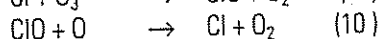
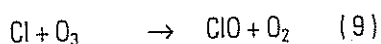


The next developments in the theory of stratospheric ozone took place in the early 1970s when Crutzen [5] proposed the catalytic cycle involving NO_x (NO + NO₂), and Johnson [6] suggested that nitrogen oxides from the exhaust

of supersonic aircraft flying in the stratosphere would cause depletion of the ozone layer, with serious consequences for life due to the increased transmittance of ultraviolet light.



In 1974, more urgency was given to the problem of ozone depletion by the suggestion of Molina and Rowland [7] that chlorine atoms, produced by photochemical degradation of chlorofluorocarbons (CFCs) in the upper atmosphere, may lead to large depletions of ozone via the catalytic cycle:



CFCs were rapidly accumulating in the atmosphere at that time, and it was recognized that, because of their long atmospheric lifetime, any effects of these compounds would be impossible to reverse on effective timescales. Thus arose the need for predictive mathematical models which would simulate the behavior of atmospheric ozone now and in the future.

Efforts over the past 20 years have been devoted to the development of such models. The earlier one-dimensional (altitude) transport models have now been largely superseded by two-dimensional (altitude-latitude) and three-dimensional (altitude-latitude-longitude) models, all of which contain upwards of 200 elementary gas-phase reactions. The performance of these models and the chemical kinetics data base used in their formulation have been reviewed and evaluated periodically, so that predictions of future ozone change are as scientifically sound as possible. To this end, an international panel of experts in atmospheric kinetics and photochemistry was convened

in 1977 to provide the necessary evaluated data for stratospheric modelers. This IUPAC subcommittee is chaired by Prof. J. A. Kerr, and it has published two major evaluations during his time at the EAWAG [8, 9].

A major surprise arose in 1985 when large springtime depletions of ozone over Antarctica – the “ozone hole” – were first reported. These changes were not predicted by the models. Subsequent intensive studies, both in the field and in the laboratory, have revealed the occurrence of novel chemical processes in the lower stratosphere. These include heterogeneous reactions occurring on the surfaces of polar stratospheric clouds which form by condensation of nitric acid and water. These reactions lead to conversion of most of the chlorine to catalytically active forms. This development has focused on chlorine as the most serious threat to the ozone layer at present and has resulted in a large effort to replace the long-lived CFCs by molecules with similar properties that are more readily removed from the atmosphere, for example, by reaction with OH radicals in the troposphere.

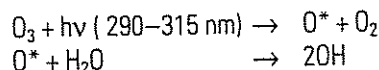
The crowning glory for atmospheric chemistry came in 1995 when Crutzen, Molina and Rowland were awarded the Nobel Prize for Chemistry for their work on stratospheric chemistry. Their efforts stimulated research on the role of manmade Cl compounds in depleting stratospheric ozone and led to the Montreal Protocol and its on-going amendments to control the production and use of CFCs and related compounds.

Tropospheric Chemistry

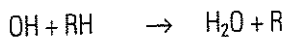
The phenomenon of photochemical or summer smog was first observed in Los Angeles in the late

1940s, with its features of reduced visibility, eye irritation and plant damage. This triggered numerous laboratory studies of chemical reactions under atmospherically related conditions. Haagen-Smit and coworkers [10, 11] at Caltech in Pasadena were the first to show in laboratory experiments that ozone was generated from the ultraviolet irradiation of air containing hydrocarbons and oxides of nitrogen, thereby establishing the photochemical nature of the problem.

The application of the principles of physical chemistry to photochemical air pollution were clearly set out in 1961 by Leighton in his classic monograph [12]. A significant breakthrough in understanding the driving force for the degradation of volatile organic compounds (VOCs) released into the atmosphere came in 1971 with the proposal of Levy [13] that relatively large concentrations of OH and HO₂ radicals are present in the sunlit atmosphere. The OH radicals arise from the photolysis of the background ozone and the subsequent reaction of the excited oxygen atoms (O*) with atmospheric water:



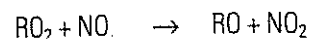
The author's introduction to atmospheric chemistry began in 1970 when he spent the first of three consecutive summers working with Jack Calvert at Ohio State University pioneering the development of the first comprehensive mechanism of photochemical oxidant formation [14]. The detailed mechanism is complex but is soundly based on laboratory studies of the products and rates of the elementary gas-phase reactions which make up the complete pattern of hundreds of reactions. The basic mechanistic framework consists of OH attack on a VOC released into the atmosphere:



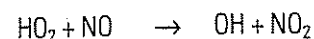
followed by the rapid oxidation of the product alkyl radical (R) to the less reactive alkylperoxy radical (RO_2)



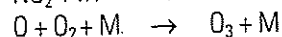
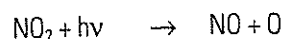
The RO_2 radicals react rapidly, however, with NO in the polluted atmosphere to generate the corresponding alkoxy radical (RO):



This reaction together with its HO_2 analogue



act as the driving force for converting NO to NO_2 , resulting in the generation of ozone via the sequence;



The alkoxy radicals (RO), which are generated in the above sequence, undergo a variety of reactions in the atmosphere, all of which ultimately lead to carbonyl products such as aldehydes and ketones. Some of these initial products undergo further oxidative reactions to form peroxyacetyl nitrate (PAN), $\text{CH}_3\text{COO}_2\text{NO}_2$, a photooxidant and a major component of summer smog.

Since the 1970s, steady progress has been made, by way of laboratory studies, in deriving the details of the chemical mechanisms of a wide range of organic compounds which are found in the troposphere. Each class of compound (e.g. hydrocarbons such as alkanes, alkenes and aromatics and oxygenates such as alcohols, ethers, aldehydes and ketones) requires detailed investigations of the products of the hydroxyl-initiated oxidation processes. Over the past seven years, the Atmospheric Chemistry Group at the EAWAG has carried out a number of such studies, utilizing the unique analytical expertise and facilities of the

EAWAG. Notable achievements of the group have been

- i) in observing for the first time the hydroxy carbonyl products from the isomerization of alkoxy radicals under atmospherically related conditions,
- ii) in obtaining detailed pictures of the atmospheric degradations of ether-type molecules and
- iii) in making more extensive and accurate measurements of the kinetics of PAN-forming reactions than hitherto possible.

The driving force behind such kinetic and mechanistic research is to characterize the processes for application in mathematical models of the troposphere which calculate the oxidant-creating potentials of individual VOCs. This, in turn, is the type of quantitative information which is essential in making scientifically sound emission control strategies.

All of the above considerations refer specifically to gas-phase reactions but, of course, these are not the only type of reaction that occur in the atmosphere; witness the role of liquid-phase and solid-phase reactions in creating the atmo-

spheric aerosol particles responsible for the reduced visibility of summer smog. One important example of the role of atmospheric aquatic chemistry is in connection with the acid deposition problem. The gaseous SO_2 , which is emitted to the troposphere from the combustion of S-containing fossil fuels, is converted to H_2SO_4 relatively slowly in the gas phase by a sequence of reactions initiated by hydroxyl radicals. SO_2 is highly soluble in the atmospheric aquatic phase, however, and there it is rapidly oxidized to SO_4^{2-} by dissolved oxidants such as H_2O_2 and O_3 . This type of atmospheric aquatic reaction has long been of interest to the EAWAG.

The Future for Atmospheric Chemistry

Although progress in understanding the chemistry of the atmosphere has been significant over the past 20 years or so, many questions remain to be answered. As for the stratosphere, where ozone depletions are now recognized as having occurred in mid-latitudes as well as at the South Pole, one of the most

- [1] Chapman S., (1930): A theory of upper atmospheric ozone, Mem. Roy. Met. Soc. 3, 103.
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- [6] Johnston H.S., (1971): Reduction of stratospheric ozone by oxides of nitrogen catalysis from supersonic transport exhaust, Science 173, 517.
- [7] Molina M.J., Rowland F.S., (1974): Stratospheric sink for chlorofluoromethanes: chlorine atom-catalysed destruction of ozone, Nature 249, 810.
- [8] Atkinson R., Baulch D.L., Cox R.A., Hampson Jr. R.F., Kerr J.A., Troe, J., (1992): Evaluated kinetic and photochemical data for atmospheric chemistry. Supplement IV, IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry, J. Phys. Chem. Ref. Data 21, 1125.
- [9] Atkinson R., Baulch D.L., Cox R.A., Hampson Jr. R.F., Kerr J.A., Rossi M.J., Troe, J., (1997): Evaluated kinetic and photochemical data for atmospheric chemistry. Supplement V, IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry, J. Phys. Chem. Ref. Data 26, 521.
- [10] Haagen-Smit A.J., (1952): Ind. Eng. Chem. 44, 1342.
- [11] Haagen-Smit A.J., Bradley C.E., (1953): Ind. Eng. Chem. 45, 2086.
- [12] Leighton R.A., Photochemistry of Air Pollution, Academic Press, New York, 1961.
- [13] Levy II H., (1971): Normal atmosphere: large radical and formaldehyde concentrations predicted, Science 173, 141.
- [14] Demerjian K.L., Kerr J.A., Calvert J.G., (1974): The mechanism of photochemical smog formation, Advan. Environ. Sci. Technol. 4, 1.

pressing issues concerns the role of sulfate aerosol particles. These particles are formed through the atmospheric oxidation of carbonyl sulphide (OCS) and sulphur dioxide (SO₂), the latter reaching the stratosphere during periods of intense volcanic activity. The sulfate particles may bring about additional ozone-depleting reactions in a manner similar to the polar stratospheric clouds over Antarctica. Other stratospheric topics under active investigation in laboratory and field studies include the roles of bromine compounds, especially methyl bromide (CH₃Br, widely used as a fumigant in strawberry fields) and iodine compounds, such trifluoromethyl

iodide (CF₃I). Both bromine and iodine compounds, should they reach the stratosphere in significant amounts, would be considerably more efficient than chlorine compounds in causing ozone depletion.

In tropospheric chemistry, a break through in unravelling the details of the mechanisms of the atmospheric oxidation of aromatic compounds is likely to come soon. Much effort is going into laboratory studies of alkoxy radicals, which are the key intermediates in determining the initial distributions of products from all volatile organic compounds released into the atmosphere. Unfortunately, alkoxy radicals are among the most

difficult gas-phase transient species to study in the laboratory, and progress is likely to be slow.

The role of solid and liquid aerosol particles in tropospheric chemistry will certainly be investigated in more detail in the future. Here, progress is unlikely to be rapid due to the considerable difficulties in creating and controlling the nature of the atmospheric particles under laboratory conditions, as well as trying to study the rates and mechanisms of the reactions on the surfaces of such particles.

One thing seems certain about the future of atmospheric chemistry – there are still more surprises to come.

Application of EAWAG-Concepts in the Evaluation of Streams

The EAWAG has been developing interdisciplinary approaches to evaluate stream quality since 1991, which was reported in Vol. 39 of EAWAG news (1995). The concept itself was first published in 1994 under the title "Concept for the Evaluation and Development of Streams and Stream Systems in Canton Zürich" and included methodologies for morphological, biological and chemical evaluations as well as guidelines for developing methods to return streams to as close to their natural state as possible. In 1995, a "Manual for the Evaluation of Swiss Streams" was published which detailed methods and criteria for ecomorphology, hydrology and fisheries biology.

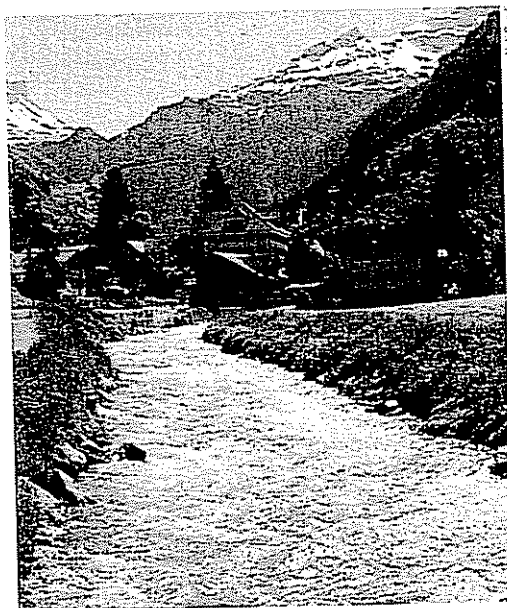
The methods which were developed at the EAWAG, in cooperation with other scientific institutions and government agencies, have

been put to the test by diploma research at ETH-Zürich and the University of Innsbruck. In the process, the methods have been adapted to the parameters of other geographical regions (e.g., Luxembourg) and larger rivers (the Rhine

in the Alpine section). In the Austrian state of Tirol, all of the medium and large streams are currently being inventoried employing the methods for ecomorphological evaluation. Even the Southern Tirol (Italy) is in the process of extensively mapping the ecomorphological status of its streams using EAWAG methods.

In cooperation with the Federal Offices of Environment, Forests and Landscape (BUWAL) and of Water Management (BWW) as well as various cantons, the original EAWAG methods are being modified so that they may be applied to Switzerland in general. The modular concept for an overall evaluation as well as the final method for ecomorphological evaluations is expected to be published by the end of 1997.

M. Hütte, U. Bundi



Obstructed Anterior Schächen near Unterschächen (Canton Uri, Switzerland).

The Course in Ecotoxicology "coetox"*

Who is responsible for keeping water non-toxic, everywhere and all the time? Do wastewater treatment plants clean water to a satisfactory level? What are the causes of observed fish kills or the decline in raptor populations? How toxic may abandoned polluted areas or soils be? Where do the tens of thousands of chemicals go that we use every day? What effects do they have? What is the measure for toxicity? How can we gather information on ecotoxicity? How do we interpret and evaluate this information? Ecotoxicology tackles these and similar questions.

In 1994, the Institute of Environmental Sciences at the EPF Lausanne, in cooperation with ecotoxicologists from the EAWAG and representatives from the BUWAL (Swiss Federal Agency for the Environment, Forests and Landscape), industry, higher education and government agencies, initiated a series of courses on various topics in ecotoxicology in order to accelerate dissemination and exchange of knowledge in this relatively young science.

Courses held so far have typically had 15–30 participants and were received very positively. The most appreciated aspects of the courses were the practical exercises, demonstrations and site visits, as well as the exchange of experiences with colleagues. Participants have come from government agencies, engineering and consulting firms, industry and the scientific community, bringing with them backgrounds predominantly in engineering and natural sciences.

Discussions in the courses held thus far led to the following conclusions:

- In everyday practice, ecotoxicology problems are very common and very real. Solutions have to be found as a joint effort between science and practice, involving a host of disciplines such as ecology, physiology, physics, chemistry and risk analysis.

- No compound can be proven or guaranteed to be non-toxic. Predictions relating to potential problems must be extrapolated from observed detrimental effects and, therefore, have limitations. It takes solid knowledge in the field and practical experience to assess these limitations.

- Ecotoxicology is evolving very rapidly. The need for continuing education will remain high for the next several years. New integrated approaches such as risk-benefit analyses and ecological analyses (life-cycle analyses) have to be developed further and be increas-

Courses held so far

Block 1:

Introduction to ecotoxicology (June 94)

Block 2:

Ecotoxicologie expérimentale (septembre 94)

Block 3:

Fate and effect of chemicals in artificial and natural ecosystems (November 94)

Block 4:

Life cycle analysis and Eco labels – an introduction to the ecological evaluation of products (August 95)

Block 5:

Ecotoxicologie des décharges et des sites contaminés (octobre 95)

Block 6:

Workshop on ecotoxicological risks and social benefits – responsibilities and jurisdiction (had to be canceled due to low enrollment)

Block 7:

Méthodes immunologiques et biomarqueurs en écotoxicologie (juin 96)

Block 8:

Management of toxic trace chemicals such as nonylphenoethoxylates (October 96)

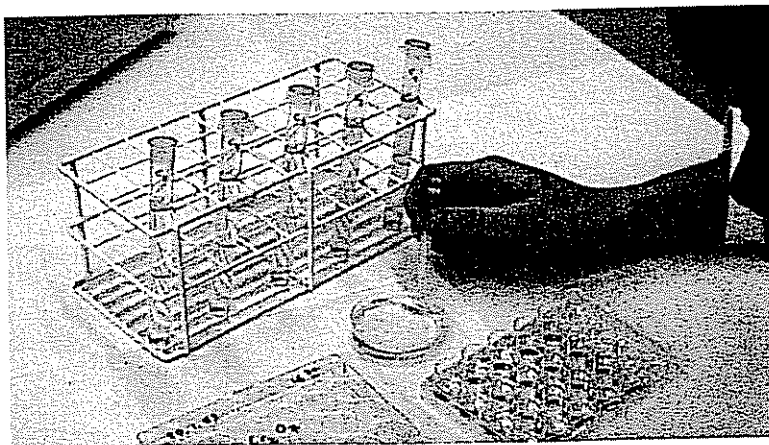
Block 9:

Introduction to ecotoxicology. Theory and practice (9–11 September 1997)

ingly applied to real problems. Tools can be expected to become better and more available (sw-instruments, on-line databases, better test systems).

Course on Estrogenic Effects and Cooperation with Industry

Out of the broad selection of course themes, we would like to discuss in more detail the topic of course block 8, *Management of toxic trace chemicals such as nonylphenoethoxylates*. This course dealt with an explosive theme which currently attracts a lot of interest: estrogenic effects of chemicals in the environment. As might be expected, a higher than usual proportion of the course participants were representatives from industry, with an extensive knowledge of the topic. Nonylphenoethoxylates have become a hot topic because of the hormone-like effects of their degradation products, name-



A test using algae to assess the toxicity of chemicals.

* coetox = collaboration in ecotoxicology, a cooperation between the Institute of Environmental Sciences at EPFL and the EAWAG.

Poster Presentations: Making Them the Best!

ly nonylphenoles. In particular, it was the observation of reduced sperm counts in men that brought the press into the ring and caused not only scientific controversy but also political action. In some applications, nonylphenoxylates have already been banned or voluntarily withdrawn, and more are to come. The declared goal of OSPAR (*Oslo and Paris Conventions for the Prevention of Marine Pollution*) to ban nonylphenoles altogether has mobilized the affected manufacturers. They are not willing to give up a market on the order of hundreds of millions of Swiss Francs without a fight. Interests are not only economic, however; in many applications, no environmentally acceptable alternative product is available. The question boils down to an evaluation of benefits and risks and leads to another situation where no satisfactory solution is yet available.

During the course it became very clear that industry is interested in finding environmentally compatible products, but that the bottom line and market shares come first. The environmental sciences, on the other hand, are in a state of emergency as far as evaluation of environmental compatibility goes. Such conflicts of interest are part of everyday life. They cannot be avoided or solved once and for all. Affected parties have to cooperate and find a balance between the public, long-term interest and the commercial, short-term gain. In the case of estrogen mimicking chemicals, this process is in high gear.

Overall, the collaboration between EPFL and the EAWAG in organizing these ecotoxicology courses has worked very well and it has been decided that the series will continue. Another introductory course in ecotoxicology has been offered in September 1997.

*Herbert Güttinger (EAWAG)
Joseph Taradellas (IGE/EPFL)*

Last November, Ph.D. students from ETH's Institute of Experimental Ecology organized a conference for fellow postgraduate students in the field of terrestrial ecology. Various workshops were integrated into the one-day program, including one entitled "Powerful Posters".

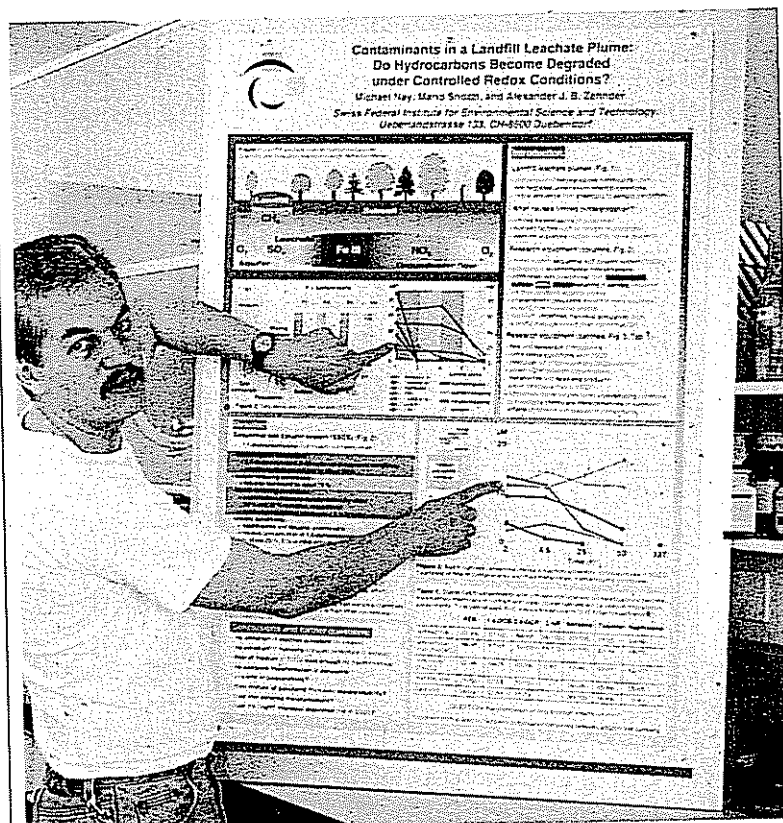
During the workshop, participants compiled a list of characteristics of effective poster presentations. The results have since been summarized as guidelines for poster presentations and can be accessed from the WWW-site of ETH's Center for Teaching and Learning (<http://www.diz.ethz.ch/DiZ/>).

No sooner had the workshop finished but came the first success story! Michael Nay, a Ph.D. student at EAWAG and one of the workshop participants, presented his latest research results as a poster at the annual meeting of the Swiss Microbiology Society in St. Gallen (Contaminants in a Landfill Leachate Plume: Do

Hydrocarbons Become Degraded Under Controlled Redox Conditions? M. Nay, M. Snozzi, A.J.B. Zehnder). His efforts were promptly rewarded with first prize, for the best poster of 50 presentations at the meeting. The jury particularly praised the color coding which linked the situation in the field with the laboratory experiments. This added such clarity that explanatory text could be kept to a minimum. Where text was still necessary, full sentences were avoided, and the information was summarized with bullets and key words, written large enough to allow the reader to get an overview of the essential points quickly and easily.

The guidelines on the web site of the Center for Teaching and Learning focus on criteria for the didactic quality of posters. It goes without saying that the authors still carry full responsibility for its scientific quality!

Pamela Alean-Kirkpatrick (Center for Teaching and Learning, ETH)



Inside EAWAG

Otto Jaag Award 1996

This year's Otto Jaag Award is shared by Jörg Klausen (EAWAG) and Michael Gfeller (ETHZ/ITÖ). Both researchers were recognized for their work on transformations of organic compounds in the presence of mineral phases.

The work of Jörg Klausen is entitled "Abiotic Redox Transformations of Aromatic Nitro and Amino Compounds in Suspensions of Soil Minerals: Laboratory Studies in Batch and Flow-Through Reactors". Aromatic compounds containing nitro- and amino-groups are being produced in large quantities for the use in pesticides, explosives, or as intermediate compounds. As a consequence of their widespread use and inappropriate storage in numerous ammunition factories and depots, these compounds have become common contaminants in ground water and soil. Many of these compounds, e.g., trinitrotoluene (TNT) and 3,4-dichloroaniline, are extremely resistant to biological degradation. Under certain redox conditions, however, they may be amenable to transformation. For example, nitroaromatic compounds can be reduced to their corresponding amino compounds, while anilines are susceptible to oxidative transformations

which typically lead to a number of products. From an ecotoxicological standpoint, redox transformations of such compounds may be undesirable, since they can lead to the formation of extremely toxic compounds. On the other hand, they open interesting possibilities for modern *in situ* remediation technologies, where such processes have been shown to cause some problematic compounds to become immobilized or more amenable to biodegradation. Either case requires a fundamental knowledge of the relevant redox partners and the corresponding reaction mechanisms in order to assess the danger or benefit of such reactions.

In the first part of his work, Jörg Klausen designed some batch experiments examining the reduction kinetics of monosubstituted nitrobenzenes by adsorbed Fe(II) in suspensions of some common soil minerals. The experiments demonstrate that Fe(II), which is adsorbed to iron oxyhydroxides or similar surface coatings, can play an important role in the reductive transformation of organic contaminants in a subsurface environment. The work also enhances our understanding of redox processes involved in the reductive



Jörg Klausen

In 1998 at The Johns Hopkins University, Dept. of Geography and Environmental Engineering, 313 Ames Hall, Baltimore, MD, 21218-2686, U.S.A.

treatment of ground water where elementary iron is used as the reductant.

In a second part of his research, Jörg Klausen examined the oxidation kinetics of monosubstituted anilines by MnO₂ in batch and well-mixed flow-through reactors, with a special emphasis on the behavior of such heterogeneous systems over longer periods of time. Results indicate that MnO₂ can play an important role in oxidative transformations of organic contaminants, provided that dissolved organic material and other higher valent metal cations are present in relatively low concentrations.

Meeting at EAWAG Research Center in Kastanienbaum



On 16–18 September 16–18 1996, 47 aquatic physicists from all over Europe (Germany, Hungary, Sweden, Estonia, Italy, Spain, France and Switzerland) gathered at the EAWAG Research Center for Limnology (FOZL) in Kastanienbaum/LU for a workshop on physical pro-

cesses in water bodies. Special attention was given to currents induced by density gradients, processes at interfaces and internal mixing and waves.

The new Research Center proved to be an excellent meeting place for groups of up to 50 people. The beautiful and quiet surroundings were highly appreciated and were very conducive to discussions among meeting participants.

A. Wüest et D.M. Imboden

Professor Alistair Kerr has retired

At the end of the summer semester of 1996 Professor Alistair Kerr retired from his positions at the EAWAG and the Swiss Federal Institute of Technology (ETH) Zürich. Alistair Kerr had studied chemistry in Edinburgh and Birmingham. After a long period of intensive research in Wales he returned to the University of Birmingham as professor for physical chemistry where he concentrated on the kinetics of chemical reactions in the gas phase. This research led him to his work in atmospheric chemistry which he pursued as a visiting scientist at several leading American research institutions. In 1989, he joined the EAWAG to lead the research group on reaction kinetics in the gas phase. At ETH Zürich, he taught courses in atmospheric chemistry for the Department of Environmental Sciences. Among his colleagues in Dübendorf and Zürich,

the quiet and collected Alistair Kerr was very much appreciated and recognized for his technical expertise. His didactically excellent lectures were always a special treat. His excellent lectures and presentations were particularly enjoyed by faculty and students alike. He received the title of Full Professor

in 1994. Following his retirement in Switzerland he returned to Birmingham and joined, among other things, the editorial board of Environmental Science and Technology, a publication of the American Chemical Society. We wish him good health and many years of productivity. *Walter Giger*



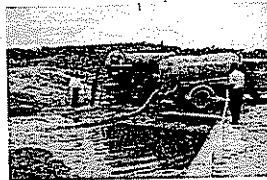
From left to right: Konrad Stemmler, Alistair Kerr, Stephan Seefeld, Gerrit Locke, and Wolfgang Mengon.

Treatment of Faecal Sludges in the Tropics

The new SANDEC report sets out to provide guidelines for the preliminary design of faecal sludge treatment schemes comprising solids-liquid separation and stabilisation ponds. The document is based on the results of collaborative field research conducted by the Ghana Water Research Institute and SANDEC on full and pilot-scale faecal sludge (FS) treatment plants located in Accra, Ghana. Published and unpublished documents relating to the subject were also reviewed and taken into consideration in the discussion and recommendation of specific options.

The authors first inform on faecal sludge quantities and characteristics. Faecal sludges may be divided into two different categories, viz. low-strength sludges (septage in most cases) and high-strength sludges as collected from bucket latrines and unsewered public toilets. The document then proceeds to discuss results of field research conducted on FS pretreatment; i.e., solids-liquid separation in sedimentation/thickening tanks and dewatering/drying beds. Solids-liquid separation in sedimentation units prior to the pond system has been

SANDEC Report No. 17/96
Solids Separation and Pond Systems
for the
Treatment of Faecal Sludges
in the Tropics
Lessons Learnt and Recommendations for Preliminary Design



Udo Heins, Seth A. Larmie, Martin Straus
Swiss Federal Institute for Environmental Science and Technology (EAWAG)
Department of Water and Sanitation in Developing Countries (SANDEC)

found to contribute to considerable land saving and to simplify pond operation as compared to schemes where solids-liquid separation is integrated in the primary pond. A main chapter discusses anaerobic pond technology for high-strength wastes and the results of field investigations conducted with anaerobic ponds. Use of facultative ponds is also described, with special focus on ammonia toxicity for algae from high ammonium levels in fresh and highly concentrated faecal sludges.

Effluent and solids quality standards for faecal sludge treatment plants are discussed and a set of guideline values proposed. A listing of researchable questions and suggested further field studies relating to the treatment options dealt with in this document is also provided.

Schemes comprising anaerobic and facultative ponds and a separate pretreatment step for solids-liquid separation are recommended by the authors as a suitable technical option for treatment of low to medium-strength sludges such as septage. Guidance on the preliminary design of such schemes is provided. Special attention should be paid to potential ammonia toxicity for algae.

Particular problems may arise when having to treat high-strength, fresh and largely undigested sludges typical of bucket latrines and unsewered public toilets. These hardly lend themselves to solids-liquid separation and, hence, to pond treatment. High ammonia levels may also inhibit the anaerobic stabilisation process either in anaerobic ponds or in digester tanks.

Udo Heins and Martin Straus
(Orders to Hauser@eawag.ch or phone +41-1-823 52 86/fax 53 99)

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