Assessment of extraneous water inflow in separate sewer networks

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ABSTRACT
Separate sewer systems provide due to the separate transport and treatment of waste water and rain water an efficient sewerage technology. But the advantage compared to combined system technology gets lost if the input of extraneous water exceeds the capacity of the system. Especially the input of rainwater into the waste water pipes depending on the drained area is responsible for an overload of the sewer system and the wastewater treatment plant (WWTP). In the paper the input of extraneous water induced by groundwater and rainwater in different rural catchments in the City of Dresden is assessed. On the base of a hydrodynamic network model a case study is carried out for one of these catchments. The analysis of the current status of the studied area allows the identification of rehabilitation activities and, furthermore, gives an indication on their extent and effects.

KEYWORDS
Extraneous water; infiltration; rehabilitation; separated sewer system

EXTRANEOUS WATER SOURCES IN SEPARATE SEWER SYSTEMS
In Germany often separate systems are situated in rural areas or on the periphery of cities. In these areas, characterised by single residential housing with a low population density, the boundary conditions are favourable for a two-pipe-system – i.e. the separate system.
The main advantage of the separated systems is supposed to be that sewage water ought to be transported and treated separately from the rainwater and therefore the systems work with a high efficiency. But the real operation of a lot of separate sewer systems suffers from the inflow of extraneous water.

In the sewage network of separate systems extraneous water includes two main fractions. Besides the groundwater inflow through leaky pipes or connected groundwater drainage pipes extraneous water consists of rainwater inflow. The groundwater inflow is related to the seasonal variation of the groundwater level (KARPF and KREBS, 2004; ATV-DVWK, 2003). On the other hand a large variation of extraneous water inflow can be recognised if impervious area is connected to the waste water pipes and rainwater thus directly introduced into these pipes. The influence of precipitation on the waste water system ranges from a temporal increase of the runoff in the system up to an overload of the sewer networks capacity, pumping stations or/and the waste water treatment plant (WWTP). The systems overload can induce a flushing or wash-out of sewage or sludge into the receiving water.

REHABILITATION STRATEGIES
In general rehabilitation activities in sewer systems to minimize the extraneous water are induced by acute and non acute problems. Non-acute problems are often increasing costs of

the waste water treatment caused by extraneous water input (DECKER, 1998; KROISS and PRENDL, 1996; MICHALSKA and PECHER, 2002). In dependence of specific boundary conditions the acceptance of extraneous water can be a partial advantage as compared to rehabilitation activities. However, it is useful to perform a cost-efficiency-analysis and to combine the reduction of extraneous water inflow with other rehabilitation goals, e.g. hydraulic rehabilitation of ageing-induced network reconstruction or street reconstruction.
Acute problems with extraneous water are given if limits of regulations are exceeded non-tolerably. In these cases, rehabilitation activities are indispensable. The capacity overload of waste water pipes and the WWTP in separate sewer systems during rain events represents an acute problem. The main strategy is the reduction of drained area connected to the sewage system in order to minimize the rainwater input. Additional activities are the lowering of groundwater inflow by rehabilitation of leaky sewers and disconnection of drainage pipes.
Another strategy to solve the rain induced extraneous water problem in separate sewer systems is the modification of the system. The modification can include the construction of overflows and retention tanks or the expansion of the WWTP. The separate system becomes more similar to a combined sewer system. This strategy is feasible only if the receiving water is resilient enough to buffer the hydraulic and load peaks of overflows. Furthermore, a increased complexity of the system must be recognized and therefore, the strategy to modify the separate sewer system seems to be an emergency solution, which is hardly covered by regulations.
In any case, rehabilitation requires efficient methods to identify major sources of extraneous water inflow and thorough analysis of useful strategies to tackle the problem. In the following, it will be shown how the identification of extraneous water sources can be realised. The effects of rehabilitation activities in a rural catchment area in the City of Dresden will be examined and discussed.

SEPARATION OF GROUNDWATER AND RAINWATER INPUT

The origin of extraneous water inflow in a catchment can be analysed by fractionation of the runoff measurements, i.e. by assigning to total flow rate to waste water flow, groundwater and rainwater inflow (for methods see WITTENBERG and BROMBACH, 2002; LFU, 2001).
A statistical method developed in a research project funded by the Evironment Agency of the German State Baden Wuerttemberg (LFU, 2001) was applied in the City of Dresden. The result of the flow fractionation related to the small test catchment is shown in Figure 1.

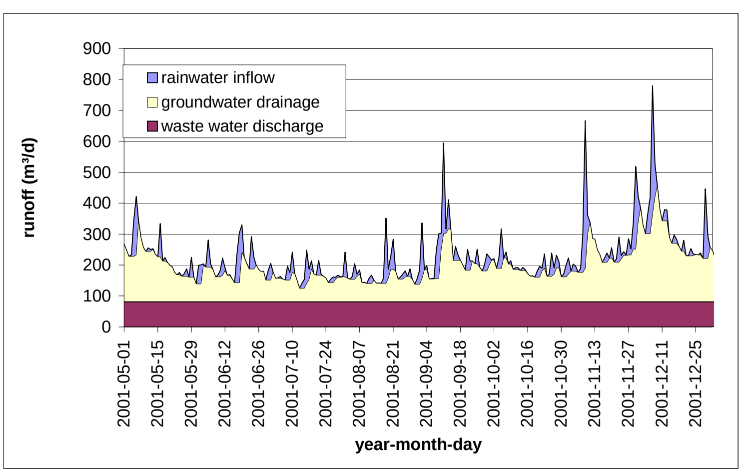

Figure 1: Flow fractionation into sewage flow, groundwater drainage and rainwater inflow in a rural catchment of the City of Dresden

Due to dry-weather measurements the fractionation method was calibrated. The base flow consists of groundwater inflow and waste water discharge in the considered period. The waste water discharge was assessed by measurements of the drinking water supply. The daily rainwater runoff is represented by the difference of runoff measurements and base flow respective the dry weather flow.

The result of the measurement data analysis in 5 rural catchments is shown in Figure 2. Due to the relative consideration of the extraneous water input, the evaluation of the catchments areas with different catchment size is possible. The groundwater inflow is related to the surface of the pipes, which represents the potential surface for groundwater infiltration, while the rainwater input is related to the number of manholes, which represents on the one hand the size of the catchment area, on the other hand potential number and locations of rainwater inflow. (Note that due to the independent nominators, the columns of groundwater and rainwater inflow cannot be compared directly for the same catchment and refer to different scales!) The values illustrated in Figure 2 are based on annual balances of the year 2001. Figure 2 clearly shows that the two systems whose WWTP is often overloaded suffer from significantly higher specific groundwater and rainwater inputs than the other three networks.

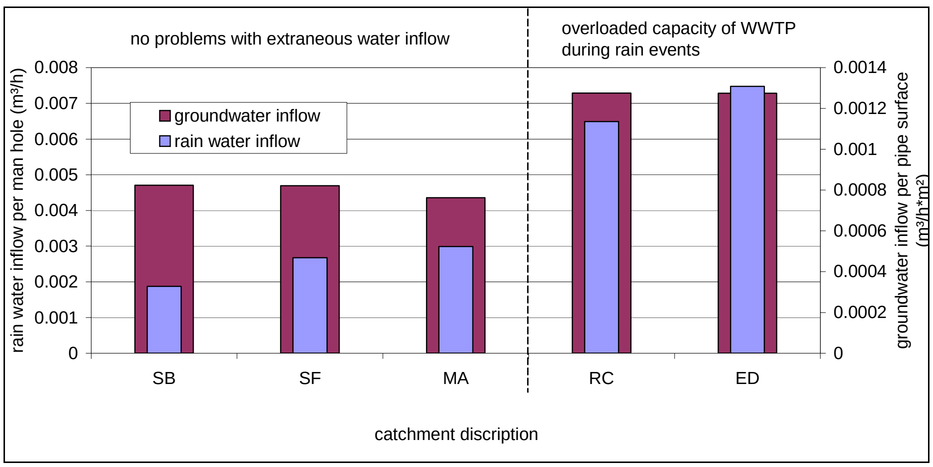

Figure 2: Specific rainwater and groundwater inflow balanced for 5 rural catchments of the city of Dresden

CASE STUDY IN A RURAL CATCHMENT AREA

The variation and dependency of rain inflow was examined in the catchment ED, where the WWTP is often overloaded during rain events. The catchment size of ED amounts to about 0.60 km². The percentage of impervious area is approximated according to geographical information with 25% of the total area. 5 % of the impervious area consists of streets. The population density is about 2100 inhabitants/km². At first the current status of the area is considered by analyzing the dependence of rainfall and runoff. The critical rain intensity, which leads to WWTP overload, is identified on the basis of a hydrodynamic network model. To assess rehabilitation strategies and their combinations scenario analysis was carried out by parameter variation.

Examination of the current status

The dependence between rainfall and runoff volumes in the system is illustrated in Figure 3. Monthly values of rainfall and rainwater runoff from 6 month in 2001 (May until October) are approximated with an exponential function.

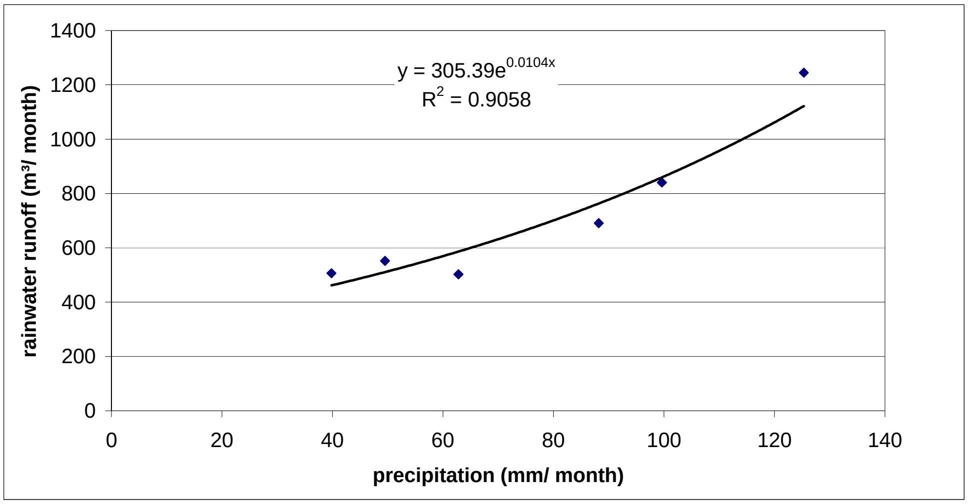

Figure 3: Monthly rainfall and rainwater runoff volumes in the catchment ED

Based on the precipitation height h_P, on the assumption of some wetting and depression loss $h_{P,L}$ and on the rainwater runoff Q_R derived from flow fractionation the size of the drained area A can be estimated by Equation 1.

$$A = \frac{Q_R}{h_P - h_{P,L}} \qquad \text{(Equation 1)}$$

In the catchment area ED the estimation of the drained impervious area based on an assumed precipitation loss of 1.8 mm per rainy day yields about 0.015 km². This represents roughly 10% of the impervious area of the village. By simulation of 15-minutes rain events with different intensities the current status and the problems in the catchment area can be analysed. Input data of the hydrodynamic model includes the calculated drained area, the minimum and maximum groundwater drainage flow estimated by the fractionation method described above, and the maximum hourly waste water discharge with a threefold value of the average flow. The simulations were performed with the software HYSTEM-EXTRAN (itwh, 2002). Results are shown in figure 4.

Overloading of the WWTP can be expected in the intensity range of 2.5 mm to 3.5 mm per 15 min event. The range of 1 mm is the consequence of the variation of the base flow due to seasonal variation of groundwater drainage. According to the German guideline ATV-DVWK A131 for WWTP design (ATV-DVWK, 2000) the sewer system and WWTP has to be operated with the same flow rates. The guideline ATV A118 (ATV, 1999) used for the design of sewer systems contains ranges of extraneous water in separate systems. According to the guideline ATV A118 specific extraneous water inflow during dry weather may vary from 0.05 up to 0.15 L/(ha·s), specific rainwater input from 0.2 – 0.7 L/(ha·s).

The range of WWTP inflow capacity and the current capacity of the WWTP in the studied catchment ED are illustrated in Figure 4. On the one hand, it can be deduced that the capacity of the WWTP corresponds to the German standards, while, on the other hand, a potential expansion of the WWTP capacity is acceptable.

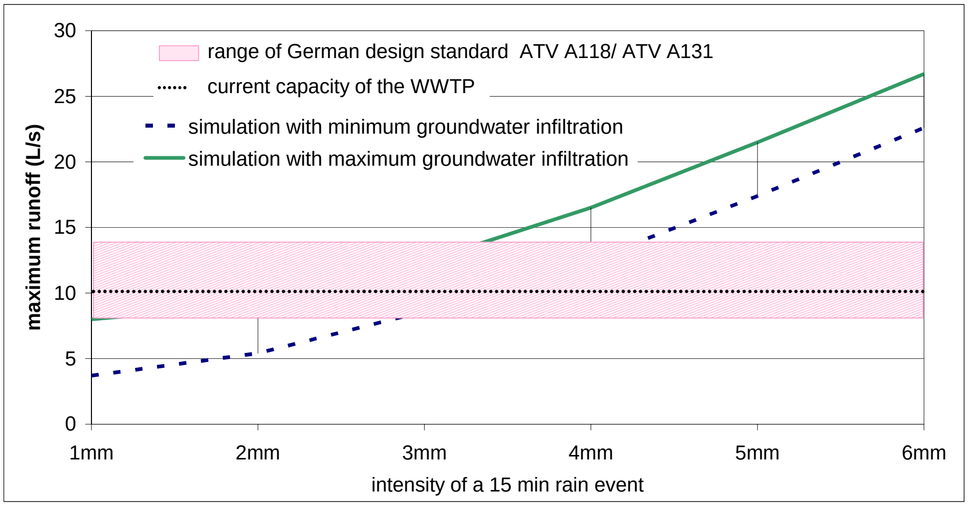

Figure 4: Simulation of the runoff in the sewer system of the village ED

Rehabilitation scenarios

Three rehabilitation strategies or respective combinations would contribute to an improvement in catchment ED. These are reduction of drained area, minimizing of groundwater drainage and expansion of the WWTP. The rehabilitation scenarios are characterised by a reduction of drained area by 10%, 30%, 60% and 80%. The groundwater drainage is varied from 50 % up to 400 % of the mean sewage flow. The capacity of the WWTP is increased to the recommended upper limit of the German guideline ATV A 118 (ATV, 1999). The rain intensity was kept constant with 104 L/(s·ha), i.e. the intensity of a rain event with the duration of 15 min and the recurrence interval of once per year. In Figure 5 the result of 4 scenarios with a maximum groundwater input are illustrated and referred to the current and maximum capacity of the WWTP.

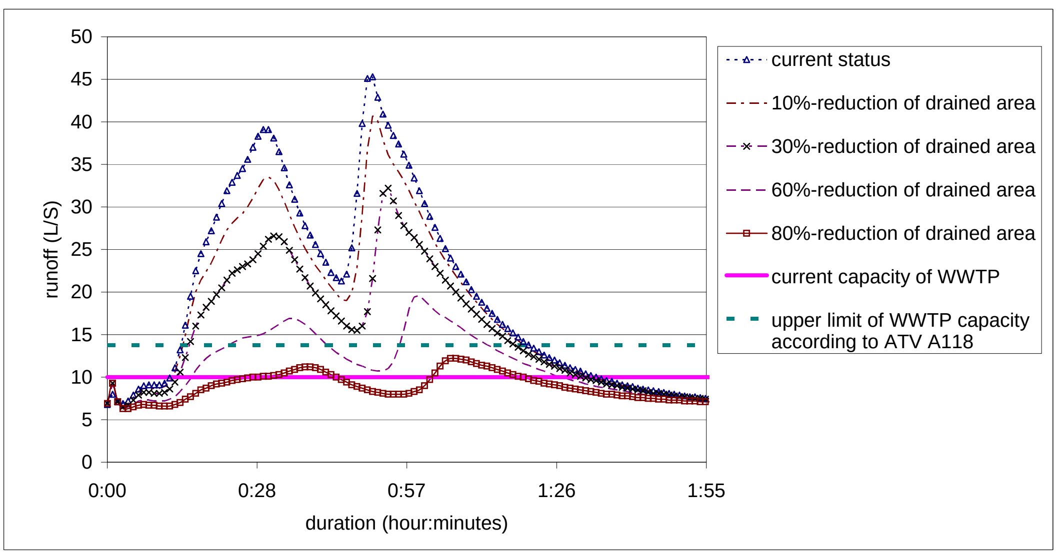

Figure 5: Simulations of the runoff in the sewer system during a 15-min rain event with different drained surface areas in catchment ED

It can be deduced that the reduction of the drained area has to reach the order of 80% in order to guarantee no overload of the WWTP during the one years 15-minutes-event. This applies only if the WWTP capacity is increased significantly almost to the upper limit according to ATV A118.
The influence of minimizing groundwater inflow is assessed by comparing the overload volume during the 15-minutes-rain-event. Figure 6 shows the decrease of the overload volume due to the reduction of drained area, groundwater inflow and expansion of the WWTP.

The groundwater input is varied from the maximum down to a minimum level, corresponding to the seasonal variation (0.5 – 4 L/s). The mean groundwater infiltration represents the estimated yearly average. It is assumed that the reduction of groundwater drainage by 75 % is feasible by rehabilitation activities. This lowered level of groundwater drainage corresponds to 33 % of the dry weather flow.

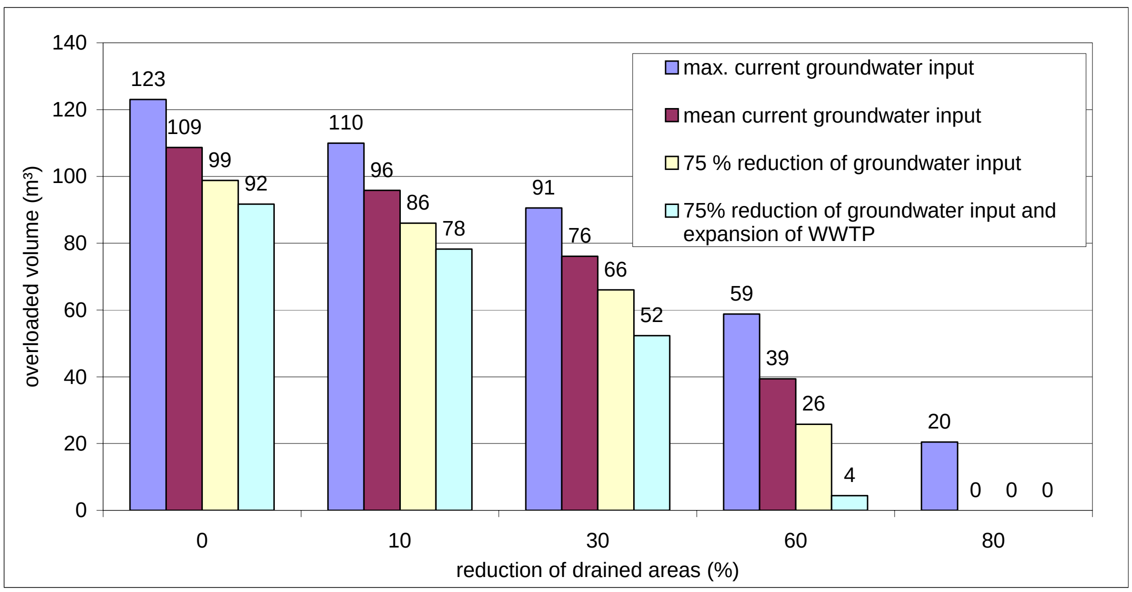

Figure 6: Efficiency of scenarios to reduce the surface area connected to the sewer system in combination with the reduction of groundwater inflow

From Figure 6 it can be interpreted that the efficiency of the groundwater inflow reduction increases with a decrease of the connected surface area. (The differences between the columns increase with the decrease of the drained area.) The same synergy effect can be observed if the WWTP is expanded. The effect can be explained by the differences of the dispersion of the runoff during the 15 min rain event (see Figure 5). A small or no reduction of the drained surface area causes a steep increase of the runoff; whereas a significant reduction of drained surface area causes a runoff shape with a smoother increase. It can be concluded that rehabilitation of groundwater and the expansion of the WWTP are more efficient if a significant reduction of the drained surface area applies (over 60 %) in the considered area.

DISCUSSION

The examination of the catchment area ED shows that the rehabilitation strategies to reduce extraneous water inflow have to be significant. The question is whether a reduction of drained surface area by 60 to more than 80 % is feasible. In case the main part of the drained area is

street surface a far going reduction can be realised, usually by sealing the manholes and is thus feasible. If the main input of rain-induced extraneous water is caused by drained private areas it is very difficult to improve the conditions. On the one hand, the identification of the drained areas is very difficult and, on the other hand, private pipes must be disconnected which is an extremely complicated legal act.
The reduction of the groundwater input and the expansion of the WWTP can reduce the necessary size of the drained surface area, which has to be disconnected. The prediction of the effects of the WWTPs expansion is relatively certain, while statements about the efficiency of rehabilitation activities to minimize groundwater drainage are uncertain in principle. In order to decrease these uncertainties the description of interactions between groundwater and sewer system are needed. It is of vital importance to identify the main path of groundwater into the sewer system for efficient rehabilitation. Two paths should be distinguished: on the one hand the infiltration of groundwater into main sewers of the system, on the other hand the infiltration by direct drainage of groundwater in small pipes e.g. house connection pipes. In the case of groundwater infiltration in main leaky sewers the input of groundwater is reduced automatically if the rainwater runoff causes a superior water level in the pipes as compared to the groundwater level around the pipes. In this case rehabilitation activities to seal main sewers are not efficient to reduce the runoff during rain events. However, the sealing of small pipes which are characterized by relatively low water levels during rain events might be theoretically more justified, while it must be considered that activities on a large scale are needed for noticeable effects.

CONCLUSIONS

The identification of the fractions of groundwater and rainwater induced extraneous water is feasible by the separation methods. The evaluation of catchment wide infiltration could be realised by correlating extraneous water to structural data of sub-catchments.

Based on the analyses of rainfall and runoff the drained surface area connected to the sewage system can be estimated. Simulations of rain events in a case study clarified that already 10 % of the impervious area connected to the sewage system are heavily influencing the runoff volume and cause an overload of the WWTP capacity. Furthermore, the analysis shows that the reduction of drained surface area is crucial. The efficiencies of the expansion of the WWTP and of activities to reduce groundwater inflow increase over-proportionately with the decrease of drained surface area.

Depending on the runoff-induced water levels in the pipes of the sewer system the groundwater infiltration varies. Hence, activities to minimize groundwater drainage require the examination of groundwater levels in the catchment area.

The expansion of the WWTP, which is a reasonable additional activity besides the reduction of drained surface area to prevent an overload of the WWTP capacity, requires the assessment of peak flows during rain events and their effects on the receiving water in order to identify the decisive bottle necks.

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