Integrated assessment of a new central storage tunnel on treatment plant’s performance in Graz (Austria)

Etude intégrée d'un nouveau tunnel de stockage central sur la performance d'une station d'épuration à Graz (Autriche)

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RÉSUMÉ

Un modèle de simulation intégré du système de traitement des eaux usées de la ville de Graz en Autriche, comprenant le système d’assainissement et la station d’épuration (STEP), a été construit pour évaluer différents scénarios d’exploitation d’un tunnel de stockage central récemment construit (TSC). L’objectif est d’améliorer les performances en matière de traitement de la station d’épuration de la ville de Graz et, par conséquent, les émissions totales vers la rivière Mur. Un modèle conceptuel de type grey-box a été utilisé pour représenter le réseau d’assainissement existant et des modèles détaillés ont été utilisés pour le tunnel de stockage et la station d’épuration. L’intégration du modèle a été effectuée en utilisant des interfaces texte pour les connexions séquentielles et des corrélations complètes entre les sous-modèles quand des interactions bidirectionnelles devaient être envisagées. Le calibrage du modèle a été réalisé séparément pour chaque sous-modèle. Les résultats exemplaires de l’étude qui ont été présentés montraient le potentiel de l’application de stratégies de gestion sur le système avec une réduction d’environ 45% des émissions totales de DCO vers la rivière.

ABSTRACT

An integrated simulation model of the urban wastewater system of the city of Graz (Austria) including the sewer system and the wastewater treatment plant (WWTP) was built to evaluate different operating scenarios of a recently installed central storage tunnel (CST) in view of the treatment performance of the WWTP Graz (Austria) and consequently of the total emissions to the river Mur. A conceptual grey-box model was used to represent the existing sewer system and detailed models were used for the CST and the WWTP. Model integration was done by using script-based interfaces for sequential connections and full sub-model linkage when bi-directional interactions had to be considered. Model calibration was carried out for each sub-model separately. The presented exemplary results of the study showed the potential of applying management strategies in the system by a reduction of the total emissions to the river for COD of about 45%.

KEYWORDS

Integrated modelling, model interfacing and integration, monitoring, treatment performance, total emissions

1 INTRODUCTION

The urban drainage system of Graz (Austria) is currently facing new challenges concerning an increasing population in the city and the simultaneous need of more storage volume in the system. The wastewater treatment plant (WWTP) of Graz was originally designed for 270,000 inhabitants in 2001. Since then, the city's population grew from 225,000 in 2001 to 270,000 in 2015, which leads the WWTP already to its treatment capacity. Independently, the first stage of a new central storage tunnel (CST) providing additional storage volume was built in the south of the city. An extension of this central storage tunnel (CST) to the city centre is planned in the near future which will result in a total additional storage volume, which will be more than the current average daily dry weather flow to the WWTP. The purpose of the CST is to collect and temporarily store emissions from connected combined sewer overflows (CSOs) during rainfall events and route them to the WWTP for treatment. This measure will support the city to reach the state of the art for CSO emissions in Austria (OEWAV, 2007; Kleidorfer and Rauch, 2011). Due to the fact, that the WWTP is already reaching its treatment capacity, the additional volume from the CST will increase the load to the WWTP furthermore.

The potential effects regarding WWTP performance and total emissions of the drainage system to the river Mur were investigated by using an integrated model approach of the city's urban wastewater system including the sewer system, the CST and the WWTP to show a holistic picture of the system's situation regarding rainfall – runoff processes in the drainage system and treatment process at the WWTP (refer to Rauch et al., 2002; Grau et al., 2009; Muschalla et al., 2009; Laniak et al., 2013). The estimation of the overall performance of the system was conducted by simulating rainfall events combined with different operational scenarios of the CST. The objective of this study was to derive best management strategies to minimise the total emissions from the integrated system.

2 METHODOLOGY

2.1 Case Study

Together with the construction of a hydroelectric power plant (HPP) the first stage of a new central storage tunnel (CST) alongside the river Mur was built to increase the storage volume in the existing drainage system from 32,000 m³ by additional 25,000 m³ (additional 91,000 m³ in the final stage). The already operated first stage of the CST (cross-section: 3.2 m width, 2.5 m height) collects and temporarily stores discharges from three CSO structures to route them either to the WWTP or directly to the river Mur (emergency CSO). Figure 1 shows an overview of the CST including all relevant facilities. To activate the storage volume of the CST, four control points (CP0 – CP3) equipped with multiple water level sensors were installed. The control points CP2 and CP3 contain a moveable weir (retractable into the ground) dividing the first stage of the CST into two storage cascades (eight movable weirs will be available in the final stage of the CST). Discharges into the river out of the overall drainage system are possible via three pathways: i) an emergency CSO of the CST at control point CP1, ii) the overflow of the CSO tank before the WWTP and iii) the outlet of the WWTP.

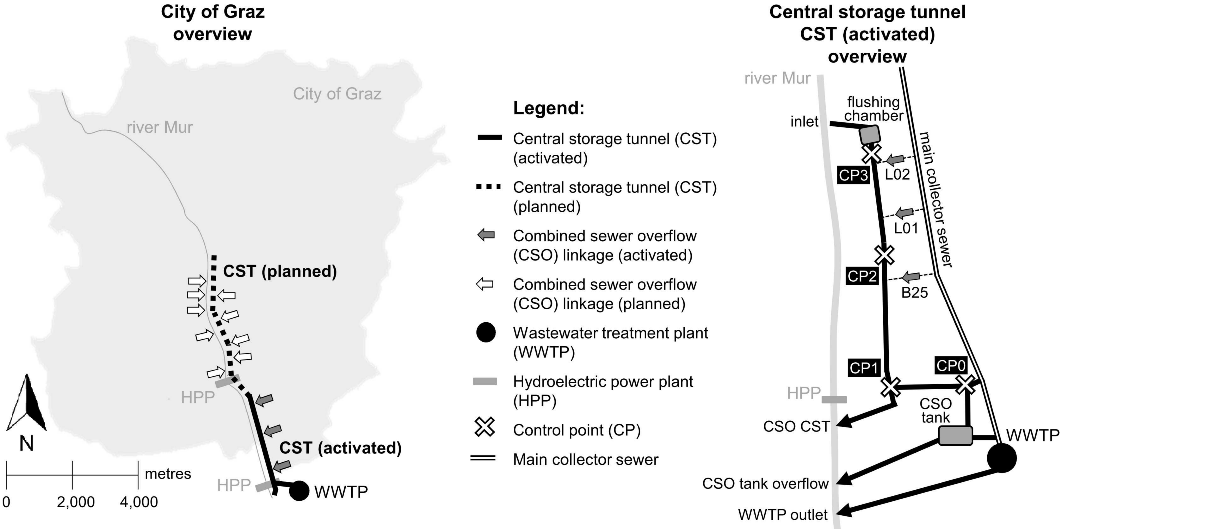

Figure 1: Left: Overview of the central storage tunnel CST to collect CSO discharges in Graz (Austria).
Right: Overview of the already operated part of the CST including control facilities and emissions pathways.

2.2 Model Setup

An integrated model was set up by creating coherent sub-models (Figure 2). To reduce model complexity and to increase simulation speed, a methodology was applied using the method of boundary relocation (Vanrolleghem et al., 2005) and three rigorous integration techniques (Muschalla et al., 2015): (i) Semantic Integration (ii) Methodological Integration, and (iii) Technical Integration. Each independent sub-model was calibrated separately and connected via sequential script-based model interfaces or by direct connections where bi-directional interaction is required to simulate system-wide control actions. Rainfall information from the city's precipitation measurement network serves as the input to a conceptual grey-box rainfall-runoff model (Breinholt et al., 2011) of the existing sewer system (KOSIM 7, Itwh, 2008). Water quality of the sum parameters chemical oxygen demand (COD), total nitrogen (N_{tot}) and total phosphorus (P_{tot}) were modelled by using a constant concentration approach including an uncertainty of ±20%. More detailed models were required for the CST and the WWTP. A detailed hydrodynamic water quality model was built to represent the CST including actuators for control purposes (SWMM5, James et al., 2010). A detailed dynamic model of the WWTP (SIMBA#, ifak, 2014) was developed based on the activated sludge model ASM3-BioP (Rieger et al., 2001).

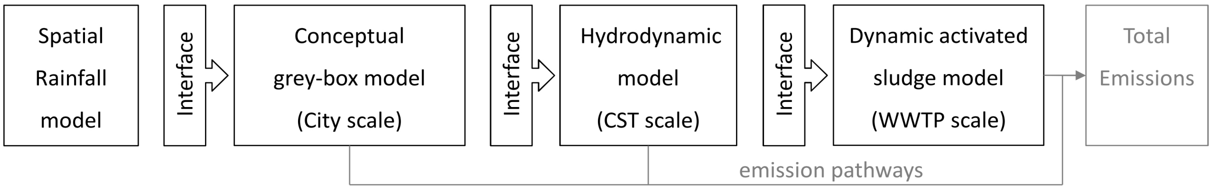

Figure 2: Schematic structure of the integrated simulation model containing model emission pathways.

The calibration and validation process of the model was conducted as a two-step approach. First, each sub-model was calibrated and validated separately against available monitoring data for dry weather and wet weather conditions (hydraulics and water quality). Second, the whole integrated model was validated against available simultaneous monitoring data.

To compare all simulation scenarios, a synthetic rainfall event of Euler Type-II was used as model input (rainfall characteristics: 1-year return period, duration of 90 min, intensity of 9.5 mm/5min, amount of 26 mm, rainfall start at midnight). This specific rainfall events ensures a total filling of the CST (first stage and final stage) and an initial hydraulic peak for the WWTP.

Three different scenarios were compared in this study. Scenario 1 "Reference" simulates no storage operation of the CST (discharged volume into the CST would be directly routed to the river Mur). Scenario 2 "CST slow" simulates a throttled emptying of the CST to the WWTP by a constant flow rate of 0.6 m^3/s. Scenario 3 "CST fast" simulates an emptying of the CST to the WWTP as fast as possible by a maximum flow rate of 3.2 m^3/s (equivalent to the design flow rate of the WWTP).

3 RESULTS AND DISCUSSION

Table 1 presents the results of the calibration and validation (results are presented in brackets) of each sub-model. The grey-box model was evaluated on annual based data showing deviations for flow rate of 0.5% (4.0%) and for water quality parameters (COD, N_{tot}, P_{tot}) of -0.8% (-7.3%), -4.2% (-9.6%) and 8.6% (13.5%) for dry weather and wet weather conditions respectively. The hydrodynamic model of the CST was evaluated on event based data (1 min interval for 12 events) with deviations for flow rate of 11% (18.5%) for dry weather and 19% (24.2%) for wet weather conditions. Because water quality parameters are only routed through the CST model, no evaluation was done in that case. The dynamic WWTP model was evaluated on daily based data (measured daily mean concentrations from the WWTP operator for a four year period) showing deviations in the WWTP effluent for water quality parameters (COD, N_{tot}, P_{tot}) of 10.2% (9.8%), 7.1% (4.4%) and 5.1% (-5.5%) for dry weather and 13.3% (12.9%), 19.4% (14.7%) and 23.6% (28.8%) for wet weather conditions. All resulting deviations are within the range of typical uncertainties for online measurements with 10% for flow rates and 25-30% for water quality parameters (Caradot et al., 2013).

Table 1: Results of sub-model calibration and validation

Relative deviations (%) of sub-model calibration and validation (in brackets)									
Type of sub-model	temporal resolution	Flow rate		COD		N_{tot}		P_{tot}	
		dry w.	wet w.	dry w.	wet w.	dry w.	wet w.	dry w.	wet w.
Grey-box model	annual base	+0.5 (+4.0)	+0.5 (+4.0)	-0.8 (-7.3)	-0.8 (-7.3)	-4.2 (-9.6)	-4.2 (-9.6)	+8.6 (+13.5)	+8.6 (+13.5)
Hydrodynamic model	event base	+11.0 (+18.5)	+19.0 (+24.2)	-	-	-	-	-	-
Dynamic activated sludge model	daily base	-	-	+10.2 (+9.8)	+13.3 (+12.9)	+7.1 (+4.4)	+19.4 (+14.7)	+5.1 (-5.5)	+23.6 (+28.8)

The calibrated and validated integrated model was applied to simulate the impact of a rainfall event on different operating scenarios of the CST on the WWTP treatment performance. The final evaluation was based on the total emissions to the river Mur including the effluent of the WWTP, the emergency CSO of the CST, and the CSO tank overflow. Exemplary, comparative simulation results of the total hydraulic and water quality emissions for the final stage of the CST are presented in Figure 3. The left part of the figure shows the discharged flow volume into the river Mur of about 370,000 m³ for all scenarios. An amount of more than 130,000 m³ is discharged in scenario 1 by the emergency CSO of the CST without treatment by the WWTP. This amount can be reduced to 30,000 m³ in scenario 2 and 3, where additional 110,000 m³ are routed to the WWTP for treatment. The right part of the figure shows the corresponding discharge load for COD for the three scenarios. The total COD emissions in scenario 1 are about 19,000 kg, where 14,000 kg are discharged by the CST and 5,000 kg are discharge by the WWTP effluent. This total COD emissions can be reduced to about 11,000 kg in scenario 2 and 3, where the COD emission by the CST can be reduced by about 45%.

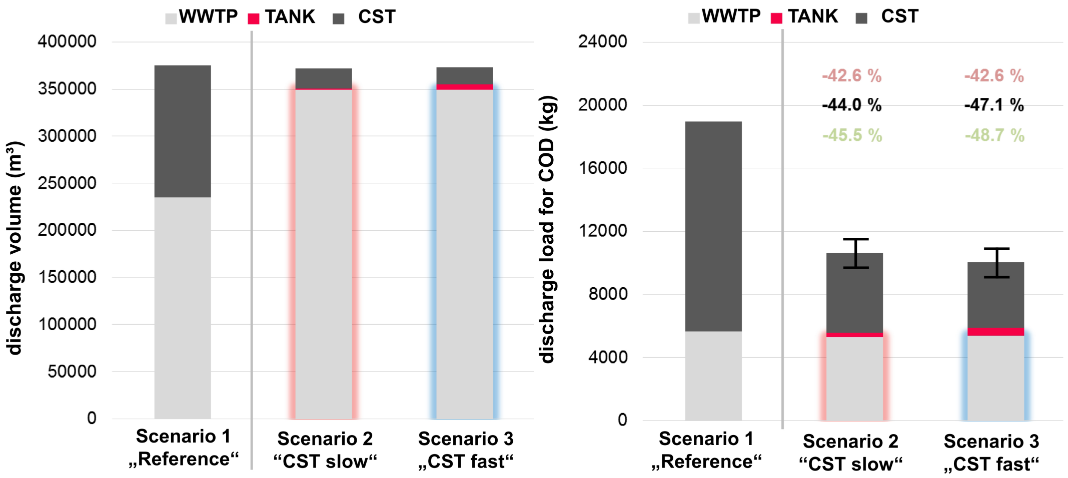

Figure 3: Left: Simulated total hydraulic emissions for the final stage of the integral system. Right: Simulated total COD emissions for the final stage of the integral system.

4 CONCLUSIONS AND OUTLOOK

An integrated simulation model (sewer system and WWTP) was built to evaluate different operating scenarios of a recently installed central storage tunnel (CST) in view of the treatment performance of the WWTP Graz (Austria) and consequently of the total emissions to the river Mur. A conceptual grey-box model was used to represent the existing sewer system and detailed models were used for the CST and the WWTP. Model integration was done by using script-based interfaces for sequential connections and full sub-model linkage when bi-directional interactions had to be considered. Model calibration was carried out for each sub-model separately. The presented exemplary results of the study showed the potential of applying management strategies in the system by a reduction of the total emissions to the river for COD of about 45%.

In a planned second phase of the study, starting in spring 2016, the existing monitoring equipment will be extended by additional hydraulic and water quality sensors at sensitive points of the integral system to gain more detailed information for model calibration and impact evaluation of potential management strategies. Therefore, a combination of conventional and surrogate measurement devices will be applied. The target of the further study is to identify best management strategies for the CST that comprise i) optimal operation strategies to minimize the total emission of the integrated system, ii) optimal operation strategies of the WWTP to deal with increasing population and increasing storage volume in the system and iii) flushing and emptying scenarios of the CST to maximize the automated sediment removal with a minimized impact on the treatment efficiency of the WWTP.

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