Sewers as drainage systems – quantification of groundwater infiltration

Les réseaux comme système de drainage – évaluation des infiltrations d'eaux souterraines

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RESUME

Le 'infiltration de aux souterraines dans des réseaux d'assainissement réduit leur efficacité et peut avoir de ce fait comme conséquence une détérioation de la qualité des milieux récepteurs. En dehors des impacts bien connus associés aux eaux parasites, le rôle de drain joue par les égouts pendant le périodes pluvieuses et les inondations pourraient diminuer le risques de remontée des nappes d'eaux souterrains. L'efficacité de ce drainage est évaluée dans la ville Dresde. Les investigations portent sur le rôle du réseau d'assainissement de Dresde pendant et après l'inondation d'août 2002, quand le niveau des eaux souterraines a atteint son niveau record depuis que les données sont enregistrées. Pour estimer et prévoir l'effet du drainage un modèle hydrologique de fuite a été calibré et utilisé. De plus, les exfiltrations des égouts ont été évaluées.

ABSTRACT

The infiltration of groundwater into sewer systems reduces the efficiency of the sewer networks and may thereby result in a deterioration of receiving water quality. Besides these widely known impacts of parasite water sewers are serving as drainage systems during wet-weather periods and flood events and could diminish problems of increasing groundwater levels. The "efficiency" of this drainage effect is evaluated in the city of Dresden. The investigations deal with the effects of the Dresden sewer system during and after the flood event in August 2002, when the groundwater level rose to a maximum level since data were recorded. To estimate and predict the drainage effect the hydrological leakage model is calibrated and used. Furthermore, the leakage of sewers has been assessed.

KEYWORDS

groundwater drainage, groundwater infiltration, leakage model, parasite water

INTRODUCTION

The infiltration of groundwater into sewer systems is an important topic of wastewater management since decades. Scientists and engineers described the effects of parasitic water inflow with regard to operation and increasing costs of sewer systems and wastewater treatment plants (Kroiss and Prendtl, 1996; Decker, 1998; Michalska and Pecher, 2000). By affecting the frequency of combined sewer overflows, the impact to receiving waters may also be influenced significantly. Therefore, it is accepted practice and established in regulations of environmental authorities that sewers are to be rehabilitated as far as possible in order to reduce infiltration. On the other hand, when the groundwater level rises due to changing external boundary conditions or due to a flood event, the sewer system acts as a drainage system. Having tight sewers would, in those cases, cause the groundwater level to remain high for a much longer time period or even entire sub-catchments are wetted (Reichel and Getta, 2000). In order to tackle this problem, basic information about the interaction between sewers and groundwater is needed.

In the City of Dresden the flood event in August 2002 caused the groundwater level to rise to a height that was never recorded before. Large areas were wetted and the statics of buildings endangered. Since the wastewater treatment plant (WWTP) was flooded by the river Elbe the sewer system had no function during the flood event, but exhibited an increased parasite water flow during a long period of time after the flood event.

As a consequence of the flood a strategy to protect historical and important public buildings is being worked out. The sewer system may be implemented as a part of a protection strategy. For this reason it is essential to explore the function of the sewer system with regard to drainage of groundwater during and after floods.

The balance of infiltration rates with measurements of runoff in sewers during the flood events is impossible due to the breakdown of the system. So it was necessary to model the infiltration of groundwater to assess the efficiency of drainage and the attenuation of groundwater waves during extreme situations.

In this paper, the set-up and calibration of the model is introduced applications are discussed and the potential of the approach is evaluated.

SIMILARITIES OF TECHNICAL AND NATURAL SYSTEMS

It was shown by WITTENBERG and BROMBACH (2002) that sewer systems behave similar as watercourses with regard to infiltration of groundwater.

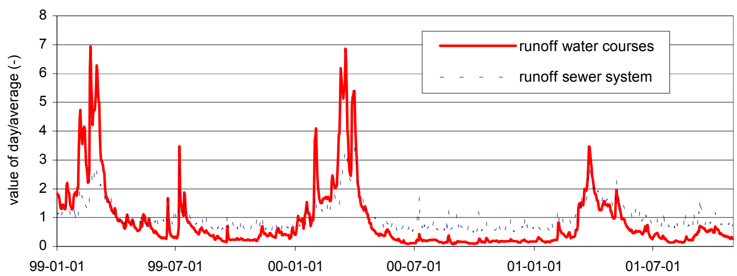

Figure 1: Normalised flow rate measurements of water courses and sewer system in the City of Dresden

For the catchment

of the City of Dresden it could be shown that the behaviour of the sewer system on the one hand and those of rivers and creeks in the city on the other hand is similar.In Figure 1 plots of the normalised flow rate of the rivers and the WWTP inflow are compared. The plots show a clear synchronity of the hydrographs.

The main reason for the correlation is the similarity of groundwater infiltration processes into the surface water and into sewer pipes.

Groundwater effects to sewer pipes can be identified by correlating the dry-weather flow in the system to the groundwater-influenced length of sewer pipes. Figure 2 shows the respective correlation.

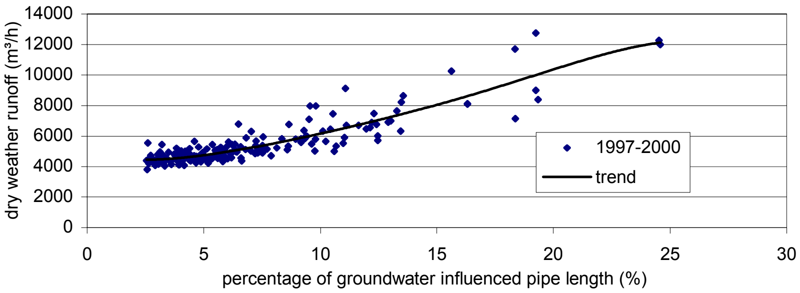

Figure 2: Correlation between percentage of groundwater-influenced length of sewer pipes and dry-weather runoff

THE LEAKAGE APPROACH

Based on the similar behaviour of the natural and technical systems the leakage-approach, which is widely used for modelling hydrological interactions between aquifer and surface water, was applied to estimate groundwater infiltration. The leakage approach is related to the wetted area of the river bed and the difference between groundwater and surface water level. Furthermore, a specific leakage factor is essential for the calculation of infiltration rates, representing a specific resistance. As an integrative parameter the leakage factor describes various attributes of the soil layer of the river bed and thereby the potential of exchange between the compartments ground- and surface water. According to GUSTAFSSON (2000) the Leakage-model can be modified for the simulation of groundwater infiltration into sewer systems (Equation 1).

$$Q_{Infiltration} = k_L \cdot A_S \cdot (h_G - h_S) \qquad \textit{(requirement: } h_S < h_G\textit{)} \qquad \text{(Equation 1)}$$

$Q_{Infiltration}$	infiltration of groundwater (m^3/s)
A_S	groundwater-influenced pipe surface (m^2)
h_S	water level of sewer pipes (m)
h_G	groundwater level (m)
k_L	leakage factor (s^{-1})

The groundwater level, which is needed to calculate the groundwater-influenced surface of the sewer system, can either be modelled or interpolated based on measurements. The water level in the sewer pipe can be modelled as well, however, it is also feasible to simply estimate it. The leakage factor has to be calibrated. This was realised on the basis of wastewater flow and groundwater level measurements of preceding months and years.

CALIBRATION OF LEAKAGE FACTORS

The calibration of the leakage factors of the Dresden sewer pipes was based on Equation 2.

$$k_{L,T} = \frac{Q_{Infiltration,T}}{\sum_{i=1}^{n} \left[\left(h_{G,i,T} - h_{S,i,T} \right) \cdot A_{S,i,T} \right]} \qquad \textit{(Equation 2)}$$

$k_{L,T}$	integral leakage factor at time T
$Q_{Infiltration,T}$	balanced infiltration of groundwater at time T
$H_{G,i,T}$	groundwater level at the sewer pipe i at time T
$H_{S,i,T}$	water level in the sewer pipe i at time T
$A_{S,i,T}$	groundwater-influenced pipe surface of pipe i at time T

The estimation of the groundwater level at each pipe and the groundwater-influenced pipe surface of the sewer are based on the interpolation of groundwater measurements. The dynamics of water levels in the pipes were estimated according to measurements of water levels in the system. The infiltration was balanced by calculating the difference of wastewater flow and the average consumption of drinking water. Because of uncertainties associated to balanced drainage rates (KARPF and KREBS, 2003) the variation of infiltration rates ($Q_{Intiltration}$) was smoothened.

The leakage factor calculated with equation 2 represents an integral parameter for all groundwater-influenced pipes at a certain time *T*. In order to refer individual leakage factors to pipes the calculation had been carried out for 240 time spots from 1995 to 1999 and represents a kind of a calibration under various groundwater conditions. Thereby, the leakage factor of each groundwater-influenced pipe was approximated to be some weighted average of all calibration cases.

During the flood event in August 2002 much more pipes were influenced by groundwater than during the calibration period from 1995 to 1999. For this reason calibrated leakage factors were not available for a number of pipes. For these pipes the average of the calibrated factors will be used for further considerations.

VERIFICATION OF THE LEAKAGE MODEL

The infiltration rates have been simulated by applying equation 1 for the period from 1995 to 2003 (Figure 3). Comparing the results of the simulation with balanced infiltration rates, it can be seen that the leakage approach yields a realistic approximation of the infiltration. Besides the time period used for calibration, in the years from 2000 to 2003 the balanced and simulated infiltration rates are also in reasonable agreement, although the deviations are somewhat more significant. It is obvious, that the simulated infiltration peaks are significantly higher than the balanced infiltration. The explanation for this is that under extreme event conditions wastewater flows and resulting balanced infiltration rates are influenced by sewer overflows. Furthermore, the balanced infiltration rates are affected by uncertainties of input data e.g. difficult to determine inflow of external areas.

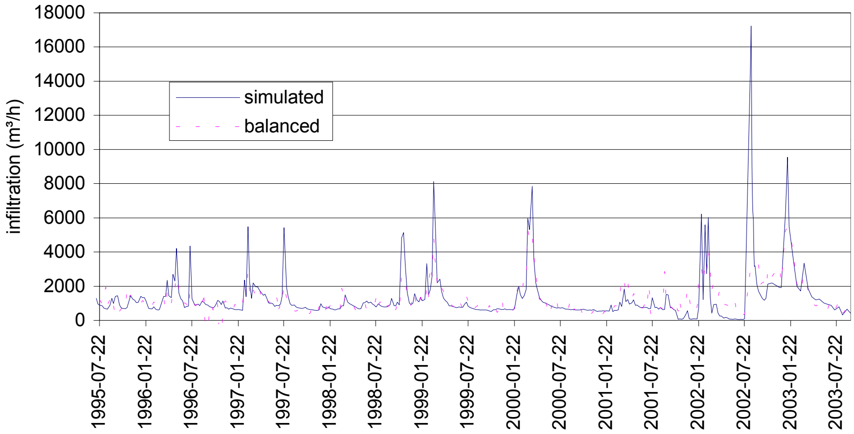

Figure 3: Balanced and simulated infiltration of groundwater into sewers in the City of Dresden

APPLICATION OF THE MODEL FOR THE CITY OF DRESDEN

During the flood in August 2002 the groundwater level in the investigation area of approximately 70 km² rose on average 3 meters higher than the mean value of the years 1995 to 2001. The peak infiltration rates during the flood in August 2002 are estimated to be 17,000 to 18,000 m³/h (see Figure 3). If the pore volume of the groundwater aquifer is assumed to be 30%, the daily infiltration of groundwater and the runoff in the sewer system would cause a reduction of groundwater level height of 2 cm per day throughout the catchment.

Considering a longer time period the reduction of groundwater height by the sewer systems drainage effect has a significant importance in the city of Dresden. The average reduction in 6 month with an average infiltration of about 3000 m³/h yields to about 0.6 m. Furthermore, the drainage effect is rather inhomogeneous depending on local boundary conditions. Following this, the local reduction of groundwater levels is expected to be much higher than the average number of 0.6 m in 6 months.

Besides the estimation of infiltration rates and its consequence for the groundwater balance basic findings on the distribution and the inhomogeneity of the sewer systems leakage and the associated infiltration could be identified. By means of the estimation of the spatial variability of infiltration rates, rehabilitation and inspection can be prioritised. In Figure 4 the infiltration into sewers classified by pipe dimension is illustrated. 80% of the parasite water inflow is caused by sewers with a profile height larger than 1,200 mm and the respective house connections.

The leakage of pipes represented by the value of the leakage factor is sorted as a function of the pipes diameter in Figure 4. Pipes with a smaller dimension have a lower leakage than larger pipes. The surrounding soil of most of the smaller pipes consists of a cohesive soil layer rather than being surrounded by a sand bed and thus causes a more effective sealing.

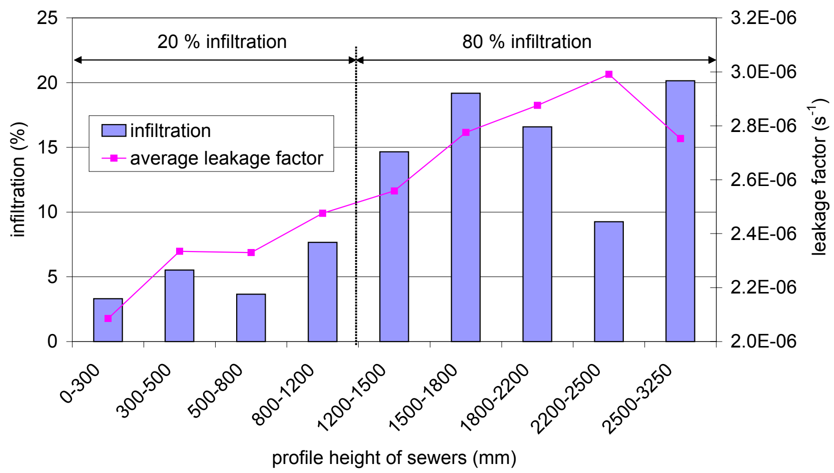

Figure 4: Infiltration and leakage factors depending on the profile height of sewers in the City of Dresden

CONCLUSION

The leakage model known from describing interactions between rivers and groundwater aquifers has been successfully applied to simulate the dynamics of groundwater infiltration into the sewer system. Main requirements for the calibration of the leakage factor are the availability of data concerning the groundwater level, pipe parameters, preferably on a GIS system, and balanced infiltration rates for.

The simulation of groundwater infiltration showed that the groundwater peak level cannot be lowered by the drainage effect of the sewer. However, the drainage effects of the sewer system exhibited a major influence to lower high groundwater levels during some months after the flood and prevented some sub-catchments from being flooded by groundwater for a longer period of time.

Besides the assessment of drainage effects the leakage model gives essential information about the leakage of sewers and emphases of infiltration. This is useful especially for the prioritisation of rehabilitation activities in sewer networks.

The importance of model approaches simulating relations between sewers and groundwater will increase. Concepts for future activities to manage catchment areas will need the quantification, localisation and prediction of groundwater drainage to estimate impacts to the water balance in urban areas.

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