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EFFECTS OF INTEGRATED STORMWATER MANAGEMENT STRATEGIES ON THE COMBINED SEWER SYSTEM AND THE WASTEWATER TREATMENT PLANT–RIVER SYSTEM

A. Welker, U. Leinweber, K. Klepiszewski and T. G. Schmitt

Fachgebiet Siedlungswasserwirtschaft, University of Kaiserslautern, Paul-Ehrlich-Str. 14, 67663 Kaiserslautern, Germany

ABSTRACT

This is an investigation into possible changes to quantity and composition of sewage in the combined sewer system and the waste water treatment plant (WWTP) caused by new stormwater management strategies (mainly by disconnecting areas from the sewer system). Various scenarios were developed and the consequences on the water systems were calculated by using the simulation model KOSMO, in a fictional catchment.

The results of the combined sewer overflow-calculation show an enormous decrease of the overflow annual load for different parameters (COD, ammonia) by the reduction of impervious surfaces. Thus, the overflow concentrations of some parameters increase dramatically under these conditions, in particular the ammonia concentration might cause critical situations (e.g. sensitive receiving water). © 1999 IAWQ Published by Elsevier Science Ltd. All rights reserved

KEYWORDS

Combined sewer overflow; integrated stormwater management; pollutant control; source control.

INTRODUCTION

Integrated stormwater management strategies have effected great changes in urban drainage systems. In future basic sewer systems (combined and separate sewer systems) will exist in a modified form.

Important stormwater management measures reduce the impervious surfaces in urban catchments (e.g. stormwater infiltration of specific parts of the stormwater runoff like roof runoff), this will be called "disconnection of areas" in the following. These variations in the catchments have enormous direct effects not only on the flow quantities but also on the pollution of stormwater or the combined sewer flow.

In recent studies predominately positive effects of the disconnection of areas have been described, mainly considering the reduced flow quantities, resulting in smaller storage tank volumes in case of combined sewer

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systems. Though little effort was made concerning the question, under which conditions the pollution of the combined sewer flow will change while establishing stormwater management strategies. This depends on the parameters observed (nutrients, pollutants) as well as on the specific procedures in the catchment (e.g. utilization of the disconnected areas). In this context, it seems to be an indispensable requirement and a main objective of this study not only to investigate single components of the urban drainage system (e.g. storm water tanks). Thus, an overall approach should be taken into account by considering interactions of the sewer system with the WWTP (wastewater treatment plant) and the receiving water.

DESCRIPTION OF THE FICTIONAL CATCHMENT

The studies were conducted in a fictional catchment (100 ha) with a population of 5,000 inhabitants. The catchment has a total impervious area of 47 ha (A_u) and was divided into two parts, the centre (30 ha) and the outskirts (70 ha), which is a typical partition in rural German areas. Furthermore, the surface was divided into different parts, according to its utilization (roofs, roads and green) which is important in view of the different scenarios of disconnection and the calculation of the varying runoff concentrations.

The catchment has a combined sewer system including a combined sewer overflow (CSO) at the end of the drainage area. The CSO is designed as an inline stormwater tank retaining the first flush of stormwater, its volume is adjusted to the various connected impervious areas. The sewer system leads to a WWTP, conceived as a sludge stabilization facility without primary sedimentation, designed using the German guideline A 131 (ATV, 1991).

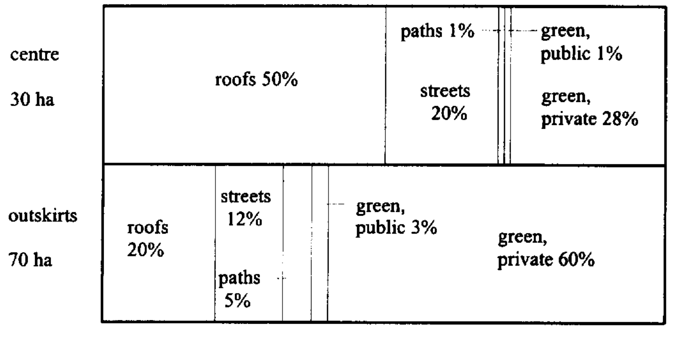

Figure 1. Schematic representation of areas inside the catchment.

SCENARIOS AND THEIR EFFECT ON THE COMPOSITION OF THE RUNOFF

Besides the first scenario with 100% surface runoff drainage into the sewer system, the following scenarios were developed:

- scenario 1: 100% surface runoff drainage (A_u = 47 ha)
- scenario 2: 70% surface runoff drainage, disconnection of all roof areas in the outskirts (A_u = 33 ha)
- scenario 3: 21% surface runoff drainage, disconnection of all roof and street areas in the outskirts (A_u = 10 ha)

Concentrations of pollutants and other parameters in different runoff and wastewater flows were taken from various investigations and are summarized in Table 1. These data were used as input-data for the simulation model KOSMO.

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Table 1. Concentrations of various parameters in dry weather flow, WWTP effluent and different surface runoffs

	Concentration [mg/l]					
Parameter	COD	BOD	SS	NH_4-N	Cu	Pb
street runoff	100	30	600	1.0	0.100	0.140
roof runoff	30	10	50	1.0	0.200	0.070
dry weather flow	600	300	280	35	0.150	0.100
WWTP effluent	60	10	20	10	0.030	0.020

As a new aspect, the surface runoff concentrations of the different scenarios were calculated, based on the area partition in the catchment by using the different concentrations of runoff from roofs and streets (see Table 2).

Table 2. Concentrations of surface runoff considering different scenarios

	Concentration [mg/l]					
Scenario	COD	BOD	SS	NH_4-N	Cu	Pb
1	57	18	262	1	0.165	0.097
2	68	21	352	1	0.151	0.108
3	100	30	600	1	0.110	0.140

As shown in Table 2, nearly all concentrations of surface runoff are increasing from scenario 1 to 3. Only copper which mostly originates from roof material, leads to minor concentrations when the total of connected impervious areas is reduced. Since the impact of ammonia from roof or street areas is nearly the same, no variation in the concentrations can be observed.

Considering possible changes in the sewer system it can be supposed that, with an increasing disconnection of areas, the influence of dry weather flow will increase which will probably lead to higher concentrations, especially of ammonia. Therefore a main objective of this investigation was to get more information on the changes in the sewer system (concentration and load of pollutants and nutrients) and their consequences on the receiving water from combined sewer overflows with integrated urban stormwater management. In the following the investigation methods and an extract of results are presented, the detailed data are summarized elsewhere (Klepiszewski, 1997).

EFFECTS OF THE DISCONNECTION OF AREAS CONCERNING COD AND AMMONIA

The long-term simulation of pollution load has become part of the planning process and the design procedure for combined sewer overflow structures in Germany (ATV, 1992; Schmitt, 1993). Combined sewer overflow simulation models compute surface runoff, combined sewer flow and pollution load for a series of storm events or continuous rainfall data (long-term simulation). In this study the pollution load simulation has been performed by using the simulation model KOSMO (Schmitt, 1993) with a series of storm events from a one-year rainfall record. KOSMO considers relevant processes like surface pollution with an exponential accumulation equation while surface runoff is computed with a hydrological method. Prescreening of continuous rainfall data is applied to identify rainfall runoff periods which are relevant for overflow occurance. For these periods, the sewer flow is computed by dynamic flow routing, modelling pollution transport as an advective process. Flow control and overflow structures are simulated according to the actual hydraulic conditions (Schmitt, 1993).

For the different scenarios, flow and pollution load directed towards the wastewater treatment plant or directly discharged to receiving waters were balanced and the amount of overflow volume and load was quantified. Additionally, other data, like overflow events and concentrations, were calculated.

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Effects on the overflow characteristics (CSO)

The introduction of stormwater management measures like infiltration trenches or the usage of stormwater is reducing the total volume of water entering the sewer system and the amount of water flowing to the CSO. This effect influences the overflow characteristics and the different runoff concentrations (see above). Another important point is that as a consequence of the decreasing total volume of runoff, and a constant amount of dry weather flow, the ratio between surface runoff and dry weather flow, called mixing ratio in the following, will change negatively.

The results of the pollution load simulation show a clear reduction in almost all overflow parameters. The overflow volume decreases by 90%, the yearly overflow duration drops by 79%, whereas the number of overflow events remains at nearly the same level, as demonstrated in other investigations (Jacobsen and Mikkelsen, 1996; Stecker and Staak, 1996).

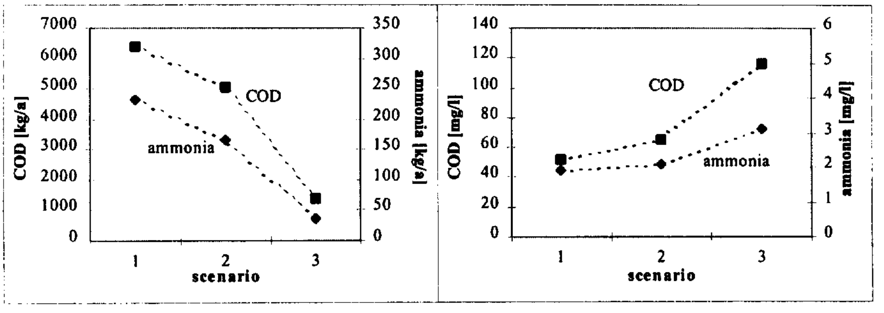

Figure 2. CSO discharge as annual load [kg/a] and mean annual concentration of COD and ammonia [mg/l] considering different scenarios of disconnection.

Figure 2 shows some of the overflow characteristics computed for the different scenarios. High benefits are reached in a 78% reduction of annual Chemical Oxygen Demand (COD) overflow loads which can be explained by the decrease of the total flow volumes. However, the average annual concentrations rise from 52 mg/l to 117 mg/l (125%) concerning COD and from 1.9 mg/l to 3.1 mg/l (63%) concerning ammonia.

Effects on the receiving water (CSO)

The general impacts of the CSO on the receiving water can be caused by physical (e.g. shear stress), chemical (e.g. oxygen depletion) or combined effects.

In order to quantify the basic chemical impacts on the receiving water in this study, two types of flow waters were defined which can be distinguished by the mean base flow discharge. The first type has a mean base flow of 50 l/s and the second one a mean base flow of 500 l/s, the background level concentrations were defined with reference to studies from Wolf and Borchardt, related to the quality class II for flow waters according to German standards (1990).

For the purpose of getting a first survey of possible influences on the river ecosystem, a single rain event was chosen and the resulting overflow concentrations from the model KOSMO were collected. In a simple mixing calculation, the resulting concentrations in the receiving water were evaluated, based on the concentration values of the overflow, the basic levels of the receiving water and the flows in both water components (see Table 3).

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Table 3. Ratio mean base flow (MBF)/overflow (Qo) and calculated concentrations of COD and NH4-N in the receiving water for a single rain event

Water flow types	Scenario	MBF/Q_0	COD [mg/l]	NH_4-N [mg/l]
	1	0.13	65*	1.79*
1	2	0.15	92*	1.75*
(MBF_1=50 l/s)	3	0.41	185*	2.87*
	1	1.26	39*	0.94
2	2	1.54	48*	0.85
(MBF_2=500 l/s)	3	4.08	60*	0.86

basic level concentration in receiving water: COD 12 mg/l, NH_4-N 0,1 mg/l

*exceeds values of standards for flow water quality class II: COD 20 mg/l, NH_4-N 1 mg/l

In spite of the fact that the chosen method can only give a rough picture of the real situation, significant results regarding the different river types can be observed. Compared to the quality values for flow water class II of the German federal state of Northrhine-Westphalia (Anonymous, 1991) the calculated concentrations in the receiving water often exceed these standards. This effect is mainly caused by the decrease of the overflow duration, when areas are disconnected. The COD standard of 20 mg/l went beyond all results from the scenarios in both water types. The ammonia value of 1 mg/l was exceeded in the first water type (50 l/s) in all scenarios with an increasing tendency.

Even though these results are not based on a detailed river simulation model, it can be concluded that depending on the local conditions (e.g. physical and chemical situation of the receiving water) an increasing impact on the receiving water with disconnected areas is possible, especially concerning the quantity of ammonia.

Effects on total discharge from the treatment plant and the CSO

There is common consensus about the fact that the total discharge from a WWTP and a CSO to the same receiving water should be considered in an integrated approach for stormwater management strategies. Though there still remains the question of which substances and which parameters are the most important ones. Some specialists argue that loads should be considered, others support the opinion that concentrations are more important for the receiving water. Therefore this study took both the load and concentration from different substances into account (see above) and calculated the total discharge from the WWTP and the CSO with simulation models.

For simulating processes in the WWTP in this study the simulation program DENIKA is used for two purposes. Firstly, for dimensioning the aeration tank of the WWTP, and secondly for the calculation of effluent loads and concentrations. The aeration tank in DENIKA is dimensioned according to the German guidelines A131 (1991). In contradiction to more detailed models, DENIKA predominately considers processes in the aeration tank with a quasi-dynamic simulation approach (Hartwig, 1991) by omitting processes in the primary and final settling clarifier. In order to minimise these deficits of DENIKA, considering the settling processes, an active sludge process with aerobic sludge stabilisation was chosen, where a primary settlement tank is usually not implemented. Since ammonia was chosen as a relevant parameter which is nearly completely dissolved in water, the lack of modeling the processes in the final clarifier is negligible.

In Figure 3 the calculated loads and concentrations of ammonia from the two outlets WWTP and CSO are illustrated for a single rain event.

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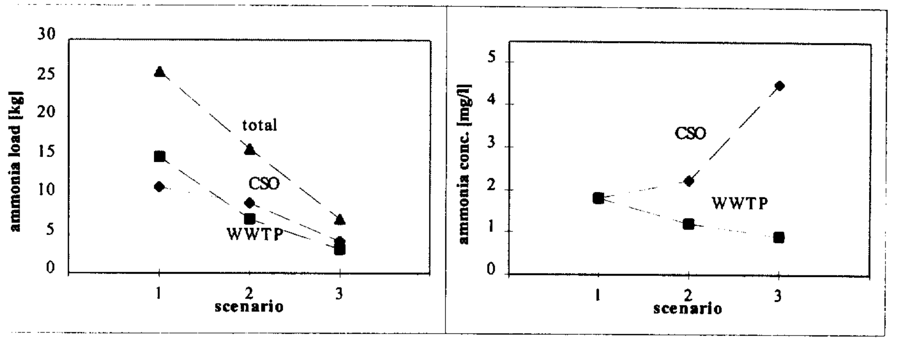

Figure 3. Total discharge of ammonia as loads and concentrations from WWTP and CSO for a single rain event.

The results demonstrate that the establishment of stormwater management measures obviously reduces the total overflow ammonia load. A similar effect could be shown for other parameters like COD (not illustrated in Figure 3), the details are collected elsewhere (Klepiszewski, 1997). The relevant parameter for the design of CSOs following the German guideline A128 is the annual COD overflow load, instead of ammonia. Considering this parameter, the disconnection of areas can therefore be interpreted as a means for reducing overflow annual COD loads, and thus justifies a reduction of CSO volumes.

As described before, regarding the ammonia concentrations in the CSOs the increase is in proportion to the decrease of connected areas. At the same time concentrations in the effluent of the WWTP decrease, depending on the level of stormwater management measures. Whether these two effects result in a decreasing or an increasing overall impact on the receiving waters, depends on the local conditions and is, up to now, only predictable for specific situations.

CONCLUSIONS

The disconnection of impervious areas in a catchment influences the amount and composition of the surface runoff. As the results of this work, based on computer simulation, show, the situation at the combined sewer overflow changes completely.

Considering the CSO annual load, a significant decrease can be demonstrated for the parameters ammonia and COD. If the annual COD load is a relevant parameter for the judgement of CSO discharges in the future, exclusively positive effects of new storm water management strategies can be formulated.

There still remains the question, whether or not the predicted amount of disconnected areas is realistic. Nowadays it seems that a percentage of up to 60% or even 79% of disconnected areas cannot be reached, whereas studies in two Dutch catchments show that the percentage of disconnection has been evaluated to be 65% (Geldorf et al., 1994). Nevertheless, the advantages of infiltration concepts or similar measures, often described in studies should be examined under a more practical aspect. Regarding the emitted concentrations from CSO and WWTP, especially for ammonia, further examinations should be performed to obtain more information on the possible pollution situation of the receiving water.

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