

## Assessment of Combined Sewer Overflows under Climate Change Urban Drainage Pilot Study Linz

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### Short Abstract

The possible impact of climate change on urban drainage systems has been a topic of intensive scientific discussion over the last decade. Possible increase of peak intensities will impact on surface flooding and emitted pollutants to receiving waters. This paper presents the urban drainage pilot study of Linz, Austria that is part of the 7<sup>th</sup> EU framework programme SUDPLAN. Discharges from combined sewer overflows (CSOs) to receiving waters are evaluated by aid of a rainfall-runoff and transport model based on long term simulations with (i) historical rainfall and (ii) predicted rainfall derived from a climate model. Efficiency rates based on the current Austrian requirements are calculated and compared. It is shown that the chosen climate projection leads to increased annual precipitation and peak intensities. Total spilled volume increases by approximately 17% for the future scenario. Austrian requirements are met for both scenarios as the required efficiency rates decrease with increased rainfall. It is shown that the assumption of the sedimentation efficiency in storage tanks has a major impact on the results for particulate pollutants. Therefore future work will focus on to installation of a measurement network and evaluation of sedimentation efficiency of a major storage tank.

**Keywords:** climate change, combined sewer system, combined sewer overflow, CSO efficiency rate, modelling, urban drainage

### Introduction

The possible impact of climate change on urban drainage systems has been a topic of intensive scientific discussion over the last decade. The expected modifications in intensity and frequency of extreme rainfalls (see e.g. IPCC (2007)) will affect urban drainage systems in view of both flooding and pollutant loads emitted to the environment. Regardless of the eventual impacts Ashley et al. (2005) stress that designers and operators will have to prepare for greater uncertainties in the effectiveness of drainage systems.

This paper presents the urban drainage pilot study of Linz, Austria where discharges from combined sewer overflows (CSOs) to receiving waters are evaluated by aid of a rainfall-runoff and transport model based on (i) historical rainfall and (ii) predicted rainfall derived from a climate model. Special emphasis is put on the evaluation of the current Austrian guideline 'ÖWAV Regelblatt 19' ('RB 19' in the following) on CSO design (OEWAV, 2007).

As detailed in Mailhot and Duchesne (2010) many papers have described the possible

impacts of climate change on urban drainage infrastructure and analysed the specific impacts on various urban areas. Evaluation of CSO efficiency under climate change is e.g. discussed in Butler et al. (2007) who predict a significant increase of required storage tank volume (57%) for a case study, Nie et al. (2009) estimating an increase in spilled volumes in a Norwegian case study from 35 up to 89% for a yearly time series or Kleidorfer et al. (2009) who discuss a case study independent comparison of climate change effects on urban drainage systems.

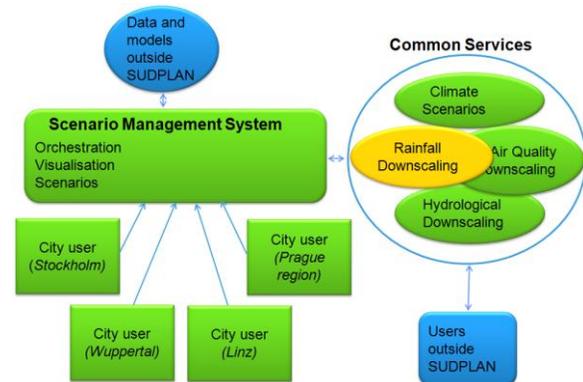
The Linz pilot study is part of the 7<sup>th</sup> European Union framework program project SUDPLAN (Sustainable Urban Development Planner, [www.sudplan.eu](http://www.sudplan.eu)). As described in Gidhagen et al. (2010) this project aims at developing an easy-to-use web-based decision support system that shall provide local information and a quality service to effectively support urban planners and decision makers in urban areas all over Europe in the areas of intense rainfall events, drought and flood risks, and severe air pollution episodes, affecting urban infrastructure and population under the influence of a changed climate.

## Methods

### *SUDPLAN Framework*

The SUDPLAN scenario management and decision support system is providing an easy-to-use web-based planning, prediction, decision support and training tool for the use in an urban context within a changing climate. The main system components are shown in Figure 1. The web-based Scenario Management System includes the client and the user interface of SUDPLAN. The Common Services provides climate information and environmental modelling tools. The SUDPLAN infrastructure includes city-specific models for the pilot cities Stockholm, Wuppertal, Linz and Prague as

well as sensors and databases. All SUDPLAN pilots have their own unique planning applications, managed together with Common Services through the Scenario Management System. The Scenario Management System will be a highly interactive graphics-based decision support environment in which users can define, manage, execute, explore and compare different scenarios. The Common Services task is to provide environmental information for European cities under present and future climate scenarios (Gidhagen et al., 2010). As the SUDPLAN project is currently on-going, full functionality is not yet implemented.



**Figure 1: Overview of SUDPLAN components and pilot studies**

### *Linz Pilot Study Catchment*

The Linz urban catchment (Linz, Austria) is situated at the Danube River (mean runoff of 2000 m<sup>3</sup>/s) and covers approximately 900 km<sup>2</sup>. The highly urbanised area of downtown Linz and 39 neighbour communes are drained to one central waste water treatment plant (WWTP). Downtown Linz is drained mainly by combined sewers, the neighbouring communes have both separate and combined systems installed. Several CSOs and storage tanks are installed in the sewer system. The total storage volume in the sewer system is estimated to 115 000 m<sup>3</sup>. The two primary clarifiers at the WWTP are used as CSO tanks

during rainfall: from the maximum WWPT inflow of approximately 8.8 m<sup>3</sup>/s, 4.7 m<sup>3</sup>/s are routed to the biological treatment. The exceeding 4.1 m<sup>3</sup>/s are spilled to the Danube River right after the primary clarifiers.

### CSO Efficiency Rates

Requirements for combined sewer systems and CSO performance in Austria are defined in the Austrian RB 19 guideline (OEWAV, 2007). A comprehensive English description of the guideline is given in Kleidorfer and Rauch (2010).

Efficiency rates for dissolved ( $\eta_d$ ) and particulate ( $\eta_p$ ) pollutants are determined by long term simulation of the sewer system according to Equation 1 and Equation 2. As the actual sedimentation efficiency  $\eta_{sed}$  of CSO structures is difficult to determine the guideline proposes typical values for sedimentation efficiency depending on the specific volume of the CSO structure.

$$\eta_d = \frac{VQ_R - VQ_O}{VQ_R} \cdot 100 \quad \text{Equation 1}$$

With:  $\eta_d$  ... CSO efficiency for dissolved pollutants (%),  $VQ_R$  ... Total volume of surface runoff (m<sup>3</sup>/yr),  $VQ_O$  ... Total volume of overflow discharge (m<sup>3</sup>/yr)

$$\eta_p = \eta_d + \frac{\sum_j VQ_{O,j} \cdot \eta_{sed}}{VQ_R} \quad \text{Equation 2}$$

With:  $\eta_p$  ... CSO efficiency for particulate pollutants (%),  $j$  ... index of CSO (-),  $\eta_{sed}$  ... sedimentation efficiency for CSO  $j$  (%),  $VQ_{O,j}$  ... volume of overflow discharge for CSO  $j$  (m<sup>3</sup>/yr)

The determined efficiency rates are then compared to *required efficiency rates* defined in the guideline. These range from 40 to 60% for dissolved and 55 to 75% for particulate pollutants. They depend on the design basis of

the WWTP in population equivalents (PE), the statistical rainfall intensity with a duration of 12 hours and return period once per year ( $r_{720,1}$ ) and the ratio of PE drained by separate and combined systems. In this study the  $r_{720,1}$  was determined from the rainfall time series by applying the procedure described in the German ATV A-121 guideline (ATV, 1985).

### Sewer System Model

The well-known open-source software SWMM 5 (Rossmann, 2007) was used as modelling tool. An aggregated model of the Linz catchment and sewer system was set up at Innsbruck University, Austria (Figure 2).



**Figure 2: Overview of the aggregated Linz catchment model in SWMM 5**

The model was analysed, tested and calibrated with state-of-the art global sensitivity analysis (Morris, 1991) and multi-objective optimisation methods (Muschalla, 2008) using the BlueM.OPT framework described in Bach et al. (2009) and Gamerith (2011). However, due to limited data from the neighbour communes and limited rainfall information the model set up and calibration proved a difficult task (Wendner, 2011).

The CSO efficiency rates were calculated from the SWMM simulation results by a script developed in the software R ([www.r-project.org/](http://www.r-project.org/)). The sedimentation efficiency  $\eta_{sed}$  for the CSO structures, however, could not be easily determined from the RB19 guideline due to the complexity of the system. As no information on actual sedimentation rates was available  $\eta_{sed}$  was arbitrarily set to 20% for all CSO tanks.

In the predicted future scenario, the catchment and sewer system characteristics (e.g. imperviousness, tank volume...) were assumed to be static.

#### *Rainfall Data and Climate Change Scenario*

In this study, a comparison of one observed historical time series and one predicted future time series is presented. As historical rainfall data a 14-year time series with a 10-min time resolution recorded in downtown Linz was available from the Austrian NIEDA tool (hydro-IT, 2007).

The predicted time series was obtained by downscaling a future global climate model projection in two steps. The projection was made by the global model ECHAM5 (Roeckner et al., 2006) forced with SRES emission scenario A1B (Nakićenović et al., 2000), representing an intermediate level of future greenhouse gas concentrations in the atmosphere, covering the period 1961-2100. This is just one possible future realization of the climate until the end of the century that is currently implemented in the SUDPLAN system. More implementations will follow until the end of the project.

In the first step, this global projection was dynamically downscaled to a 50×50 km grid over Europe using the regional model RCA3 (Kjellström et al., 2005). From these results, 30-min precipitation time series from five model grid cells centred over Linz were extracted.

In the second step, the regional results were further downscaled to local scale by the Delta Change method described e.g. in Olsson et al. (2009). By analysing the extracted RCA3 data, future local changes in the frequency distribution of precipitation intensities between periods 1993-2006 (available observations) and 2079-2092 (representing 2071-2100) were estimated on a seasonal basis. The final predicted time series was obtained by applying the estimated changes to the historical time series. For further details about the methodology and its implementation in the SUDPLAN system, see Olsson et al. (2009) and Olsson et al. (2011).

## **Results**

### *Model Evaluation and Calibration*

The model was calibrated using data from three water level measurements installed in the sewer system. Measurement data was available from 2004 onwards. Since 2005 a real time control system of the sewer network is in place that is occasionally switched to half-manual operation. Therefore only the data from 2004 could be used in the calibration process. Important model parameters for calibration were determined in a global sensitivity analysis. Five independent events were used in calibration and the Nash-Sutcliffe efficiency coefficient and the percentage bias between measured and simulated water levels were evaluated and minimised in an automated calibration procedure.

Major uncertainties are introduced due to limited rainfall information as only rainfall data from one single rain gauge was used for the whole catchment. In addition the highly uncertain data from the neighbour communes introduces important uncertainties as was shown in the global sensitivity analysis. Details on the sensitivity analysis and model optimisation are given in Gamerith et al. (in preparation).

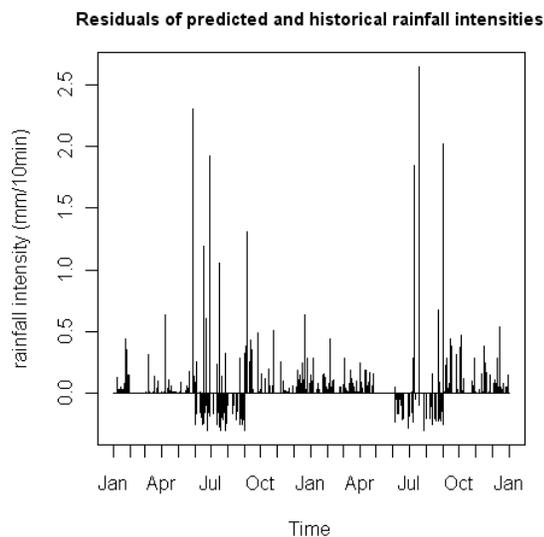
*Comparison of Rainfall Characteristics and Required Efficiency Rates*

Table 1 shows a comparison of the characteristics of the historical and the predicted rainfall time series. In this scenario the annual rainfall depth increases by approximately 8%, the  $r_{720,1}$  by 12%.

**Table 1: Comparison of historical and predicted rainfall time series characteristics**

Rainfall time series	Period	Mean annual rainfall depth mm/yr	$r_{720,1}$ mm
-	Y-M-D		
Historical	1993-01-01	850	35.1
	2007-01-01		
Predicted	2079-01-01	918	39.3
	2093-01-01		

Figure 3 shows the residuals between predicted and historical rainfall for a period of 2 years. Rainfall intensities tend to increase in winter and decrease during the summer period. Strong intensities are generally increased.



**Figure 3: Residuals of predicted and historical rainfall intensities.**

Based on these two rainfall time series the required efficiency rates for the Linz

catchment were determined for dissolved and particulate pollutants (see Table 2).

**Table 2: Required efficiency rates for the investigated scenarios**

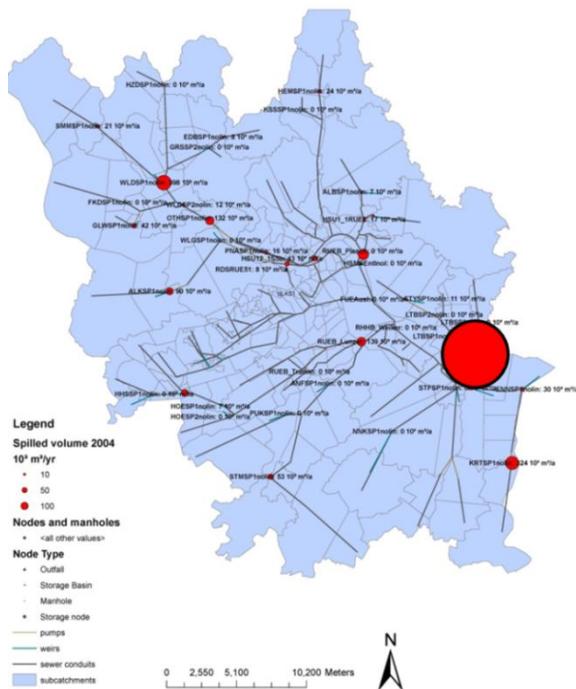
Rainfall time series	Required efficiency rates	
	$\eta_d$ %	$\eta_p$ %
-		
Historical	57.4	72.4
Predicted	55.4	70.4

As the WWTP size is not likely to decrease significantly and no adaptations in the drainage system were considered, only the  $r_{720,1}$  impacts on the required efficiency. It can be seen that due to the increase of the  $r_{720,1}$  the required efficiency rates decrease by 2% for the predicted rainfall time series. This decrease is justified in the RB 19 guideline as the environmental impact of CSOs is assumed to reduce if more water is available in the region.

*Evaluation of Current State with Historic Rainfall Time Series*

In a first step the current system was evaluated by simulating one single year (2004) in order to identify the most important CSO structures. Figure 4 shows the annual overflow volumes in relative size.

From the 44 modelled CSO structures the primary clarifiers at the WWPT proved to be by far the most important. Approximately 57% of the total overflow volume can be apportioned to these tanks. From the remaining structures, 11 CSOs were identified to have significant impact, covering 37% of the total overflow volume. Hence, 94% of the overflow total annual overflow volume can be apportioned to 12 CSO structures. The rest was considered non influential in terms of spilled loads.



**Figure 4: CSO overflow volumes in 2004. Size of the red dots shows relative volume.**

In a second step, the current network was assessed according to the RB 19 guideline using the complete 14-year historical rainfall time series. As shown in Table 3 the requirements are met for both dissolved and particulate pollutants.

**Table 3: Results for historical time series**

	$\eta_d$	$\eta_p$
-	%	%
required efficiency rate	57.4	72.4
calculated efficiency rate	67.4	73.9

As the assumptions on the sedimentation efficiency in the CSO structures are highly uncertain a comparison of the obtained  $\eta_p$  for varying  $\eta_{sed}$  between 10 to 30 % is shown in Table 4. When reducing the assumed sedimentation efficiency the requirements are no longer satisfied. Therefore it is of major importance to assess the actual sedimentation

efficiency, especially of the primary clarifiers at the WWTP as major CSO.

**Table 4: CSO efficiency rates with different assumptions of sedimentation efficiency**

Sedimentation efficiency $\eta_{SED}(\%)$	10	20	30
Calculated efficiency $\eta_p(\%)$	70.4	73.6	76.7

*Comparison of Results for Historical and Predicted Rainfall*

Table 5 shows a comparison of the 12 CSOs that were identified as influential for the historical and the predicted rainfall time series. The total overflow volumes in the catchment increase by approx. 17%. The loads spilled by the most important CSO structure – the primary clarifiers at the WWTP (WWTTPC) – increase by about 15.5%. Hence a significant influence can be identified.

**Table 5: Comparison of overflow volumes for historical and predicted rainfall for the 12 influential CSO structures.**

CSO structure name	overflow volume		difference	
	historical $10^3 \text{ m}^3$	predicted $10^3 \text{ m}^3$	abs. $10^3 \text{ m}^3$	rel. %
WWTTPC	59033	68227	9194	15.57
AB_PLE	3891	5428	1537	39.51
HSU12	1297	1544	247	19.06
ALKSP1	2704	3185	481	17.78
HEMSP1	7565	8980	1415	18.70
KRTSP1	1705	1947	242	14.18
LTBSP1	1094	1395	301	27.49
NNKSP1	2477	2631	154	6.21
OTHSP1	4060	4709	649	15.99
WSEE3	2986	3963	977	32.73
WLDSP1	7050	7839	789	11.19
WLGSP1	3162	3825	663	20.97
<b>Totals</b>	<b>97025</b>	<b>113673</b>	<b>16649</b>	<b>17.16</b>

The efficiency rates calculated for the predicted rainfall time series are shown in Table 6.

**Table 6: Results for predicted time series**

	$\eta_d$	$\eta_p$
-	%	%
required efficiency rate	55.4	70.4
calculated efficiency rate	64.5	71.3

Compared to the historical time series the calculated efficiency rates decrease by 2.9 and 2.6 percentage points for dissolved and particulate pollutants respectively. The requirements, however, are still met as also the required efficiency rate decreases.

### Discussion and Conclusions

This paper discusses the assessment of possible impacts of climate change on combined sewer overflow behaviour in the urban drainage pilot study Linz, Austria that is part of the EU FP7 project SUDPLAN. The system's performance is assessed by long term simulations with a historical and a predicted rainfall time series in a SWMM 5 sewer model. Special emphasis is laid on the evaluation of the current Austrian 'RB 19' guideline on CSO design. In a first assessment, 12 of 44 modelled CSO structures were identified as influential. The primary clarifiers at the WWTP that are also used as CSO tanks during rainfall proved to be the most important structure contributing with approx. 57% to the total overflow volume.

Concerning the impacts of the climate change scenario the following major findings can be stated:

- The predicted rainfall (climate model projection ECHAM5\_A1B\_3) shows a decrease of rainfall intensities in the summer period and an increase in winter.

Strong precipitations intensities generally increase.

- The total overflow volume is increased by approximately 17%.
- The requirements as defined in the Austrian RB 19 guideline are met for both dissolved and particulate pollutants for the historical and the predicted time series. While the system efficiency decreases with the predicted time series also the requirements decrease with increased rainfall.
- For particulate pollutants, an important impact of the assumption of the sedimentation efficiency for storage tanks was identified. This efficiency, however, is only estimated and its true value is not known.

For a more comprehensive assessment of the Linz pilot study, additional climate model projections will be applied to estimate an uncertainty range of predicted rainfall and different development scenarios. In addition the installation of a measurement network will allow assessing the actual sedimentation efficiency in the primary clarifiers during storm water conditions. In its final realization in late 2012 the SUDPLAN project will allow direct rainfall downscaling and the evaluation of impacts of future scenarios directly by the stakeholder via an internet platform to prepare proper mitigation strategies and measures in time.

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