Potentials of Real Time Control, Stormwater Infiltration and Urine Separation to Minimize River Impacts

Dynamic Long Time Simulation of Sewer Network, Pumping Stations, Pressure Pipes and Waste Water Treatment Plant

Potentialités de la gestion en temps réel, de l'infiltration des eaux pluviales et de la séparation des urines pour minimiser les impacts sur les cours d'eau

Christian Peters[1], S. Keller[2], Dr. H. Sieker[3], Prof. Dr. M. Jekel[1]

[1]Technische Universität Berlin, Department of Water Quality Control
christian.peters@tu-berlin.de
[2] Berliner Wasserbetriebe; [3]Ingenieurgesellschaft Prof. Dr. Sieker

RESUME

La rivière Panke (Berlin) est soumise à une pression hydraulique et des polluants venant de canalisations séparées et combinées. Le pompage des eaux usées par des tuyaux de pompage est à l'origine des dégâts importants dans les stations d'épuration (STEP) pendant des périodes de pluies. Pour trouver une bonne solution à ce problème, il est essentiel de ne point définir une seule approche dès le début mais de mettre en exergue différentes formes d'approches. Pour cette raison une étude à simulation intégrée est recommandée; car celle-ci permet l'évaluation du potentiel des données suivantes : la gestion du temps réels, de l'infiltration pluviale, du stockage et de la séparation des urines. Des critères d'évaluation sont développés et des analyses à caractères multiples sont appliquées. Malgré la limitation spatiale, l'infiltration a un potentiel élevé et est effective aussi bien dans l'écoulement des eaux mixtes que dans les STEPs. A cause du pourcentage élevé des systèmes séparés, le système de séparation d'urine possède un potentiel similaire à celui de l'infiltration. Des stratégies innovantes de contrôle peuvent produire une amélioration significative (comparable à l'infiltration ~10% de la superficie des surfaces imperméables).

ABSTRACT

River Panke (Berlin, Germany) suffers from hydraulic peak loads and pollutant loads from separate sewers and combined sewer overflows (CSOs). Pumping the wastewater through long pressure pipes causes extreme peak loads to the wastewater treatment plant (WWTP) during stormwater events. In order to find a good solution, it is essential not to decide on one approach at the beginning, but to evaluate a number of different approaches. For this reason, an integrated simulation study is carried out, assessing the potentials of real time control (RTC), stormwater infiltration, storage and urine separation. Criteria for the assessment are derived and multi-criteria analysis is applied. Despite spatial limitations, infiltration has the highest potential and is very effective with respect to both overflows and the WWTP. Due to a high percentage of SSs, urine separation has a similar potential and causes the strongest benefits at the WWTP. Unconventional control strategies can lead to significant improvement (comparable to infiltrating the water from ~10% of the sealed area).

KEYWORDS

Decision support, integrated models, long time simulation, real time control, scenario evaluation, ,stormwater infiltration.

INTRODUCTION

1.1 Background

The presented work is based on the WSM300 project (Schröter 2004; Peters, Mühleck et al. 2005; Sieker, Bandermann et al. 2005) funded by the DBU (German foundation for the Environment). The motivation for the project was the fact that today's water management practice is often inconsistently structured. The potential scope of action is not clearly depicted and then systematically explored, stakeholders are involved too late, many objectives are neglected and only a very limited number of options are taken into account. To help overcome these problems, a methodology and supporting tools were developed. WSM300's focus was primarily on the general framework. This paper focuses on one of WSM300's case studies. Within the scope of a PhD thesis, WSM300's methodology is applied and enhanced, and additional options are developed and evaluated.

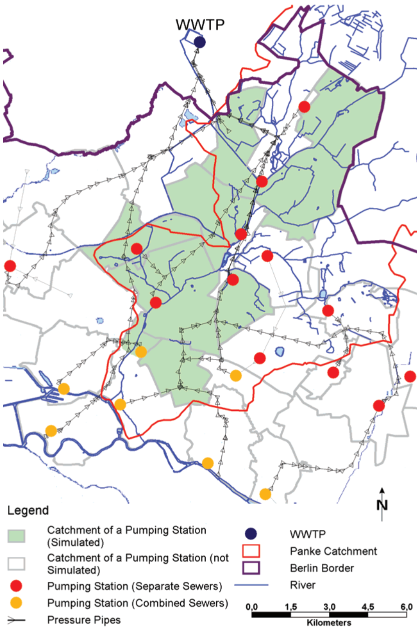

Figure 1: The Investigated Area

1.2 The Catchment Area of the River Panke and Its Problems

The catchment area (~200 km²) of the river Panke (Figure 1, dark grey outline) is situated in the northeast of Berlin (bold black border), Germany. It suffers from hydraulic peak loads and pollutant loads from separate sewers and CSOs. As a result of the hydraulic peak loads, flood protection measures had to be implemented and river Panke suffers from structural degradation (Figure 2). A high percentage of paved area results in low dry weather flows.

Berlin's city centre is drained using combined sewers (light grey dots), whereas the suburban areas utilise separate sewers (dark grey dots). Mainly due to incorrect connections and manhole covers, the wastewater pipes in separate systems (SSs) are also affected by stormwater. The wastewater from both systems runs to pumping stations (light and dark grey dots) and is pumped from there through a network of pressure pipes (black arrows) to one of Berlin's six WWTPs (black dot). The pressure pipe network causes high peak loads to the WWTP during rainfall events: when the pumps increase the hydraulic load, the pipes still contain dry weather concentrations. It can take up to ten hours until diluted water reaches the WWTP.

1.3 Objectives

The objective of the present study is to provide a good basis for deciding what methods to choose in order to improve the current situation in the catchment. Therefore, a number of **distinct** scenarios (see Chapter 2.4) need to be developed and their effects must be calculated and assessed.

Figure 2: River Panke in Berlin

2 METHODS

2.1 Description of the Procedure

1. Determine problems and define objectives.

2. Define criteria for scenario comparison that represent the objectives.

3. Outline different scenarios to improve the situation.

4. Choose simulation models that are able to simulate the scenarios and to calculate values for the chosen criteria. The criteria may need to be adapted so that they can be calculated by models with an appropriate effort. Nevertheless, the criteria must represent the objectives!

5. Built and calibrate the model system.

6. Develop detailed scenarios and implement into models.

7. Calculate scenario-effects.

8. Evaluation

9. Refine scenarios and repeat from step 6 until a satisfactory solution is achieved.

2.2 Scope of the Investigations

In order to limit the task to a manageable size, not every system component of potential interest could be implemented into simulation models. Therefore, a selection had to be made. The focus was laid on the field of stormwater in combined sewers, unintended stormwater in separate wastewater sewers and the interaction between catchment, pressure pipes and the WWTP. As a consequence, the model system contains the following components:

- Rainfall runoff model and sewer network model (hydrological; STORM, Ingenieurges. Prof. Dr. Sieker mbH 2003) for the catchment areas of 7 pumping stations (Figure 2): 2 combined systems (CSs); 5 SSs, only wastewater sewer including unintended stormwater, no stormwater sewer.
  The model depicts 243109 inhabitants and 447 ha of sealed area.
- Pressure pipe network and pumping stations (own modules for MATLAB Simulink)
- WWTP (Activated Sludge Model No. 1, IWA Task Group … 2000, SIMBA, ifak system 2001)

The river itself is not included in the model.

The entire Berlin system consists of six WWTPs and a huge network of pressure pipes. It was impossible to model the whole system; thus, only the WWTP that accounts for most of Panke catchment's sewage and its corresponding pipes are included in the model. The modelled combined sewer catchments pump only partially to the modelled WWTP, but were connected to it in this study (through existing pipes) in order to analyse the interactions between catchment, pressure pipes and the WWTP. The modelled catchments account for ~37% of the inhabitants and ~33% of the impervious area connected to the WWTP. In the model the flux is scaled up by 1/0.37 before and scaled down by 0.37 after the WWTP.

With the described model system, the following problems stated in the introduction can be addressed:

- Hydraulic peak loads and pollutant loads from separate wastewater sewers and combined sewer overflows (CSOs).
- High peak loads to the WWTP induced by the pressure pipe network.

Even if the chosen scenarios do not contain river restoration measures, the problem of flood protection and structural degradation is partly addressed, as the reduction of hydraulic peak loads is a prerequisite for river restoration in many cases.

Rainfall has strong influence on the system and is highly variable. As a result, river impacts exhibit a high variance in different years! Therefore, long-time simulations were carried out using historical rainfall data over a period of 30 years (1965 - 1994). As rainfall is also highly dynamic, a short simulation step of 5 minutes had to be chosen (the WWTP uses dynamic step size, which may be even shorter). With current computer technology, these kinds of simulations are possible: one scenario takes approximately 8 hours computation time.

2.3 Criteria for Scenario Comparison

Schilling, Bauwens et al. (1997) provide an overview of river impacts caused by urban drainage. With this basis and taking into account the different time scales (acute, delayed, accumulating), in which the impacts occur, criteria shown in Table 1 were chosen for scenario comparison. The criterion peak load is calculated taking into account the maximum hourly loads that are exceeded in 12 h per year.

Peak Loads			Mean Loads		
Criterion		Impacts	Criterion		Impacts
Q	[m³/h]	Hydraulic stress for biocoenosis Morphology Flood protection			
NH_4	[g/h]	Acute NH_3 toxicity	NH_4	[kg/a]	Delayed toxic effects of NH_4 Delayed oxygen depletion
COD	[kg/h]	Acute oxygen depletion	COD	[t/a]	Delayed oxygen depletion Particulate COD: Adsorbed Heavy metals and toxic organics
			P	[kg/a]	eutrophication

Table 1: Criteria for Scenario Comparison

2.4 Scenarios

Status Quo. As described in the introduction and "Scope of the Investigations".

Additional storage volumes for unintended stormwater in wastewater sewers: at each of the **S**S's pumping stations, infinite storage volumes are added to the model (**StS**).

Stormwater infiltration: In the areas with **s**eparate sewers 100% of the impervious area that is connected to the wastewater sewer is disconnected and the stormwater is infiltrated through trench troughs and trench trough systems. As stormwater sewers are unavailable in some areas, overflow water remains connected to the wastewater sewer (**InfS100**). The maximum possible fraction of roof and paved backyard area that can be disconnected and infiltrated in the **C**S had been estimated on house block scale (Ingenieurges. Prof. Dr. Sieker mbH 1999). For streets, half of this fraction is assumed, leading to a maximum of 24% of the impervious area that can be disconnected in total (**InfCMax(24)**). **InfMax(C24S100)** is the combination of InfC24 and InfS100. The hypothetic scenario **Inf100** disconnects 100% in separate and CSs.

Urine separation is one of the so called new or ecological sanitation concepts mainly targeting nutrient recovery. A good introduction on the topic is given in (Lange & Otterpohl 2000). Urine contains approximately 80% of the Nitrogen and 45% of the Phosphorus in household wastewater. It is collected separately using urine separation toilets and collected for agricultural use. However, those benefits are not accounted for in this work, but rather only the effects on the wastewater system are considered. Separation efficiency is assumed to be 75%. Nomenclature: **Urs[S/C][% of inhabitants utilising urine separation]**; [S/C]: S => SS; C => CS; omitted => both; e.g.: **UrsC17.**

Real time control (RTC) of pumping stations: Scenarios aiming for overflow reduction by optimal usage of the available storage volumes (pumping stations and sewers). Option: increased **p**umping **c**apacity by 1.6 (**RTC+PC**). As a reference for optimal storage volume usage, a hypothetical scenario unifies all available volumes in the system in a **c**entral **st**orage tank (**CSt**) at the WWTP.

Passing lane (PL): Scenarios aiming to reduce the WWTP peak load effect caused by the pressure pipes. From each pumping station there are at least two possible paths to the WWPT (these can be parallel pipes or also completely different paths, not all used in status quo and depicted in Figure 1). **PL** scenarios use one pipe for wastewater and switch to the other during stormwater events. When the hydraulic load to the WWTP increases, it is not fed with highly concentrated wastewater like in status quo, but with water from the stormwater pipe that contains diluted water from the last stormwater event. Options: Increased maximum hydraulic load to the WWTP, e.g. **PL 2.4** (2.4 x dry weather peak); combination with **RTC** scenarios. As a reference in the hypothetical **NoPP** scenario, the lengths of the pressure pipes were set to zero.

2.5 Model System

A general overview of the system is provided in chapter 2.2.

Special attention has been given to the SS's wastewater pipe. The flow is composed of three components (Peters & König 2001):

- wastewater: daily hydrograph
- infiltration water: triangular annual hydrograph
- unintended stormwater: 3.5% to 6% of the impervious area is connected to the sewer

The values for the components were identified through calibration at the pumping stations (five years of daily data).Figure 3 shows the implementation in the model. Each sub-catchment contains one module for each of the three components.

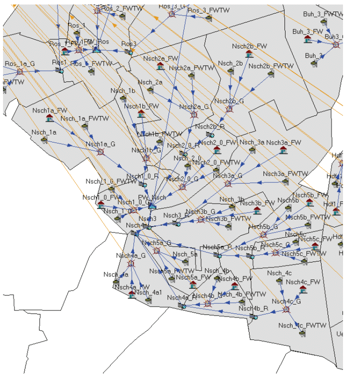

Figure 3: Rainfall Runoff and Sewer Model (1 Pumping Station)

The module for the pressure pipes (Figure 4) had to be developed by the author, as it was not available in standard software. The hydraulic principle is very simple: outflow equals inflow; the latter being defined by the pump or the preceding pipe. A 100% plug flow is modelled for the concentrations. Therefore, the pipe is divided into a number of segments that store the concentrations and move through the pipe.

The WWTP (2003) consists of 6 parallel lines featuring nitrification, denitrification, biological and additional chemical phosphate removal. As phosphorous is not included in ASM1 and there was no sufficient data to use ASM2d or ASM3 + BioP, a rather simple approach was chosen: dissolved P is assumed to be constant, particulate P is calculated as a percentage of TSS in the effluent. The model is based on data from 2003 and depicts one average line consisting of a primary clarifier, seven ASM-tanks in a row and a secondary clarifier (SIMBA NK3S, ifak system 2001). Two weeks of online data (2h-mean) and 4 month of daily data were available for calibration.

The calibration results in Figure 5 display good compliance. A comparison with annual mean data confirms that, only ammonia peaks are, unlike in Figure 5, slightly underestimated. Wastewater temperature usually drops during stormwater events. It is therefore modelled by assigning different temperatures to stormwater and wastewater and mixing them together.

Method for Scenario Comparison

Primarily benefit analysis (Eisenführ & Weber 1999; Peters, Mühleck et al. 2005) was used, but because the objective for all criteria is value reduction, it was modified (inverted) to an impact analysis in order to simplify interpretation of the results. An impact function is defined for all criteria, assigning a value from 0 (very good) to 1 (very poor) to each criterion's value. These impacts are multiplied with weighting factors and added to the total impact for each scenario (Figure 6).

Linear impact functions were chosen, assigning 0 to zero emissions, 0.5 to status quo and 1 to 2 x status quo. A weighting factor of 25% was assigned to Q, NH_4, COD and P. The factors for NH_4 and COD were split into peak and mean (with 12.5% each). To allow for a more detailed interpretation, all criteria were divided into WWTP emissions and overflow emissions. Weighting factors were divided proportionally to the emissions in status quo, so that the reduction of e.g. 1 t COD/year overflow emission or WWTP emission leads to the same result.

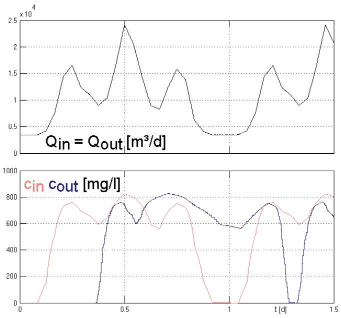

Figure 4: Pressure Pipe Module

3 RESULTS

Additional storage volumes (**StS**) and stormwater infiltration in the SSs (**InfS100**) lead to an almost equal reduction of overflow emissions. As storage volumes are assumed to be infinite, emergency overflows are reduced to zero. Stormwater infiltration reduces the number of emergency overflows to 6 in 30 years. One would expect the storage scenario to have a negative influence on the WWTP. However, the influence is negligible. One reason is that the storage is only utilized during very strong rainfalls, which occur only in summer when the WWTP's performance is at its best. Infiltration has a strong positive influence on the WWTP's effluent.

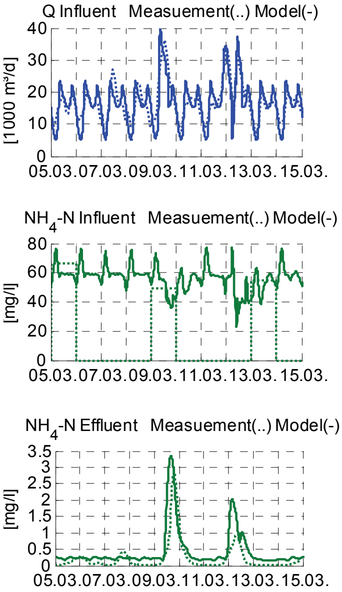

Figure 5: Calibration Results

InfC17 disconnects the same absolute amount of impervious area in the CSs as **InfS100** in the SSs. InfC17 reduces overflow loads to a much greater extent, but the WWTP's emissions to a lesser one in exchange. The reasons include:

1) In the **InfS100** scenario, during most rainfall events, no stormwater enters into the wastewater sewer and the in status quo already available storage volumes (pumping stations, sewers) remain unused.

2) Due to pumping capacity limitations in the CSs, InfC17 reduces the hydraulic peak load to the WWTP during most events.

In total, **InfC17** exhibits a slightly better performance.

InfMax(C24S100) represents the upper limit of improvement that can be achieved by infiltration. Overflows are reduced to ~73% (peak) and ~56% (mean). The WWTP's ammonia effluent loads are reduced to 40% (peak) and to 58% (mean). The hypothetical **Inf100** further reduces overflows and WWTP emissions.

Compared to **InfC17, UrsC17** performs at least equally or better at the WWTP, but worse with respect to the overflow emissions. Compared to InfS100 (disconnects the same absolute amount of area as InfM17), it performs worse or equally at the WWTP. => Depending on weather infiltration primarily reduces overflows or WWTP influent, it may be more or less effective at the WWTP than urine separation. In total infiltration performs clearly better.

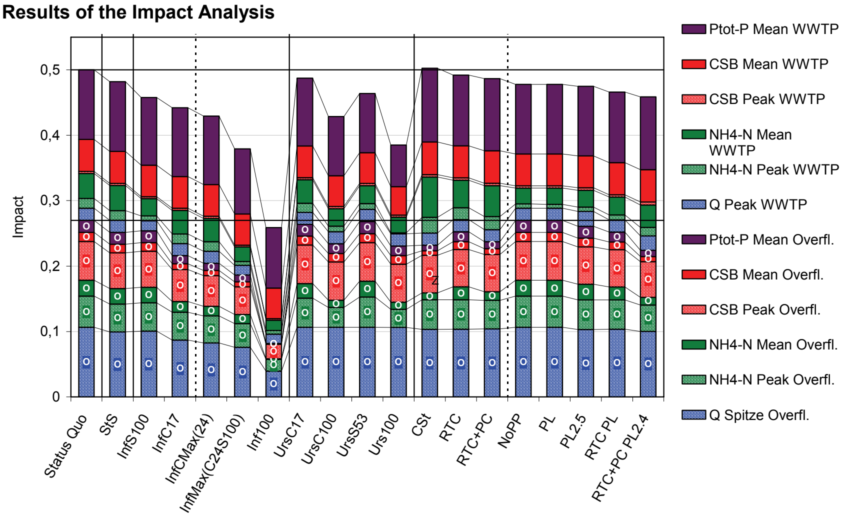

Figure 6: Results of the Impact Analysis

Urs100 represents the upper limit of improvement that can be achieved by urine separation. Compared to InfMax, and even Inf100, it performs significantly better with respect to the WWTP's ammonia peak (reduced to 11%), P mean (reduced to 60%) and at the WWTP in total. Its performance is worse with respect to all other criteria In total it performs slightly worse than InfMax and significantly worse than Inf100.

UrsC100 and **UrsS53** separately collect the urine of the same number of inhabitants. **UrsC17** performs clearly better. The reason is that the CSs contribute to the overflow volumes to a much greater extent than the SSs. Therefore, reducing nutrient concentrations has a much greater effect.

The hypothetic central storage basin (**CSt**) significantly reduces mean overflow loads and peak loads slightly. However, the water that does not overflow has to be treated and the WWTP's emissions rise, so that this scenario in total performs slightly worse than status quo. This principle is true for the **RCT** scenarios that only aim for an optimal storage usage, too. However, it was possible to reduce total emissions by reducing the maximum WWTP inflow during the emptying of the storage basins (**RTC, RTC+PC**). Increasing pumping capacity (**RTC+PC**) further reduces emissions.

Using different pipes during stormwater events (**PL** scenarios) significantly reduces the WWTP's ammonia emissions. The real **PL** scenario performs as good as the hypothetic **NoPP** scenario. Reducing the WWTP's emissions opens the option of increasing the maximum WWTP inflow (**PL 2.5**) if the secondary clarifier is capable. This basically leads to a shift of the emissions from the overflows to the WWTP. Combination of PL and RTC scenarios (**RTC PL**), leads to further reduced overflow emissions. **RTC+PC PL 2.4** demonstrates how far overflow emissions can be reduced by RTC: peak to ~91% and mean to ~52%.

4 CONCLUSIONS

Modelling technique

The pressure pipes have a significant influence on the WWTP and it is essential to include them in the model. It is necessary to use a biochemical WWTP model – a simple approach, e.g. fixed degradation rates is not sufficient. Modelling of wastewater temperature has significant effects on the WWTP and needs further investigation.

Scenario Results

Stormwater infiltration in SSs performs in total better than storage.

Taking into account the high percentage of SSs and that due to spatial limitations 100% infiltration is impossible, urine separation has almost the same potential as infiltration on the whole. It results in the strongest benefits at the WWTP. Infiltration is clearly better for reducing overflow emissions and is the only scenario that reduces hydraulic peak loads.

Collecting the urine of a percentage of inhabitants in the CS performs significantly worse than disconnecting the same percentage of sealed area and infiltrating the water.

Urine separation is more effective in CSs as in SSs.

RTC strategies that only aim for an optimal usage of storage volumes can significantly reduce mean overflow loads and slightly reduce peak overflow loads. In exchange the WWTP's emissions rise. Total emissions can be reduced slightly by reducing the maximum WWTP inflow during the emptying of the storage basins.

Using different pipes during stormwater events dramatically reduces the WWTP's ammonia emissions, making it predestined for a combination other RTC strategies. It also opens the possibility of increasing the WWTP's maximum hydraulic load if the secondary clarifier is capable. The benefit from these scenarios is comparable to disconnecting and infiltrating ~12% of the CSs sealed area or ~10% of the total sealed area.

5 OUTLOOK

Detailed information on all stated aspects will be published in a PhD thesis by the author. Further aspects in that thesis will be the influence of modelling temperature, the influence of the pressure pipe network and the effects of combining different scenarios.

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