Chapter I

Integrating Better Stormwater Management Practices in Urban Stormwater Pollution Modeling

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In Germany and elsewhere, discussion of alternative methods of urban stormwater management have led to the belief that an economically and ecologically sound combination of central and distributed methods will be the concept of the future. However introduction of methods other than traditional combined sewer systems has been limited by the shortage of planning tools and technologies. Adding a number of frequently used better stormwater management practices (BSMPs) has widely extended the use of an existing stormwater water balance and pollution load model.

1.1 Introduction

Urban drainage in 70% of German communities is based on combined sewage systems. Domestic, industrial and surface stormwater runoff is conveyed by a single pipe system. During intensive storms the stormwater component can become more than 100 times larger than the dry weather component. However wastewater treatment plants in Germany are designed to treat only two to three times the dry weather flow. Consequently combined sewage has to be stored in retention basins to be treated later. Due to economical and other restrictions, the storage provided is limited, resulting in an average of 20 to 40 overflows per year.

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Design and operation of combined sewer systems will continue to be a central task of water resources development and management. At the end of the 80's the total storage volume necessary was estimated to be 20 Million m³ (Brombach, 1988; Meißner, 1988). Assuming that 40% of this total volume has already been constructed, a future investment of 25 billion DM (~20 Billion C\$) must be expected, using the present average unit cost of 2000-3000 DM/m³. Besides the fact that this figure is of outstanding importance for the national economy, the limited ecological function of combined sewer overflows in respect to water quality in receiving waters is likewise important. The dominant ecological objective of design and operation of such structures and systems has to be the minimization of these impacts, especially of those causing negative long-term effects. To improve the ecological performance of traditional combined sewer systems, new concepts and technologies have been developed which are here subsumed under the phrase *better stormwater management practices*. Elsewhere these measures are included in the term *Best Management Practices* (BMPs).

Urban water resources planning must aim at a generally accepted compromise between public investment and operation cost and residual hydraulic and pollution loads for receiving water bodies. For these optimizing and compromising procedures, efficient computational design methods and models which include new and alternative stormwater treatment technologies are required.

1.2 Design Standards of German Federal States (Bundeslaender)

Design standards and planning techniques vary widely from state to state in the Federal Republic of Germany. For most tasks in the design of urban drainage and wastewater treatment, the German Society of Sanitary Engineering (ATV) has developed generally accepted standards and design rules. Code A 128 for combined sewer systems was revised by ATV in 1992. However, general acceptance could not be reached in this case. Although the code has been accepted in principle, several states have formulated addenda and modifications.

In Hessen, for example, it is compulsory to apply the continuous long-term pollution load model SMUSI to prove that the annual load emitted does not exceed 250 kg COD/ha for the complete drainage system connected to a treatment plant (shown as a straight line in Figure 1.3). The simulation is carried out using a nine months representative continuous rainfall time series, and is based on a fixed annual pollution load potential of 600 kg COD/ha/year. Lower Saxony chose a similar procedure: a different model with a similar structure is applied, using 10 years of historical rainfall records. Other states still apply the old version of code A 128 (1977) (ATV, 1977), while most of remaining states

apply the new code A-128 (ATV, 1992). North-Rhine-Westphalia chose a special procedure to check systems by applying the emission e_0 according to A-128 (1992). The emission rate is the emitted rainfall volume divided by the total effective rainfall volume on impervious areas - in this case the pollution load is simply replaced by a water quantity criterion. The state decision is based on a long-term study of the reliability of pollution load models. It was proved that, without accurate model calibration based on accurate measurements, which are hardly available and too expensive for standard application, the uncertainty of pollution load modeling is too high.

The disadvantage of the standard procedure proposed in code A 128 is that it does not consider special and extended measures for stormwater treatment. Although special checking procedures like pollution load modeling are mentioned in the code, their application is considered to be an exception. However, the provision of alternative and extended stormwater technologies are just such exceptions, which become more and more standard due to changing legislation and public consciousness. Due to the difficulties in proving the efficiency of extended and alternative measures their general acceptance in planning and administration is relatively low. Institutions and citizens are willing to invest if the positive result is acknowledged in monetary or other form. Methods are now urgently needed to quantify their positive effects and to facilitate their further dissemination and acceptance.

Clearly engineering codes and standards do not have only positive effects: in this case they can produce excessive public investment and hinder innovative planners from applying new methodologies, which might be economically and ecologically sounder than traditional technologies supported by the codes.

1.3 Extended Technologies for Stormwater Treatment

According to code A 128, the layout and design of traditional stormwater treatment facilities are based on the variation of stormwater retention volume and its 'optimum' distribution within the drainage system. If for a chosen configuration the emitted COD load does not exceed prescribed limits, the system fulfills the legal requirement and is exempted from payment of pollution emission fees. Exceptionally sensitive receiving waters can require more restrictions. Yet, in most cases improved protection can hardly be achieved by providing larger retention basins. The positive effect of incremental increases in storage becomes smaller. Figure 1.1, produced by applying the SMUSI model, makes this relationship evident.

Innovative and alternative concepts and technologies aiming at quality improvement of combined stormwater discharges can replace economically questionable basin volumes. Structural technologies include chemical, physical,

Figure 1.1 Relationship between specific emission rate and specific retention volume.

biological and mixed; they are usually combined with a combined sewer overflow. But approaches aimed at the reduction of stormwater in the combined sewer, such as distributed infiltration and on-site stormwater storage with subsequent usage, also have to be investigated, as they add to the reduction of pollution emitted. A survey of such approaches with related references is given in Table 1.1.

Table 1.1 Technologies for extended stormwater treatment (numerical references listed at end of chapter).

Basic concept	Technology
Mechanical	Screens [18] Sieves [18] Separators (e.g. Vortex) [8] Filtration [11]
Physicochemical	Flotation [12] Flocculation / Precipitation [17] Flocculation / Precipitation with filtration [17]
Biological	Ponds and wetlands [4],[5] Sand filters [9],[20]
Reduction of stormwater runoff	Infiltration (decentral) [3],[19] Storage and usage [6]

Methods of stormwater management may be divided into four main groups:

1. Mechanical approaches, such as sieves, meshes or similar provide better separation of solid particles from combined sewer flow than is achieved in traditional combined sewer overflows. In special cases filtration plants can be provided.
2. Physicochemical approaches, where the composition of combined sewerage is changed by chemical additives to improve separation characteristics for liquid and solid components. The physical part consists of sedimentation, flotation and filtration.
3. Biological approaches, where purification by a combination of physical, chemical and biological processes is achieved. The physical component is the necessary storage to provide adequate residence times for reactions and biochemical degradation processes relying on digestion of microorganisms like fungi, algae, and bacteria.
4. Stormwater surface runoff reduction, where the formation of stormwater and the disconnection of impervious areas from the network leads to reduced combined stormwater overflow and related pollution load.

Note that, due to direct interdependencies, the estimation of the efficiency of systems containing a mixed set of such technologies is hardly reliable without the application of suitable models.

1.4 Simulation of Extended and Alternative Measures

Adequate integration of such technologies suffers from limited scientific knowledge and practical experience. Often, very few pilot plants have been constructed and those that have, have been operated only for limited periods. Due to incomplete and partly unverified data, it is not yet possible to simulate single components at the desired accuracy. Yet, to fill the existing gap, simplified simulation modules have been developed based on an intensive literature search and review and on questioning of experts. The modules were then implemented into the existing pollution load model SMUSI (Mehler, 1996; Mehler and Leichtfuß, 1997). Modules are described in Table 1.2. It must be mentioned that the extended model should not be used to design and layout alternative and extended measures, as the assessment must be done by the user by selecting adequate model parameters. It has to be remembered that the evaluation and comparison of different alternatives has been the major objective of model development and modification.

Table 1.2 Simulation approaches of extended stormwater treatment technologies in pollution load model SMUSI 4.0.

Technology	Simulation approach
Sieves	Percentage of filterable solids (AFS) in overflow volume of a retention basin
Separators	Percentage of separated solids (represented as AFS) in connection with or as replacement of overflow basins
Sedimentation basins	Sedimentation efficiency (percentage of settleable solids) of a basin behind an overflow basin
Filtration	Percentage of retained filterable solids (AFS) behind an overflow basin
Flocculation/Precipitation	Improved retention of pollutants in overflow basins (higher efficiency of sedimentation)
Flocculation/Precipitation + Filtration	Improved retention of pollutants in overflow basin inclusive removal
Sand filter	Retention and biological degradation in an aerated soil layer behind overflow basins
Ponds and wetlands	Retention and biological degradation in open water bodies behind overflow basins
Stormwater storage and usage	Less polluted roofs are connected to a tank. Stored water is used for garden and lawn watering (evaporated) or for toilet flushing and laundry, effluent connected to sewer system
Decentral Infiltration	Connection of less polluted surfaces to decentral infiltration pools

1.5 Comparative Assessment

Several simulation runs were made for a fictitious simple drainage system consisting of a single urban catchment draining into a combined sewer overflow basin:

Total area:	A_{tot}	=	20 ha
% Imperviousness:		=	0.5
Connected imp. area:	A_{red}	=	10 ha
Slope class (A 118):	avge	=	2
SCS-CN:	CN	=	70
Maximum time of flow:	tf	=	10 min
Population:		=	2000
Pop. Density:		=	200 pers/ha _{Acon} resp. 100 pers/ha _{Atot}
Mean dry weather flow:	Q_s	=	3.0 l/s (= 129,6 l/pers d)
Sewer infiltration :	Q_f	=	2.0 l/s (= 0,1 l/s ha)

Type of basin: in-system

Basin volume: $V_{\text{basin}} = 200 \text{ m}^3 (20 \text{ m}^3/\text{ha}_{\text{Acon}})$

Basin outflow (orifice): $Q_{\text{orifice}} = 8.0 \text{ l/s} (2 \cdot Q_s + Q_f)$

To determine annual pollution load, long-term simulation was carried out using a representative rainfall time series (yearly precipitation: 625 mm). Then several different treatment technologies were applied - mean efficiencies and estimated percentages of households applying stormwater use and on-site infiltration were taken from literature. Mean values were also varied within their plausibility limits to assess uncertainty. Figure 1.2 shows the result of the comparison for filterable solids (FS), and includes the traditional solution.

Figure 1.2 Emission load of filterable solids for different BSMPs.

In Germany chemical oxygen demand (COD) is used as a lumped parameter for evaluating the function of stormwater treatment facilities. SMUSI assumes that 30% of filterable solids is COD. Simulation results for COD are given in Figure 1.3, which also shows the present upper limit of permitted COD emission load. It is obvious that technologies mainly aiming at reducing filterable solids like separators, sieves and filters only produce a small additional reduction of design criterion COD. Technologies assumed to have a direct impact on COD reduction definitely have a higher efficiency (e.g. sand filters, physicochemical technologies and stormwater use).

Figure 1.3 COD emission loads for different BSMPs.

1.6 Considering BSMPs during Planning

By implementing extended stormwater management in simulation models, their influence on traditional stormwater treatment structures can be quantified. Assuming that the chosen test catchment is located in Hessen, 140 m³ of additional retention volume would be needed according to the code. The estimated unit cost being 2000 to 3000 DM/ m³, public investment of between 280,000 and 420,000 DM would be necessary. It is obvious that such unit cost is above that of luxury housing. It is not surprising that in small communities the unit price of water supply and combined systems treatment will soon be in the range of 15 to 20 C\$. In several cases the willingness and opportunity of German citizens to pay has been exceeded.

With the modified model the effect of extended practices on pollution load emission can be analyzed, and alternative solutions that also fulfill the standards can be identified. BSMPs must first be dimensioned by suitable procedures to facilitate model parameters in a plausible and reliable range. Cost of alternative measures can be estimated and compared with the cost of stormwater basins. This comparison should not only cover construction cost; it should also include operational and management costs. Besides the economic criteria, other effects on the receiving waters should be considered. Some of the BSMPs e.g. well-planned

vegetated sand filters, have positive effects such as effective pollution retention and degradation (see Figures 1.2 and 1.3). For sand filters this efficiency is provided by minimum retention volume and an upper limit of annual hydraulic load (m/year) (Meißner, 1988).

To support planners in the pre-selection of integrated BSMPs, an evaluation matrix was developed based on a literature search and multiple simulation runs. Table 1.3 contains advantages and disadvantages of different BSMPs for some chosen criteria or categories (Mehler, 1996). The chosen criteria are explained below. The catalog is the result of subjective analysis and needs further future discussion of disciplines involved.

Efficiency - Pollution load:	load reduction of the technology
Hydraulic efficiency:	hydraulic retention of the technology
Planning cost:	cost for pre-planning and design
Investment cost:	construction cost
Operation cost:	material cost
Technical effort:	amount of excavation, mass of concrete
Maintenance cost:	cost of personnel
Life time:	duration up to reinvestment
Probability of reliability:	forced and planned outage during life time
Controllability:	procedures for checking operation
Land demand:	location and size of required land
Engineering code available:	legally introduced codes available
Acceptance:	accepted by authorities and the public
Theory:	state of science
Experience:	frequency and duration of application

1.7 Summary

Extended and alternative technologies for stormwater treatment are not included in most simulation models, e.g. pollution load models for the analysis of combined sewer systems. Some basic research projects and pilot plants have proved, however, the large potential such technologies might have. Unfortunately, the integrated use of different practices is restricted by the fact that the necessary design tools are missing tools from planning and water authority practices. By modifying and extending the simulation model SMUSI it is now possible to analyze and assess the efficiency of many of these practices. It has to be stressed that the design and layout of single measures and their integrated modeling in SMUSI must be kept separated until more knowledge and experience is available.

Estimation of model parameters describing the efficiency of alternative technologies incurs considerable uncertainty. Some of the alternative practices have only been applied as part of a few pilot projects, so generalization of results

is foolhardy. It is most important that exchange of ideas and practical experience improve and that general knowledge be consolidated.

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