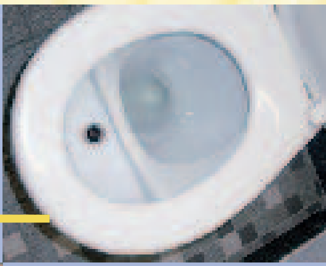
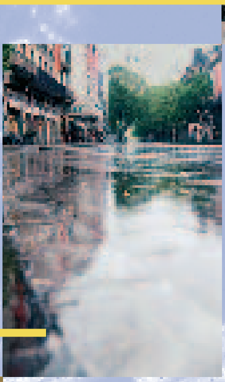
EAWAG

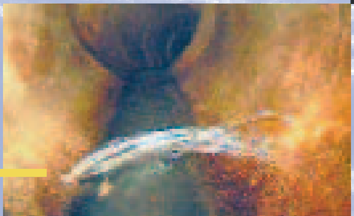
EAWAG news

57e December 2003
Swiss Federal Institute for Environmental Science and Technology (EAWAG),
A Research Institute of the ETH-Domain • CH-8600 Dübendorf

Urban Wastewater Management in Transition







EAWAG

EAWAG news 57e • Dec. 2003
Information Bulletin of the EAWAG

Urban Wastewater Management in Transition

Lead Article

Research Reports

In Brief

Publisher Distribution and © by:
EAWAG, P.O. Box 611, CH-8600 Dübendorf
Phone +41-1-823 55 11
Fax +41-1-823 53 75
http://www.eawag.ch

Editor Martina Bauchrowitz, EAWAG

Translations Norbert Swoboda, USA

Linguistic revision Patricia Colberg, USA;
Helen Brügger-Clarke, Zurich

Figures Yvonne Lehnhard, EAWAG; Peter Nadler, Küsnacht

Publication Three times yearly in English, German and French. Chinese edition in cooperation with INFOTERRA China National Focal Point.

Cover Photos Y. Lehnhard, M. Strauss, V. Krejci, EAWAG; TBS Identity, Zurich; Entsorgung + Recycling Zurich

Design inform, 8005 Zurich

Layout Peter Nadler, 8700 Küsnacht

Printed on original recycled paper

Subscriptions and changes of address New subscribers are welcome! Please find the order form in the middle of this issue.

ISSN 1440-5289

Editorial

Willi Gujer, member of the EAWAG-directorate and professor for urban water management at ETH Zurich.

Urban wastewater management is perceived as a vast public effort. In Switzerland, we have accomplished the task by investing more than 60 billion Swiss francs, and the resulting infrastructure provides an immense service to those 97 % of the Swiss population who have access. One might think that all problems have been solved and that we could tackle new challenges.

Infrastructures grow old, become damaged and fail to function; society evolves and calls for innovation and often more; science progresses and provides new insights; well established concepts are further enhanced. What serves us today, will be obsolete tomorrow, must be adapted, improved and further advanced.

This issue of the EAWAG news discusses many aspects of urban wastewater management and presents them from a fresh perspective. This raises various questions. The answers may have large effects on the existing system: Is it sensible to control micropollutants and their effects on ecosystems by fighting the symptoms? Wouldn't measures at the source be the better option? Are consumers both able and willing to take greater responsibility in the future or is the concept of decentralized sanitation fantasy? Can we, in our federal state system, further improve the institutional framework, efficiency of decision-making, and security of decision pathways? Or do we have to rely more strongly on structures provided by the private sector? What are the risks of a damaged drainage system? How can we use our experience best to support developing countries in their decisions and progress? Etc.

Obviously, the drainage system that offers us great convenience and that we all have been enjoying for many years is far less static than we tend to perceive it as consumers and even as experts in the field. It is becoming clear that in addition to the traditional end-of-pipe solutions, processes in the socio-economic sector are gaining in importance today. We increasingly view urban wastewater management as an integrated system that, in addition to ecological and technical standards, must meet socio-economic criteria.

The required infrastructure must be vital and evolve with society, thus creating an interesting and fascinating field for study. What we present here as innovative and ambitious, will soon become routine, which then again is to be amended and questioned.

Urban wastewater management is in transition – and that is good!

W. Gujer

From Transport to Water Protection

Urban drainage is in transition from functioning simply as a transport system to becoming an important element of water protection; however, this transition has been only partially successful since certain properties of today's sewage system represent inherent weaknesses. The cleaning efficiency of the sewage system as a whole, for example, is limited due to significant dilution with grey water and leaky sewage pipes. It is with this background that science is looking for ways to optimize existing structures and develop alternative approaches bringing sustainable urban drainage to a higher level.

The urban drainage system is one of the major public works achievements in Switzerland of the last 100 years (Tab. 1 and Fig. 1) [1, 2]. Over 95% of the Swiss population is served by 40 000 km of sewage pipes and countless other structures related to sewage removal. With 18 billion ton kilometers, the urban drainage system is one of the largest and most efficient transport systems in the country. For comparison: the entire volume of goods transported by rail and on roads in 1997 amounted to 26.6 ton kilometers. In a single year, Switzerland's 964 sewage treatment plants process two billion tons of sewage, producing 209 000 tons of sewage sludge [3], 250 000 tons of carbon, 20 000 tons of nitrogen, and 4000 tons of phosphorus.

Disposal at the Push of a Button has its Price

Far more important than the obvious performance numbers are the hidden benefits of these treatment plants:

- Public health: The ability to dispose of feces and used water efficiently and in nearly unlimited quantities has practically eliminated water-borne diseases in Switzerland. If there is a rare outbreak, it usually can be attributed to a problem in either the sewage system or the wastewater treatment plant. For example in 1998, the drinking water supply of the community of La Neuveville was contaminated due to a defective pumping plant. Sewage leaked into the ground water, which in this case was the community's source of drinking water.
- Protection of infrastructure: Efficient drainage of rain water from urban areas reduces the number of floods and associated damage.
- Water protection: Thanks to the increased number of wastewater treatment plants, general water quality has improved dramatically over the last 40 years. It has become the exception that public beaches are closed due to concerns over water quality.
- Comfort: Last, but not least, urban drainage offers in its prevalent form a level of comfort that was unthinkable not too long ago. There is hardly any other service that is as simple and comfortable to use. All kinds of liquid waste disappear within seconds simply by pressing a lever or button. As far as the consumer is concerned, the wastewater system requires virtually no maintenance, and unpleasant odors are a thing of the past.

Such an accomplishment has, of course, its price. The replacement cost of the entire urban drainage system in Switzerland is approximately 60 billion CHF [4, 5]. This corresponds to roughly 15% of the esti-

5000–3000 B.C.	Pipes and open half-pipes made of fired clay for drainage of villages in the Euphrates valley
2500–1500 B.C.	Bathrooms, toilets and street sewers in the Indus civilization
2000 B.C.	Pipes for water supply, rain water storage and wastewater facilities in the palace of Knossos
300 B.C.	Expansion of the sewer system in Rome
1591	Proposals for sewage treatment in London
1660	Water closets (WC) in England und France
After 1760	Drain fields for waste water
1830	Severe cholera epidemic in London
1840–1850	Construction of the sewer system in London
1848	First modern sewer system in Hamburg
1873	Sewer system in Berlin
1884	Typhoid epidemic in Zurich
1888	Fisheries legislation in Switzerland with regulations on water protection
1892	Biological wastewater treatment in England
1895	First settling basin in Germany
Around 1908	First biological investigation of water pollution by waste water
1916	First mechanical-biological treatment plant in Switzerland (St. Gallen)
1971	Water Protection Law in Switzerland
1975	Regulations on wastewater discharge in Switzerland enacted

Tab. 1: Development of wastewater technology [after 1].

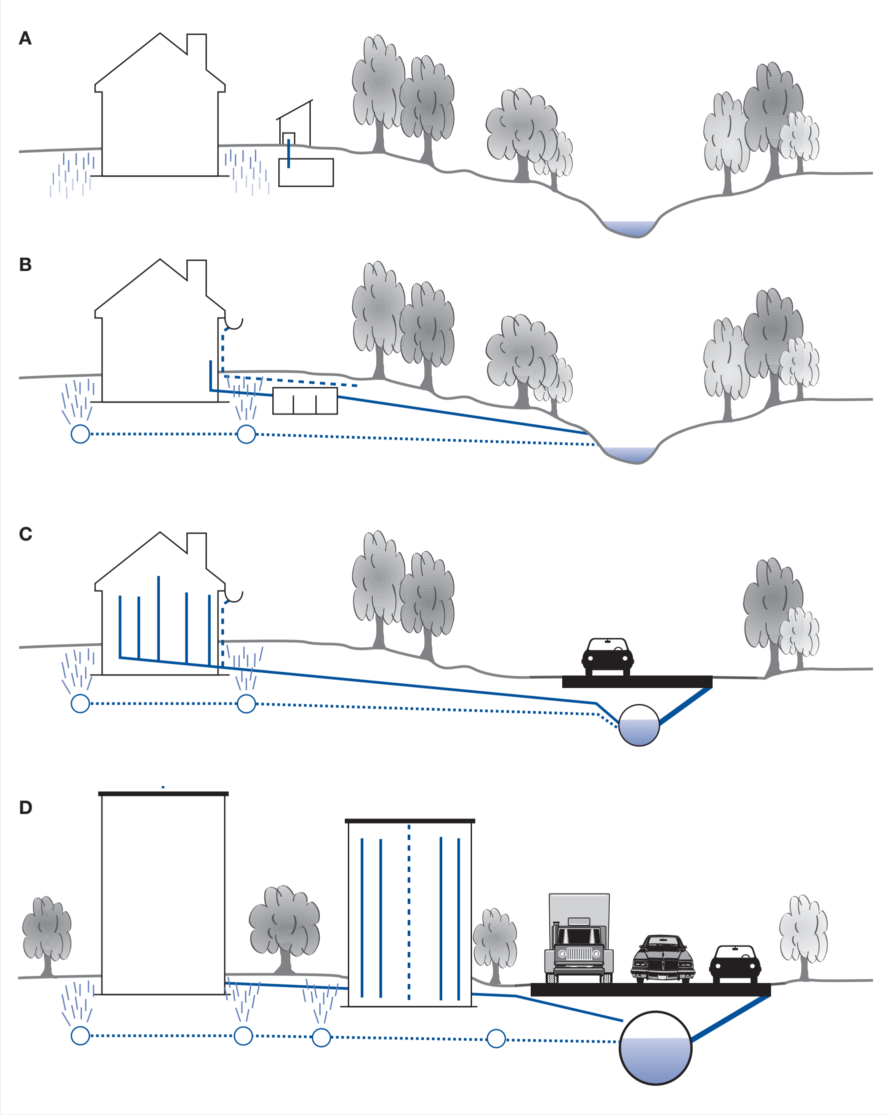


Fig. 1: Historic development of urban drainage [adopted from 1].
A: The cistern or pit system.
B: The pit system had to be abandoned after central water supply systems, bath tubs and flushing toilets were introduced. In addition to waste water, drainage water (in order to improve conditions in basements) was soon discharged into streams as well.
C: The volume of waste water increases with the living standard. Some streams were transformed into sewers.
D: Even today, growing cities require capacity increases in the urban drainage systems.

mated value of all civil engineering structures in Switzerland. The sewage system represents approximately 80 % of this value; the wastewater treatment plants comprise the balance. The total operational cost of urban drainage, including annual depreciation, interest on financing and actual operation, amounts to approximately 3 billion CHF. This amount represents a considerable 2.6 % of the total income of the public sector.

This large and valuable infrastructure must remain organized and managed efficiently. The consumer expects uninterrupted service and a high level of quality at low costs. Compared to the value of the infrastructure, the organization of the urban drainage system has several shortcomings. Necessary organizational and planning processes are often inadequate or non-existent, important information for new investments is incomplete, and planning and control instruments (e.g., clear performance standards, periodic evaluations) are rarely in place. We must provide managerial personnel of wastewater treatment plants with simple and practical tools to evaluate and optimize organization and planning (see article by S. Binggeli, p. 32).

Demand: Sustainable Urban Drainage

Urban drainage is a system that has evolved over time. The original focus, to quickly and efficiently remove waste water from urban areas, has gradually shifted towards the protection of water resources and, more generally, the sustainable development of society. We are realizing, however, that the original purpose of the sewage system does not agree – may even conflict – with these new emphases.

Rain water: Because of capacity issues, combined sewage systems (i.e., sewage systems that have to transport both sewage and rain water), have so-called combined sewer overflow tanks. They initiate when the sewage system is approaching its capacity limit during rain events; rain water containing some proportion of raw sewage is released directly into surface waters. Typically, 5–20 % of the sewage by-passes sewage treatment plants, significantly reducing the overall efficiency of urban drainage systems. Additional structures that temporarily store the mixed water, or possibly even treat it, can relieve the treatment plants and surface waters to some degree. Such structures must be designed for large volumes of water, but are not used during dry weather or during low intensity rain events (i.e., >97 % of the time), and so are relatively expensive. The project STORM (see article by V. Krejci, p. 21) is developing a practical and transparent process for planning new technical solutions for rainwater drainage and treatment and includes consideration of local characteristics of streams and lakes, potential uncertainties, types of contamination, and a broad spectrum of potential remedial actions and their cost efficiencies.

Infiltration: An alternative to channeled drainage of rain water is infiltration into the soil. It has been shown repeatedly over the last few years, however, that rain water is not necessarily free of pollution. This is particularly true for rain water running off roofs or roads. This source of contamination can be considerable and poses an entirely new technical challenge, since this type of contamination is very different from that of domestic waste water. Crucial parameters of concern include the mass fluxes involved, the dynamics of the pollutants, and the

Photographs: Entsorgung + Recycling Zurich

Underground in Zurich.

capacities of barrier systems that protect surface water, ground water and the soil (see article by M. Boller, p. 25).

Invisible infrastructure: The infrastructure is largely hidden underground and is difficult to access and inspect. Only massive leaks are immediately detectable. With current methods, small to moderate defects require an enormous effort before they can be detected, and then they are usually found as individual leakage points. Urban sewage systems have a relatively long theoretical life span, but are subject to continuous stress due to traffic and soil movement. In combination with natural fatigue of the pipe materials, damages arise that allow exfiltration of sewage and/or infiltration of ground water. New measuring techniques are aimed at quantifying these processes, thereby enabling us to more efficiently plan remediation or reconstruction of defective sections of the sewage system (see article by J. Rieckermann, p. 29).

Dilution and mixing: The principle of the hydraulic sewer system is based on waste being transported by a large volume of water. The resulting dilution of the pollutants and the mixing of different types of waste water make the cleanup more difficult and limits the efficiency of the wastewater treatment plant. This, in turn also increases the risk that undesirable compounds are not completely removed and reach surface waters with the wastewater effluent. From the point of view of water protection, the hydraulic sewer system is a relatively poor system.

Micropollutants: Because of improvements in analytical chemistry, increasing numbers of pharmaceutical chemicals are readily detected in surface waters. These compounds are dangerous because they can accumulate in organisms, e.g., in fatty tissues, and/or because they can have effects at extremely low concentrations, as is the case for hormonally-active compounds. One of the ingredients of the birth control pill, 17α-ethinylestradiol, has measurable effects on fish at concentrations below 1 ng/l [6]. The risks associated with such contaminants are extremely difficult to assess. Based on the cautionary principle, however, it ist possible to take first measures now. In his article on page 7, H.R. Siegrist discusses the current state of knowledge and discusses various measures that deal with the problem at both the source and in wastewater treatment.

Conservative infrastructure: Urban drainage is a rather inflexible system. Innumerable elements of different age and lifespan must function as a whole. In order to make the best use of our considerable investments, we are more or less forced to continuously replace and maintain individual elements [7]; therefore, it appears to be unlikely, that in the short- to mid-term, decentralized (small-scale) systems can become successfully established, regardless of whether or not it would be beneficial from an environmental or economic point of view.

Preliminary results from a German research project on “Integrated Microsystems for Supply” show, however, that the inert structure of urban water management is being confronted by factors that could create new dynamic forces leading to change (see article by D. Rothenberger, p. 11). Short-range shifts in population densities from urban centers to suburbs, for example, are already having a severe impact on investment needs and technical concepts. Other examples include water conservation efforts and budgetary constraints that cause investments to be postponed in many locations. The synergism of all of these factors might favor small-scale solutions in certain selected regions or consumer and/or application niches.

In Demand: Innovative Concepts in Urban Drainage

As illustrated in Figure 2, the first generation sewage system is currently being replaced in many areas of Switzerland. In light of the serious disadvantages and high cost of the urban drainage system as a whole, it is beneficial to consider devising fundamentally new concepts that can be integrated into the current system, but which offer new options for the future.

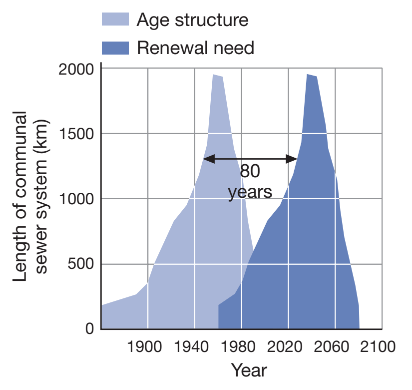


Fig. 2: Age structure of the sewer system in Canton Berne [4].

Maintenance work in the sewer system by employees of “Entsorgung + Recycling Zurich”.

EAWAG is intensively pursuing such an alternative concept in the research project NOVAQUATIS, dealing with the separate collection and treatment of urine. Urine accounts for less than 0.5% of the total volume of waste water, but contains over 85% of the nitrogen compounds, 50% of the phosphorus and a large fraction of the hormones and pharmaceuticals in the waste, thus contributing substantially to the overall load in wastewater treatment plants [8]. It is interesting to note that this technology is very flexible and is easily integrated into the existing infrastructure and has benefits even in combined sewer systems. It has been shown that partial collection and storage of urine can help to “even out” peak loads in wastewater treatment plants [9].

EAWAG is not only concerned with the technical realization of this innovative concept, but with gauging public acceptance of such a “novelty”. The success of any innovative technology in the real world depends on a number of factors. In today’s world of urban drainage, technical decisions are made largely without any input from the public. Far-reaching changes of the current system, such as changes at the source, however, require the involvement of all affected parties at the earliest possible stage. For this reason, the NOVAQUATIS project has conducted several acceptance studies (see article by J. Lienert, p. 14). Results thus far indicate that the introduction of separate urine collection would not be met by any substantial resistance, provided certain conditions are satisfied. Obviously, wastewater experts still play a key role in successfully implementing new concepts and making them practical in everyday life.

Another indication that our urban drainage system is not sustainable in the long term are the difficulties we are facing when attempting to introduce hydraulic sewer systems in developing or underdeveloped countries:

- integration into a comprehensive system of waste disposal is not feasible,
- high resource consumption (water, sewer system),
- lack of flexibility in the case of major population movements or growth,
- need for highly centralized organization,
- high costs.

Based on the Bellagio principles, which were formulated in 2000, EAWAG has developed a new concept for the practical application of integrated waste disposal in developing countries which puts the household at the center of the entire planning process (see article by A. Morel, p. 18). This “household-centred” approach is of interest also in Switzerland because it demonstrates, with a modern understanding of the issues, how the entire waste disposal concept can be rebuilt from the ground up and how the system can be operated with less capital investment and resource consumption. If we succeed in learning from such approaches and are able to integrate them into our existing structures, we will be able to operate our urban drainage systems sustainably and at a high level for a long time to come.

Max Maurer, chemical and process engineer, working in the area of wastewater treatment and sustainable urban water management in the department “Environmental Engineering” at EAWAG.

[1] Krejci, V., Lange J., Schilling W. (1992): Gewässerschutz bei Regenwetter. GAIA *1,* 72–83.

[2] Illi M. (1992): Von der Schissgruob zur modernen Stadtentwässerung. Hrsg.: Stadtentwässerung Zürich, Verlag: Neue Zürcher Zeitung, 264 S.

[3] Stadelmann X. F., Külling D., Herter U. (2002): Sewage Sludge: Fertilizer or Waste? EAWAG news *53,* 9–11.

[4] Lehmann M. (1994): Volkswirtschaftliche Bedeutung der Siedlungswasserwirtschaft. Gas, Wasser, Abwasser *74,* 442–447.

[5] Bundesamt für Umwelt, Wald und Landschaft BUWAL (2003): Kosten der Abwasserentsorgung. Mitteilungen zum Gewässerschutz, Nr. 42, BUWAL, Bern, 48 S. .

[6] Petersen G.I., Norrgren L., Holbech H., Lundgren A., Koivisto S. (2001): Suitablilty of zebrafish as testorganism for detection of endocrine disrupting chemicals. Nordic Council of Ministers. TemaNord 2001, 597 p.

[7] Larsen T.A., Gujer W. (2001): Waste design and source control lead to flexibility in wastewater management. Water Science and Technology *45,* 309–318.

[8] Larsen T.A., Gujer W. (1996): Separate management of anthropogenic nutrient solutions (human urine). Water Science and Technology *34,* 87–94.

[9] Abegglen C., Maurer M. (2003): Nitrifikationskapazität der ARA Arosa. EAWAG-Jahresbericht 2002, S. 22–23.

Micropollutants – New Challenge in Wastewater Disposal?

Through improved methods of chemical analysis, pharmaceutical and hormone-active substances are increasingly being detected in our water bodies. In most cases, they enter the waste water after being excreted in urine. In the sewage plant, a fraction of the substances is eliminated through sorption and biological degradation. The remaining part enters water bodies with the treated waste water. This article describes possible measures aiming at eliminating the residual substances. These include on the one hand, permanent measures at the source such as an eco label for pharmaceuticals, the pre-treatment of hospital waste waters and the separate treatment of urine. However, on the other hand, as the measures at the source can only be implemented over the long term, it is expedient to also consider technical measures such as raising the sludge age in the activated sludge tanks of sewage treatment plants and, for critical cases, the ozonation of the purified waste water.

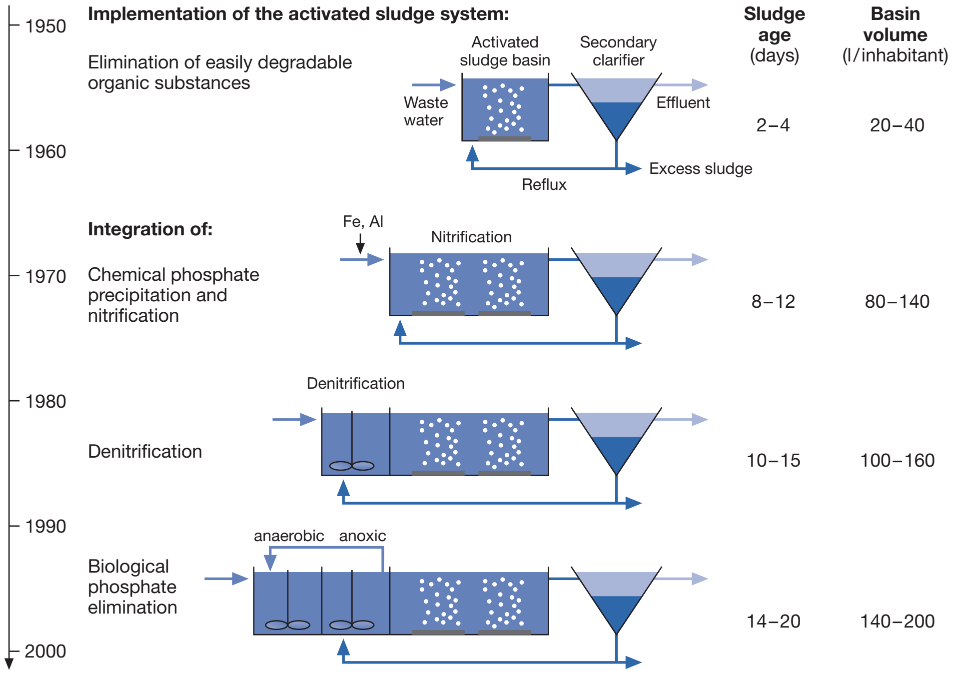
Today around 100 000 different chemicals are registered in the European Union (EU), of which some 30 000 are distributed on the market in quantities in excess of one tonne. [1]. It is unavoidable that during manufacturing, disposal and use of the substances, a proportion will enter the environment. Through constantly improving methods of chemical analysis, compounds in very low concentration ranges (micro- and nanograms per litre) are increasingly being detected in water bodies and in the sewage sludge; these are designated micropollutants. Amongst these are well known representatives such as the pesticide atrazine, the plastics additive bisphenol A and the petrol antiknock additive methyl-tertiary-butyl-methyl-ether. Less well known is that these also include many compounds used daily, for example, medicaments. Approximately 3300 different substances are used as medicaments in the EU today. Significant in terms of quantity are active agents used, amongst other purposes, as painkillers, antibiotics, antidiabetics, beta blockers, contraceptives, lipid reducers, psychotropic or cytostatic agents.

Pharmaceutical Residues in Water – a Hazard not to be Underestimated

Normally pharmaceutical substances enter the wastewater system through natural ex-

Historical Development of the Activated Sludge Method

Over the course of time, several processes have become integrated in the activated sludge system: At the beginning, sewage plants were designed only for the decomposition of organic substances. Since the end of the 1960s, phosphate was removed by chemical precipitation in order to reduce the phosphate loading of the lakes. Nitrogen, originating mostly from urine, has been eliminated since the end of the 1970s. By means of the nitrification process, ammonium which is toxic for fish is converted to the less critical nitrate. Nitrate, however, carries the risk of nitrogen over-fertilization of the coastal waters. Therefore, since the 1980s, nitrification has, in most cases, been supplemented with a partial denitrification in which the nitrate is converted to molecular nitrogen. The biological phosphate elimination through an upstream anaerobic zone was introduced in the 1990s. This brings about an enrichment in the sludge of bacteria with polyphosphate storage.



cretions such as urine or faeces. However, a considerable proportion of the pharmaceuticals contained in the waste water is also introduced through improper disposal via the toilet. A German study [2] investigated the occurrence of 55 pharmaceutical active agents and 9 metabolites in the discharge of 49 sewage treatment plants as well as in the receiving water bodies. Here, 36 active agents and 5 metabolites were detected in the sewage plant effluents in concentrations of up to several µg/l. Even in the water bodies, peak concentrations were measured in excess of 1 µg/l (e.g. beta blockers and anti-epileptic agents).

In addition, there has been much discussion in recent years of new environmental effects, such as excess female hormones in fish. This is partly a result of the chronic introduction of hormone-active (endocrine) substances. These include, along with the body's natural hormones, which are also discharged with the urine, pharmaceutical substances used for their hormonal effect, such as for example, contraceptives and antidiabetics. A hormonal secondary effect is also attributed to some other pharmaceutical active agents, such as β-sitosterol (cholesterine reducing agent) and clenbuterol (asthma relief agent), in addition to their principal non-hormonal effects. For most pharmaceuticals however, no endocrine effects are known. But this may simply be due to the fact that they have never been tested for any hormonal effects. It cannot therefore be ruled out that the group of pharmaceutical active agents with undesirable hormonal secondary effects is much larger than is generally assumed.

Unfortunately, little is known up to now how pharmaceutical residues behave on passing through the waste water in the sewage plant and the processes through which they are eliminated from the waste water. But such data would, on one hand, be indispensable for a more comprehensive environmental risk estimation and on the other hand provide the basis for elaborating measures to improve the biological and chemical degradation capability in sewage plants. By means of selected examples, this article provides an overview of the elimination processes and presents possible measures for discussion.

Elimination Process in the Municipal Sewage Treatment Plant

Whether trace substances can be eliminated in a sewage treatment plant depends essentially on the level of development of the biological purification stage. In the last 40 years, biological wastewater purification has been adapted step by step to the tightening of wastewater-introduction conditions. This is described in the box on page 7 using the most commonly employed activated sludge method.

The most important elimination processes are:

- the sorption to suspended solids in the waste water, which are removed by sedimentation as primary and secondary sludges in the primary and secondary clarifiers;
- the decomposition of substances through bacteria in the activated sludge, which is designated as biological mineralization or transformation;
- stripping by aeration; although for the trace substances under consideration, this process is negligible as they are mostly large, lipophile and only partially uncharged molecules with low volatility.

Sorption

In the case of the sorption of organic trace substances, a distinction is made between:

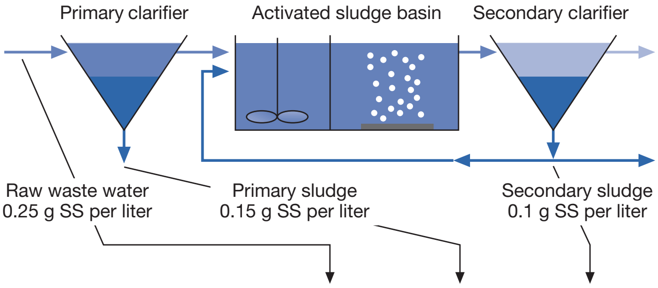
- absorption: hydrophobic interactions of the aliphatic and aromatic groups of a compound with the lipophile cell membrane of the microorganisms and the fat fractions of the sludge;
- adsorption: electrostatic interactions of positively charged groups of chemicals with the negatively charged surfaces of the microorganisms.

The quantity sorbed by a substance (C_{sorbed}), can be expressed by a simplified linear model. It is dependent upon the sorption constant K_d, the concentration of suspended solids (SS) to which the substance can adhere and the proportion of the substance present in dissolved form ($C_{dissolved}$):

$$C_{sorbed} = K_d \cdot SS \cdot C_{dissolved}$$

The sorption constant K_d has the unit l/g. With predominantly hydrophobic interactions, K_d can be estimated from the octanol-water distribution coefficient, or with electrostatic interactions, it must be determined by means of sorption trials.

A substance which sorbs relatively well to suspended solids is the antibiotic norfloxacin (Fig. 1) [3, 4]. The sorption is based to a large extent on electrostatic interactions between the positively charged amino group of norfloxacin and the negatively charged surfaces of the microorganisms. In a study carried out in the Zurich sewage plant at Werdhölzli, EAWAG was able to confirm that with an excess sludge production of 0.15 g/l, up to 80% norfloxacin is sorbed to the secondary sludge [4]. The reason for this is that microorganisms in the secondary sludge represent the greater proportion of the suspended solids, resulting in a relatively high sorption constant $K_d \approx 25$ l/g. For the primary sludge however, the sorption constant of norfloxacin is only $K_d \approx 2$, because in spite of having the same concentration of suspended solids, the primary sludge contains essentially fewer microorganisms but has instead a large fat fraction. Thus, only ca. 20% norfloxacin is sorbed to the primary sludge. With other substances, such as the anti-inflammatory diclofenac (active agent of voltaren) and



Compound	K_d (l/g)	Sorbed fraction in % ($100 \cdot K_d \cdot SS/(1+K_d \cdot SS)$		
Diclofenac	0.45/0.05	10	6	0,5
Ethinylestradiol	0.35/0.27	8	5	3
Norfloxacin	2/25	33	23	72

Fig. 1: Sorption constant and sorbed proportion of selected compounds to the suspended solids in the inflow as well as in the primary (with reference to the raw inflow) and the secondary sludges (with reference to the outflow of the primary clarifier) [3, 4]. Column K_d: first value for primary sludge, second value for secondary sludge.

substances belonging to the estrogen group, the proportion sorbed is essentially smaller (Fig. 1).

Sewage sludge is an important indicator for documenting the anthropogenic loading of the waste water through problematic substances. It is therefore important to retain the quality control, also after the ban of agricultural use of sewage sludge.

Biological Degradation

As the discussed trace substances mostly occur in the waste water in concentrations of 10^{-5}–10^{-9} g/l, biological degradation is only possible where the bacteria have a primary substrate available. In the case of the biological degradation of trace substances, a distinction is made between:

- co-metabolism, in which the bacteria only partly break down or convert the trace substance and do not use it as a carbon source;
- mixed substrate growth, in which the bacteria use the trace substance as a carbon and energy source, and hence totally mineralize it.

The transformation or decomposition of a substance can take place under aerobic and/or anaerobic conditions. It arises through the chance affinity of a trace substance with the bacterial enzymes in the activated sludge. Here the chance of decomposition also increases with the age of the sludge (Fig. 2). The reason is that the bacterial symbiosis becomes more diversified because slower growing bacteria can also grow in the sludge. This is demonstrated for instance with diclofenac and the contraceptive 17α-ethinylestradiol. A significant decomposition of both substances is only detectable when the activated sludge in the aerobic part of the plant is around 8 days old. With increasing sludge age the bacteria compete for more complex, less easily degradable compounds. However, the decomposition of the trace substances can be impaired in spite of a high sludge age. This may be the case when easily degradable substrates are present in the sludge or during periods of increased substrate loads. The natural estrogens 17β-estradiol and estron are mineralized in both the aerobic and the anoxic part of the biological purification stage. On the other hand, the synthetic 17α-ethinylestradiol decomposes only under aerobic conditions. Figure 3 summarizes the results of a study on the fate of 17α-ethinylestradiol [5].

Due to the low concentrations of trace substances, the decomposition occurs mostly as a first order reaction:

$r_{decomposition} = k_{decomposition} \cdot SS \cdot C_{micropollutant}$

In this case, a cascade type arrangement of the aerated basin is advantageous because this results in lower discharge concentrations than is the case with a fully intermixed basin.

Measures Taken at Source

Of course many active agents of pharmaceuticals or their intermediates represent polar substances which are biologically degradable to only a small degree or not at all and whose sorbing behavior to particles is similarly restricted. On passing through the sewage plant, they are only partly eliminated and end up in the water body with the sewage plant outflow. A permanent solution to this problem is only possible with measures taken at source.

Environment label for pharmaceuticals: It is hardly likely that a medicament would be banned because it is not biologically degradable in the environment. But in Sweden, an environment label is being introduced with the assistance of the chemical industry which enables the physician and the patient, where medicaments with a similar action are available, to select the treatment which is most environment-friendly [6].

Improving the environment assessment: Up to now, the ecotoxicological assessment of a chemical compound has mostly been based on a determination of the acute or chronic toxicity in the environmental systems. However, substances used because of their hormonal effect, as well as substances suspected of exercising a secondary hormonal effect in addition to their principal effect, must be given special attention [7]. It must be taken into account that hormone-active substances can be effective even in the smallest concentrations. Furthermore, when estimating the concentrations in the water body, the behavior of the substances in the sewage plant and the seasonal variation in the consumption of medicaments must be included in the calculation, which is not always a simple matter.

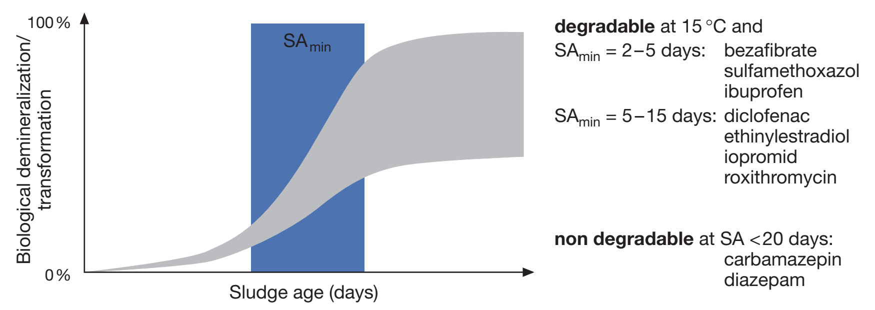


Fig. 2: The biological breakdown or transformation of a compound is dependent upon the age (SA) of the activated sludge [3].

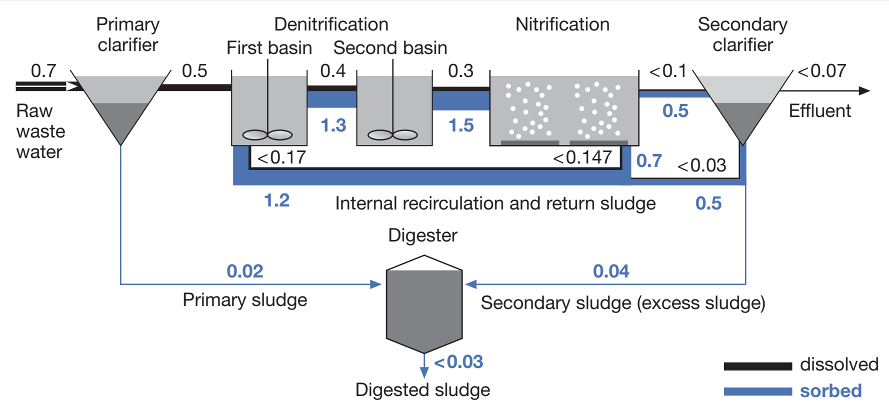


Fig. 3: Substance flow and breakdown of the contraceptive 17α-ethinylestradiol in the sewage plant at Wiesbaden, Germany [5]. The data are in g per day. The value in the inflow covers both the free dissolved and conjugated ethinylestradiol.

Separate treatment of hospital wastewater: Hospital waste water is, in most cases, heavily contaminated with medicaments. Moreover, it seems that the development of bacterial resistances may especially occur in hospital waste water because it also contains a considerable amount of antibiotics than domestic waste water [8]. The separate treatment of hospital waste water, for instance with a membrane bioreactor for separating the germs and by means of ozonation of the discharge resulting in the oxidation of the dissolved, persistent pharmaceuticals is therefore to be considered.

Urine separation: Since pharmaceutical substances and hormones are to a great extent excreted with the urine, a separation and separate treatment of the urine would significantly reduce the medicament loading of the waste water (see also the article by J. Lienert, p. 14). This would allow reusing treated waste water in toilets and gardening and therefore reducing drinking and wastewater fees.

Percolation of rain water: A separated drainage and percolation for the rain water reduces both the heavy metal load and the burden of organic pollutants in the wastewater and sewage sludge (see also the article by M. Boller, p. 25).

Further Measures in Municipal Wastewater Treatment

As the introduction of the described measures to be taken at the source is rather time-consuming and certainly requires a number of decades, it is reasonable in the short term to develop additional chemical or physical measures for wastewater treatment. But these technical measures should not replace the measures at source.

Increasing the sludge age: Organic trace substances are significantly better decomposed when the age of the activated sludge is around eight days or more (Fig. 2). But not all sewage plants in Switzerland and the EU satisfy these requirements. Upgrading of medium sized and larger sewage plants to a total sludge age of 10–15 days – nitrification combined with denitrification (see box on p. 7) – is therefore beneficient. This would have the additional advantage of efficiently eliminating the nitrogen so that the EU requirement specifying 70–80% nitrogen elimination for sewage plants in the catchments of sensitive water bodies such as the Rhine, could be satisfied simultaneously. If the plants were also to be extended with an upstream anaerobic zone for the biological phosphorus elimination (see box on p. 7), the possibility for a separate partial recovery of the phosphate by redissolving polyphosphate from the excess sludge combined with chemical precipitation would arise. This is a technique which has up to now undergone few large-scale trials but which is investigated together with the phosphate industry in Holland. This would partially permit restarting the recycling of phosphorus, which was interrupted by the ban on the use of sewage sludge for agricultural purposes [9].

Ozonation of the biologically purified discharge: In the case of ecotoxicological doubts (insufficient dilution of the waste water in the receiving body, high sensitivity of the water body and direct infiltration of the wastewater into the underground) partial ozonation of the biologically purified waste water should be taken into account before the sewage is discharged. After treatment with 5–10 mg ozone per m^3 waste water, pharmaceuticals are normally no longer detectable [10]. Only the iodized radiological contrast agents mostly originating from hospital waste water were unable to be totally oxidized. The effectiveness of the ozone is dependent on the background level of the waste water with dissolved organic carbon and the chemical properties of the residual substances [11]. An ozone concentration of 5 g/m^3 is, in most cases, sufficient with the low background loads occurring in Switzerland. Although the price is only a few cents per m^3 of waste water, the energy expenditure is ca. 0.1 kWh/m^3, and is therefore significant in comparison with the total energy consumption of a plant. Thus, the application of the process is limited to critical cases. In any case, the fate of the metabolites occurring with the ozonation is to be investigated prior to any large-scale application.

Advanced processes, such as nanofiltration and active carbon adsorption, are too costly and only of interest if the waste water is used for groundwater recharging or directly as drinking water. Certainly in the short term, measures taken at the level of the sewage plant will bring quicker success. But in the long term, permanent measures taken at the source are preferable.

Hansruedi Siegrist, environment engineer is head of the department "Environmental Engineering"; he is studying the chemical, physical and biological processes of municipal wastewater treatment.

Coauthors: Adriano Joss, Alfredo Alder, Christa McArdell-Bürgisser, Anke Göbel, Elvira Keller, EAWAG, und Thomas Ternes, Bundesanstalt für Gewässerkunde, D-56068 Koblenz

[1] Giger W. (2002): Dealing with Risk Factors. EAWAG news *53,* 3–5.

[2] Ternes T. (1998): Occurrence of drugs in German sewage treatment plants and rivers. Water Research *32,* 3245–3260.

[3] EU-Project Poseidon (2002/2003): Periodic Reports. www.eu-poseidon.com.

[4] Golet E., Xifra I., Siegrist H., Alder A., Giger W. (2003): Environmental exposure assessment of fluoroquinolone antibacterial agents from sewage to soil. Environmental Science & Technology *37,* 3243–3249.

[5] Andersen H., Siegrist H., Halling-Sørensen B., Ternes T. (2003): Fate of estrogens in a municipal sewage treatment plant. Environmental Science & Technology, *37,* 4021–4026.

[6] Wennmalm A. (2003): A proposed environmental classification system for medicinal products. Envirpharma conference, Lyon, France.

[7] Knacker T. (2003): Preliminary Environmental risk assessment for pharmaceuticals and personal care products (PPCPs). Envirpharma conference, Lyon, France.

[8] Giger W., Alder A., Golet E., Kohler H., McArdell C., Molnar E., Pham Thi N., Siegrist H. (2003): Antibiotikaspuren auf dem Weg von Spital- und Gemeindeabwasser in die Fliessgewässer: Umweltanalytische Untersuchungen über Einträge und Verhalten. Tutzing Symposium, Deutschland.

[9] Roeleveld P., Loeffen P., Temmink H., Klapwijk B. (2003): Dutch analysis for P-recovery from municipal wastewater. Proceedings of the international conference: Biosolids 2003 – Wastewater as a resource, Trondheim, Norway, p. 263–270.

[10] Ternes T., Stüber J., Herrmann N., McDowell D., Ried A., Kampmann M., Teiser B. (2003): Ozonation: a tool for removal of pharmaceuticals, contrast media and musk fragrances from wastewater? Water Research *37,* 1976–1982.

[11] Huber M., Canonica S., Park G., von Gunten U. (2002): Oxidation of pharmaceuticals during ozonation and advanced oxidation processes. Environmental Science & Technology *37,* 1016–1024.

The Driving Forces for Change in Wastewater Treatment

How do changes in the economic and social framework affect the future technical development of wastewater treatment? The EAWAG research group CIRUS – Centre for Innovation Research in the Utility Sector – focuses on this question in the German study "Integrated Microsystems for Supply".

A number of promising innovations, such as the separation of wastewater streams and the reuse of minimally-polluted waste water, have been discussed in wastewater treatment circles for some time. If implemented, they could result in an improvement of the currently centralized sewage and wastewater treatment systems [1]. Since, however, wastewater systems have such a long operational life-span, characterized by equally long-term investment cycles, such innovations are not easily realized. At present, there appear to be changes in the driving forces that could affect the assessment of alternative approaches and thus the future of wastewater treatment.

The goal of the research group CIRUS at EAWAG is to analyze in detail what these driving forces are and what effects they may have on wastewater treatment. The EAWAG group is collaborating with German researchers, focusing on electricity, gas and telecommunication. The project "Integrated Microsystems for Supply" is funded by the German Federal Ministry of Education and Research.

Using an extensive literature search and the results of some 20 interviews conducted with experts from the water and sanitation utilities, associations, construction companies, regulatory agencies, consumer protection organizations and research institutions, roughly two dozen factors that drive changes in this field were identified. We weighed these factors according to the impact and uncertainty concerning their potential for inducing change [2]. Some selected results are presented in this article.

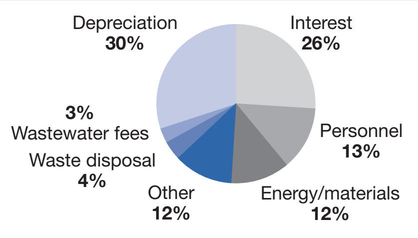


Fig. 1: Breakdown of costs in wastewater treatment [5].

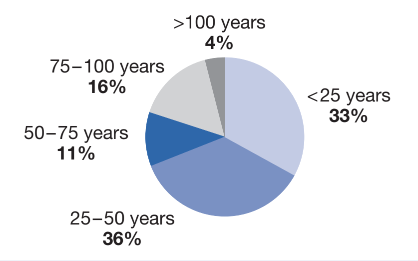


Fig. 2: Age structure of the German sewage system [10].

Fees and Fee Structures

In Germany, fees for wastewater treatment are currently calculated to cover only actual costs. Municipalities are allowed to pass on the full cost to the consumer, but are not allowed to derive any profit. In 2002, the average wastewater fee was 2.24 €/m^3, which translates to an annual cost of 117 € per person [3].

Between 1988 and 1996, the fees increase after adjustment for inflation amounted to 55% [4], leveling off between 1997 and 2002. The price for drinking water must also be considered a driving force since it affects consumption and so indirectly impacts the resulting volume of waste water requiring treatment. Between 1992 and 2001, the price increase (excluding inflation) for drinking water was just under 28%.

From the perspective of the waste treatment industry, the reciprocal character of the cost vs. price structure is extremely important: In wastewater treatment, the short-term fixed costs, i.e., the costs that are independent of changes in the volume of waste water to be treated, amount to roughly 75% of the total costs [5]. Figure 1 provides an overview of the entire cost structure in the wastewater treatment sector. On the other hand, the price structure has a relatively low share of fixed elements (between 10–30% of the total bill), which is often a reflection of environmental policy and incentives for efficient use of the water resources. But this also implies that the consumer has a much higher financial saving from reduced consumption than the utility. This, in turn, leads to price increases, which are needed to cover fixed costs for the capital intensive centralized infrastructure.

Backlog on Investment

Also critical to future development will be the manner in which investments in wastewater treatment plants and other infrastructure are managed. Figure 2 illustrates that 31% of the public sewage system is older than 50 years. With an average lifetime of approximately 70 years for sewage pipes, we can estimate that between 20 and 30% of the roughly 450 000 km of sewage pipes in Germany are currently in need of replacement. According to Stein [6], immediate needs are even higher in the Eastern part of Germany, where 50% or more of the sewage system may need to be replaced. Normally, an annual renewal rate of 1.5% is deemed adequate.

This discrepancy between theoretical renewal rates and the actual replacement needs is a consequence of investments that have been delayed too long. Facing ever

Interview partner working in the area of research:

"As a private citizen, I want to use as little water as possible, not because drinking water is scarce, but because I want to pay as little as possible for drinking water and wastewater disposal. Therefore, I go out and buy a water saving toilet, a water saving washing machine and a water saving dish washer. So, my interests are, diametrically opposed to the interests of the operators of the centralized water systems – and actually, they are outside their area of influence."

Interview partner from one of the sector associations:

"… the market does not give centralized systems any special consideration … operators of wastewater treatment plants look at their system of sewage pipes and figure that everybody is forced to connect to it, so everything will come out ok. But if Matushita in Japan or Technics, Miele, Bosch and Siemens bring a wastewater-free dish washer on the market, who says that this does not throw the whole system and that everything can go into the garbage? And which politician would dare to demand that such a machine not be built? … All this has dramatic consequences for centralized systems. Meanwhile, they keep harassing those few rain water users. They have no idea what is going on in other areas, or they just don't have anything to say in those areas."

tighter financial situations, communities have cut maintenance from their budgets. In 2000, investments were at roughly 50% of what should have been spent. A significant portion of the fees collected was used for purposes unrelated to wastewater treatment [7]. With estimated replacement costs of 500 € per meter of sewage canal, and an annual renewal rate of 1.5% for the entire system, the annual investment amounts to 3.4 billion €. Replacing the 20% of the system that is older than 75 years all at once, would amount to 45 billion €. This translates to an average per capita cost of 562 €, only making up for overdue investments. This amount is almost five times the current annual per capita bill for wastewater treatment.

Population Decrease

Additional challenges for wastewater treatment planning in Germany arise from decreasing birth rates and the migration from cities to suburbs. According to current predictions, only a few German cities will have a stable population after 2015. In the eastern part of Germany, as many as 25% of the apartments could be untenanted [8].

Significantly decreasing populations cause the central water and wastewater systems to operate well below the nominal load for which they were designed, which leads to hygiene problems and technical difficulties. For example, drinking water could become contaminated with microorganisms if the retention period in the pipelines becomes too long. Regular flushing of the pipes is a possible remedy, although this would increase the cost, which in turn would have to be shouldered by a shrinking number of users.

Decrease in Water Consumption

Overall, water consumption has significantly dropped over the last few years. Between 1990 and 2001, the average water consumption per person and per day fell by 15% from 150 liters to 128 liters. These numbers include private households and small commercial operations. The consensus according to our interviewees is that the reduction is due to greater environmental awareness and to the increased cost of drinking water and wastewater treatment.

Another factor that has very recently gained importance are innovative and more efficient appliances and hardware, including water-saving faucets in showers and sinks and smaller toilet tanks, which already are widely used. They may be installed at very low cost, often just a few Euros, but have a relatively high water-saving effect. Once manufacturers of dishwashers and washing machines, in particular, discovered that water efficiency is an attractive marketing tool, water consumption for such appliances dropped significantly (Fig. 3). More recently, they have developed some pilot models of appliances that internally cycle at least part of the water they use [9].

Advances in Membrane Technology

Advances in membrane technology play an important role in further reducing water consumption. This is a so-called enabler technology, i.e., it facilitates the development of alternative systems. Due to their relatively high efficiency but small size, these membrane systems are well suited for applications in small, decentralized operations. Some of the interviewees consider progress in membrane technology to be one of the

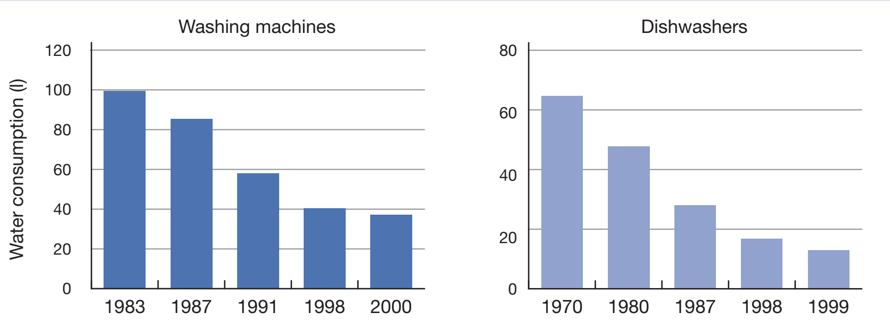


Fig. 3: Water consumption of household appliances clearly decreased in the past 20–30 years [11].

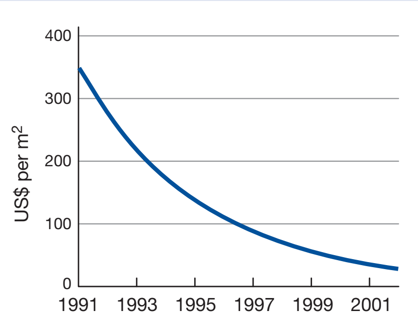


Fig. 4: Cost decrease for ultrafiltration membranes [12].

most important prerequisites for the viability of decentralized technologies. Membrane technology can, for example, increase efficiency and reduce the size of treatment systems for so-called grey water, i.e., minimally polluted water from showers and sinks. This technology could rapidly bring such recycling systems into the range of economic feasibility for households and small commercial operations. Considering that the cost per m^2 filter area has been steadily falling (Fig. 4), it seems likely that membrane technologies will soon be able to penetrate the household and commercial market sectors.

Moving Away from Centralized Solutions?

According to the majority of our interviewees, urban water management is considered a rather stable, long term-oriented and not very innovative sector. Summarizing all potential driving forces for change, however, scenarios can be developed that would lead to major change. On one hand, the mostly communal operators of water systems are faced with a rather unfavorable cost/price structure, high investment needs and tight budgets; on the other hand, the volume of waste water has decreased significantly over the past 15 years, a trend that is likely to continue in the decades ahead considering projected demographic developments, additional fee increases and new technologies. Both of these processes overlap and reinforce one another, while the wastewater treatment industry has very little influence over either [2].

Figure 5 illustrates the dynamics that the combination of these forces could unleash and summarizes how these changes could pose a serious challenge for the currently centralized systems. The proper operation, maintenance and service of an alternative, decentralized system is critical and could spawn the development of a sector, transforming former water suppliers and waste disposal operators to service providers.

It appears unlikely at this point in time, however, that the centralized water and wastewater systems will be replaced entirely by decentralized alternatives in the short- to mid-term. It is likely, though, that decentralized concepts may become established in certain niches, such as urban areas or regions where a high investment need coincides with a dramatic decrease in water demand. This would, for example, apply to newly constructed or newly rebuilt areas, which would not have to be connected to the existing sewage system, but would function as nearly zero wastewater producers, using a combination of approaches such as the recycling of process water, separation of wastewater streams, decentralized treatment of rain water, and small community treatment plants. The question which political decision makers have to face, as for example in some regions in eastern Germany, is whether or not additional investments in centralized systems are economically and technically reasonable.

No one can predict with any certainty what developments will actually take place. It is useful for the forward-looking water supplier or wastewater treatment operator, however, to study possible development scenarios in greater depth. The detailed formulation of scenarios for the development of the infrastructure and of consequences for the various actors (regulator, industry and consumer) will comprise the next phase of the project and is scheduled to be published in spring 2004.

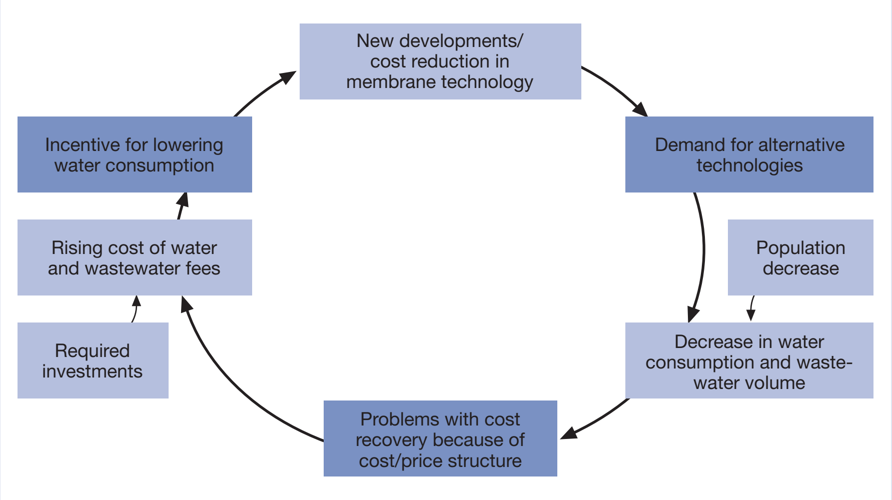


Fig. 5: Effects of the driving forces.

Dieter Rothenberger, environmental economist, is working in the department "Applied Water Ecology" within the working group CIRUS, where he is dealing with sustainable transformation and deregulation of infrastructure sectors as well as strategies for the supply industry and regulatory agencies.

Further information:
www.cirus.eawag.ch
www.mikrosysteme.org

[1] ATV-DVWK (2002): Überlegungen zu einer nachhaltigen Siedlungswasserwirtschaft. Arbeitsbericht der Arbeitsgruppe GB-5.1. Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall (ATV-DVWK), Hennef, 40 S.

[2] Rothenberger D. (2003): Report zur Entwicklung des Versorgungssektors Wasser. Bericht zum Projekt "Integrierte Mikrosysteme der Versorgung», Bundesministerium für Bildung und Forschung, Deutschland, 124 S., www.mikrosysteme.org/documents/Report_Wasser.pdf

[3] ATV/DVWK/BGW (2003): Marktdaten Abwasser 2002. Ergebnisse einer ATV-DVWK/BGW-Umfrage. Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall (ATV-DVWK), Hennef, 12 S.

[4] Rudolph K.-U., Kraemer A.R., Hansen W., Staffel U. (1999): Vergleich der Abwassergebühren im europäischen Rahmen. Umweltbundesamt, Berlin, 172 S.

[5] Bundesverband Gas und Wasser (2002): Trinkwasser-Marktdaten. www.bundesverband-gas-und-wasser.de/bgw

[6] Stein D. (2001): Sanierung der Kanalisationen. Eine finanzielle und technische Herausforderung. www.ruhr-uni-bochum.de/rubin/rbin2_95/rubin7.htm

[7] bbr Fachmagazin für Wasser und Leitungstiefbau (2003): Aus den Augen, aus dem Sinn? *54,* 10–12.

[8] Pfeiffer U., Simons H. Porsch L. (2000): Wohnungswirtschaftlicher Strukturwandel in den neuen Bundesländern. Bericht der Kommission im Auftrag des Bundesministeriums für Verkehr, Bau- und Wohnungswesen. Berlin, 89 S.

[9] Lange J., Otterpohl R. (2000): Abwasser. Handbuch zu einer zukunftsfähigen Wasserwirtschaft. Mallbeton, Donaueschingen, 301 S.

[10] Esch B., Thaler S. (1998): Abwasserentsorgung in Deutschland – Statistik. Korrespondenz Abwasser *45,* 850–864.

[11] Miele (2003): Information der Öffentlichkeitsarbeit der Miele & Cie. KG.

[12] Gimbel, R. (2003): Membraneinsatz in der Trinkwasserversorgung. Vortrag im Rahmen des Workshops "Forschung in Deutschland – Wasserforschung im bmb+f" anlässlich des Kongresses "Wasser Berlin" am 9.4.2003. Berlin.

NoMix Technology: How Good is the Acceptability?

The successful implementation of an innovative technology depends on many factors. Apart from its technical superiority compared to traditional solutions, the needs of the stakeholders play a vital role. We were interested to know whether the market is ready for the NoMix technology, a sanitary concept for urine source separation, which would revolutionize our current system of wastewater management. Surveys showed that consumers and farmers have a positive attitude, given that the NoMix technology is adequate, inexpensive, and safe. Sanitary firms are confident that they can further develop NoMix toilets, but they demand strong commitment from wastewater professionals who will, therefore, play a deciding role in putting the NoMix technology into practice.

Originally, the urban wastewater system was designed as a transport system. The underlying principle has hardly changed over the past hundred years. More and more, wastewater professionals realize that it is difficult to meet modern requirements of water pollution control with these old structures. On the one hand, the urban wastewater system still has gaps, e.g. houses that are not connected to the sewer system or leaky sewers and combined sewer overflows which discharge untreated waste water directly into surface waters or into the ground water. On the other hand, wastewater treatment plants have to meet increasing demands; e.g. it is still unknown whether micropollutants such as pharmaceuticals and synthetic or natural hormones, which are mainly excreted via urine, can be efficiently eliminated in treatment plants. Measures at source – such as urine separation – could help solving such problems. Additionally, although only 0.5% of the waste water from households is urine, this fraction is responsible for most of the nutrients arriving at wastewater treatment plants. Urine, therefore, significantly contributes to the charge of the treatment plants. The separate collection and treatment of urine, thus, offers entirely new possibilities to increase the efficiency of wastewater treatment [1].


Y. Lehnhard, EAWAG

Would you buy these vegetables if you knew they were produced with an urine fertilizer?

Urine Source Separation via NoMix Technology

The NoMix technology consists of specifically designed toilets for the separate collection of urine. The urine is stored in urine tanks and can then be transported to the treatment plant at favorable times, either via the existing sewer system or by special trucks. Additionally, the urine could be treated in special urine processing plants (Tab. 1). These would offer the advantage of an easier elimination of micropollutants. The raw urine could also be processed into a fertilizer product, which could partially replace artificial mineral fertilizers. Technology version A – separate collection and use of stored urine as fertilizer – is already being practiced. Versions B and C, however, are new, but they could easily be integrated into the existing sewer system and have advantages for the treatment plants (Tab. 1). Thus, introducing the NoMix technology could increase the efficiency of treatment plants, improve water pollution control and close nutrient cycles. At EAWAG, the interdisciplinary research project NOVAQUATIS deals with the NoMix technology [2]. Issues addressed are in addition to sanitary technology, storage, transport and processing of urine, production of fertilizer also the question whether this technology can win the necessary acceptance of stakeholders. Traditionally, new technologies in wastewater management were developed by professionals without participation of the public. This is not appropriate for urine separation in households. Therefore, already at an early stage of the research, NOVAQUATIS integrates users of NoMix toilets, farmers applying urine-based fertilizer, the sanitary industry, as well as wastewater professionals who will have to apply and promote this new technology. In this article, we present the results of several surveys and a theoretical analysis.

Positive Response of Consumers and Farmers

Consumer attitudes towards the NoMix technology were explored in several focus groups [3]. Focus groups are moderated group discussions with informed citizens on a well-defined topic. The 44 participants were informed by a computer based information system [4] and visited a NoMix toilet. 71% of the men and 89% of the women thought the NoMix toilet is a good or very good idea. With 88%, most of the men would move into an apartment with NoMix technology, but only 42% would buy a NoMix toilet. Similarly, 79% of the women could imagine living in a flat with NoMix technology and even 63% were willing to buy a NoMix toilet. Consumers stressed the importance that the new technology would equal today's level of comfort and cost. Interestingly, only 16% of the men stated that they do not sit down for urinating, which is necessary for the functioning of the NoMix toilets available today. With 72%, the majority of the interviewed persons would also buy food grown with the help of a urine-based fertilizer and even 80% prefer urine-based fertilizer to artificial mineral fertilizer. However, the participants emphasized that any risk concerning hygiene and micropollutants would have to be excluded.

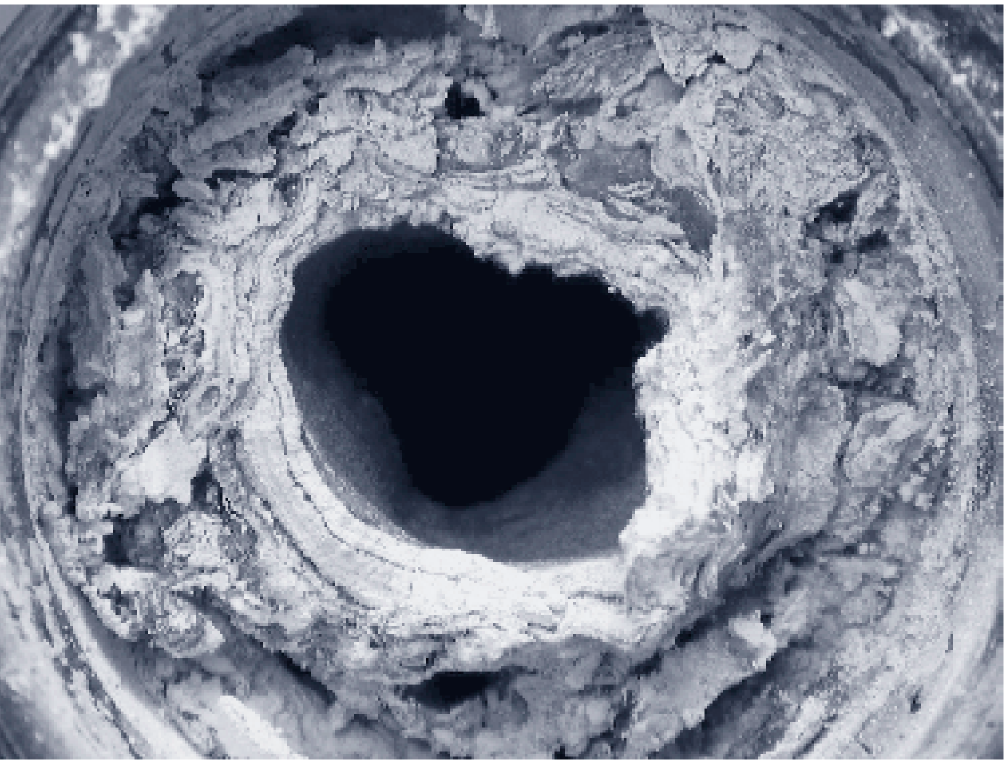
A mail survey among 467 farmers in the German speaking part of Switzerland showed similar results [5]. Unfortunately, this survey cannot be regarded as representative: first, because only 27% of the questionnaires were returned and second, because the answers of IP- (integrated production) and organic farmers differed significantly. Nevertheless, the survey gave some important indications: 57% of the farmers regard urine source separation as a good or very good idea and 42% would purchase a urine-based fertilizer product. The chances of opening a market for a urine-based fertilizer are presumably high in those cases where additional fertilizer is purchased anyway, i.e. especially for IP- and vegetable production. Farmers also demand a product without risk: 30% mentioned concerns that the fertilizer might contain micropollutants. The preferred type of fertilizer would be a grainy and odorless nitrogen fertilizer. From these first surveys, we conclude that the NoMix technology could be accepted, given it is cheap, safe, and at least as comfortable as the current technology.

Sanitary Industry: Market for NoMix Does not yet Exist

Urine source separation is a technology that has been applied for several millenniums. Thirty years ago, this tradition was again

	NoMix technology version		
	A	**B**	**C**
Duration of storage	6 months Local storage of urine for hygienization	3–7 days Short-term local storage of urine	1–2 days NoMix toilet with integrated urine tank
Transport	Trucks	Sewer system Central control of urine drainage via existing sewer system during nights without rainfall (i.e. while minimal amounts of other waste water is drained via the system) Before reaching the general treatment plant, urine is led to a special processing plant	Sewer system Central control of urine drainage via existing sewer system (see version B)
Urine processing	No	Yes In central urine processing plants Removal of micropollutants and processing into a fertilizer product	Yes Together with waste water in existing treatment plants
Nutrient recycling	Yes Direct use of stored urine as fertilizer in agriculture	Yes Fertilizer product for agriculture (maybe industry)	No
Main intention	Nutrient recycling Improved water pollution control with simpler wastewater treatment plants	Nutrient recycling Improved water pollution control with simpler wastewater treatment plants	Transition scenario "Peak-shaving" of nutrient load in treatment plants, thus increasing capacities Less urine in combined sewer overflows, where untreated waste water is directly discharged to surface waters
Literature	Johansson, 2001 [6]	Larsen and Gujer, 1996 [1]	Rauch et al., 2003 [12]

Tab. 1: Attributes of the three NoMix technology versions [7]. All three versions consist of a NoMix toilet and a urine collection tank.


K. Udert, EAWAG

A urine conducting pipe clogged by urine precipitates.

taken up in Scandinavia and from 1990 on, modern NoMix toilets were produced in Sweden. Between 1992 and 1996, about 3000 NoMix toilets were installed in more than 15 pilot projects [6, 7]. A technologically refined and attractive NoMix toilet is available today [8]. However, it is essential to further improve the sanitary technology, since some problems are still unsolved such as the precipitation of urine which leads to a clogging of the urine conducting pipes and to the development of unpleasant odors [9]. Since beginning of the project, NOVAQUATIS has kept in close contact with the sanitary industry. The larger companies are convinced that the development of modern NoMix installations is possible. Unfortunately, the market for NoMix technology is not yet visible. Therefore, the sanitary industry is still hesitant to invest on a large scale.

Wastewater Professionals Holding the Key Position

How can the NoMix technology gain broader acceptance and wider diffusion? Presumably, the attitude of the wastewater professionals is the most critical factor for the development of the NoMix technology. In order to understand the attitudes of wastewater professionals and to identify the crucial factors, we used the classical diffusion theory. Rogers [10] defined five main attributes, which are relevant for the diffusion rate of an innovation – i.e., relative advantage, compatibility, complexity, observability, and trialability (definitions see Tab. 2). Moreover, according to the diffusion theory, the acceptance of an innovation over time normally follows an s-shaped curve. After a rather slow start, a successful innovation "takes off" and adoption occurs rapidly (Fig. 1). It seems that wastewater professionals re-

Definition of attributes (according to Rogers, 1983 [10])	**Possible attitude of wastewater professionals**
The **relative advantage** is the degree to which an innovation is perceived as being better than the idea it supersedes (often expressed as economic advantage, status giving etc.).	Large uncertainties: ▪ Benefit for ecology is significant, but difficult to quantify ▪ Costs are unknown in initial stage
Compatibility is the degree to which an innovation is perceived as consistent with the existing values, past experience, and needs of potential adopters.	▪ NoMix technology has to prove its superiority in practice ▪ Paradigm shift from central wastewater treatment in treatment plants to a decentralized system "at source" is necessary ▪ Contradictory to traditional approaches of problem solving
Complexity is the degree to which an innovation is perceived as difficult to understand and use (not to be confounded with the notion of complexity in natural sciences).	Separation of liquid wastes: ▪ Possibly difficult to understand (yet well known from solid wastes) ▪ Technological challenge
Trialability is the degree to which an innovation may be experimented with on a limited basis.	Limited trialability, especially of technology version B and C (Tab.1)
Observability is the degree to which the results of an innovation are visible to others.	Limited observability, because of ▪ Preventive measures ▪ Long periods of time ▪ Abstract concepts

Tab. 2: The five attributes, often of prime importance for the diffusion rate of an innovation [10], and their application on the possible attitude of wastewater professionals towards the NoMix technology [7].

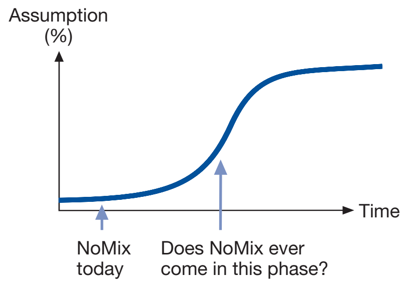


Fig. 1: Diffusion of innovations [10]. After a rather slow start, a successful innovation suddenly "takes off".

gard the NoMix technology as disadvantageous in most of the five attributes (Tab. 2) [7]. In the following, two of the most relevant attributes are discussed in more detail:

- The **relevant advantage** of an innovation compared to the existing technology is often assessed by a cost-benefit-analysis, e.g. by comparison of ecological advantage and monetary expenses. This kind of analysis is difficult to perform in the case of the NoMix technology, because of numerous uncertainties, especially concerning the costs, which exist in the initial stage. Therefore, a relatively cheap technology such as version C (Tab. 1), which allows depreciating investments already made in the existing system, will have better chances.
- The **compatibility** of NoMix with an existing technology is perceived as low. Especially wastewater professionals are – with good reason – convinced that the existing system is very successful concerning hygiene and comfort. A new technology will have to prove its equality. Another obstacle for the implementation of the NoMix technology is the necessity of a paradigm shift leading away from a central wastewater treatment in treatment plants to a decentralized collection and processing of urine. Yet, presumably many wastewater professionals do not see any urgency to give up the current system. Up to now, it was possible to solve new wastewater problems in a single step within the treatment plant. Thus, from a traditional point of view, searching for radically new approaches in order to solve many problems simultaneously is unfamiliar. Hence, the technology versions which can easily be integrated in the existing structures are probably more successful.

This first analysis [7] might explain why the diffusion of NoMix technology among wastewater professionals is rather slow. Further studies are needed in order to better identify those factors, which might cause a breakthrough for the NoMix technology. This is why pilot projects demonstrating a successful implementation play a very important role [11].

First Pilot Building with NoMix Technology: Cantonal Library in Liestal

For the first time in Switzerland, the NoMix technology will be fully implemented in the cantonal library of Basel-Landschaft in Liestal. The installations for urine source separation consist of NoMix toilets, a urine collection tank and a computer-controlled release of the urine from the storage tanks. The pilot building is expected to be finished in 2005. It offers ideal conditions to test the innovative sanitary technology, because the toilets will be visited by a mixed and interested public with a diverse socio-cultural background. Based on the experiences made here, guidelines for future construction purposes shall be defined [11].

On a smaller scale, the NoMix technology is already being tested in a series of other projects: four apartments in a Swiss city were equipped with NoMix toilets, and EAWAG and the University of Applied Sciences Basel (FHBB) are also testing different types of NoMix toilets. These projects are very important in order to identify the flaws of the new technology and to explore user attitudes with the help of questionnaire surveys. The experiences will lead to recommendations for the further development of the NoMix technology by the sanitary industry.

In conclusion, society seems to be open for the new, unconventional NoMix technology and the sanitary industry seems to be willing to advance the technology. Therefore, the crucial factor for a successful diffusion of the NoMix technology is presumably its acceptance by wastewater professionals. Transition scenarios that can easily be integrated into the existing system (version C, Tab. 1) have good chances of being accepted by all stakeholders – including wastewater professionals.

Judit Lienert, biologist, is coordinating the project NOVAQUATIS as deputy project manager. She is interested in interdisciplinary and transdisciplinary research and the intersection of science and practical application.

Tove A. Larsen, chemical engineer and project manager of NOVAQUATIS. She examines possibilities of introducing a sustainable urban wastewater management.

Further information: www.novaquatis.eawag.ch

[1] Larsen T.A., Gujer W. (1996): Separate management of anthropogenic nutrient solutions (human urine). Water Science and Technology *34,* 87–94.

[2] Lienert J., Larsen T.A. (2002): Urinseparierung – eine Alternative für die schweizerische Siedlungswasserwirtschaft? gwa – Gas Wasser Abwasser *11,* 819–826.

[3] Pahl-Wostl C., Schönborn A., Willi N., Muncke J., Larsen T.A. (2003): Investigating consumer attitudes towards the new technology of urine separation. Water Science and Technology *48,* 57–65.

[4] http://www.novaquatis.eawag.ch/english/NoMixtool_e.html

[5] Lienert J., Haller M., Berner A., Stauffacher M., Larsen T.A. (2003): How farmers in Switzerland perceive fertilizers from recycled anthropogenic nutrients (urine). Water Science and Technology *48,* 47–56.

[6] Johansson M. (2001): Urine separation – closing the nutrient cycle. Final report on the R&D project “Source-separated human urine – a future source of fertilizer for agriculture in the Stockholm region?» Stockholm Water Company, Stockholm, 40 p.

[7] Larsen T.A., Lienert J. (2002): Societal implications of re-engineering the toilet. Proceedings of the IWA Leading Edge Conference Series “Sustainability in the Water Sector», Venice, p. 29. Water Intelligence Online, submitted.

[8] www.roevac.com

[9] Udert K., Larsen T.A., Gujer W. (2003): Estimating the precipitation potential in urine-collecting systems. Water Research *37,* 2571–2582.

[10] Rogers E.M. (1983): Diffusion of Innovations. Collier Macmillan Publishers, London, 453 p.

[11] Kühni M., Koch G., Ott E. (2002): Zukunftsweisende Sanitär- und Abwassertechnik – Erstes Pilotprojekt der Schweiz für Urinseparierung, -speicherung und -steuerung im technischen Massstab. gwa – Gas Wasser Abwasser *11,* 827–835.

[12] Rauch W., Brockmann D., Peters I., Larsen T.A., Gujer W. (2003): Combining urine separation with waste design: an analysis using a stochastic model for urine production. Water Research *37,* 681–689.

Alternative Environmental Sanitation Approaches in Developing Countries

Half of the world population does not have access to hygienic sanitation systems. The conventional "top-down approaches" often fail. Therefore, EAWAG together with an international group of experts developed the "Household-Centred Environmental Sanitation (HCES) Approach" which places the household in the centre of the planning process.

The number of people around the world who still do not have access to adequate water, sanitation, drainage and solid waste disposal services is alarming (see box). This worrying situation provides sufficient evidence that past and current conventional approaches to environmental sanitation are unable to make a significant dent in the service backlog which still exists. At the same time, the world's natural supply of freshwater is subject to increasing environmental and economic pressures. The situation is likely to worsen dramatically unless determined action is taken. Continuing increases of population and per capita water demand, fuelled by improving economic conditions, will further contaminate and deplete finite and often over-exploited sources of water.

A new approach has been developed by EAWAG in cooperation with international leading experts to overcome the serious lack of sanitation services, causing illnesses and slowing the economic progress of hundreds of millions of people in developing countries: the "Household-Centred Environmental Sanitation (HCES) Approach".

New Paradigm and Working Principles are Needed

There is a need to challenge conventional thinking. This must be done persuasively to the wider international water resources and waste management community, as well as among the broader community of economic, social, and urban policy-makers. The basis for this need is as follows:

- "Business as usual" cannot provide services for the poor; the rapid rate of urbanization poses particular problems of squalor, human indignity, and threat of epidemic.
- "Business as usual" is not sustainable even in the industrialized world; sewage and drainage systems are over-extended and the use of water of drinking quality to transport human excreta is extravagant and wasteful.
- Centralized systems designed and implemented without consultation with, and the participation of, stakeholders at all levels are outmoded responses to public health and environmental problems. Stakeholder participation is vital.
- There is a lack of integration between excreta disposal, wastewater disposal, solid waste disposal, and storm drainage. Many problems would be resolved by a new paradigm that places all aspects of water and waste within one integrated service delivery framework.
- The increasing need for environmental protection and freshwater savings requires that waste water and wastes be recycled and used as a resource. This must be achieved within a circular system based on the household, community, and municipality, rather than a linear system.
- The export of industrialized world models of sanitation to environments characterized by water and resource scarcity is inappropriate, and amounts to a continuation of wrong solutions.

Source [4]

- **1.1 billion people do not have access to safe drinking water.**
- **2.4 billion people do not have access to proper sanitation.**
- **50% of all solid waste is uncollected.**
- **No one knows how many people are flooded out each year.**
- **3 billion people have to survive on less than 2 US$ per day.**

In the light of these compelling arguments for radical re-thinking, the so-called Bellagio Principles [1, see box], must be seen as the underpinning basis for the new HCES approach. This concept includes two components: the Household-Centred Approach and the Circular System of Resource Management. It offers the promise of overcoming the shortcomings of "business as usual" because its two components correct existing unsustainable practices of planning and resource management.

Stakeholders at All Levels Participate in the Planning Process

The Household-Centred Approach is a radical departure from past central planning approaches (Fig. 1). It places the stakeholder at the core of the planning process. Therefore, the approach responds directly

The Bellagio Principles

Meeting at Bellagio, Italy in February 2000, an expert group brought together by the Environmental Sanitation Working Group of the Water Supply and Sanitation Collaborative Council (WSSCC) agreed that current waste management policies and practices are abusive to human well-being, economically unaffordable and environmentally unsustainable. They formulated the following principles [1]:

1. Human dignity, quality of life and environmental security at household level should be at the centre of the new approach, which should be responsive and accountable to needs and demands in the local and national setting.

2. In line with good governance principles, decision-making should involve participation of all stakeholders, especially the consumers and providers of services.

3. Waste should be considered a resource, and its management should be holistic and form part of integrated water resources, nutrient flows and waste management processes.

4. The domain in which environmental sanitation problems are resolved should be kept to the minimum practicable size (household, community, town, district, catchment, city) and wastes diluted as little as possible.

to the needs and demands of the user, rather than central planner's often ill-informed opinions about them. It is based on the following principles:

- Stakeholders are members of a "zone", and act as members of that zone (zones range from households to the nation). Participation is in accordance with the manner in which those zones are organized.
- Zones may be defined by political boundaries (for example, city wards and towns) or reflect common interests (for example, watersheds or river basins).
- Decisions are reached through consultation with all stakeholders affected by the decision, in accordance with the methods selected by the zone in question (for example, votes at national level in a democratic system, town hall meetings at local level, or informal discussions at neighborhood level).
- Problems should be solved as close to their source as possible. Only if the affected zone is unable to solve the problem should the problem be "exported", that is, referred to the zone at the next level.
- Decisions, and the responsibility for implementing them, flow from the household to the community to the city and finally to the central government. Thus, individual households determine what on-site sanitation they want; together with other households, they decide on the piped water system they want for their community, together with other communities, they determine how the city should treat and dispose of its waste water. Policies and regulations are determined by central government, with implementation delegated to the appropriate levels flowing towards the household.

Recycling and Reuse of Resources is Fundamental

The Circular System of Resource Management (Fig. 2) is an important principle of the HCES approach. It aims at minimizing waste transfer across circle boundaries by reducing waste-generating inputs and maximum recycling/reuse activities in each circle. In contrast to the current linear system, the Circular System of Resource Management emphasizes conservation of resources, and the recycling and reuse of resources. Resources in the case of environmental sanitation are water, goods used by households, commerce and industry, and rain water. The circular system practices what economists preach: waste is a misplaced resource.

Implications of Applying the HCES Approach

Implementation of the HCES approach requires stakeholders within the zone to plan and implement environmental sanitation infrastructure and service delivery in a sustainable way. The approaches that should guide them in arriving at such sustainable solutions within each zone include some or all of the following [2]:

- Water demand management: in order to minimize wasteful use of water, and so reduce the need for new source development and limit the production of waste water.
- Reuse and recycling of water: in order to minimize the need for wastewater collection, treatment and disposal.
- Solid waste recycling: in order to reduce the burden of collecting and disposing of solid wastes.
- Nutrient recovery: either at the household level (for example, ecological sanitation), or on a wider scale (for example, urban agriculture).

R. Schertenleib, EAWAG

About 40% of the world population do not have access to proper sanitation.

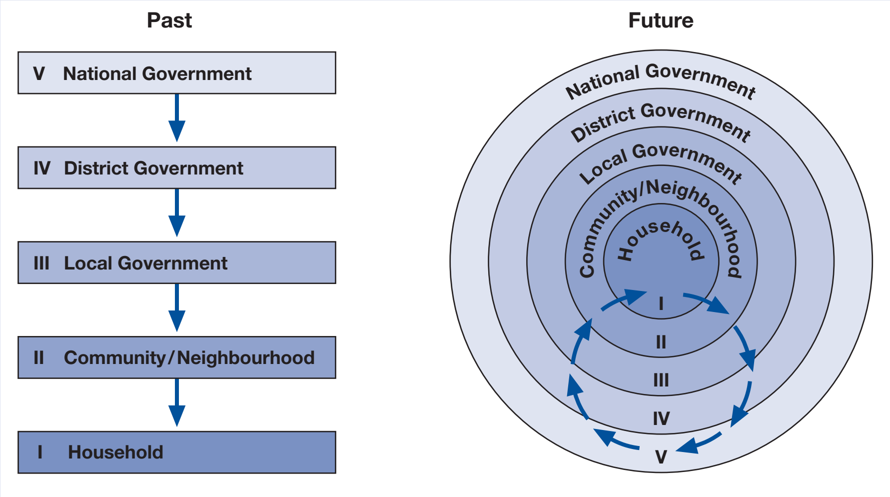


Fig. 1: The household at the core of the planning process. The HCES approach attempts to avoid the problems resulting from either "top-down" or "bottom-up" approaches, by employing both within an integrated framework.

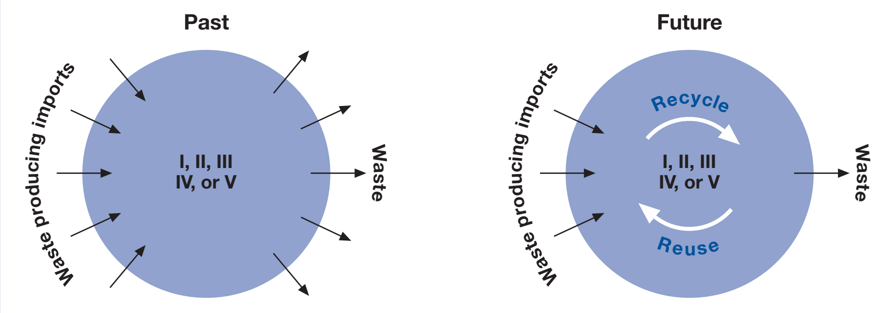


Fig. 2: The Circular System of Resource Management: Minimizing imports and maximizing recycling and reuse within boundaries.

- Improved rainwater management: reducing runoff by local measures, including detention and treatment, and the reuse of storm water to benefit the community.
- Strong emphasis on intermediate technologies: so as to encourage household- and community-level construction, operation and management of facilities, and permit reuse and/or disposal at the local level.
- Institutional arrangements and mechanisms: that stress the involvement of the users, encourage the participation of the private sector, facilitate cooperation across zone or sub-zone boundaries, and ensure the provision of technical assistance across zone boundaries where needed.
- Economic analysis procedures: that clearly illustrate the economic benefits of good planning as well as the consequences of sub-optimal development.
- Effective and sustainable financial incentives: to encourage the adoption of economically-desirable alternatives.
- Financial procedures: that determine whether problems should be solved within the zone itself, or whether a joint solution should be selected to serve more than one zone.
- Cost recovery practices: (predominantly user charges in Zones I and II; tax revenues elsewhere) that ensure financial viability, are socially equitable, and promote the "circular system" and the productive use of "waste".

Guideline for Implementing the HCES Approach

Successful implementation of the HCES approach requires the dissemination of information and assistance to those responsible for improving environmental services. Therefore, provisional guidelines were prepared which are mainly targeted at municipal planners (especially those responsible for planning urban environmental services) and civic officials, such as mayors and city managers [3]. These are the people who will initially have to take the decisions on whether and how to apply HCES, who will implement and support the process, and who will be responsible to their citizens for the results. The guideline is intended to assist them to understand the HCES approach, to apply it in their own context, and to be able to explain it to the user communities. The provisional guideline provides specific assistance for the development and implementation of the HCES approach.
It comprises two sections dealing with the creation of an "enabling environment" and the procedure to go through a 10-step process.

An "enabling environment" is important for the success of any investment program, but it is especially vital when applying an innovative approach, such as HCES. Most of the critical elements (Fig. 3) should be identified or become evident during the program development process. Ideally, they should be identified, at least in broad terms, prior to the program launch so that the entire process does not start off with misunderstandings. It is essential that they are recognized before or during the identification and evaluation of options at the latest, since if these critical elements cannot be assured, then some of the options may not be feasible.

The ten typical steps involved in developing and implementing an HCES program are presented in sequence (Fig. 3), but in practice they will usually overlap. Some steps may need to be repeated more than once in an iteration to find acceptable solutions, and they will always need to be undertaken bearing in mind the concerns of the municipality as a whole.

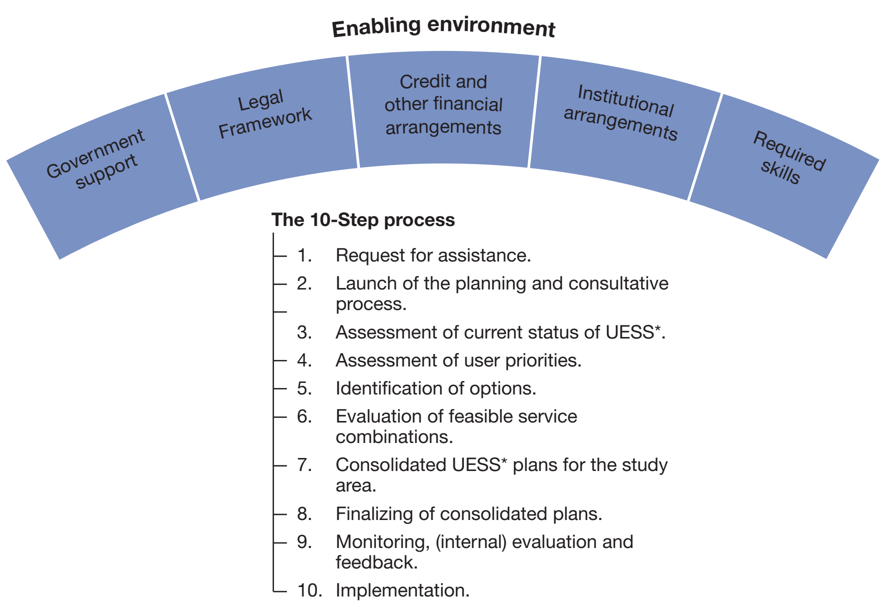
The provisional guideline will be tested in selected projects, which will be subjected to careful monitoring and evaluation. That process will not only test the provisional guideline and reveal areas which need to be improved; it will also bring out the topics which need to be particularly stressed during implementation, and the issues which are likely to arise.

Projects based on the HCES approach will take more time to develop than single-sector, capital-intensive projects. The investment in development is justified, as the HCES approach offers the one result that previous approaches have been unable to achieve: sustainability.

Antoine Morel, environmental engineer in the department "Water and Sanitation in Developing Countries – SANDEC" since 2001. He works in the fields of strategic environmental sanitation planning and decentralised wastewater management in developing countries.

Coauthors: Roland Schertenleib, Chris Zurbrügg

Further Informationen: www.sandec.eawag.ch, www.wsscc.org



The 10-Step process

1. Request for assistance.
2. Launch of the planning and consultative process.
3. Assessment of current status of UESS*.
4. Assessment of user priorities.
5. Identification of options.
6. Evaluation of feasible service combinations.
7. Consolidated UESS* plans for the study area.
8. Finalizing of consolidated plans.
9. Monitoring, (internal) evaluation and feedback.
10. Implementation.

Fig. 3: The two main components of the provisional guideline for the implementation of the HCES approach: the enabling environment and the 10-step process. *UESS = Urban environmental sanitation services.

[1] EAWAG/SANDEC and Water Supply and Sanitation Collaborative Council – WSSCC (2000): Bellagio expert consultation on environmental sanitation in the 21st century. Report of the Bellagio Workshop, February 2000. www.sandec.ch/Publications/PublicationsHome.htm

[2] Schertenleib R. (2001): The Bellagio principles and a household centred approach in environmental sanitation. In: C. Werner, J. Schlick, G. Witte, A. Hildebrandt (eds.) Proceedings of the 1st International Symposium on Ecological Sanitation – Closing the loop in wastewater management and sanitation, October 2000, Bonn, Germany. Publisher: Gesellschaft für Technische Zusammenarbeit, Eschborn, Germany, p. 52–57.

[3] Schertenleib R., Morel A., Kalbermatten J., Saywell D. (2003): Guidelines for the implementation of the Bellagio principles and the household-centred environmental sanitation approach (HCES). In: C. Werner, J. Schlick, G. Witte, A. Hildebrandt (eds.) Proceedings of the 2nd International Symposium on Ecological Sanitation, April 2003, Lübeck, Germany. Publisher: Gesellschaft für Technische Zusammenarbeit, Eschborn, Germany, in press.

[4] WHO, UNICEF, WSSCC (2000): Global water supply and sanitation assessment 2000 Report. Geneva, Switzerland, 80 p.

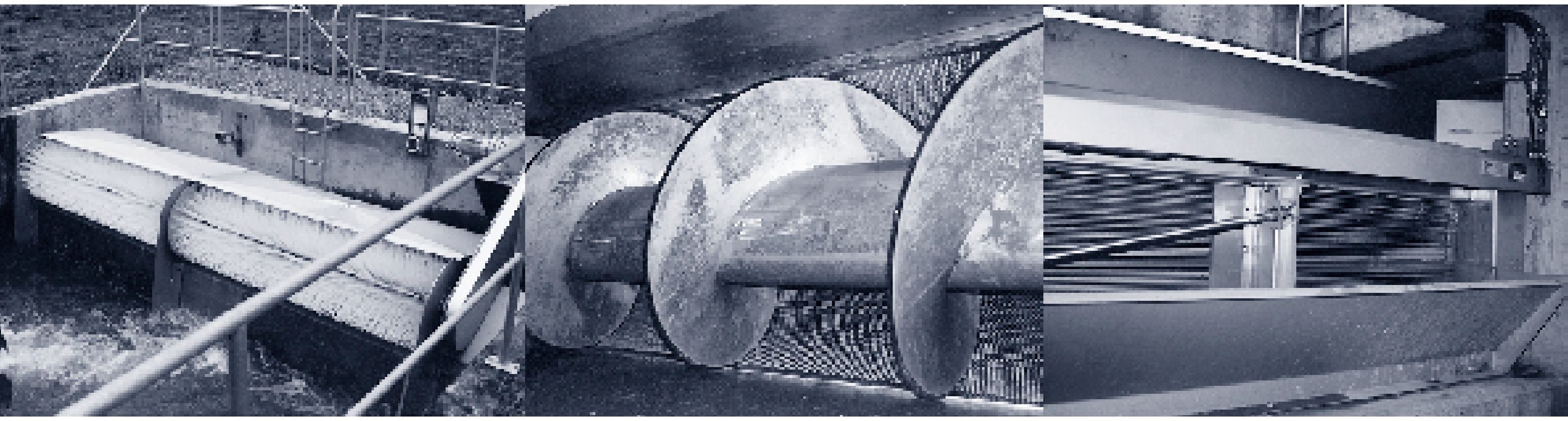
Project STORM – Wastewater Discharge During Rain Events

During rainy periods, only some of the waste water runs through treatment plants. In combined sewer systems, the excess flow is discharged directly or, after some simple treatment, into surface waters. Until recently, planning for these overflow structures has been based on unspecific problem criteria and empirical methods. In order to improve water protection and cost efficiency, environmental factors and uncertainty assessments will increasingly become incorporated into the planning and decision-making processes.

There is rarely another problem that is similar in complexity and that exhibits dynamic and stochastic like that of the discharge of sewage into surface waters during rain events. This is especially true for the rainfall runoff from towns and villages, because in urbanized areas, the majority of the rain water cannot infiltrate the soil and so has to be removed through the sewer system. In the combined sewer system, which represents the majority of systems in Switzerland, rainfall runoff mixes with domestic and industrial sewage, is treated in the wastewater treatment plant, and is subsequently discharged into streams and lakes. During intense rain events, the treatment plants are not able to process the entire discharge of waste water. This is because the treatment plants are, for various reasons, designed to treat no more than twice the water flow occurring during dry weather (≈ equivalent

Locality of manifestation/problem and potential effects	**Potential causes**	**Examples of possible measures**		
		in urban areas	**in urban drainage**	**in the stream or lake**
Urban area, sewer system				
Frequent and long-lasting combined sewage overflow	Infiltration and minimally contaminated water in combined sewer systems	Separate collection of rainfall runoff, soil infiltration	Reduce collection of clean water	
Frequent and long-lasting combined sewage overflow	Malfunction of the overflow structures		Adjustment of the outflow regulation	
Streams and lakes				
Aesthetic impacts: affecting well-being of humans	Discharge of gross pollutants (toilet articles, etc.), odors, dyes	Retention of domestic or industrial waste water	Screens/sieves	
Colmation of the stream bed: oxygen deficit in the stream bed and in the interstitial spaces of the hyporheic zone	Solids in waste water, discharge of easily degradable particulate contaminants	Reduction of deposits in the sewer system	Removal, treatment (e.g., sedimentation, vortex separators), optimization of operation	
Public health: increased infection risk	Discharge of bacteria, pathogens		Relocation of discharge point, storage, real time control	Warning, temporary ban on bathing
Hydraulic impact: drifting or elimination of organisms	Sediment transport and high flow velocity caused by sewer discharge	Unsealing, utilization of rain water, retention, infiltration	Relocation of discharge point, storage, real time control	Profile modifications, substrate improvements (creation of refuge space)
Acute problems (toxicity, NH_3, O_2): damage to or elimination of organisms	Discharge of toxic compounds, unnaturally low water levels, high pH values, high temperature in streams	Storage of domestic or industrial waste water	Relocation of discharge point, storage, real time control, treatment	Shading by trees and other plants, improvements of the hydraulic regime
Eutrophication: damage to organisms	Input of nutrients	Source control	Storage, real time control	Shading by trees and other plants
Chronic toxicity: damage to organisms	Input of heavy metals, pesticides, hormonally active compounds, etc.	Source control	Treatment (e.g., soil filters, phys.-chem. treatment, wastewater treatment plant)	

Tab. 1: Relationships between problems caused by wastewater discharge during rain events, the nature of these problems, and possible remedies. This table shows some selected examples.



Possible remedies (from left to right): rotating brush – sieve with cleaning spiral blades – screen – underground combined sewage overflow tank – above ground combined sewage overflow tank, integrated into the landscape (bottom).

to rainfall runoff during weak rain events). During intense rain events then, a fraction of the combined sewage is discharged directly into surface waters, mostly without any kind of treatment.

Protecting Surface Waters from Sewage Discharge

One possible strategy for protecting surface waters from receiving sewage discharge during rainy periods is to collect the rainfall runoff separately; such a separate sewer system would then only discharge rainfall runoff into streams and lakes. At first glance, this solution appears to make sense, although it is not without its problems. Rainfall runoff originating in urbanized areas is usually more or less polluted, with roofs and streets serving as the main sources of contaminants. It is, therefore, more common that combined sewer systems are supplemented by overflow tanks [1]. These tanks can temporarily store the combined sewage overflow before it is fed into the treatment plants. The main advantage is that this prevents many negative impacts on surface waters by solid waste (toilet paper, tissues, toilet articles), which are highly problematic for esthetic and public health reasons (Tab. 1) and can remain visible for months. Thus far, Switzerland has invested 2 billion CHF into the construction and operation of such overflow tanks. In separate sewer systems, rainfall runoff is normally not treated in any way. Many surface waters are, therefore, still receiving polluted rainfall runoff, either from separate or from combined sewer systems. In the mid-term, we should anticipate additional investments of approximately the same order of magnitude as that which has been spent until now.

Since the overall goals remain optimization of water protection and the most efficient use of available financial resources, we need to plan for dealing with rainfall runoff drainage issues according to new criteria. This task is the focus of the project "STORM – Wastewater Discharge During Rain Events», a joint undertaking by the Swiss Agency for the Environment, Forests and Landscape (SAEFL), the Swiss Water Pollution Control Association (VSA), and EAWAG. This article summarizes some early results.

New Principles in the Planning Process

Immission-oriented approach: Until now, the general approach has been to consider rainfall runoff discharge from an emissions standpoint; that is, the main concern is about the pollutant types and loads that are discharged from sewer systems into surface waters. The conditions and specific properties of the receiving streams or lakes are considered only at a very rudimentary level. We propose to shift any future planning – as far as our knowledge allows us – towards an immission-oriented approach (see box), where we take the characteristics of the specific stream or lake into consideration.

Tailored solutions based on effect prognosis: Unfortunately, past solutions for wastewater drainage during wet weather were not evaluated for their environmental effects. It is, therefore, difficult to assess how effectively aquatic communities are being pro-

Type of water body	Aesthetics	Public health (pathogens)	Temperature	Mechanical and hydraulic stress	Chemical parameters			
					Ammonia[1]	TSS[2]	Nutrients	Other compounds[3]
Spring	Yes	No	Yes	Yes	Yes	Yes	No	Currently no reliable information available
Small lowland stream	Yes	No	Yes	Yes	Yes	Yes	No	
Small stream in lower Alps	Yes	No	Yes	Yes	Yes	Yes	No	
Large lowland stream	Yes	Yes	Possibly[4]	Possibly[4]	Yes	Yes	No	
Large stream in lower Alps	Yes	Yes	Possibly[4]	Possibly[4]	Yes	No	No	
Larger streams	Yes	Yes	No	No	No	No	Yes	
Small lake (pond)	Yes	Yes	No	No	No	Yes	Yes	
Large lake	Yes	Yes	No	No	No	Yes	Yes	

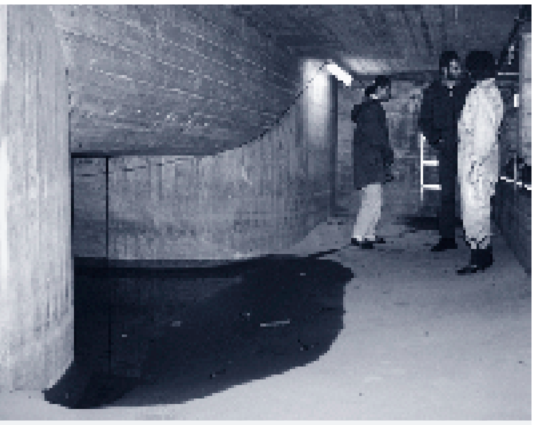
[1] Acute toxicity due to ammonia

[2] TSS = total suspended solids

[3] e.g., hormonally active compounds, aromatic and polychlorinated hydrocarbons, etc.

[4] According to problem identification

Tab. 2: Relevance of specific problem areas in wastewater discharge from combined sewer systems and the discharge of rainfall runoff from separate sewer systems. An entry of "No" indicates that that particular aspect is not relevant for the corresponding water type; for example, public health aspects are not relevant in small streams since humans do not normally use these streams for bathing.



Fotos: V. Krejci, EAWAG

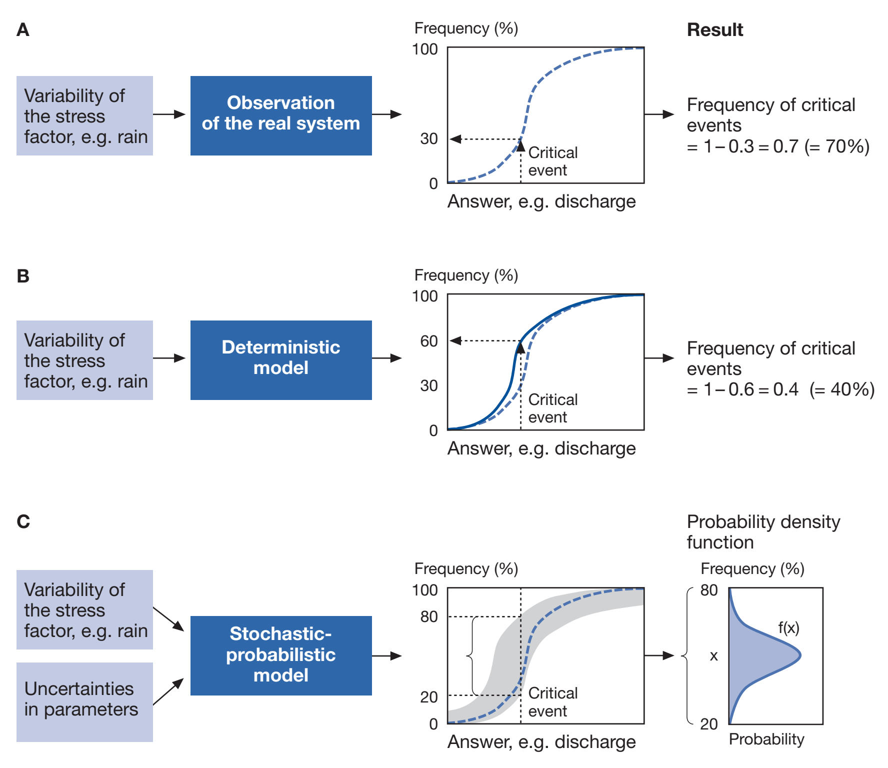


Fig. 1: Planning tools for estimating the probability of critical events during rain events. Critical events are defined by predetermined requirements; exceeding a certain discharge where sediment transport begins would be an example for such a critical event.
A: The frequency of critical events is determined from observations on real systems. Dashed line = cumulative frequency curve for the observed event. For comparison, this curve is also plotted in B and C.
B: The frequency of critical events is calculated in a deterministic model where variability in rainfall is included in the model calculations. Due to uncertainties that were not included in the calculations, reality (A) and the calculated curve are not identical.
C: The new stochastic-probabilistic model can calculate the probability of a certain frequency of critical events. The computer calculation incorporates rainfall variability as well as uncertainties in other parameters. The frequency with which critical events occur lies in a certain range, between 20% and 80% in the example shown here. All values for x = frequency of critical event enter the probability density function x = f(x).

tected from negative effects of wastewater discharge by the currently existing overflow tanks, particularly during critical periods. For this reason, we recommend that any future plan be accompanied by a detailed prognosis enumerating the specific effects of the plan. This should allow us to devise tailored solutions that take into account all specific and local conditions.

Consideration of planning uncertainties: Whenever a system like urban drainage is to be represented by a model, simplifying assumptions have to be made. These assumptions give rise to a number of uncertainties. Since the water itself is also described by a number of parameters that must be considered in the planning process, this creates additional uncertainties. Some of these assumptions or uncertainties are:

- The model structure: Is the model accurate enough to represent the system? Are the calculated demands for water discharge during rain events reasonable and realistic?
- Empirically determined model parameters (e.g., pollutant concentrations, temperature, etc.) are subject to measurement errors.
- Certain model parameters exhibit a high degree of variability (e.g., precipitation intensity, duration and frequency, flow rate in streams).

These uncertainties have to be identified during the effect prognosis, which is accomplished with the use of stochastic-probabilistic modeling (Fig. 1). Uncertainties can either be accepted, or the planning can yield a step by step solution. This means that initially a limited amount of money is invested in smaller measures which are then tested for a certain amount of time. Experiences from this phase feedback into the effect prognosis, leading to a more refined and optimized solution. This approach is obviously closely linked to financial resources.

The Immission Oriented Approach

In contrast to the emission approach, which only takes into account the pollutants that are being discharged with the combined sewer overflow and storm water, the immission approach represents an integrated way of analyzing the problem and considers any type of impact as well as properties of the receiving water body. Relevant parameters are those that allow the assessment of stream conditions during critical periods:

- **the type of impact (Tab. 1);**
- **the intensity of the impact, e.g., pollutant concentrations (chemical), concentrations of pathogens (public health), temperature changes (physical), and discharge or sweeping force (mechanical);**
- **the duration of the impact;**
- **the frequency of events;**
- **seasonal restrictions or deviations;**
- **characteristic properties of the stream or lake being affected (Tab. 2), e.g., type of water body (spring, lowland stream, lake), properties (discharge, nutrient concentrations, species diversity), condition (natural/modified, sensitive/non-sensitive).**

Planning of additional measures: Until now, planners have primarily considered combined sewage overflow tanks to deal with problems related to water pollution control during wet weather. There are, however, a range of other solutions that may be cheaper (Tab. 1) and should be considered as well. In order to promote these principles in the planning of new projects, STORM is aiming to provide the following tools:

- a compilation of the demands on wastewater discharge during rain events, based on requirements that also include characteristics of the surface water receiving the discharge;
- a methodical concept for the planning and design of specific measures;
- a computer model than can predict uncertainties contained in the planning process [2, 3].

With the help of these tools, it should become possible to formulate new guidelines for combined sewer overflow and stormwater discharge in Switzerland.

How Does the New Planning Concept Work?

We would now like to present a simple example to illustrate how these new principles can contribute to the planning process. Let us consider a small stream that is already protected from wastewater discharge by an overflow tank; however, this tank is not large enough to prevent wastewater discharge even during moderate rain events. During minor rain events, the impact is primarily an increase in pollutants, while the hydraulic impact is the main problem during stronger rain events. During the general planning stage, we first identify the problems and document a need for remediation. Investigations reveal that the primary problems during discharge of the combined sewage are increased ammonia loads and higher sediment transport. According to VSA recommendations [4], this yields the following discharge requirements:

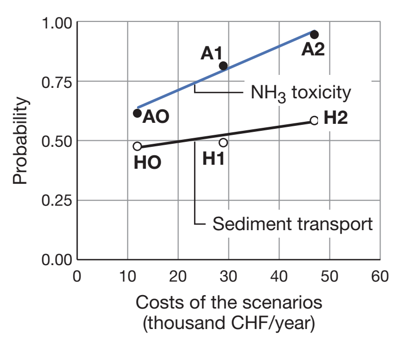


Fig. 2: Cost efficiency of different remedies (scenario 0 = status quo: A0/H0, scenario 1: A1/H1, scenario 2: A2/H2; for a detailed description of scenarios, see text). A: ammonia, H: hydraulic impact (sediment transport).

- the critical ammonia load may be exceeded only once in a 5 year period,
- the critical (sediment transporting) flow may be exceeded no more than 10 times per year.

For this example, we will model three different alternatives:

- Scenario 0 = status quo with a basin volume of 120 m^3 and annual costs of 12 000 CHF.
- Scenario 1 with an expanded overflow basin of 520 m^3 and annual costs of 29 000 CHF.
- Scenario 2 with an expanded overflow basin of 1320 m^3 and annual costs of 47 000 CHF.

We are using a stochastic-probabilistic model. In order to assess uncertainties, model parameters are not represented (as is usual) by a single value, but by a range of values and a distribution function. For example, pH values range between 7.8 and 8.3 and exhibit a log-normal distribution; the discharge coefficient varies randomly and is equally distributed in the range of 80–120 % of the expected value. With the exception of a small number of parameters, where more certain values are available, all parameters are described in this fashion. In preparation of the Monte Carlo simulation, random sets of parameters were selected, where the parameter values were chosen from within their predetermined range. For each set of parameters, long-term simulations were calculated with the same 10-year rain series (Fig. 1).

The simulation showed that there is only a 48 % probability that scenario 0 can fulfill the riverbed erosion requirement; even in scenario 2, this probability only increases to 60 % (Fig. 2). The requirement of ammonia loads, however, can be satisfied with nearly 100 % probability in scenario 2. These fairly well defined probabilities for meeting certain requirements provide an additional tool in the decision making process. Planners and decision makers can opt for a relatively expensive alternative, maximizing the probability for meeting the discharge requirements, but taking the risk of possible over-investment. Alternatively, they could choose a dynamic approach, i.e., make a lower investment by building a smaller basin, while conducting further investigations and thereby reducing uncertainties.

This example illustrates that the stochastic-probabilistic approach to the planning process requires a different kind of communication (e.g., in the handling of uncertainties) than the traditional planning process. While this approach yields better information, it is also more demanding of the participants.

Vladimir Krejci, hydraulic and environmental engineer, was a research scientist at EAWAG until 2001. He currently is an engineering consultant. He also is lecturer at the University of Applied Sciences Zurich and a member of various professional commissions of the VSA (Swiss Water Pollution Control Association) and the ATV-DVWK (German Association of specialist working in the fields of Water Management, Waste water and Waste).

Coauthors: Simon Kreikenbaum, Luca Rossi, Rolf Fankhauser

[1] Eidgenössisches Amt für Umweltschutz AfU (1977): Empfehlungen für die Bemessung und Gestaltung von Hochwasserentlastungen und Regenüberlaufbecken. AfU, Bern, 9 S.

[2] Kreikenbaum S., Krejci V., Rauch W., Rossi L. (2002): Probabilistic modeling as a new planning approach to stormwater management. 9th International Conference on Urban Drainage, Portland, USA.

[3] Rauch W., Krejci V., Gujer W. (2000): REBEKA – Ein Simulationsprogramm zur Abschätzung der Beeinträchtigung der Fliessgewässer durch Abwassereinleitungen aus der Siedlungsentwässerung bei Regenwetter, EAWAG, Dübendorf.

[4] Verband Schweizer Abwasser und Gewässerschutzfachleute VSA (2000): Zustandsbericht Gewässer – Teil Gewässerschutz, Empfehlungen für die Bearbeitung des Zustandsberichts Gewässer im Generellen Entwässerungsplan (GEP). VSA, Zürich, 23 S.

Toward Sustainable Urban Stormwater Management

As a result of the decision made in the nineties to install separate stormwater drainage for settlements, our current methods of wastewater disposal will change considerably in future years and decades. There is, however, more and more evidence that also rain water carries a certain pollutant load. In order to find suitable measures for the protection of the environment, sources, concentrations and hydraulic dynamics need to be well characterized. This article introduces instruments for the reduction of substantial load and first steps of their implementation.

Most of the rain water in Switzerland is still collected in combined sewer systems. Rain water is therefore mixed with waste water from households and industries before it is treated in a sewage treatment plant and eventually discharged into receiving waters. The early nineties brought about a process of rethinking. The detour via treatment plants was considered not to be appropriate for the less unpolluted rain water, which should rather be infiltrated on site or be discharged separately from waste water. In the meantime, however, it has become clear that rain water carries pollutants and that the earlier assessment was too optimistic, especially in case of runoff from impervious surfaces such as roofs and roads. Appropriate measures for the prevention of water pollution and the protection of soils and sediments must be based on knowledge of the substances carried by rain water and their behavior in the environment. Therefore, EAWAG is involved in various projects dealing with sustainable urban stormwater management. This article gives an overview of current research projects and introduces possible measures.

The Properties of Surfaces Count

Surface runoff originates from a diversity of surfaces consisting of many different materials which is why any effort to assess the properties of surface runoff for every single possible case is impractical. Nevertheless, in order to cover a maximum number of situations, urban surfaces are classified according to their specific pollution potential (Tab. 1), a vital step in order to provide a practical instrument for the user. Accordingly, public authorities and professional associations have worked out a number of guidelines during the last few years, such as the recommendations on “Water protection in drainage of traffic routes” and the guideline on “Stormwater management” [1, 2]. Traffic routes (roads, aerodromes and rail) cover roughly 60 % and roofs approxi-

Surface	Indication of pollution potential in surface runoff	Classification of pollution
Roofs and green areas		
Green areas and green roofs without pesticide containing linings	Good and efficient retention of water and contaminants on the roof.	low
Roofs of mainly inert materials and low metal content, glass roofs, terraces	Contamination similar to rain water. Slow accumulation of pollutants in infiltration sites.	low
Roofs of mainly inert materials and usual degree of metal containing installations such as Cu, Sn, Zn and Pb	Rapid accumulation of heavy metals in infiltration sites. Heavy metal adsorbents are recommended for roofs with metal areas of 20 – 50 m^2.	medium
Roofs with higher content of metal sheets from Cu, Sn, Zn, Pb	The protection of soil and water requires treatment of the surface runoff from these roofs. The following areas are considered as heavily polluted: a) in case of infiltration >50 m^2 b) in case of direct discharge >500 m^2.	high
Parking lots, driveways and roads		
Driveways, private and public parking in residential areas, bicycle tracks, pavements, small roads without high traffic densitiy	Low pollution potential under normal use. Partial biodegradation of organics where areas are permeable.	low
Shipment and storage space and working areas with handling of hazardous substances	Loss of fuel, contaminants from maintenance work, shipment and storage may lead to soil and groundwater pollution.	medium
Public parking with high traffic density (e.g. shopping centers)	Increased soil and groundwater pollution potential. If made permeable, some organics may be biodegraded in top soil.	medium to high
Roads	Pollution potential depending on traffic volume, types of vehicles, way of driving and maintenance. Perpendicular to the road, contaminations with heavy metals and PAH (polycyclic aromatic hydrocarbons) mostly decrease with increasing distance from the road.	depending on traffic volume

Tab. 1: Classification of urban surfaces according to their pollution potential.

Parameter	Unit	Green roof	Gravel roof	Tile roof with metal installations	Metal roof from Cu, Zn, Pb	Motorway	Urban roads
Reference		EAWAG	EAWAG	EAWAG	EAWAG	EAWAG	Xanthopoulos & Hahn [10]
pH		6.7–7.5	5.5–7.9	5.5–7.5	–	7.0–7.5	6.4
TOC	mg C/l	4–20	5–10	5–15	–	10–20	–
DOC	mg C/l	–	3–10	2–14	–	5–10	12
TSS	mg/l	–	2–5	15–40	–	150–250	560
NO_3	mg N/l	1–2	2–5	0.3–0.7	–	6	0.6
Ca	mg/l	20–60	10–25	1.5–2.5	–	–	–
Pb	µg/l	6–15	2–10	10–70	5000–7000	300	311
Cd	µg/l	u.E.g.	0.05–0.1	0.1–0.5	–	4.5	6.4
Cu	µg/l	5–10	15–25	100–300	800–2000	150	108
Zn	µg/l	u.E.g.	10–40	50–200	1000–4000	500	603
PAH	µg/l	–	–	–	–	3	3.1
Atrazine	ng/l	–	100	100–1600	–	–	–
Mecoprop	ng/l	–	1500–5000	–	–	–	–

Tab. 3: Weight mean concentrations in different runoffs from roofs and roads.
TOC = total organic carbon, DOC = dissolved organic carbon, TSS = total suspended solids, PAH = polycyclic aromatic hydrocarbons.

mately 30% of the impervious surfaces in Switzerland. Therefore, the main focus has to be on pollutants emitted from these surfaces (Tab. 2). Table 3 shows the average concentration of pollutants for different roofs and roads.

Heavy metals washed off roofs are predominant in the total runoff from settlements. Depending on the catchment, copper emitted from roofs, e.g., can form a fraction of 30–60% of the total copper load in urban waste water. A study on metals currently used in roof construction showed that 30% of all metal materials are zinc and 70% copper. The equivalent is a per capita amount of 2.9 m² of copper sheet.

Source	Contaminant
Roofs	
Metal installations, sheets, facades	Cu, Zn, Pb, Sn
Atmospheric washout	Pesticides (e.g. Atrazine)
Flat roof linings	Pesticides (e.g. Mecoprop)
Roads	
Gasoline, Catalyst	Pb, Ni, Co, Pt, Pd, Rh, PAH, MTBE
Brakes	Cu, Cr, Ni, Pb, Zn, Fe
Tires	Zn, Pb, Cu, Cr, Ni, Cd
Road material	Ni, Mn, Pb,Cr, Zn, As, PAH
Road maintenance	Pesticides, salts

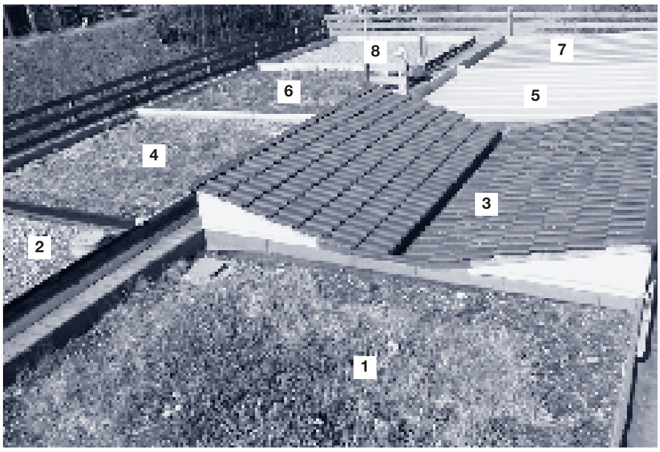
Tab. 2: Contaminants in stormwater runoff from roofs and roads.

Pollutants from Roofs and Roads

At present, EAWAG, working together with the Laboratory for Water Protection of the Canton Berne and the Technical College in Burgdorf, examines the behavior of different model roofs during rain weather. A gravel flat roof as reference roof, four green flat roofs, a tiled roof with copper installations and two metal roofs made of copper titanium zinc and tinned copper sheet are being probed simultaneously (Fig. 1). Furthermore, the runoff from the metal roofs is collected and deviated over an adsorbing filter in order to test its retention capacity. Not surprisingly, the roofs with metal components show higher rates of copper and zinc drainage (Fig. 2). However, more than 97% of the metals are retained by the adsorbent.

In two other projects, the project team in Burgdorf analyses the runoff and the further fate of contaminants from a highly frequented road (Fig. 3). On one hand, runoff from the road is led over three differently composed adsorbents. First results show that the most efficient of the three filters retains more than 95% of copper and zinc from the road runoff. On the other hand, a road shoulder which has been subject to traffic for 30 years is investigated in order to gain information on transport and accumulation of specific traffic induced contaminants in the soil, as well as ideas on the construction of future road shoulders.

The concentration of pollutants varies considerably depending on the surface and the



Photographs: B. Gerber, HTA Burgdorf

Fig. 1: Model roofs examined by EAWAG.

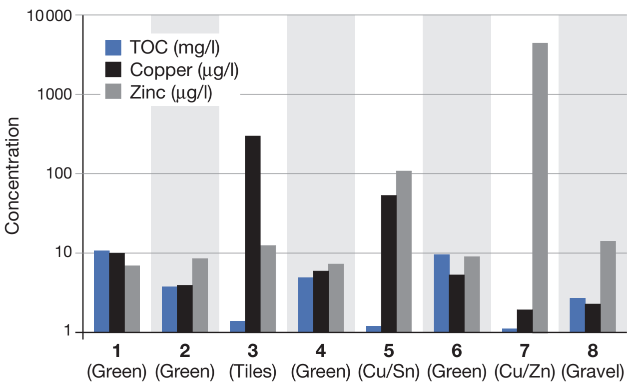


Fig. 2: Average copper, zinc and TOC-concentrations in the runoff of the examined model roofs. TOC = total organic carbon.

Fig. 3: Connection of the road runoff with the test facility.

duration of a rain event. Especially at the beginning of a rain event, during the so-called “first flush”, great amounts of pollutants are carried away (Fig. 4) [3]. However, there are also substances which only become mobile after a longer duration of rainfall, such as the pesticide Mecoprop, used in insulation sheets of flat roofs. It only dissolves after the roof has been sufficiently moistened (Fig. 3).

Effects of the New Stormwater Management

The new pathways for stormwater runoff are clearly defined in Swiss legislation and guidelines. The priorities are: 1. decentralized infiltration, 2. direct discharge into surface waters, and 3. discharge into combined sewers. Furthermore, there is an increasing interest in the further use of storm water [4].

Yet, whatever pathway the storm water takes or how it may be used, the pollutants contained cause increasing pollution of soils, sediments and surface waters. One example are the copper concentrations in sediments of Lake Geneva near Lausanne, which clearly document how discharge from combined or separate sewer systems pollute the environment (Fig. 5) [5]. At the discharge site, concentrations of more than 500 mg copper per kg sediment can be measured. A parallel study at the same site revealed that the plankton is also highly affected by the wastewater discharge [5].
As the new directives for urban stormwater drainage are mainly applied for renovated or new buildings, the new stormwater management will only be implemented step by step during the next decades. Hence, there is sufficient time for the necessary development of innovative measures which guarantee pollution of the environment by stormwater discharge be reduced to a minimum. In general, there are two ways of controlling the runoff quality: source control and the development of barrier systems.

Source Control

The key to advances in sustainability is the control of pollutant emissions at the source. This is possible by means of legislation, economical incentives and voluntary renunciation which will normally lead to a practicable long term solution. However, as pollutants accumulate in soils and sediments very slowly, environmental effects will only become visible after decades. Therefore, there is only restricted political awareness and as a result restrictions on a legal basis are barely feasible. Yet, information and education of stakeholders with respect to environmental and ecotoxicological issues, guidelines for the use of building materials for houses, roads and motor vehicles, as well as the perception of the public for certain environmental problems should be promoted. A very positive example in this context is the recommendation for architects and clients given by the Swiss federal coordinating authority for building and real estate on “metals for roofs and facades” which facilitates the choice of environmen-

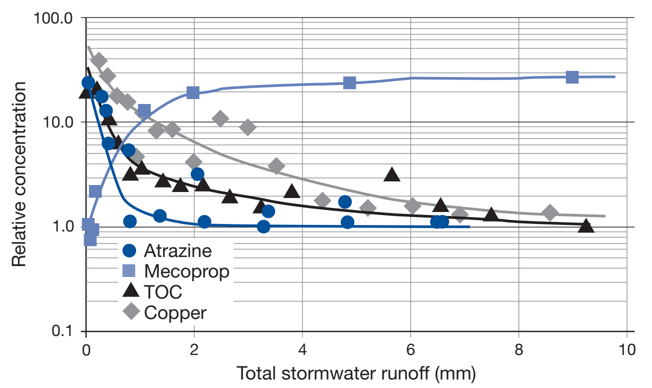


Fig. 4: First flush patterns of different pollutants in roof runoff. Atrazine and Mecoprop are pesticides. TOC = total organic carbon.

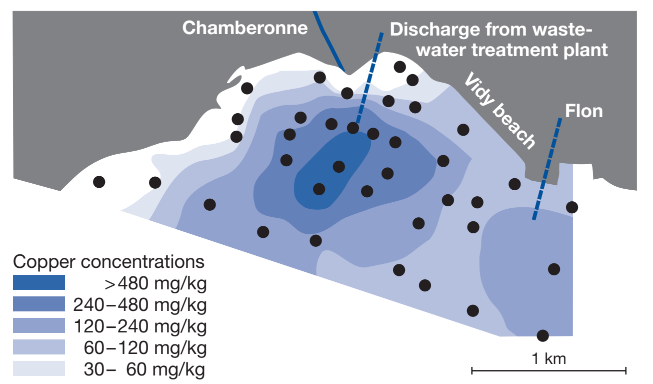


Fig. 5: Accumulation of copper in the sediments of the bay of Lausanne as a result of wastewater discharge.

tally harmless metals for the cladding of buildings. Copper, zinc and lead are identified as most hazardous substances and alternatives are shown [6].

Setting up Barriers

Despite increasing efforts into source control, one must be aware that large amounts of undesirable materials are currently installed in buildings and that it will take decades to replace them by more environmentally friendly materials. Until this goal has been reached, the emission of heavy metals caused by corrosion and of organic micropollutants will steadily increase. In order to avoid further spreading, specially designed barrier systems are needed, which ensure the best possible protection of waters, soils and sediments. Setting up barriers to the transport of certain substances is a technical option to divert, separate or concentrate pollutants. However, barrier systems do not achieve a 100% elimination of substances. At present, infiltration into natural soils and passage through granulated adsorbents are suggested barrier systems.

Natural soil passage: Natural soils with sufficient permeability are suitable for the retention of pollutants. The soil material is usually available on site and can be used in infiltration basins. Various investigations have shown that retention of pollutants occurs mainly in the top 30–50 cm of the soil. Being not degradable, they accumulate over a long period of time and the permitted pollutant limits given by legislation will sooner or later be exceeded. The drawback of soil passage is that a natural good is used for the retention of contaminants and therefore turns into hazardous waste. Remediation or deposition of such soils is necessary at the latest when infiltration basins are deconstructed.

Artificial adsorber systems: Because special adsorber layers have significantly higher retention capacities, the volume of polluted soils can be reduced and the efficiency is higher than that of natural soils. Various laboratory and pilot studies at EAWAG and first major installations have shown that the adsorber systems serve their purpose [7]. Among different media proposed as adsorbing layers, granulated iron-hydroxide has proven to be especially suitable for the removal of heavy metals (Fig. 6). Compared to natural soils, the adsorption capacity achieved with this material is ten times higher, thus eventually reducing deposition volumes.

Because of this excellent performance, the guidelines of the Swiss Water Pollution Control Association demand adsorber systems of different types for the infiltration of runoff from roofs with copper and zinc surfaces of over 50 m^2 and for direct discharge from roofs of more than 500 m^2 [2].

Blue-green Environments

Traditionally, efforts have been made to hide the stormwater drainage underground. Today, architects and engineers are called upon to integrate the rain water into so-called blue-green environments and thus make it visible. The new technical systems for stormwater management may be designed in a way that the desired tasks as retention, contaminant barrier, infiltration and direct discharge can be combined in a creative manner and also fulfill aesthetic requirements when integrated in settlements. Green roofs, open channels, small creeks, ponds, reed beds and other planted units may become elements of landscaping which accompany the rainwater until infiltration, direct discharge or reuse [8, 9].

Challenge for Engineers, Scientists and Inventors

The implementation of the new ideas on stormwater handling will take decades. Renovation of the stormwater drainage systems may be considered as part of a more integral development of urban water concepts where changes in water supply and wastewater management should take place simultaneously. An important element is the separation of water fluxes from settlements according to their quality. Dual systems for water supply (separation of drinking water and service water), the separation of wastewater fluxes into grey and black water, urine separation, nutrient management at the source as well as dry toilets and other alternatives of sanitation facilities are currently studied in science and practice. The new urban water concepts challenge engineers, scientists and inventors to study and introduce innovative technologies and solutions, thus increasing sustainability in future urban water management.

Markus Boller, engineer, is head of the department "Urban water management". He is professor for water supply and water technology at the ETH Zurich. His main research interests are in the field of water supply, stormwater disposal, and nutrient recycling.

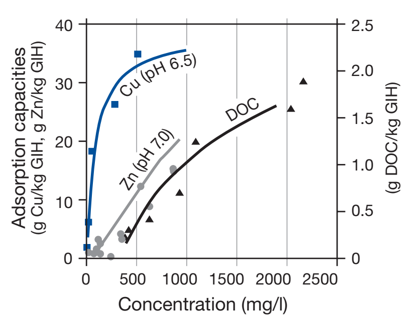


Fig. 6: Adsorption isothermes for copper, zinc and DOC on granulated iron-hydroxide. DOC = dissolved organic carbon.

[1] Bundesamt für Umwelt, Wald und Landschaft BUWAL (2002): Wegleitung – Gewässerschutz bei der Entwässerung von Verkehrswegen. BUWAL, Bern, 57 S.

[2] Verband Schweizer Abwasser und Gewässerschutzfachleute VSA (2002): Richtlinie zur "Regenwasserentsorgung». VSA, Zürich, 120 S.

[3] Boller M. (1998): New pathways for rainwater. EAWAG news *44,* 6–11.

[4] Bundesamt für Umwelt, Wald und Landschaft BUWAL (2003): Regenwasser richtig nutzen. BUWAL, Bern, 15 S.

[5] Rossi L., Loizeau J.-L., Wildi W. (2003): Contamination and toxicity of lake sediments due to urban stormwater pollution. SETAC Europe, 13th Annual Meeting, Hamburg Germany. Data from: Institut Forel (1996). Assainissement de la baie de Vidy: Qualité des sédiments, impact de la station d'épuration. Genève, Université de Genève, Institut Forel: 42.

[6] Koordination für Bau- und Liegenschaftsorgane des Bundes KBOB (2001): Metalle für Dächer und Fassaden, Empfehlung nachhaltiges Bauen. KBOB, Bern, 10 S.

[7] Steiner M. (2002): Kupferadsorption an granuliertem Eisenhydroxid, Dissertation, ETHZ/EAWAG, 157 S., im Druck.

[8] Gewässerschutzamt des Kantons Bern GSA (1999): Versickerung und Retention von Regenwasser. GSA, Kanton Bern.

[9] Bundesamt für Umwelt, Wald und Landschaft BUWAL (2000): Wohin mit dem Regenwasser? – Beispiele aus der Praxis, BUWAL, Bern, 59 S.

[10] Xanthopoulos C., Hahn H. (1995): Schadstoffe im Regenwasserabfluss III. Schriftenreihe des Instituts für Siedlungswasserwirtschaft Karlsruhe, 537 S.

How "Tight" is our Sewer System?

Urban sewer systems are subjected to constant stress by traffic and soil movement. Combined with natural fatigue of materials, these conditions lead to damage to underground pipes, causing exfiltration of sewage into the ground water as well as infiltration of ground water into the sewer pipes. EAWAG is currently developing a new method to quantify these processes by using both natural and artificial tracers, which will help us in planning more efficient remedial action.

Although urban sewer networks are built for longevity, damage occurs over time and systems inevitably develop leaks. If such leaks are situated below the groundwater table, clean ground water may infiltrate sewer pipes; but if the leak lies above the groundwater table, raw sewage may exfiltrate into the surrounding soil.

Exfiltration of raw sewage from leaking sewer pipes is considered to be a serious threat to humans and the environment since it can directly impact drinking water [1]. Infiltration of ground water is a problem as well, since sewage is diluted and wastewater treatment plants receive an unnecessarily large hydraulic load. Neither situation is normally recognized until they reach rather serious proportions. This is mainly due to the fact that sewer pipes are located underground and that these processes are, for all practical purposes, invisible. Traditional monitoring techniques are very labor-intensive and yield rather imprecise results (see box).

Traditional Measurement Methods

The amount of exfiltration is typically assessed in leak tests using water or air [3]. Such tests are expensive and only provide information about certain problem spots; extrapolation over an entire sewage system is too uncertain. Using classic methods for a comprehensive assessment of the amount of exfiltration, which would be needed to develop efficient remediation plans, is therefore impractical.

Traditionally, infiltration of ground water is determined simply by measuring runoff volumes [4]. The assumption is that during periods of low flow (usually Sunday night until Monday morning), the sewage component is practically zero, and the flow consists exclusively of infiltrated ground water. This assumption is becoming more and more problematic, however, as even private households run machines that use water during the night in order to reduce operating costs. Sewage systems are also growing with expanding agglomerations. In some sections of the sewage system, there may be sewage flow at any time of the day because it arrives with varying delays from different parts of the system.

For this reason, EAWAG is developing new methods for the measurement of water infiltration and exfiltration. This project is part of a larger European research project, APUSS (Assessment of the Performance of Urban Sewer Systems) which was initiated in 2001 and aims to assess the condition of urban sewer systems based on infiltration and exfiltration of water. Methods developed as part of this project will aid in designing more efficient remediation plans for urban sewer systems.

The new methods use both natural and artificial tracers (see box on p. 30); by measuring increases or decreases in the amount of a given tracer, we can calculate the amount of water entering and leaving the sewer system.

Exfiltration Measurements with Artificial Tracers

Exfiltration is measured by employing artificial tracers that are added to the sewage (see box on p. 30). If the sewer system is leaking, part of the added tracer will be lost with the leaking sewage. This loss is directly linked to exfiltration; for example, if 10% of the tracer is lost, it can be concluded that 10% of the sewage is leaving the pipe in that particular section of the sewage system [2]. The operating principles of this method are summarized as follows (Fig. 1):

- The tracer is added at two points: at the beginning (indicator signal) and at the end (reference signal) of the section to be tested. The indicator signal is attenuated by exfiltration, indicating whether or not water is leaving the pipe. The reference signal is not affected by exfiltration; it merely serves to quantify the diminution of the indicator signal. It is important in making these measurements that the tracer and the sewage are completely mixed.
- If the tracer is dosed in slugs, a single tracer compound may be used. At the measuring point, pulse-shaped concentration curves are observed (Fig. 2). Measurements are taken directly in the sewage stream with so-called in-line probes, which provide high temporal resolution. This approach allows for differentiation between the indicator pulse, the reference pulse and the natural background. For continuous tracer addition, two different tracer compounds would have to be used, and the measurement would yield twice the measurement error of a pulsed tracer addition.
- The tracer addition at the reference site is delayed relative to the addition at the indicator site. In this way, both pulses overlap at the measurement point (Fig. 2). This

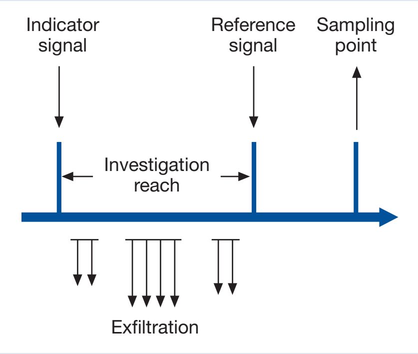


Fig. 1: Schematic representation of an experiment for quantifying exfiltration.

Artificial and Natural Tracers

Artificial Tracers, **e.g., simple or fluorescent dyes, particles, chloride in the form of sodium chloride or lithium in the form of lithium chloride, are compounds that are added to the sewage stream at a particular location and measured at a second location. They must meet the following requirements:**

- **low natural abundance,**
- **low detection limit,**
- **no interactions with other compounds,**
- **no toxicity,**
- **good solubility and mixing characteristics in water,**
- **inexpensive.**

Natural Tracers **are specific properties of a local drinking water, ground water or sewage water, such as their stable isotope composition, which can be used to distinguish different types of water.**

method has the advantage that potential measurement errors (e.g., changes in sewage composition, error or drift in the probe signal) affect both tracer signals equally and so are cancelled out.

▪ Since the amount of added tracer at the indicator site is known, the peak area may be used as the reference signal to estimate how large the indicator signal should be if no exfiltration would occur. The difference between this estimate and the measured indicator signal tells us whether or not the sewage pipe in that particular test section is leaking.

J. Rieckermann, EAWAG

Exfiltration experiment: addition of NaCl solution as a reference signal.

NaCl as a Tracer for Exfiltration

Figure 2 shows a typical experiment in which NaCl is used as a salt tracer. The probes used are conductivity probes, which indirectly measure NaCl concentrations in the water stream. In the experiment shown here, the test section was 285 m long, the average runoff volume during dry weather was 25 l/s, and the average natural background conductivity was 0.8 mS/cm; generally, it is preferable to measure longer test sections (up to several kilometers), since this would maximize the number of leakage points identified in one test. Before conducting the actual measurement, runoff volume and conductivity should be measured for approximately two days. Based on these background parameters, we can calculate how much NaCl should be added at the indicator and reference points. In this case, 1.9 kg of NaCl was added at the indicator point, and three additions of 0.4 kg NaCl were made at the reference point approximately 10 minutes later. The results of this experiment indicate that there were no leaks present in this test section.

Infiltration Measurements with Natural Tracers

Infiltration cannot be measured using artificial tracers. Homogenous distribution of tracers throughout an entire aquifer is neither feasible nor desirable for environmental reasons. Rather, specific natural characteristics of the local drinking water, ground water and sewage have to be used as natural indicators of mixing and dilution processes (see box).

It is rare to find a direct natural tracer since sewage typically contains a vast number of different compounds. These compounds usually exhibit large daily fluctuations and so obscure the natural tracer signal. An example of a suitable tracer system, however, would be the isotopic composition of water. It is predominantly determined by the topographic elevation of the region where ground water and surface water are recharged by the local precipitation (altitude effect). This method can be used when a town uses drinking water from a watershed that is situated significantly higher or lower than the urbanized area. In such a situation, significant differences in the isotopic compositions of the drinking water, the waste water and the ground water can be expected, allowing for quantification of the various mixing ratios.

For more general situations, however, another method appears to be promising: the fraction of infiltrating water can be determined by comparing the time series for pollutant concentrations and discharge volume. A suitable lump-sum parameter representing pollutant concentration is, for example, the chemical oxygen demand (COD). This parameter indicates how much oxygen is required for complete oxidation of the organic and inorganic pollutants contained in the sewage stream. Modern in-line probes are able to determine COD equivalents directly by measuring light absorption in the UV range (Fig. 3). These probes record the signal with high temporal resolution, thus providing the basis for a detailed data and error analysis.

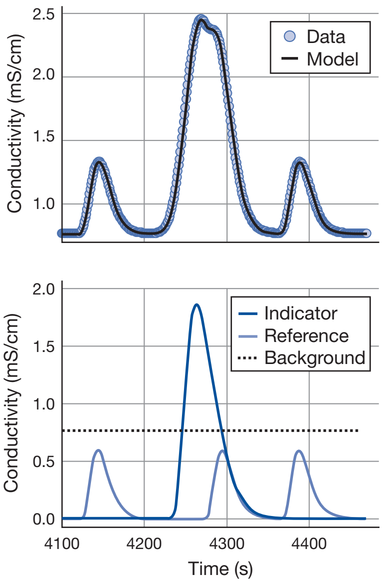


Fig. 2: Results of an experiment measuring exfiltration. NaCl was used as an artificial tracer.
Top: measured and calculated tracer signal.
Bottom: separation of the measured signal into the indicator and reference signals with subtraction of the natural background.

Pollutants as Infiltration Tracers

Figure 3 shows the results of a measurement campaign that was conducted in the winter of 2002–03 at the influent of a cooperative wastewater treatment plant which serves approximately 23 500 people. The COD equivalents and the wastewater volume were registered with a temporal resolution of 3 minutes. Data processing was performed with a mixing model using the data for the two measured parameters. This required additional assumptions which were made based on external information. The COD value for infiltrating water was assumed to be negligible. The volume of infiltrating water consists of two components: a constant base flow and an exponentially decreasing interflow. In the simplified case illustrated here, we also assumed that the COD concentration of the actual foul sewage component was approximately constant. The total variation of the COD concentration in the waste water is therefore determined by the diurnal hydrograph of the sewage flow (24 hr rhythm) and the slowly fluctuating amount of infiltrating water (exponential decline after long rainy periods). A short rain event on 26 December 2002 (sharp increase in wastewater volume at mid-day) was not caught by the model.

Are these Methods Usable in their Practical Application?

We are currently developing a general methodical guide that will allow the user to measure exfiltration in any sewage system. The guide helps the users choose the best combination of tracer, measuring method and dosage protocol for their particular situation. Analysis of our field experiments conducted thus far indicates that the detection limit for exfiltration is about 10 %. Since typical losses are rather low (below 5 %), the quantification methods will have to become more accurate in order to be useful in real applications.

Whether or not our method for measuring infiltration will be an improvement over traditional methods will depend on the reliability of the model assumptions that have to be made. Furthermore, pollutant concentrations and runoff volume will have to be measured with high accuracy in order to achieve an overall accuracy of 10 to 20 % for infiltration values. We will use the stable isotope methods to further validate our new approach. Both methods are currently being tested in different countries and in a variety of sewage systems as part of the APUSS project.

Exfiltration und Infiltration as "Benchmarking" Tools

If exfiltration and infiltration could be established nationally or internationally as indicators, these parameters could be used to "benchmark" sewage systems. A comparative evaluation of the structural integrity of different sewer systems is currently very difficult to make. It normally takes years to collect data for an entire sewage system by the traditional method using a mobile camera (CCTV). In addition, damage classification varies with both the technique and operator, which makes overall comparisons problematic. An objective comparison of different sewage systems or operating strategies will only be possible if we have assessment tools that yield reproducible results in a useful time frame. Whether our methods will prove to be such tools will depend on whether or not we can achieve the necessary measurement accuracy.

Jörg Rieckermann, engineer, is working on his doctoral thesis in the department of "Environmental Engineering" where he is developing a method for the measurement of exfiltration with artificial tracers.

Coauthors: Oliver Kracht, Willi Gujer

[1] Bishop P.K., Misstear B.D., White M., Harding N.J. (1998): Impacts of sewers on groundwater quality. Journal of the Chartered Institution of Water and Environment Management *12,* 216–223.

[2] Rieckermann J., Gujer W. (2002): Quantifying exfiltration from leaky sewers with artificial tracers. Proceedings of the International Conference on "Sewer Operation and Maintenance 2002». Bradford, UK.

[3] Stein D. (1999): Instandhaltung von Kanalisationen. Ernst & Sohn, Berlin, 948 S.

[4] Schweizer Bundesamt für Umweltschutz (1984): Methoden zur Bestimmung der Fremdwassermenge in Kanalisationen und Kläranlagen. Bundesamt für Umweltschutz, Bern, 51 S.

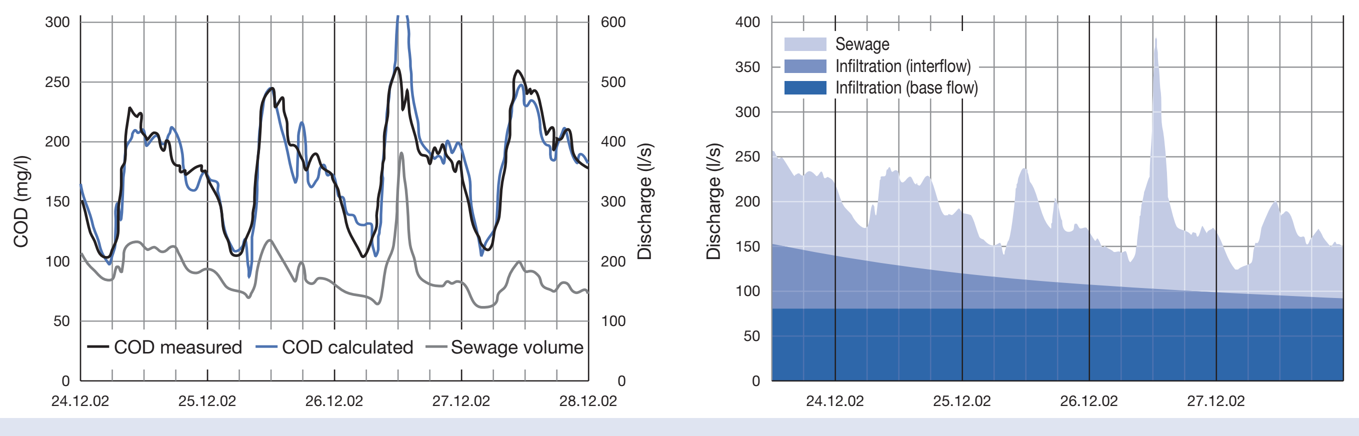


Fig. 3: Results of a measurement campaign determining infiltration. Chemical oxygen demand (COD) was used as the natural tracer. Left: comparison of COD measurements with model calculations. Right: identification of different water components. In this test section, "foreign" water accounted for an average of 60 % of the total runoff.

Management of Wastewater Treatment Plants on the Test Stand

Each year, two billion tons of waste water are collected from urban areas, then treated and returned to the natural water cycle. In order to process such an enormous volume of water, the technical and logistical processes must work together flawlessly. Weak links in the organizational process are not only economically relevant, but may pose a safety risk. Evaluation and optimization of the logistical and organizational frameworks should, therefore, be a fixed part of the overall operation. EAWAG has developed a new procedure for self evaluation and process reengineering, allowing wastewater treatment plants to conduct extensive process analysis and to improve them where necessary.

Wastewater treatment no longer has the status it had only a few decades ago. Problems regarding streams and lakes appear to be solved, urban water hygiene has been accomplished, and drinking water quality meets regulatory requirements. Today, the average citizen expects high system reliability, transparent use of public funds, and democratic involvement in decisions that have far-reaching implications (Tab. 1). As a consumer, a citizen desires low supply and disposal fees, no limitations on his/her personal freedom (7 x 24 hours availability), and fast, uncomplicated permitting procedures for new hook-ups. Wastewater treatment plant operators are, therefore, experiencing ever increasing pressure to provide the best possible service at an increasingly lower cost.

Organizational Deficits

Currently, there are organizational obstacles that impact the economical operation of wastewater treatment plants and make it difficult for operators to maintain the function and value of the plant over the long term. Such deficits include, for example, poor functional job separation, excessive controls and regulations on the operational side with a simultaneous lack of control of strategic aspects, and ill-defined assignments of responsibilities. As a consequence, the entire organizational structure is characterized by a high number of internal interfaces, an excessive need for coordination, long delays in dealing with issues, and relatively high stress load on managers. In addition, decisions often have to be made based on information that is incomplete, of poor quality, or altogether unavailable. This is often due to ill-defined job assignments; if it is unclear who carries which responsibilities, it will also be unclear who needs what information.

It is rare to find operational goals that go beyond numerical water quality criteria for the water that is discharged. According to a survey of the VSA (Swiss Water Pollution Control Association), 54 % of communities or treatment cooperatives do not have any or only early stages of further reaching goal statements and multi-year plans [1]. The picture is even bleaker with regard to mission statements: only 25 % of the surveyed entities reported that they examine questions regarding their own organization or their future development (Fig. 1). Consequences of lacking goals that define the corresponding control mechanisms include unrealistically high or low expectations about quality, inadequate preparation for unexpected events, and the assumption of power according to the size of the budget, the number of employees or the value of the plant.

Interested Party	Interest
Citizen	▪ Clean streams and lakes/clean drinking water ▪ Democratic participation ▪ Protection from service disruptions ▪ Low emissions (e.g., noise, odors) ▪ Information and transparency
Customers	▪ Inexpensive connection and disposal fees
Industry/Large customers (“Key Account”)	▪ Industrial management advantages (e.g., liquidity of assets) ▪ Flexible contract conditions ▪ Rapid, uncomplicated permitting process
Private customers/small businesses (Property or house owners, wastewater producers)	▪ Low connection and disposal fees ▪ Rapid, uncomplicated permitting process ▪ No restrictions on personal freedom
Cantonal agencies	▪ Compliance with regulations and codes ▪ Reasonable monitoring effort ▪ Acceptance of imposed measures

Tab. 1: Selected interested parties in wastewater treatment issues and their interests [2].

Assessing the Need for Change

It is not trivial for individual enterprises to identify organizational shortcomings, a situation worsened by the fact that various services related to wastewater treatment are protected by “monopolies”. Examples include a police monopoly on the permitting process, the more obvious monopoly given by the need to use the existing sewage system, and the fairly direct legal monopoly incumbent in the requirement for making connections to the existing network. These monopolies have the disadvantage that wastewater treatment is not embedded in a functioning market environment, and self-regulating mechanisms, which would normally lead to better efficiency and efficacy in the service provided, are not in play.

Despite all of this, there are a number of parameters that can be used to evaluate distinct performance criteria of an individual wastewater treatment plant.

Performance indicators: Certain indices allow us to compare the service provided by different organizations (i.e., hook-up fees or operational fees). There are a number of national and international projects currently attempting to identify reliable performance indicators for wastewater treatment plants. Experience shows, however, that it is difficult to develop indicators that correctly account for different boundary conditions and other unique circumstances, (e.g., required cleaning efficiency, the type and size of the sewage system, topography, billing methods).

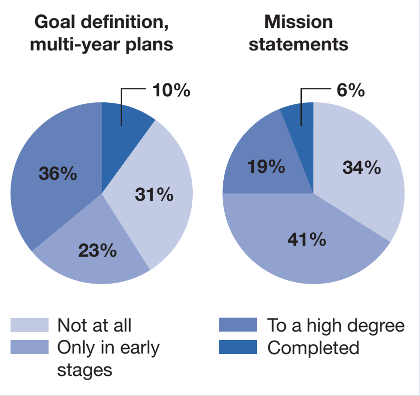


Fig. 1: Realization of goals and work on mission statements in 50 Swiss communities and cooperatives [1].

Process benchmarking: In process benchmarking, the performance of a particular plant is compared to that of the best providers. This allows the evaluation of individual processes and their costs. It also provides for a mechanism for identifying weaknesses and for recommending appropriate measures for improving performance.

Customer surveys and citizen complaints: Systematic complaint management can be a valuable source of information for improving service (i.e., complaints about traffic, odor emissions, unfriendly customer service). Continuous or periodic customer surveys are another tool that could, for example, be used during permitting procedures.

Controlling: Controlling compares specific services to the costs that were incurred. This requires, however, that the demands for the various services are clearly defined and that compliance can be strictly monitored.

Employee surveys and employee forums: Particularly in larger organizations, information about sick leave and employee turnover can provide valuable insight.

Self-monitoring: Self-monitoring provides information about the technical performance of a plant and the quality of current plant management.

Each of these parameters gives information about certain aspects of an operation. It is not possible, however, to gain a complete picture based solely on these parameters, or to identify potential organizational deficits.

Instrument for the Evaluation of the Organizational Process

This is where EAWAG wants to supply help. In collaboration with the VSA, a comprehensive tool for the evaluation of all organizational processes has been developed [2]. The tool considers all major processes relevant to a community or cooperative (Fig. 2) and is based on the model for public service and social service institutions as established by the European Foundation for Quality Management [3]. The original model was adapted to the particular mission and terminology of wastewater treatment and enhanced by additional criteria appropriate in this field. The resulting tool incorporates relevant legal criteria (particularly with respect to the Swiss legislation on water protection), Federal operation guidelines for wastewater treatment plants, as well as guidelines for organization, optimization and quality assurance in wastewater treatment [4].

In the form of a self-evaluation tool, a questionnaire with 250 detailed questions is completed by the organization under consideration. If the legal framework allows it, the answers can be weighted by the organization: each question not only asks about a degree of compliance or fulfillment, but also for an assessment of how important that particular issue is for that organization. This

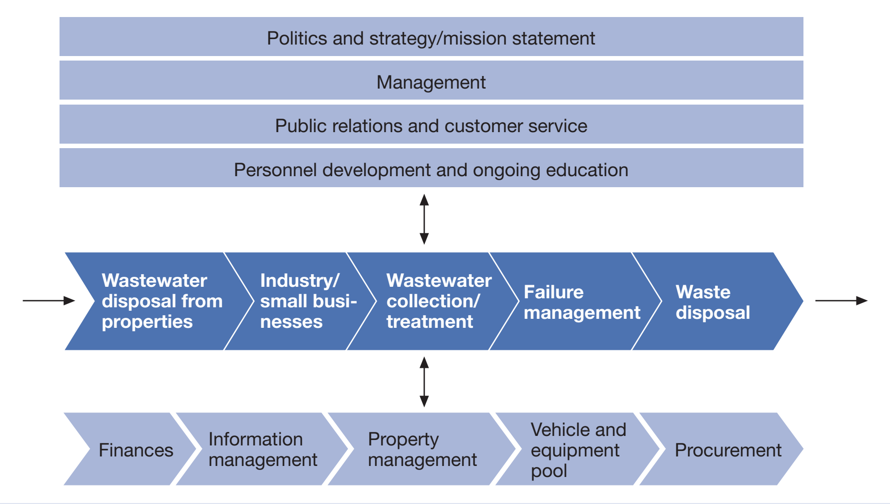


Fig. 2: Process model for the wastewater disposal system for communities and cooperatives.

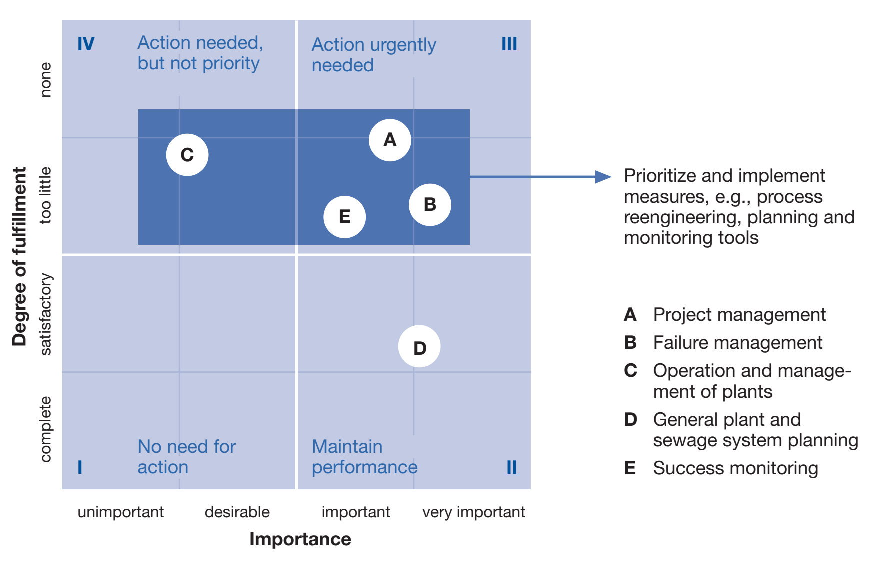


Fig. 3: Priority matrix resulting from self-evaluation.

creates a matrix of four fields, in which a given process is assigned (Fig. 3).

This subjective weighting of relevance not only reveals the need for change, but also the degree of readiness for implementing such change. Past experience has suggested that it is more fruitful to start with the implementation of changes that exhibit a high degree of readiness. This minimizes initial resistance and builds experiences which can then be applied to other areas.

The Swiss community of Hergiswil in the Canton of Nidwalden was the first to use this self-evaluation tool. Several processes were determined to be in need of improvement (Fig. 3): important management processes, as well as multi-year planning and annual success evaluations, were inadequate. There were also some deficiencies in project management and in the handling of problems in plant operation, as well as in normal plant operation and maintenance. Good marks were obtained, however, for general planning, both for the plant itself and for the sewage system as a whole.

Identification of Organizational Deficiencies – What now?

The self-evaluation tool only serves a purpose if the identified shortcomings can be systematically examined in more detail and if the corresponding measures for process reengineering can be developed according to some general guiding principles. For this reason, EAWAG has also developed a tool for process reengineering [5]. In the first step, the current work flow, responsibilities, information and data sources, implicit goals, costs and services as well as interfaces to other processes are analyzed. If the weaknesses of a particular process are already known, the task is simply to clearly define performance targets for the process. Since there are usually only a very few cases in which specific performance criteria have been agreed upon between the plant operators and the carrier organizations, criteria for process reengineering are normally based on exemplary performance agreements and process targets [5]. When developing these agreements and targets, we must consider not only technical demands, but also legal requirements, financial means and demands of the customers and citizens.

In Hergiswil, systematic analysis and the definition of clear goals led to a detailed action plan which has already largely been implemented. For the community of Hergiswil, this meant that in the short-term, a significant effort had to be made, but positive outcomes are already being realized:

- Hergiswil now has a performance agreement with the water plants, where their duties, goals and measurement parameters are clearly defined. Compliance with this agreement is checked annually by the town council; additional action will be taken as necessary.
- Long-term plans for the plant itself and for the operation were also established, allowing the plants to incorporate these goals into the general planning for maintenance and updating of the infrastructure and the general sewage system.
- Plans for the maintenance of the value of the infrastructure are implemented in the form of project management by the community, where particular attention is given to the monitoring of on-going projects. Plans to maintain infrastructure value are directly coupled to the general accounting for the plant.
- Disruptions in plant operation, particularly due to flooding, will be handled more efficiently, thus avoiding negative impacts on the environment.
- By linking newly established performance criteria, by establishing a maintenance schedule for sewage pipes and by introducing a competitive bidding process, an annual savings of approximately 30% was achieved for sewer cleaning.
- In the general operation and maintenance of the wastewater treatment plant, potential annual savings of roughly 13% were identified, although these savings have not yet been realized.

Today, Hergiswil is one of the few communities whose wastewater treatment plants and drinking water supply plants are certified according to ISO 9001:2000. All of the implemented changes are by now well established, and the new management tools have gained a permanent place in the planning structure of the community. This high degree of acceptance may be attributed to the fact that from the beginning, all affected parties were fully integrated in all projects and actively participated in working towards solutions.

Stefan Binggeli, engineer, has developed the two methods for self-evaluation and process reengineering as part of his dissertation in the department "Environmental Engineering" at EAWAG. Since then, he has founded the spin-off company Infraconcept, where he specializes in consulting services in the area of public and private infrastructure.

[1] Wiesmann J., Binggeli S. (2002): Unternehmensführung in den Abwasserbetrieben. Gas Wasser Abwasser *82,* 451–455.
[2] Binggeli S. (2003): Leistungsprozesse der Abwasserentsorgung – Methoden und Instrumente der Bewertung und Optimierung. EAWAG und Institut für Hydromechanik und Wasserwirtschaft, ETH Zürich, Dissertation, 230 S.
[3] EFQM – European Foundation for Quality Management (1999): Das EFQM-Modell für Excellence. Öffentlicher Dienst und soziale Einrichtungen. European Foundation for Quality Management, Brüssel, 43 S.
[4] VSA – Verband Schweizer Abwasser- und Gewässerschutzfachleute (1999): Organisation, Optimierung und Qualitätssicherung von Abwasseranlagen. VSA, Zürich.
[5] Binggeli S. (2002): Prozessoptimierung in der Abwasserentsorgung. Gas Wasser Abwasser *82,* 477–482.

Publications

Please use the order form in the center fold to request reprints.

[3312] **Mettler S.** (2002): *In situ* Iron Removal from Ground Water: Fe(II) Oxygenation and Precipitation Products in a Calcareous Aquifer. Diss. ETHZ No. 14 724, Zurich.

[3313] **Boller M.A., Steiner M.** (2002): Diffuse Emission and Control of Copper in Urban Surface Runoff. Water Sci. Technol. *46* (6–7), 173–181.

[3314] **Steiner M., Boller M.** (2002): Granulated Iron-hydroxide (GEH) for the Retention of Copper from Roof Runoff. In: “Chemical Water and Wastewater Treatment VII”, H.H. Hahn, E. Hoffmann, H. Oedegaard (Eds.). IWA Publishing, London, pp. 233–242.

[3315] **Rechberger H.** (2002): Ein Beitrag zur Bewertung des Stoffhaushaltes von Metallen. Technikfolgeabschätzung – Theorie und Praxis *11* (1), 25–31.

[3316] **Rechberger H., Brunner P.H.** (2002): A New, Entropy Based Method to Support Waste and Resource Management Decisions. Environ. Sci. Technol. *36* (4), 809–816.

[3317] **Odzak N., Kistler D., Xue H., Sigg L.** (2002): *In situ* Trace Metal Speciation in a Eutrophic Lake Using the Technique of Diffusion Gradients in Thin Films (DGT). Aquatic Sci. *64,* 292–299.

[3318] **Meierhenrich U., Thiemann W., Schubert C., Barbier B., Brack A.** (2001): Isoprenoid Enantiomers as Molecular Biomarkers in Ancient Sediments. In: “Geochemistry and the Origin of Life”, A. Brack et al. (Eds.). Universal Academic Press, Tokio, pp. 269–284.

[3319] **Ashbolt N.J., Grabow W.O.K., Snozzi M.** (2002): Indicators of Microbial Water Quality. In: “Water Quality – Guidelines, Standards and Health: Assessment of Risk and Risk Management for Water-related Infectious Disease”, L. Fewtrell, J. Bartram (Eds.). IWA Publishing, London 289–316.

[3320] **Tixier C., Singer H.P., Canonica S., Müller S.R.** (2002): Phototransformation of Triclosan in Surface Waters: A Relevant Elimination Process for this Widely Used Biocide – Laboratory Studies, Field Measurements, and Modeling. Environ. Sci. Technol. *36* (16), 3482–3489.

[3321] **Rauch W., Krejci V., Gujer W.** (2002): REBEKA – a Software Tool for Planning Urban Drainage on the Basis of Predicted Impacts on Receiving Waters. Urban Water *4*, 355–361.

[3322] **Fux C., Boehler M., Huber P., Brunner I., Siegrist H.** (2002): Biological Treatment of Ammonium-rich Wastewater by Partial Nitritation and Subsequent Anaerobic Ammonium Oxidation (Anammox) in a Pilot Plant. J. Biotechnol. *99* (3), 295–306.

[3323] **Rieger L., Siegrist H., Winkler S., Saracevic E., Votava R., Nadler J.** (2002): *In situ* Measurement of Ammonium and Nitrate in the Activated Sludge Process. Water Sci. Technol. *45* (4–5), 93–100.

[3324] **Thomann M., Rieger L., Frommhold S., Siegrist H., Gujer W.** (2002): An Efficient Monitoring Concept with Control Charts for On-line Sensors. Water Sci. Technol. *46* (4–5), 107–116.

[3325] **Rauch W., Bertrand-Krajewski J.-L., Krebs P., Mark O., Schilling W., Schütze M., Vanrolleghem P.A.** (2002): Deterministic Modelling of Integrated Urban Drainage Systems. Water Sci. Technol. *45* (3), 81–94.

[3326] **Huisman J.L., Gujer W.** (2002): Modelling Wastewater Transformation in Sewers Based on ASM3. Water Sci. Technol. *45* (6), 51–60.

[3327] **Batstone D.J., Keller J., Angelidaki I., Kalyuzhnyi S.V., Pavlostathis S.G., Rozzi A., Sanders W.T.M., Siegrist H., Vavilin V.A.** (2002): The IWA Anaerobic Digestion Model No 1 (Adm1). Water Sci. Technol. *45* (10), 65–73.

[3328] **van der Nat D.** (2002): Island dynamics and organic matter processing (Tagliamento, Italy). Diss. ETHZ No. 14 812, Zurich.

[3329] **Bloesch J.** (2002): The River Danube – Between Conservation and Restoration. Limnological Reports, Internat. Assoc. for Danube Research, Vol. 34, Editura Academiei Române, Bucharest, pp. XV–XX.

[3330] **Reinartz R., Bloesch J., Ring T., Stein H.** (2002): Sturgeons Are More than Caviar: A Plea for the Revival of Sturgeons in the Danube River (Extended Abstract). Internat. Assoc. Danube Res. *34,* 505–516.

[3331] **Ward J.V., Robinson C.T., Tockner K.** (2002): Applicability of Ecological Theory to Riverine Ecosystems. Verh. Internat. Verein. Limnol. *28,* 443–450.

[3332] **Goss K.-U., Schwarzenbach R.P.** (2002): Adsorption of a Diverse Set of Organic Vapors on Quartz, $CaCO_3$, and α-Al_2O_3 at Different Relative Humidities. J. Colloid and Interface Sci. *252,* 31–41.

[3333] **Bürgi H.R., Stadelmann P.** (2002): Alteration of Phytoplankton Structure in Lake Lucerne Due to Trophic Conditions. Aquatic Ecosystem Health & Management *5* (1), 45–59.

[3334] **Bloesch J.** (2001): Auf zu neuen Ufern – Forschungsaktivitäten der IAD. Jubiläumsschrift “25 Jahre Österreichisches Nationalkomitee der Internationalen Arbeitsgemeinschaft Donauforschung – Donauforschung neu”. Schrr. Bundesamt für Wasserwirtschaft, Bd. 12, Wien, S. 91–109.

[3335] **Bloesch J.** (2002): The Danube River Basin – the Other Cradle of Europe: The Limnological Dimension. In: “Water in Europe: The Danube River – Life Line in Greater Europe”, P.A. Wilderer, B. Huba, T. Kötzle (Eds.). Academia Scientiarum et Artium Europaea Vol. 34, Nr. 12. Georg Olms Verlag, Hildesheim, Zürich, New York, pp. 51–77.

[3336] **Bloesch J.** (2002): International Association for Danube Research (IAD) – 45 Years of Limnological Engagement and Embarking on New Enterprises (Extended Abstract). 21st Conference of the Danube countries on the hydrological forecasting and hydrological bases of water management, 2–6 September 2002, Bucharest, Romania. Internat. Hydrological Programme of UNESCO. Conference Abstracts, p. 77, and Conference Proceedings + CD-ROM, National Institute of Meteorology and Hydrology, Bucharest.

[3337] **Bloesch J.** (2002): Strategies of Water Quality Monitoring in the Danube River Basin, a Review. 21st Conference of the Danube countries on the hydrological forecasting and hydrological bases of water management, 2–6 Sept. 2002, Bucharest, Romania. Internat. Hydrological Programme of UNESCO. Conference Abstracts, p. 76, and Conference Proceedings + CD-ROM, National Institute of Meteorology and Hydrology, Bucharest.

[3338] **Singer H., Müller S.R., Tixier C., Pillonel L.** (2002): Triclosan: Occurrence and Fate of a Widely Used Biocide in the Aquatic Environment: Field Measurements in Wastewater Treatment Plants, Surface Waters, and Lake Sediments. Environ. Sci. Technol. *36* (23), 4998–5004.

[3339] **Klingel F., Montangero A., Strauss M.** (2001): Nam Dinh – Planning for Improved Faecal Sludge Management and Treatment. Vietnam Water and Sanitation Association’s Yearly Conference, Hanoi, Dec. 6–7.

[3340] **Ingallinella A.M., Sanguinetti G., Fernandez R.G., Strauss M., Montangero A.** (2002): Cotreatment of Sewage and Septage in Waste Stabilization Ponds. Water Sci. Technol. *45* (1), 9–15.

[3341] **Ingallinella A.M., Sanguinetti G., Koottatet T., Montangero A., Strauss M.** (2002): The Challenge of Faecal Sludge Management in Urban Areas – Strategies, Regulations and Treatment Options. Water Sci. Technol. *46* (10), 285–294.

IN BRIEF

Zurich – Water City

TBS Identity, Zürich

Between 21st June and 20th July, Zurich turned into a “Water City”, thus honouring the International Year of Freshwater 2003. The project has raised the sensibility of the local population for a sustainable use of our precious resource water. The main emphasis was put on an open air exhibition along the Limmat. Consisting of seven sites, the water path revealed e.g. where rain water disappears in the city, where drinking water in Zurich is derived from and which species have their habitats in the lake and rivers. A website with further information, offers for schools, special events and guided tours added to the programme. The historical stroll around the Water City, the lecture of water texts in the water church, an exhibition on ground water and a panel discussion on water management met a lot of interest in the public. A competition of water stories organized by the local newspaper “Tages-Anzeiger” counted 250 participants – a great success.

Following the invitation of the Year of Freshwater, the local protagonists AWEL, EAWAG, ERZ, ewz, WVZ and WWF had jointly launched the project “Water City”. The successful team work created a strong presence of the wet element in Zurich. As main sponsors acted APG, the “Tages-Anzeiger” and the Vontobel Foundation.

For further information see: www.wasserstadt.ch

Fishnet: International and National Expert Hearing

The project Fishnet, dealing with the decline in fish catch from Swiss water systems, is entering its final stage. Results have been achieved in about 70 sub-projects and profound literature studies produced during the past 5 years. Many issues were raised during the final synthesis: Have results been assessed and authoritative international knowledge been taken in consideration adequately? Are the conclusions drawn by Fishnet convincing and appropriate? Do suggested measures promise success? On 21st/22nd August, the project management and an international group of experts discussed these and other questions at EAWAG in Kastanienbaum.

The discussion was based on the provisional report on 12 working hypotheses considering various factors (e.g. chemicals, change in temperature, quality of physical habitat) as possible causes for the decrease in fish catch. The experts confirmed and completed our conclusions and/or added critical comments. Even though the decline in fish catch is important on a national scale, it was made clear that significant local and regional variability of manifestation and causes do exist. The experts stressed the significance of ongoing research. Additionally, a national expert hearing took place on 9th September where conclusions gained and measures suggested were examined and put into a concrete form. The final report will be presented to the broad public at the end of January 2004 in Berne.

For further information see: www.fischnetz.ch

EAWAG

The Future of Aquatic Ecosystems: Endangered but not Lost

Experts from all continents gathered at the “International Conference on the Future of Aquatic Ecosystems” held between 23rd and 27th of March 2003. About 160 scientists met at the Swiss Federal Institute of Technology (ETH) in Zurich, where they pointed out trends and future prospects of aquatic ecosystems. The conference was organized by the Swiss Foundation for Environmental Conservation (FEC) and the EAWAG. Experts clearly showed their consensus that today almost all aquatic ecosystems suffer from increasing pressure, such as increasing nutrient loading, abstraction of fresh water from wetlands and coastal systems caused by irrigation, physical habitat destruction and salinization. Furthermore, the climate change was identified as a possible cause for the decline of coral reefs.

Dr Polunin presents the key outcomes of the meeting.

A closer look at past decades confirmed that effective concepts are available in order to stop those negative trends. The Stockholm convention of 1972 e.g. banned the imission of persistent organic pollutants into rivers. The eutrophication of lakes was stopped by upgrading water treatment plants and banning phosphorus in detergents. Large parts of the population support an ecologically sound flood protection allowing the revitalization of river systems.

Additionally, the wide range of scientific insights available today may help a positive influence on the development of the aquatic systems. The hindrance is not a lack of knowledge but a lack of political courage. Scientists, politicians and public must necessarily work together, dealing with uncertainty, proceeding step by step and learning from mistakes – on a local and on an international level.