# Tracer based quantification of sewer infiltration: experiences using natural isotopes ($\delta^{18}O$, $\delta^{2}H$).

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In order to obtain reliable information on the material fluxes within the urban environment, the use of artificial or natural tracers can be the optimal choice. Stable isotopes ($\delta^{18}O$ and $\delta^{2}H$ of water) provide a promising tool to quantify the discharge of extraneous waters in wastewater collection systems. Our study demonstrates the suitability of this approach in practical application. We present a detailed assessment of uncertainties and interpretation of observable effects.

Sustainable strategies for the planning, operation and maintenance of urban drainage networks require adequate knowledge about their functional behaviour and interaction with the surrounding aquifers. After decades of operation the sewer networks of many cities are in a state of disrepair. Under unfavorable conditions, the amount of groundwater infiltrating into the deteriorated pipes can even exceed 50% of the total wastewater volume. This additional hydraulic load is particularly detrimental to the pollutant removal efficiency of wastewater treatment plants. Second, available storm event capacities are reduced and emptying times of retention tanks are extended. As a result, non-treated wastewater is discharged to the environment more frequently. In addition, there is increasing evidence that in many European cities groundwater levels are controlled by the serious drainage effect of permeable sewer systems. Today, larger punctual sewer leaks can be located relatively easily by closed-circuit television or walk-through inspections. Yet, sewer infiltration typically occurs through a vast number of smaller defects, which are rather "diffusively" distributed over widespread ranges of a catchment. Practitioners therefore often address this issue by calculating the “parasitic discharge” on the assumption that the night time minimum in the diurnal wastewater hydrograph is equal to the extraneous flows. In the context of nowadays growing agglomerations this practice is considered oversimplified and can likely lead to erroneous results. However, to date little research has been devoted to the use of direct natural tracers as an alternative for the quantification of these extraneous discharges.
We demonstrate the results of a reference experiment conducted in Rümlang (CH), a commune of about 5'400 inhabitants, located at the north-eastern boarder of Zurich. The village is predominantly served with drinking water from Lake Zurich, a large fraction of which is derived from precipitation in the Alps (average altitude of the drainage basin ≈ 1220 m asl). Mean drinking water isotopic values plot at -11.3 ‰ ($\delta^{18}O$) and -80.3 ‰ ($\delta^{2}H$). In contrast, mean groundwater composition was estimated to -9.54 ‰ ($\delta^{18}O$) and -68.6 ‰ ($\delta^{2}H$), reflecting the comparable heavy isotopic signature of local precipitation (terrain ≈ 450 m asl). Figure 1 compares a time series of measured wastewater $\delta^{18}O$ values to these endmember compositions and demonstrates the resulting hydrograph separation. Groundwater infiltration amounts 712 $m^3$/day, corresponding 39% of the total daily wastewater discharge. It is remarkable, that the extraneous discharge apparently reveals certain diurnal fluctuations (in average $Q_{Infiltration}$ is higher in the day period than in the night). From

our basic understanding the actual flux of groundwater infiltrating into the sewer pipes is controlled by seasonal variations, but should not be subject to intraday fluctuations. To our interpretation, the observed variations are actually being caused by a considerable quantity of dead zone volumes distributed over the sewer network. The accuracy of the infiltration estimates fundamentally depends on both the natural variability of isotopic compositions in the aquifer and the perforation state of the sewer network (a comprehensive uncertainty analyses framework is given in Kracht et al. 2006). Thorough hydrological investigations are mandatory to define the principal pathways of all water-types in the catchment. Simultaneous use of oxygen and hydrogen isotopes proofed to be important, in order to detect and discriminate possible interferences (evaporation effects, unknown sources of infiltrating water). Beyond this, practical difficulties resulted from the regional cross-linking of drinking water systems and from smaller amounts of local drinking water abstractions, causing a disturbed tracer signal in the drinking water network. To optimize the experimental boundary conditions, it was necessary to substitute all local groundwater productions by additionally purchased lake water for a period of several weeks.

The presented tracer method has been worked out by EAWAG within the scope the European research project APUSS (Assessing Infiltration and Exfiltration on the Performance of Urban Sewer Systems, Bertrand-Krajewski et al. 2005). Along with our second approach, which is based on the combined analyses of continuous in situ flow and pollutant concentration time series (Kracht & Gujer 2005), we aim to support a complementary toolset for routine application in urban drainage engineering. International cooperation within the APUSS research project enabled tests under various conditions in several European cities. Thereby 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 5 % ($2\sigma$, related to the total wastewater discharge).

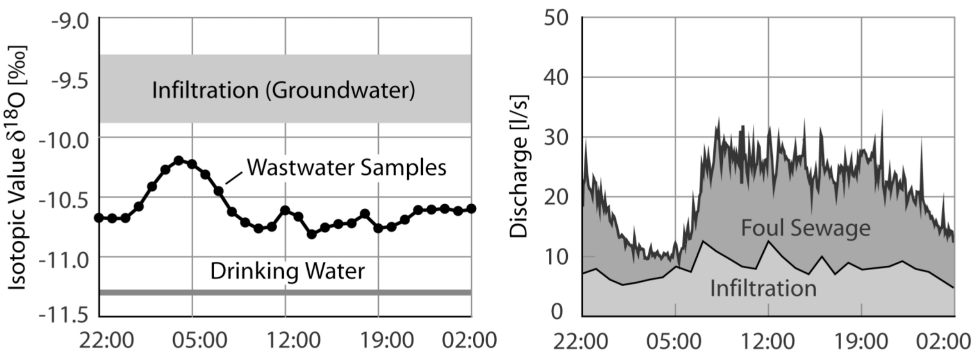


Figure 1. Isotopic characterisation and decomposition of a diurnal wastewater hydrograph into its elementary components “foul sewage” and “infiltration”.

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