Leaky sewers and micropollutants require innovative solutions

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For many generations, the population in Switzerland is living with a well-developed urban drainage system. Our ancestors mainly profited from the improved hygiene in urban areas and dry housing conditions. However, in the course of time it was recognized that discharged nutrients in urine and faeces lead to serious over-fertilisation in natural waters. The historical development (construction and extension of wastewater treatment plants, phosphate ban) shows that from time to time a reorientation is necessary to optimally adapt technical systems to changing criteria and requirements. Only an early recognition of ecological dangers or structural problems together with the development of technical solutions in due time will enable us to act proactively.

Subsequently, we present the results from three PhD theses which contribute to enhance the knowledge on crucial processes in the urban water management. On the one hand, the tools developed in these research projects will aid systematic and problem-oriented investments in future infrastructure maintenance. On the other hand, they support the evaluation of the risk potential of micropollutants.

Micropollutants affect natural waters

In recent years, different groups of substances contained in pharmaceuticals and personal care products have gained increasing attention in environmental research and engineering. Residuals of household chemicals and pharmaceutically active compounds may have adverse effects in the smallest quantities on aquatic plants and organisms. Today, high-tech analytical chemistry makes it possible to detect these so-called micropollutants already in rivers, lakes and groundwater – our natural drinking water resources.

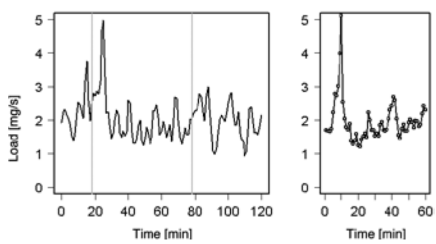
A part of these micropollutants, discharged via sewers, is eliminated almost completely in wastewater treatment plants. Certain substances, however, are only partly decomposed or are transformed into hazardous metabolites. For the evaluation of a wastewater treatment plant's performance, water samples need to be collected to determine the inflow and effluent loads of micropollutants. Such monitoring campaigns are not a trivial task because the chemical analysis of micropollutants is laborious and expensive. In practice, the number of samples is limited and measuring campaigns need to be planned accurately. In order to obtain a representative sample, it is essential to know the temporal dynamics of micropollutants.

In the context of a PhD thesis we developed a model to predict short-term variations of micropollutants. Catchment specific characteristics of the sewer system and the population are being merged in a geographic information system. In combination with sales and application data of household products, this spatial information constitutes the input into a stochastic simulation model.

We found that micropollutant concentrations are subject to surprisingly large fluctuations even within short time periods (minutes). The forecasted dynamics were confirmed by means of high frequency measuring campaigns under different conditions. These results are of great importance for future monitoring practice. Even if loads have to be assessed over longer periods (days or weeks), these short-term variations have to be taken into account when planning measuring campaigns. Otherwise large sums of money are invested to laboriously analyse non-representative samples;

Residuals of dishwasher detergents can already be detected in our natural drinking water resources.

Performing a sewer monitoring campaign to investigate the occurrence of micropollutants.



Left diagram: forecasted variations of benzotriazole (silver protection contained in dishwasher detergents) in the sewer. Right diagram: effectively measured benzotriazole loads.

Wastewater treatment plants eliminate only a certain fraction of micropollutants.

the results of which are then used for further modelling purposes and decision-making.

The simulation model was successfully applied for planning different measuring campaigns. In addition, it can also be used to estimate micropollutant loads in domestic wastewater and their stochastic variations. Thus, it provides valuable information to predict quantities of pollutants directly discharged into the natural waters via combined sewer overflows, or the expected load variations in the influent of a wastewater treatment plant. However, we recommend validating the forecast with specific measuring campaigns, since it is indeed difficult to check the available information for its completeness otherwise.

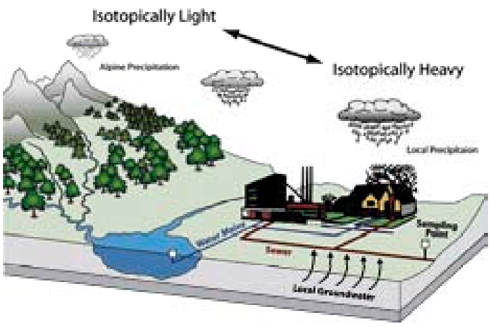
The number of substances classified as micropollutants is on the one hand determined by the progress in chemical analytics and on the other hand by the knowledge of their potential risk. At present thousands rather than hundreds of different substances are considered to be problematic compounds; wastewater treatment plants were originally not designed to eliminate them. Similar to the phosphate ban in washing powders it would make sense to take measures right at the source. Yet, an effective ban does not seem to be enforceable with regard to the multiplicity of remedies and other household chemicals beneficial for modern society. Another possibility would be to withhold such wastewater from the sewer system, collect the undiluted small volumes and treat them with special decentralised techniques.

Since the current drainage system is admittedly very comfortable for the citizens, it is difficult to be open for a reorientation or redesign and, therefore, the long living but aging sewer system will probably remain in operation for quite a while. As a short or midterm solution to effectively remove micropollutants, only extensions of existing wastewater treatment plants with additional treatment steps seem to be feasible.

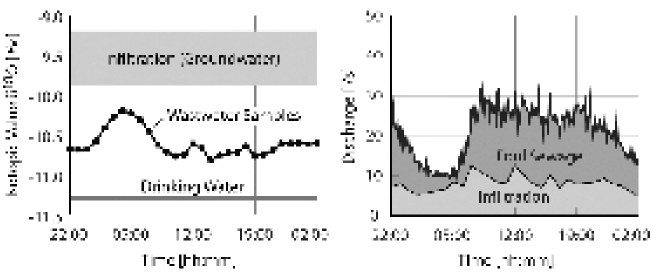
The long-term maintenance and necessary adaptations of the existing wastewater collection infrastructures cause expensive investments for a community. Sewer infiltration and wastewater losses are crucial issues when evaluating the environmental impacts caused by defective sewer systems. However, information about the water-tightness of a sewer system is often poor and investments are frequently based on uncertain information and limited data sets. The European research project APUSS (Assessing infiltration and exfiltration on the Performance of Urban Sewer Systems) has examined the potentials for a more problem oriented management of our subsurface infrastructure: can profound knowledge about the structural quality and functional efficiency of a sewer system be used as the basis for efficient planning and investment strategies?

Sewer Infiltration – A Mass Phenomenon

The term "sewer infiltration" refers to groundwater that is unwantedly discharged into our sewer systems. Depending on the varying water tables, such non-polluted "parasitic water" enters the sewers through different kind of leaks like cracks, holes and open pipe joints. In the past, sometimes even brooks were intentionally led into the sewers for flushing purposes. Nowadays, infiltration is considered to be an unwanted interference factor that should be reduced or eliminated.



Large-scale meteorological processes are responsible for the varied isotopic signatures of natural waters in different hydrological zones. If the isotopic compositions of drinking water and local groundwater are sufficiently different, they are a suitable tracer to measure infiltration. Such usable isotopic separations can exist, where the drinking water originates from a distant hydrological regime but groundwater is recharged by local precipitation.



The stable isotopes method provides a reliable quantification of the volume of infiltrating waters in a sewer system. Left: Characterization of the different waters with respect to their isotopic composition. Right: decomposition of a diurnal wastewater hydrograph into its elementary components "foul sewage" and "infiltration".

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Under unfavourable conditions, the amount of infiltrating water can even exceed 50 % of the total wastewater volume. The rehabilitation of such defective systems has a great importance for a long-term optimisation of operational procedures and the protection of receiving waters: the additional hydraulic load transferred to the wastewater treatment plant is particularly detrimental to its pollutant removal efficiency. On top, the treatment plant's available storm event capacity is cut down and emptying times of retention tanks are extended. As a result, non-treated wastewater is discharged into the environment more frequently. Additionally, infiltration causes an increase in energy consumption and operating costs of pumping stations and treatment plant infrastructures.

Larger punctual sewer leaks can be located relatively easy. However, sewer infiltration typically occurs through a vast amount of smaller defects, which are rather „diffusively" distributed over widespread ranges of the sewer system. Sound information about the extent, expansion and nature of such infiltration sources is an important basis for the evaluation of the structural quality of a sewer system. Conventional measuring practices provide only limited information about this problem. For instance, the common practice of interpreting the nocturnal discharge minimum cannot be considered at all unambiguous when applied in the context of today's growing agglomerations.

Two innovative methods for the quantification of parasitic discharges into sewers with natural tracers have been proposed as routine applications within the scope of the APUSS project. Based on natural tracer signals, these measurement procedures provide a reliable quantification and better quality knowledge than traditional approaches. The first method is based on combined analyses of continuous in situ flow and pollutant concentration time series. The second method utilises measurements of the oxygen and hydrogen isotopic ratios of the water. In the following, some details of this stable isotopes method will be discussed.

The applicability of the stable isotopes method requires a sufficient isotopic separation between local drinking water and infiltrating groundwater. An example are towns and villages from the Swiss Plateau that are obtaining their drinking water from lakes or bank filtrate of rivers whose natural hydrological catchments are partly situated in an alpine altitude. This drinking water and, consequently, the communal wastewater as well are isotopically lighter than the regional groundwater, which is recharged by local precipitation. In this way, the actual foul sewage can be differentiated from the infiltrating groundwater by means of mass spectrometry.

This new approach excludes many conventional sources of error. However, it has to be considered that the accuracy of the quantification depends fundamentally on the natural variability of isotopic compositions in the possible sources of infiltration (e.g. groundwater, brooks). Therefore it is mandatory to undertake a thorough hydrologic investigation in the catchment area. The simultaneous investigation of oxygen and hydrogen isotopes can be essential in order to detect and discriminate possible interferences (evaporation effects, unknown sources of infiltrating water). Beyond this, practical difficulties may also result from regional cross-linking of individual drinking water systems. In the case when parts of a catchment area receive water from different drinking water supplies in the course of a day, this can cause a disturbed tracer signal. To optimise the boundary conditions for one of our reference experiments, it was necessary to substitute all local groundwater production of a village by additionally supplied lake water for a period of several weeks.

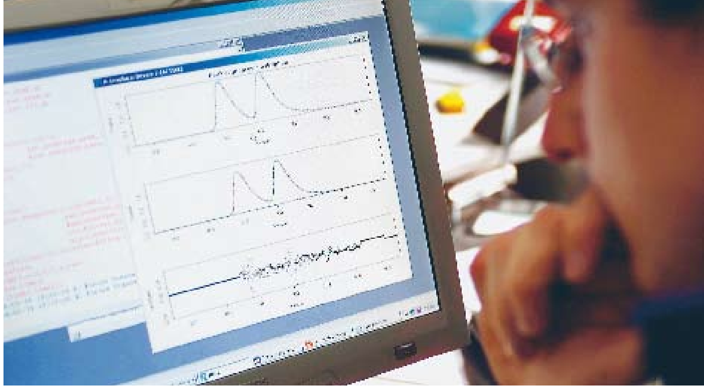
The cooperation in an international research project enabled us to test our methods in several European cities and under variable local conditions of our research partners. We received valuable feedback about the practical applicability as well as about the restrictions that have to be considered in individual cases of operation. Based on our experience, we are confident that under suitable conditions a careful experimenter can estimate infiltration ratios with an accuracy of better than 10 % (double standard deviation, related to the total infiltration).

APUSS had the objective to explore the potential of using quantitative knowledge about infiltration as a benchmark criterion for a problem-oriented rehabilitation management. Actually, this is expedient where sewer pipes are situated below the groundwater table. However, potential losses of wastewater can occur in areas with low groundwater tables. In order to provide a sound benchmarking instrument, a suitable monitoring tool for sewer exfiltration is required, too.

Tracing wastewater losses with marker substances

The pollution of groundwater by leaky sewers is, among other things, problematic regarding the above-mentioned micropollutants. However, almost nothing is actually known about the absolute magnitude of sewer leakage since suitable measuring methods are lacking. Traditional sewer investigation methods (e.g. CCTV) show holes, cracks and fissures but do not allow for reliable statements about the amount of sewer leakage.

The analysis of measured tracer signals of an exfiltration experiment requires computational modeling. In addition, advanced statistical procedures are required to reliably assess the remaining uncertainty of the computed results.



The amount of sewer leakage is generally measured with special pressure tests of individual damages or by means of groundwater modelling. Both methods are relatively complex and not necessarily informative: pressure tests are too time-consuming to assess the many defects in a sewer network at reasonable costs. Groundwater modelling delivers only integrated results over a large area, from which no concrete measures of rehabilitation concerning individual sewer reaches can be derived. In contrast to this, our method allows for direct measurements of sewer leakage over defined sewer reaches.

The fundamental idea underlying our method is simple: at the beginning of the investigation reach, the wastewater is marked with an accurately defined quantity of tracer substance, whose concentration is measured downstream at the end of the investigation reach. A mass balance over the investigation reach (comparing tracer input to output) makes it possible to determine precisely how much of the dosed tracer was lost. The practical implementation, however, requires increased know-how regarding the experimental design and statistical data analysis. On the one hand, an appropriate dosing strategy avoids systematic errors. On the other hand, advanced statistical methods (e.g. bootstrap parameter estimation) are used to assess the remaining uncertainty in the measured results.

Exfiltration experiments with salt tracers (in connection with conductivity measurements), as well as lithium and bromide (measured with ion chromatography) were performed under various real-world conditions in the region of Zurich, London, Berlin, Dresden, Lyon and Rom. At present, the tracer method is used in Haifa and Bologna.

First results suggest that in badly maintained sewers larger losses of wastewater arise locally. Since the measurements contain a certain inaccuracy, fractions of exfiltration of less than 1 to 2 % of the marked wastewater cannot be reliably detected yet.

Further results of the APUSS project suggest that wastewater losses from defective house connections can contribute significantly to the total situation. For optimal sewer rehabilitation this is particularly critical since house connections are private property and thus usually not professionally maintained. Obviously, a target-oriented approach does not only require new measuring methods but also a reorientation regarding innovative forms of organization and sewer operation concepts.

Great challenges for the future

The extensive future challenges arising in the field of urban water management require a steady advancement of available tools and methodologies. On the one hand, we must assimilate state-of-the-art knowledge from different environmental disciplines in order to assess and minimise the hazard potential of an immense multiplicity of chemical substances. On the other hand, the large financial investments for the maintenance of our sewer systems require an optimal, problem-oriented rehabilitation and investment strategy. Against this background, we developed detection methods, which make it possible to substantially improve the knowledge about important sewer processes (such as micropollutants, groundwater infiltration or sewer leakage).

Regarding the education in environmental engineering, this means that we must be prepared to increasingly deal with challenging interdisciplinary concepts. Our graduates are entitled to expect a diversified and exciting field of work. The historical development shows that from time to time a reorientation is necessary so that technical systems can be adapted optimally to the respective needs and objectives. Our research will continue to make contributions to this end, supplying the necessary knowledge and methods.

A tracer experiment is performed to quantify wastewater losses from leaky sewers. An exactly defined quantity of tracer substance is dosed to the wastewater and measured at the end of the investigation reach. Since tracer is lost together with seeping wastewater, a mass balance over the system makes it possible to quantify sewer leakage.