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SUDPLAN: Developing a Decision Support System to Cope with Climate Change - Urban Drainage Pilot Linz

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SUDPLAN: Developing a Decision Support System to Cope with Climate Change – Urban Drainage Pilot Linz

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Abstract

The EU FP7 SUDPLAN (Sustainable Urban Development Planner) project aims to set up an easy-to-use web-based Scenario Management and Decision Support System on European scale for scientists, city planners and stakeholders to deal with climate change affecting urban infrastructure. The system is validated on four pilot studies. In the Linz pilot (Austria), possible impacts of climate change on the pollutant loads spilled from a combined sewer system to receiving waters are evaluated by a sewer model and installation of a measurement network. This paper describes the SUDPLAN project and its goals and details on the aims and results so far obtained in the Linz pilot study by applying two different climate change scenarios to predict future CSO behaviour. The results for the Linz pilot show that currently the Austrian requirements on CSO spill loads are met for the Linz catchment area. For single CSO structures, overflow volumes increase in a range between 10 to 60% in the future scenarios. This could seriously affect the water quality in the receiving waters. This knowledge can help to develop proper mitigation strategies in time. Overall the SUDPLAN platform shows to be a promising tool for coping with the challenge of climate change in a community with different people involved.

Keywords
climate change, combined sewer overflow (CSO), CSO efficiency, CSO tank, decision support system, urban drainage

INTRODUCTION

Climate change and its impact on the environment have been intensively discussed in recent years and possible effects are summarised e.g. in IPCC (2007). The 7th European Union framework program project SUDPLAN (Sustainable Urban Development Planner) aims at developing an easy-to-use web-based decision-support system that allows to pro-actively reacting to possible impacts of climate change in several environmental questions with a focus on urban planning. As described in Gidhagen *et al.* (2010) and Denzer *et al.* (2011) SUDPLAN 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 by

- the design and implementation of a Scenario Management System (SMS), an execution, visualization, documentation and training environment for scientific users, city planners and managers and
- the design and implementation of so-called Common Services (CS) to deliver the necessary data to quantify, report and visualize the future risks for droughts, flooding, extreme rainfall intensities and high air pollution events over urban areas, usable throughout Europe, but at the local urban scale.

One of four independent pilot studies for evaluating the SMS and the CS is the city of Linz, Austria.

There the impacts of climate change on combined sewer overflows (CSOs) are evaluated based on long-term simulations of the sewer system according to the current Austrian guideline for CSO design (OEWAV, 2007). Several publications on the effects of climate change on urban drainage systems were issued over the last years. Ashley *et al.* (2005) stress that – independent from the eventual effects – designers and operators will have to prepare for greater uncertainties in the effectiveness of drainage systems. An overview of publications on case studies describing specific impacts of climate change on urban infrastructure in various areas is given in Mailhot and Duchesne (2010). Of special interest for the Linz Pilot study is the case study presented in Butler *et al.* (2007) who indicates that the performance of an investigated CSO tank suffers considerably when climate change is taken into account.

This paper presents some major parts of the SUDPLAN SMS and CS and describes first results obtained from the evaluation of two different, so far available climate change scenarios on the Linz pilot study. These two climate change scenarios are each applied in two different versions – with and without frequency adjustment (FA) – in long-term simulations of the sewer system to predict future CSO behaviour in the catchment.

METHODS

Pilot catchment

The Linz catchment is situated in Linz, Austria at the Danube River and covers approximately 900 km² in total. The area of downtown Linz with mainly combined sewers and 39 neighbour communes with combined and separate systems are drained to one central waste water treatment plant (WWTP). Several CSOs and CSO tanks are installed in the combined sewer system. From the estimated 115 000 m³ of total storage volume in the system approximately 70 000 m³ can be apportioned to three major storage tanks. The primary clarifiers at the WWTP are also used as CSO tanks during rainfall.

Austrian Requirements – CSO Efficiency Rates

The Austrian Regelblatt 19 guideline (OEWAV, 2007) defines the current requirements for the assessment and evaluation of CSO performance in Austria. An English description of the guideline is given in Kleidorfer and Rauch (2010). Efficiency rates for dissolved (η_d) and particulate (η_p) pollutants are calculated according to Equation 1 and Equation 2 based on long-term simulation (10 year or more) of the whole sewer system. For the sedimentation efficiency η_{sed} of CSO structures in Equation 2 the guideline proposes typical values depending on the specific volume of the CSO structure.

The calculated efficiencies are then compared to required efficiency rates that can be determined from the guideline document. 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 used rainfall time series by applying the procedure described in the German ATV A-121 guideline (ATV, 1985).

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

With: η_d … CSO efficiency for dissolved pollutants (%), VQ_R … Total volume of surface runoff (m³/yr), VQ_O … Total volume of overflow discharge (m³/yr).

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

With: η_p … CSO efficiency for particulate pollutants (%), j … index of CSO (-), η_{sed} … sedimentation efficiency for CSO j (%), $VQ_{O,j}$ … volume of overflow discharge for CSO j (m^3/yr).

For an easier comparison of the results from different scenarios, an efficiency ratio as proposed in Flamisch *et al.* (2012) according to Equation 3 is used in this contribution.

$$\upsilon = \frac{\eta_{act}}{\eta_{req}} \qquad \text{Equation 3}$$

With: υ … efficiency ratio (-), η_{act} … actual calculated CSO efficiency (%) as in Equation 1 and Equation 2, η_{req} … required efficiency determined from the guideline (%).

Climate Change Scenarios – Rainfall Data

As historical rainfall data a time series from downtown Linz was available for the period from 1993 to 2006 (hydro-IT, 2007). The time series is recorded by a tipping bucket gage located near the centre of Linz. In this study a time resolution of mm / 5 min was used.

For the scenario analysis four predicted future rainfall time series were available. They were obtained by downscaling a future global climate model projection in two steps. The projection was made by the global models ECHAM5 (E) (Roeckner *et al.*, 2006) and HADLEY (H) (Gordon *et al.*, 2000) 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. 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, representing the surrounding 30-year period) 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.

Two versions of the downscaling approach were applied to each of the two climate projections, producing four future realisations. In the first, basic version, future estimated changes in rainfall frequency (i.e. occurrence) in the climate projections were not taken into account but only changes in the probability distribution of short-term rainfall intensities. Thus the future frequency is identical to the historical, which is common Delta Change practice. In the second, upgraded version, also estimated frequency changes were transferred to the historical time series. In the following this versions are denoted with FA for Frequency Adjustment. The transfer was done by deleting or duplicating entire events based on their statistical characteristics in terms of volume and duration. For further details about the methodology and its implementation in the SUDPLAN system, see Olsson *et al.* (2009) and Olsson *et al.* (2012).

Sewer System Model

An aggregated model of the Linz catchment and sewer system was available in SWMM5 (Rossmann, 2007). The Linz catchment model was set up at Innsbruck University, Austria. The model structure (sewer mains, subcatchments, special structures and pumping stations) was evaluated in the work of Wendner (2011). In total 43 CSOs were included in the model. State-of-the art global sensitivity analysis and multi-objective optimisation methods were applied for model testing and calibration using the BlueM.OPT framework (Bach *et al.*, 2009). Due to lacking data on the sewer system especially in the neighbour communes and limited rainfall information the model set up and calibration proved a difficult task. A detailed description and results from the performed sensitivity analysis and the multi-objective model calibration are given in Gamerith *et al.* (accepted). The calibrated model was then used as basis for the following evaluations.

The CSO efficiency rates were calculated in the software R (R Development Core Team, 2011) from the SWMM5 simulation results. As no information on the actual sedimentation rates was available, the sedimentation efficiency η_{sed} was arbitrarily set to 20% for all CSO tanks. For the predicted future scenario, the catchment and sewer system characteristics were assumed not to change.

First evaluations with the historical time series described in Gamerith *et al.* (2012) identified the combined sewer overflow at the primary clarifiers on the WWTP to be by far the most important with regards to the total overflow volume. In addition it was shown that the chosen sedimentation efficiency has an important impact on the results.

SUDPLAN Scenario Management System

The SUDPLAN SMS links all relevant components (see Figure 1) and provides a graphical user interface. The system is responsible for interaction between the different components. Inputs as historical rainfall data and data from the sensor network as well as downscaled rainfall data and its link to the used local sewer model and execution of the model runs are managed by the SMS. Downscaling of the rainfall is managed by the common services.

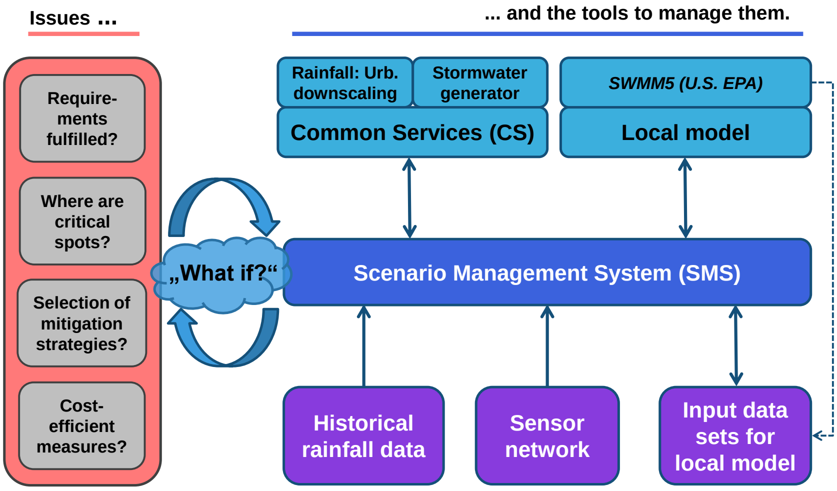
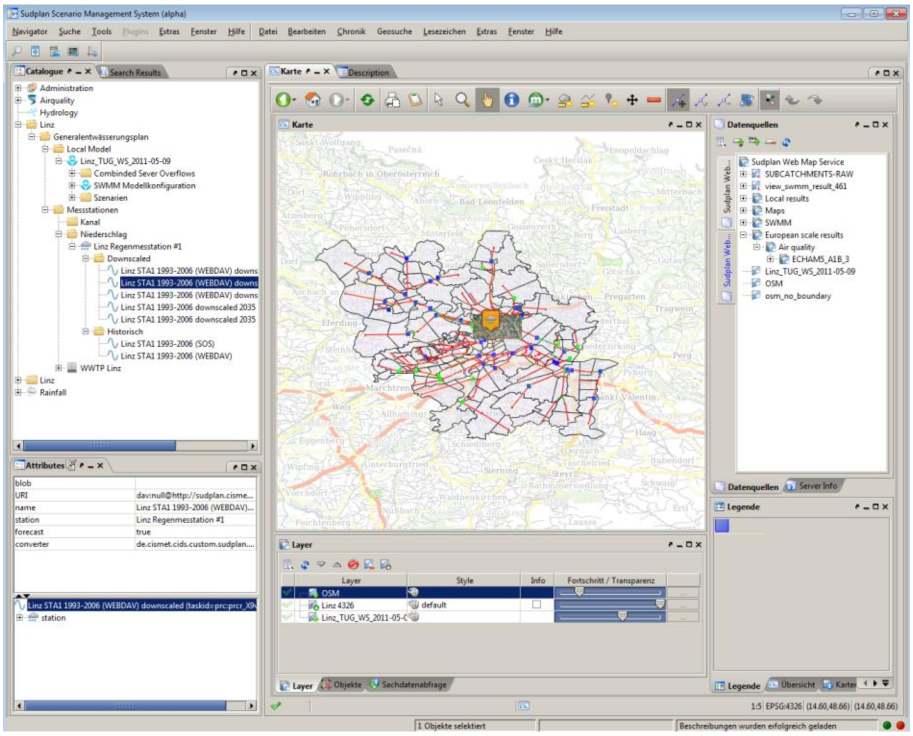


Figure 1: SUDPLAN Scenario Management System structure for Linz pilot

Figure 2 shows a screenshot of the SMS web-application for the Linz model. The following features are currently implemented.

- Choose different SWMM5 model scenarios (Hereby changes in catchment and sewer system characteristics can also be varied).
- Choose available rainfall time series or acquire a predicted rainfall time series from the downscaling provided by the common services.
- Set simulation periods and run the SWMM5 simulation with automatic calculation of the required and actual efficiency rates. The sedimentation efficiency for the CSO tanks can be defined.
- View and visualise full results from the SWMM5 report and the efficiencies according to the Austrian requirements.
- Visualisation of the model structure, other geo-referenced data as e.g. open street maps and aerial view photos and time series visualisation.



blob	
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station	Linz Regenmesstation #1
forecast	true
converter	de.cismet.cids.custom.sudplan....

Linz STA1 1993-2006 (WEBDAV) downscaled (taskid=prc:prcr_X9

station

Layer	Style	Info	Fortschritt / Transparenz
OSM			
Linz 4326	default	☐	
Linz_TUG_WS_2011-05-C			

1:5 EPSG:4326 (14.60,48.66) (14.60,48.66)

1 Objekte selektiert

Beschreibungen wurden erfolgreich geladen

Figure 2: Screenshot from SUDPLAN SMS with Linz model

RESULTS AND DISCUSSION

Result overview – Austrian requirements

Table 1 shows a summary of the obtained results for the 5 scenarios in view of the Austrian requirements. It is shown that currently the required efficiency rates for dissolved pollutants are reached for all investigated scenarios as υ_d and υ_p are greater than 1.0. The actual efficiency rates for both dissolved and particulate pollutants do not change significantly (in the range of one percentage point) between the predicted scenarios.

Table 1: Result overview efficiency rates for scenarios

Time series	Annual mean	r_{720_1}	$\eta_{d,req}$	$\eta_{d,act}$	υ_d	$\eta_{p,req}$	$\eta_{p,act}$	υ_p
	mm/a	mm	%	%	-	%	%	-
Historical	849.7	35.1	57.4	67.3	1.17	72.4	73.5	1.02
ECHAM5 (E)	941.2	39.2	55.4	63.9	1.15	70.4	70.8	1.01
ECHAM5-FA (E-FA)	941.6	40.8	54.6	64.2	1.18	69.6	71.1	1.02
HADLEY (H)	933.8	38.7	55.7	64.5	1.16	70.7	71.3	1.01
HADLEY-FA (H-FA)	932.8	40.9	54.6	64.1	1.17	69.6	70.9	1.02

A more detailed evaluation of the rainfall characteristics and the required efficiency rates according to the guideline is given in Table 2. It can be seen that the mean annual rainfall depth and the $r_{720,1}$ increase in all predicted scenarios compared to the historical time series by approximately 10% and 10 to 17% respectively. A comparison of the predicted scenarios shows that the annual rainfall depth in the ECHAM5 scenario is 1% higher than for the HADLEY scenario. The $r_{720,1}$ is higher for the scenarios where the frequency adjustment (FA) was applied. However, as the $r_{720,1}$ increases, the required efficiency rates decrease by 2 to 3 percentage points. This decrease is justified in the Austrian Regelblatt 19 guideline as the impact of CSOs is assumed to decrease if more water is available in the receiving waters of the considered region.

Table 2: Comparison of historical and predicted rainfall time series: differences in rainfall characteristics and required efficiency rates $\eta_{d,req}$

Relative difference in annual rainfall depth (%)				
Hist.	10.8	10.8	9.9	9.8
11.7	**E**	0.0	-0.8	-0.9
16.2	4.1	**E -FA**	-0.8	-0.9
10.3	-1.3	-5.1	**H**	-0.1
16.5	4.3	0.2	5.7	**H -FA**
Relative difference in $r_{720,1}$ (%)				

Absolute difference in required efficiency rates $\eta_{d,req}$ (percentage points)				
Hist.	2.0	2.8	1.8	2.9
-4.1	**E**	0.8	-0.3	0.8
-5.7	-1.6	**E - FA**	-1.1	0.0
-3.6	0.5	2.1	**H**	1.1
-5.8	-1.7	-0.1	-2.2	**H -FA**
Absolute difference in $r_{720,1}$ (mm)				

In Figure 3 the residuals of the historical and the predicted rainfall time series using the delta change method (ECHAM5 and HADLEY) are compared for a period of 2 years. It is shown that rainfall intensities tend to increase in winter and decrease during the summer period. High intensities are generally increased. The comparison of the two predicted rainfall time series shows that with the HADLEY scenario, intensities in the summer period are higher than with the ECHAM5 scenario and vice versa for the winter period.

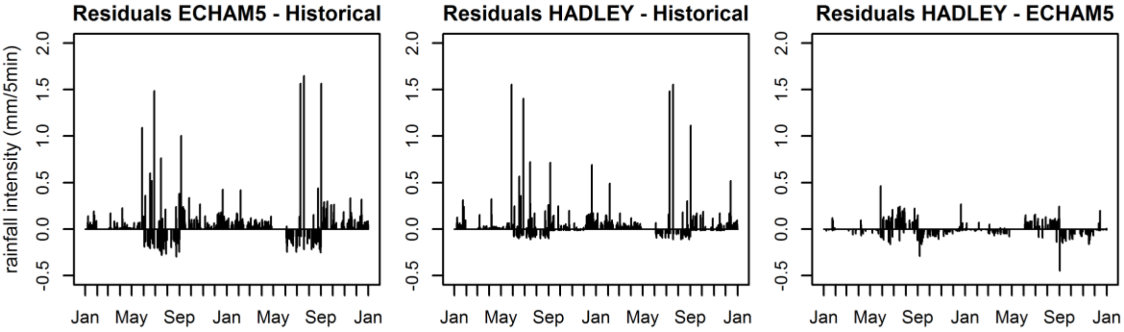

Figure 3: Comparison of residuals for historical and predicted time series (delta change method) for two years

Figure 4 shows a comparison of the HADLEY model with and without frequency adjustment for a period of one year. The shift in occurrence and frequency are visible from the series and the residuals comparison.

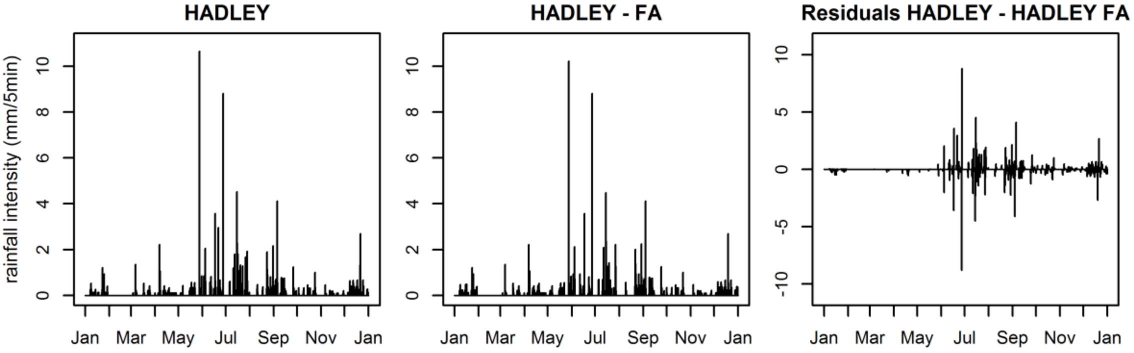

Figure 4: Comparison predicted time series with and without frequency adjustment (Hadley climate scenario)

Impact on combined sewer overflows

The future predicted scenarios lead to a change in total overflow volume from the system between 21 and 23% depending on the time series. The impact of the different scenarios was evaluated in more detail for the 14 most important CSO that contribute to approximately 95% to the total overflow volume. Figure 5 gives an overview of the overflow volume for the 14 most important

CSOs. The primary clarifiers (CSO 1) are shown to be the by far most important with a contribution of approx. 55% to the total overflow volume. Compared to the historical time series, overflow volumes increase for all four future scenarios. The right hand side of the figure shows the absolute and relative changes in overflow volume for the primary clarifiers for the four future scenarios compared to the historical rainfall time series. At this most relevant CSO the overflow volumes increase between 18 to 21%.

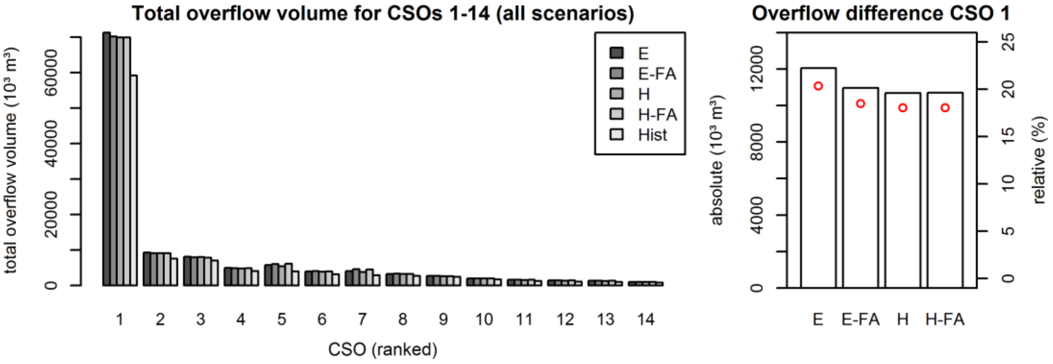

Figure 5: Total overflow volume for 14 important CSOs and climate change scenarios (right) and change in overflow volume for the rainfall scenarios for CSO 1 (left. bars showing absolute, dots the relative difference)

Figure 6 shows the differences in overflow volume (absolute and relative) for the CSOs 2 to 14 from the 14 ranked as most important. Overall the increase in overflow volume ranges from approximately 10 to 60%, depending on the overflow and the scenario. It can be seen that dependent on the chosen scenario, the increase in overflow volume can differ significantly. I.e. for overflow 2 to 4 the increase in overflow volume is highest for the ECHAM5 scenario. Overflows 5 to 7, where the absolute and relative differences compared to the historical time series are the highest are most influenced by the scenarios with frequency adjustment. A uniform trend concerning the application of frequency adjustment for all CSOs cannot be proved.

By this comparison CSOs that are especially sensitive to the effects of climate change can be identified. The impact of different scenarios can be directly assessed and a possible range of future overflow behaviour can be estimated. This different overflow behaviour of certain CSOs can seriously affect the water quality in the receiving waters depending on the actual flow rates in these waters during the overflow events. Therefore knowledge of the affected CSOs and receiving waters can be used to find proper mitigation strategies and measures in time for these areas to prevent critical water quality conditions.

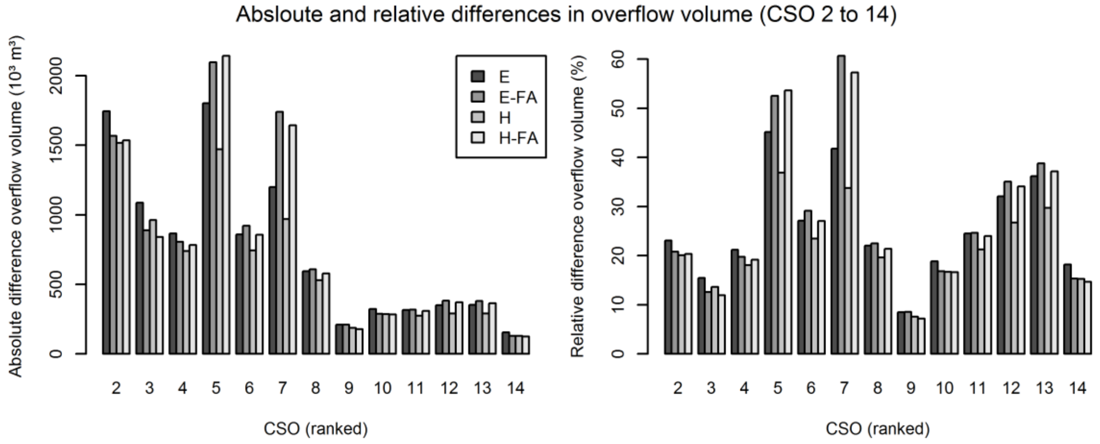

Figure 6: Absolute and relative differences in CSO overflow volume from historical time series for the predicted rainfall scenarios

CONCLUSIONS

This paper discusses a scenario management system for dealing with climate change effects that is developed in the 7th EU framework programme project SUPLAN. For the pilot study Linz, the combined sewer system is evaluated according to the current Austrian guideline on CSO design using a historical and four predicted rainfall scenarios.

- The SUDPLAN scenario management and decision support system provides an easy-to-use web-based planning, prediction, decision support and training tool, for the use in an urban context. Based on these capabilities the sewer and WWTP operator of Linz (Linz AG) will be able to estimate future spilled out CSO pollution loads from its sewer system to receiving waters and if required to prepare proper mitigation strategies and measures in time.

- The predicted rainfall series generally show a decrease of rainfall intensities in the summer period and an increase in winter. High precipitation intensities generally increase. Also the total precipitation increases by about 10%. For the so far available future scenarios differences of the total precipitation are approximately 1%.

- The requirements as defined in the Austrian Regelblatt 19 guideline are met for both dissolved and particulate pollutants for the historical and for all so far available predicted time series. While the system efficiency decreases with the predicted time series also the requirements decrease with increased rainfall.

- The total overflow volume is increased by approximately 21 – 23%. For the most important CSO structure – the primary clarifiers at the wastewater treatment plant – the overflow volume increase between 18 to 21%. For the other CSO structures, overflow volumes increase in a range between 10 to 60%. A uniform trend concerning the application of frequency adjustment in the climate change scenarios for all CSO structures cannot be proved.

- The significant increases (up to +60%) of the overflow volumes for single structures could locally seriously affect the water quality of the receiving waters and these overflows should be investigated in full detail. Knowledge of the CSOs that are sensitive to climate change can help to find proper mitigation strategies and measures in time for these areas to prevent critical water quality conditions.

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