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SOME ASPECTS OF MANAGEMENT OF THE COMBINED SEWERAGE SYSTEM IN THE CITY OF OSIJEK

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Preliminary notes

The city of Osijek has got a combined sewerage system. It is the North sewer main, constructed at the beginning of the twentieth century that constitutes the major part of the existing sewerage system. The original concept of a sewer system has been subjected to adjustments and extended on multiple occasions The South sewer main, however, has been constructed in the time frame of the last fifty years, with the final objective of transporting wastewater to the central wastewater treatment plant, whose realisation is still pending. Great contribution to the future development is recognized in establishing the high quality mathematical model for urban drainage. Unfortunately, its application and the upgrading are not making adequate progress. Nevertheless, the ongoing activities involve spatial observations of rainfall events. The objective of this paper is to present option for system management, based on examples of a combined sewer overflow. EPA SWMM5.0 model is applied as a tool and presentation includes a drainage simulation, together with management of overflows and resulting options. The paper emphasizes the necessity for further runoff measurement inside the sewerage system.

Key words: *management, modelling, sewerage system*

Neki aspekti upravljanja mješovitim kanalizacijskim sustavom na primjeru grada Osijeka

Prethodno priopćenje

Okosnicu današnjeg mješovitog kanalizacijskog sustava grada Osijeka još uvijek čini tzv. Sjeverni kolektor izveden početkom prošlog stoljeća. Uz brojne nadogradnje sustav se prilagođava suvremenim potrebama. Iako je posljednjih pedesetak godina građen i dovršen tzv. Južni kolektor s idejom odvodnje cjelokupne otpadne vode na centralni uređaj za pročišćavanje, još uvijek se realizacija uređaja tek nagovještava. U uspostavi kvalitetnog matematičkog modela otjecanja prepoznat je velik doprinos upravljanju i budućem razvoju sustava. Nažalost, u svojoj primjeni i nadogradnji ne napreduje se predviđenim intenzitetom, ali se i dalje radi na prostornom praćenju oborinskih događaja na području grada. Cilj je ovog rada pokazati mogućnost upravljanja sustavom odvodnje i to na primjeru upravljanja kišnim rasterećenjima. Primijenjen alat je model EPA SWMM5.0 kojim se simulira otjecanja uz upravljanje preljevima te se ukazuje na mogućnosti koje iz tog proizlaze. U radu se ističe potreba nastavka mjerenja otjecanja unutar mreže.

Ključne riječi: *kanalizacijski sustav, modeliranje, upravljanje*

1 Introduction
Uvod

Development of urban centres belongs among the fundamental achievements of the civilization. One of the essential characteristics of such a development is the sewerage system. It is conditioned by topography, construction range, water needs, climate, population life style, broader social relations and other. In this context, and in addition to common factors, each environment has particularities of its own. Experiences gained in regard to each individual system may be of use when it comes to solving problems with other systems.

Presently, Osijek has some 120 000 inhabitants. The town has developed on the right bank of the Drava River, so that the sewerage system is also parallel with the river, in the downstream direction. The sewerage system basis, which is still in function and presents its most vital part, is the so called north sewer main, built at the beginning of the twentieth century, between 1903 and 1914, covering the needs of 30 000 population.

The city of Osijek has got a combined sewerage system. This urban and industrial wastewater system comprises a secondary sewer network connected to two sewer mains: the North and the (recently constructed) South sewer main. At the North sewer main, there are eight combined sewer overflows with exactly the same number of discharge points into receiving water – the Drava River (four upstream overflows operate on gravity, while the four downstream ones become active under pressure but only during the backwater effect from river into sewer network). The proper town network comprises 14 pumping stations, although the collection of wastewater from certain parts of the town would not be possible without another 6 pumping stations situated in the area of Višnjevac. Until recently, Osijek wastewater outfall was at the point of the old North sewer main, at rkm 16 + 450 Drava River [1].

The quality of the wastewater collection in the town of Osijek is inappropriate according to up-to-date standards, and the evidence for this may be found in frequent flooding of town basements, odours in certain town areas, stormwater overflows operating during dry weather and so on. Ten years ago, for the purpose of reviewing the system and improvement of its operation and management, the appropriate monitoring was set up and served as a basis for modelling of the system (MOUSE). Results of those activities have indicated certain problems, and task of this paper is to further initiate the work commenced.

This paper reflects on results of modelling of runoff in sewerage system with another tool (EPA SWMM5.0), and by use of data in regard to system operation and precipitation in the town area. The objective is to, based on examples of combined sewer overflow, present some specific possibilities of the system management. In general, it is of the utmost interest to manage a sewerage system in real time, which was introduced to the engineering practise during nineties. This approach represents a deviation from what have become traditional project designing methods and sewer system management. The aim of the real-time management is to have the best use of the sewer network retention capacity in view of control of the system overload, that is network flooding; stormwater runoff frequency and volume; anticipation of flow to the wastewater treatment plant, as well as optimization of the plant's operation (by quantity and quality). Therefore, the objective concerns the

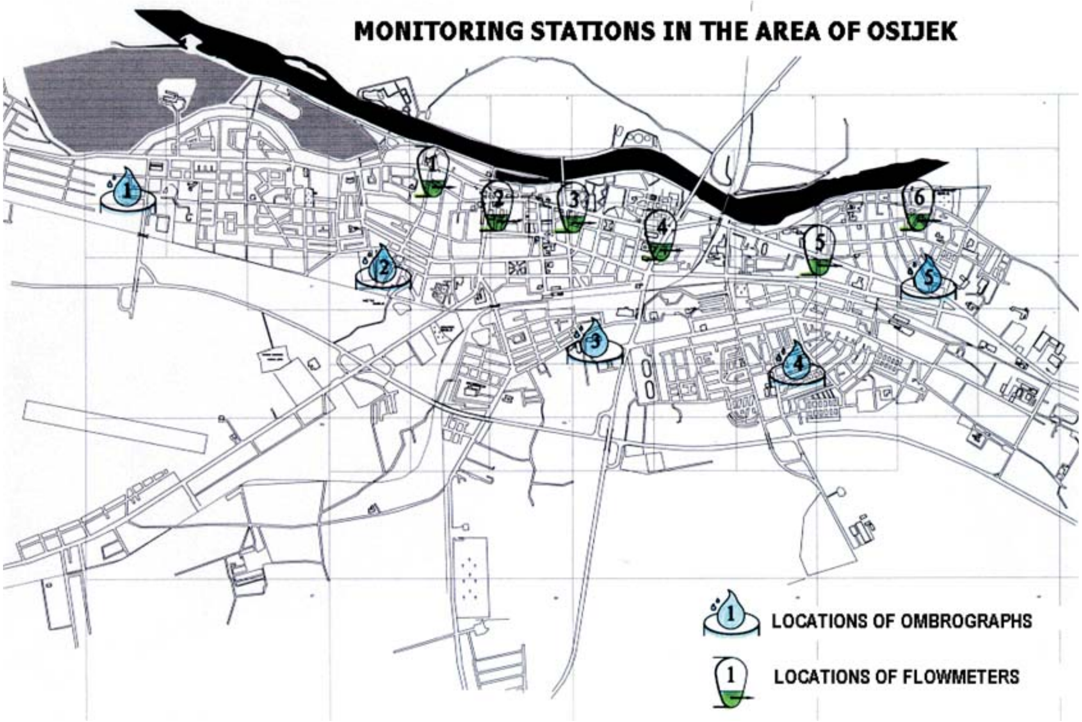

__Figure 1__ Locations of flowmeters and ombrographs in the area of Osijek
__Slika 1.__ Lokacije protokomjera i ombrografa na području grada Osijeka

prevention of the sewerage system operational problems, as well as protection of the receiving watercourse.

2 Modelling of sewer system
Modeliranje kanalizacijskog sustava

2.1 Hydrological database – the characteristics of precipitation
Hidrološka podloga – osobine lokalnih oborina

In view of development of the Osijek sewerage system, in 1998 and 1999 there was a monitoring of water levels in sewer and flows at six locations on the system. In addition, precipitation measuring instruments (ombrographs), were placed at five locations in town (Fig. 1). Possible placement locations of measuring instruments (ombrographs and flowmeters) were considered in view of surface runoff and drainage conditions, as well as particularities of the Osijek sewerage system configuration, in accordance with requirements of mathematical modelling of drainage [2]. Selected locations have been convenient in view of installation and maintenance (control, readings and safety).

In close vicinity of town the Meteorological and Hydrological Service of Croatia established and operates a meteorological station with long-term precipitation measurements and data processing. Average annual precipitation sum of 650,5 mm was recorded for the period 1961-1990; the highest average monthly precipitation was in June and amounts to 88,0 mm, while the measured daily maximum was 101,2 mm (Fig. 2).

For the purpose of real-time control of sewer system, it is necessary to have data on areal distribution of precipitation event. The analysis of precipitation events during 1999 has identified general characteristics of rain storms, as well as diversities of recorded precipitation per town area of individual precipitation events [3, 8, 9]. Figs. 3 and 4 show some of the more significant precipitation events during the observed year which, according to rain storm characteristics (rainy year, a higher rate of extreme rainfalls) was, in hydrological sense, a very interesting one.

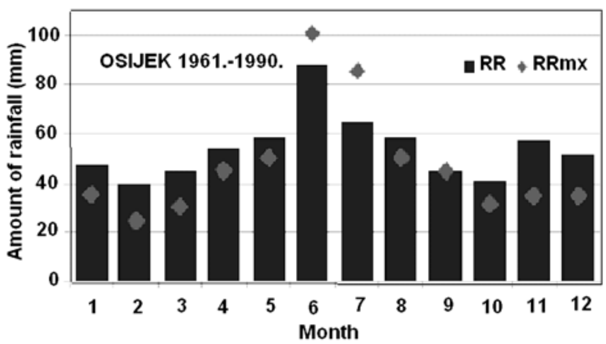

__Figure 2__ Average monthly precipitation (RR) and maximal daily precipitation (RRmx)
__Slika 2.__ Srednje mjesečne oborine (RR) i maksimalne dnevne oborine (RRmx)

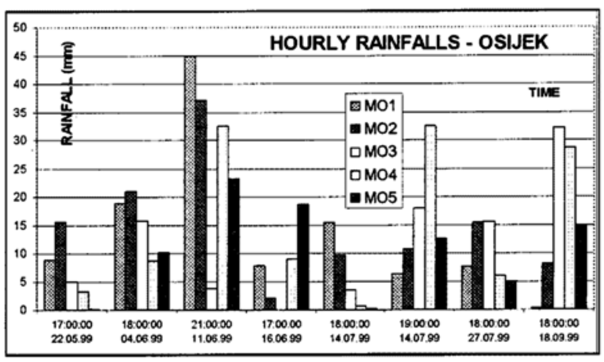

__Figure 3__ Exceptional hourly precipitation recorded during 1999 in the area of Osijek
__Slika 3.__ Izrazite satne oborine zabilježene tijekom 1999. na području Osijeka

Further analysis of precipitation recorded by ombrographs in the period from 1998 to 2002, and

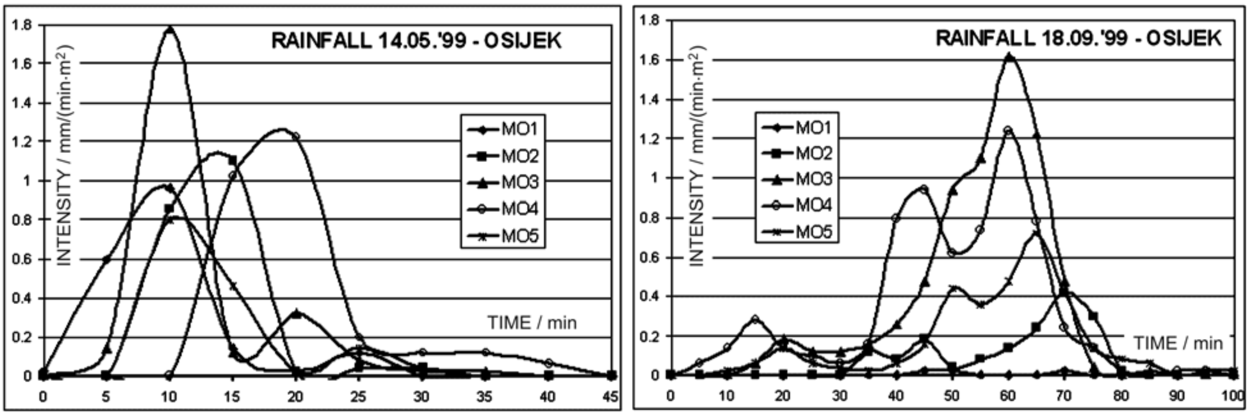

Figure 4 *Examples of recorded heavy rainfalls in Osijek* [3]
Slika 4. *Primjeri većih pljuskova i njihove registracije na pet ombrografa u Osijeku* [3]

recommendations for a design storm, has led to the idea of a typical rainstorm in the observed area of Osijek. Fig. 5 shows a design storm (detailed description may be found in literature references [5]). The rainstorm in question came as a result of the characteristics of extreme, (most often) 30 minutes long rainfall events. In this regard, in addition to recorded historical rainfalls, it has been also used for simulating runoff by modelling the Osijek sewerage system. Design storm is interesting because it is connected to a 25-year return period (for 30-minute rainfall) that also corresponds to recommended projected frequency of flooding, which, then, provides a deviation from a traditional approach [6]. Rainfalls shown in the Fig. 5, according to intensity, are of the following return periods: 8

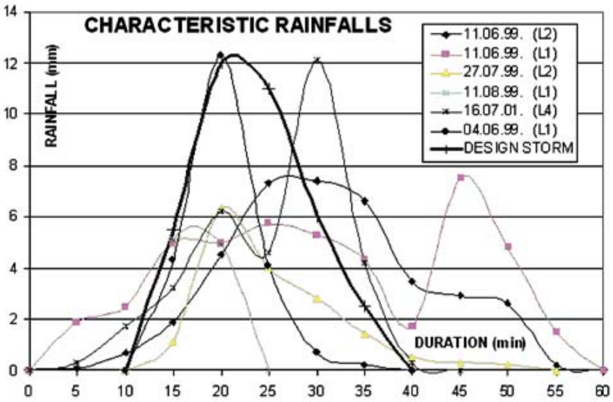

Figure 5 *Design storm and some specific (extreme) rainfalls (from 1998 to 2002) in the town of Osijek area* [5]
Slika 5. *Projektni pljusak i neke karakteristične (ekstremne) oborine (u razdoblju 1998.-2002.) na području grada Osijeka* [5]

years (rainfall on 4 June 1999); 13 years (rainfall on 11 June 1999, at station L2 and rainfall on 16 July 2001), and 14 years (rainfall on 11 June 1999, station L1).

2.2 Description of the applied mathematical model and calibration of the model

Opis primijenjenog modela i njegova kalibracija

The Storm Water Management Model - EPA SWMM5.0, applied by the US Environmental Protection Agency has been used for modelling of the town sewerage system. It is a complex dynamic model that can simulate surface runoff, water quality and the flow in the sewerage system continuously, or it can simulate particular rainfall events. This model's runoff element is based on collection of subcatchment precipitation and runoff accumulation, in addition to its pollution load. SWMM directs and transports runoff through system of conduits, channels, storage/treatment devices, pumps and regulators. SWMM tracks and explores the quality and quantity of runoff generated within each subcatchment, and the flow rate, water depth in each conduit and channel, during a simulation period, comprising different time steps. SWMM was first developed in 1971 and has undergone several upgrades since then. This model is being applied around the world, for planning, analysis and project designing in connection with wet weather runoff, combined sewer system, separate sewer system (stormwater or urban wastewater), and other drainage systems in urban areas, but has been applied in rural areas too. Applied EPA SWMM 5.0 operates in Windows and provides integrated environment

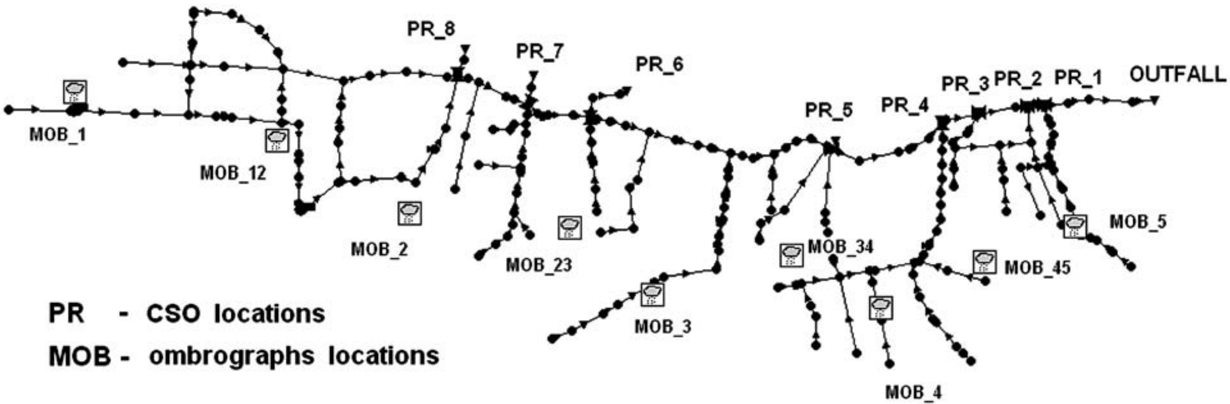

Figure 6 *Schematic overview of the Osijek sewerage system model (nodes, channels, overflows, rainfall indicators)*
Slika 6. *Shema modela kanalizacijskog sustava grada Osijeka (čvorovi, kanali, preljevi, indikatori oborina)*

for editing project input data, for hydrology and hydraulic simulation and water quality simulation, and presenting simulation results in a variety of formats. These include catchment area maps, drainage system maps, time series graphs and tables, profile plots and statistical analysis [8].

For the purpose of analysis, a quite complex (but simplified) hydraulic model of Osijek has been set, with 223 nodes, 224 channels, 116 catchment areas, 8 combined sewer overflows, 9 outfalls (8 overflows and a main outfall one). In addition, it is based on 9 (5 basic and 4 transitional)

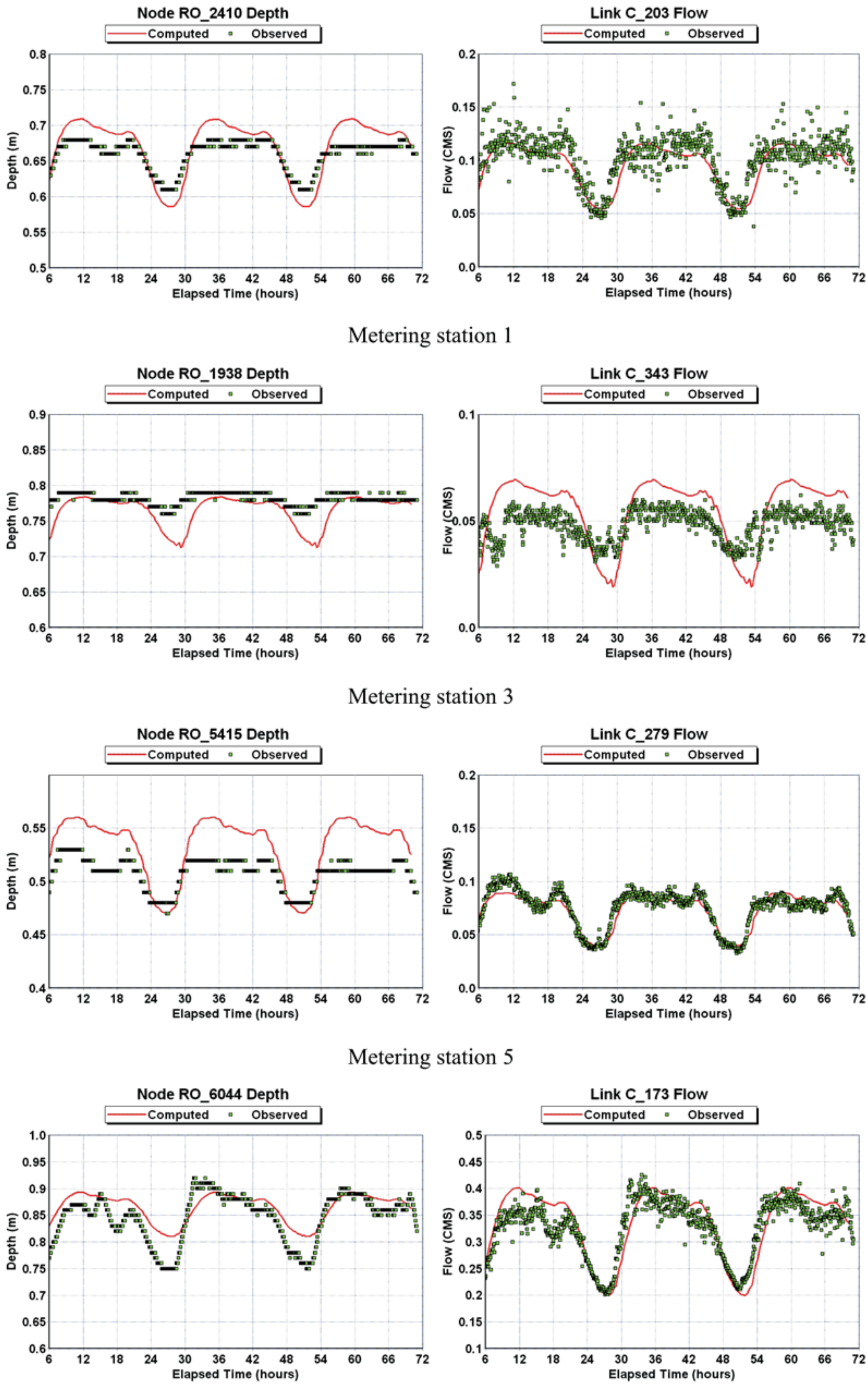

***Figure** 7 Model calibration for dry weather flow, May 1999 (metering station 1, 3, 5 and 6)*
***Slika 7.** Kalibracija modela za suhi dotok, svibanj 1999. (mjerno mjesto 1, 3, 5 i 6)*

rain metering zones (established in accordance with 5 set ombrograph stations) and 6 flow control points. The flow is simulated in EPA SWMM 5.0 environment, after the complete dynamic wave model. Fig. 6 presents the schematic overview of the hydraulic model.

When establishing the model, public utility company's data have been used – pipe diameters, slopes and relevant elevations. The sewerage system model is simplified so that the analysis does not include flow in channels of low category. Inert precipitate found at the bottom of pipes has

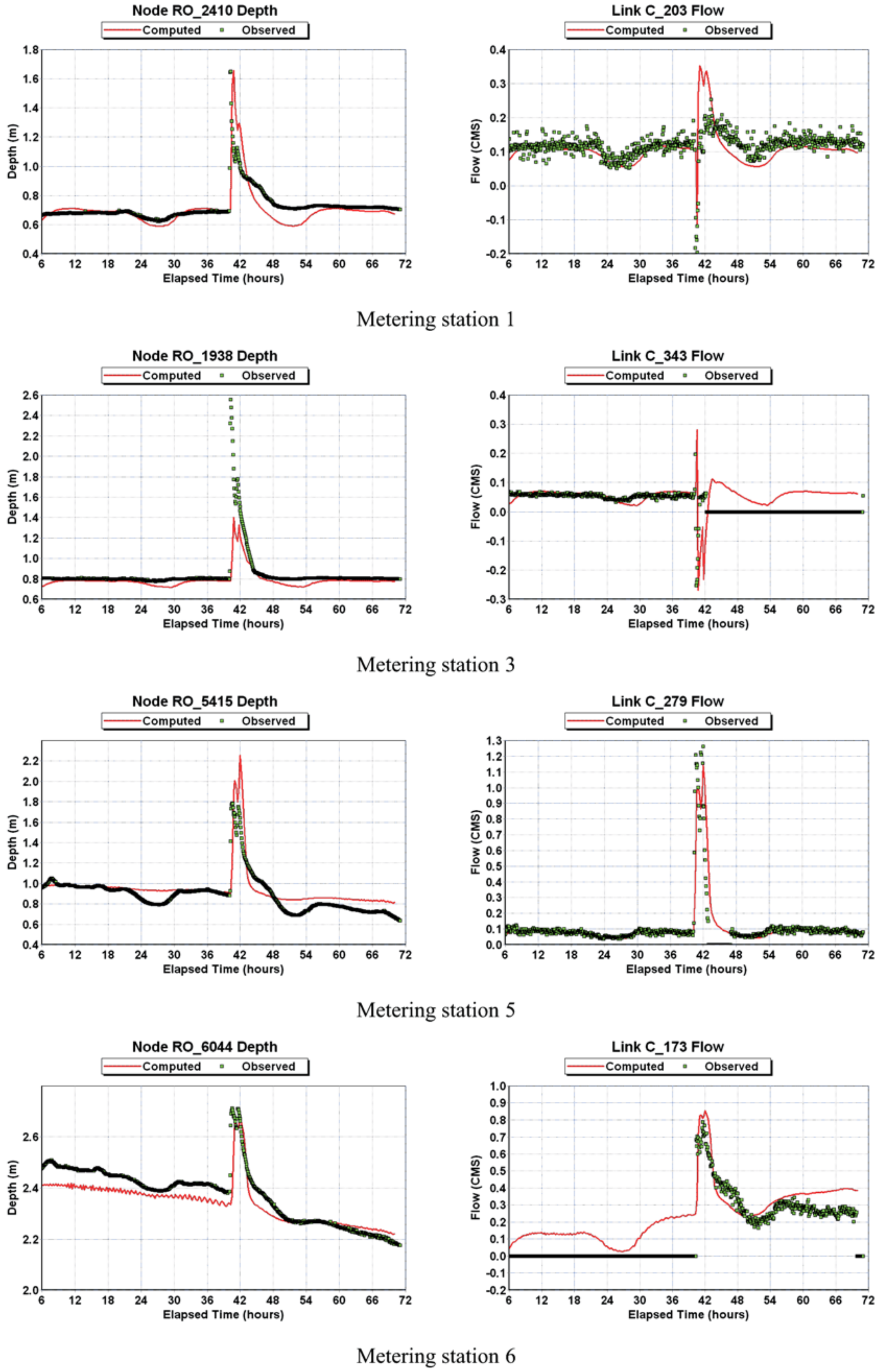

Figure 8 *Model calibration for wet weather flow, June 1999 (metering station 1, 3, 5 and 6)*
Slika 8. *Kalibracija modela za kišni dotok, lipanj 1999. (mjerno mjesto 1, 3, 5 i 6)*

been accepted in a way that slope and diameters were corrected according to values indicated, bearing in mind that in this case the immediate shorter period has been considered. Figures present results of calibration, for certain measuring stations, on dry weather (domestic and industrial wastewater) flow (03-05 May 1999) and wet weather flow for the selected precipitation event (04 June 1999) in June (Fig. 7 and Fig. 8).

The results of calibration shown in Fig. 7 and Fig. 8 indicate that the model simulations provide a very good compatibly with measured values for both, wet weather and dry weather flows (for link flow and depth in nodes). Although, in this way (with interventions in slope and diameters) calibrated model corresponds to the state of sewerage system in a certain (shorter) period of time. Calibration results would have been even better if the flow monitoring in the sewer had been conducted over a longer period.

2.3
Possibilities of combined sewer overflow control
Mogućnosti upravljanja preljevima

Stormwater overflows in a combined sewerage system represent facilities by means of which one of the most important interactions between the sewerage system and environment is achieved. Significant wastewater quantities mixed with stormwater end up in receiving bodies, without treatment, being diluted only. Nowadays, discharging such water via stormwater overflows is considered one of the most significant sources of pollution of watercourses.

There is a need and requirement for modelling a tool for characterization of a combined sewer system and impact of stormwater overflows on receiving watercourse. Although there is not always a need for analyzing this system by means of complex mathematical methods, there is still a recommendation to conduct certain stages of modelling as a support to control of stormwater overflow impacts. Sewerage system modelling has been recognized as a valuable tool that can help to analyze a sewerage system under different conditions caused by various rainfall events, as well as different impacts on water quality in cases of assessment of different control strategies and options.

Fig. 6 presents eight combined sewer overflows (four upstream are gravity ones, while four downstream are pressure ones) in the Osijek sewerage system [7, 8]. Among a number of options offered by the model, this particular selection simulates stormwater overflows in appropriate hydraulic manner.

The first established and calibrated sewers' model for the town of Osijek gives an indication of present situation. Some combined sewer overflows, and the one marked PR_6 especially, operate even during dry weather flow. In addition, it is easy to see that during equable rainfall events in town, overflows discharge water to a receiving body, the Drava River, unevenly. This opens a possibility for sewer system management with an objective of making the quantities of water at stormwater overflows even. Such a requirement has been selected for demonstration of management, since the model sewer network corresponding to particular development period does not include a wastewater treatment plant, nor has the plant been planned to be located at the system outfall, or to be designed at all, considering the current status and condition of the network. Since the combined sewer overflows take place alongside the town area, balanced overflowing would contribute to more proportional hydraulic and pollution load on a receiving body, in addition to prevention of critical pressures in the network. In order to achieve such an objective, there was a static and dynamic management of combined sewer overflows, along with a simulation of runoff at the model set.

Static management includes simple elevation of the weir crest height (by fixed upgrade). Model simulation has shown a necessary lifting of the crest (presented in Table 1) for the purpose of even operation of overflows in time of rainstorm evenly distributed across the town.

In the context of this paper, there has been a consideration of possible weir (combined sewer overflow) management strategy, or overflow management in real-time, that is dynamic management with conditions similar to static operating. Real-time management – dynamic management of overflows is possible by means of movable watergate installed at crests (Fig. 9), in line with existing overflow measurements and statically determined altitude for certain combined sewer overflows. Simulation and analysis were done for even precipitation (in this case, design storm) in the entire town, but also for rainfall event in the specific urban catchment area only. "Upstream rainfall" represents precipitation on the first ombrographs (in Fig. 6 marked as MOB_1 to MOB_23), set in the western, upstream part of the town, while there was no rainfall at other ombrographs. With "downstream precipitation" there was a simulation of rainfall at five ombrographs (in Fig. 6 marked as MOB_3 to MOB_5) located in the eastern, downstream, part of the town, while there was no rainfall at other ombrographs.

Typical CSO technology in German combined sewer systems features one central or many decentral CSO tanks with a volume of 25 to 30 m³/ha of impervious surface. Every tank has a flow control, which is limiting the flow to the WWTP to a share corresponding to the size of the catchment, typically to 2 to 4 times the peak dry weather

Table 1 *Characteristics of stormwater overflows and resulting operating values for static and dynamic control*
Tablica 1. *Karakteristike kišnih preljeva i upravljačke veličine za statičko i dinamičko upravljanje*

	INITIAL STATE			STATIC MANAGEMENT - FIXED			DINAMIC OPERATING - MOVABLE WATERGATE				
	INITIAL CHARACTERISTICS			ELEVATING	NEW CHARACTERISTIC		ELEVATING	CLOSED WATERGATE		OPENED WATERGATE	
WEIR - CSO PR $_i$	WEIR HEIGHT	HEIGHT OF WEIR OPENING	LENGHT OF WEIR	WEIR CREST	WEIR HEIGHT	HEIGHT OF WEIR OPENING	WEIR CREST	WEIR HEIGHT	HEIGHT OF WEIR OPENING	WEIR HEIGHT	HEIGHT OF WEIR OPENING
	P /m	*H* /m	m	Δ*Ps* /m	*Ps* /m	*Hs* /m	Δ*Pd* /m	*Pdc* /m	*Hdc* /m	*Pdo* /m	*Hdo* /m
PR_1	**1,76**	0,58	3,16	0,00	1,76	0,58	0,00	1,76	0,58	1,76	0,58
PR_2	**2,61**	0,50	3,00	0,00	2,61	0,50	0,00	2,61	0,50	2,61	0,50
PR_3	**1,77**	0,60	3,40	0,00	1,77	0,60	0,00	1,77	0,60	1,77	0,60
PR_4	**2,00**	0,96	3,92	**+0,25**	**2,25**	**0,71**	**+0,25**	**2,25**	**0,71**	**2,00**	**0,96**
PR_5	**1,20**	0,75	2,75	**+0,30**	**1,50**	**0,45**	**+0,30**	**1,50**	**0,45**	**1,20**	**0,75**
PR_6	**0,80**	1,05	1,50	0,00	0,80	1,05	0,00	0,80	1,05	0,80	1,05
PR_7	**0,78**	1,15	1,75	**+0,70**	**1,48**	**0,45**	**+0,70**	**1,48**	**0,45**	**0,78**	**1,15**
PR_8	**0,84**	1,15	1,46	**+0,50**	**1,34**	**0,65**	**+0,50**	**1,34**	**0,65**	**0,84**	**1,15**

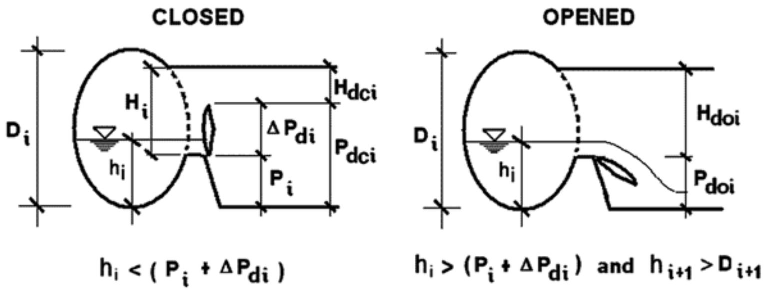

Figure 9 *Operational phases of the stormwater overflow "i", operated by a movable watergate*
Slika 9. *Operativne faze preljeva "i" upravljanog s pokretnom ustavom*

flow. CSO tanks are dimensioned by technical rules such as ATV-A 128 (1992), today frequently using numerical quantity-quality simulation 10. For comparison, there was a test if the weirs crest height P (currently existing, without flow elevation for management purposes) corresponds to those German ATV regulations. The weir crest height of PR_4 met the ATV regulations on multiple levels (even 10 times peak dry weather flow, elevated that much probably due to influence of the Drava water level). Only two CSO (PR_6 and PR_ 7) by their weir crest height did not meet the criteria. In order to meet the 4 times the peak dry weather flow criteria, they should be 20 cm higher. Since the others almost precisely corresponded to the standard (4 times the peak dry weather flow), a possible explanation may be found in the existing geometry with sediment that has changed the profile at those locations and reduced the original overflow level; however, that should be investigated by further monitoring. This particular fact has had no relevance for flow balancing via stormwater overflows subject to modeling in this paper.

For design storm of all varieties of rainfall events, there was a request for management of overflows aiming at even discharge of combined sewer overflows into a receiving body. By using a large number of simulations, it was shown that it was possible to achieve the set goal. Even discharge is achieved by operating stormwater overflows – weirs (opening/closing) towards water level limit values at certain control stations. Levels at control stations resulted from fmodel simulation, while, in practise, they should be measured directly and applied automatically. For real-time control, an automatic operating correlation has been set between water level at the node next to the managed overflow, water level by downstream overflow and the opening condition of a movable watergate at the overflow concerned. Simulation results are presented in Figures 10-12. Since operating values for static and dynamic operating are similar, the modeling results are approximate, so that only dynamic operating results have been given as representative ones.

Surely, decreasing the volume of stormwater overflows, due to elevating weir crests, results in the upstream backwater. More problematic values, i.e. nodes causing floods with larger water volumes (10 of which were recorded to last 0,09 hours, with the highest flooding volume of 0,37 hours for the smallest volume) were found around far upstream overflows (PR_8 i PR_7). Solution to

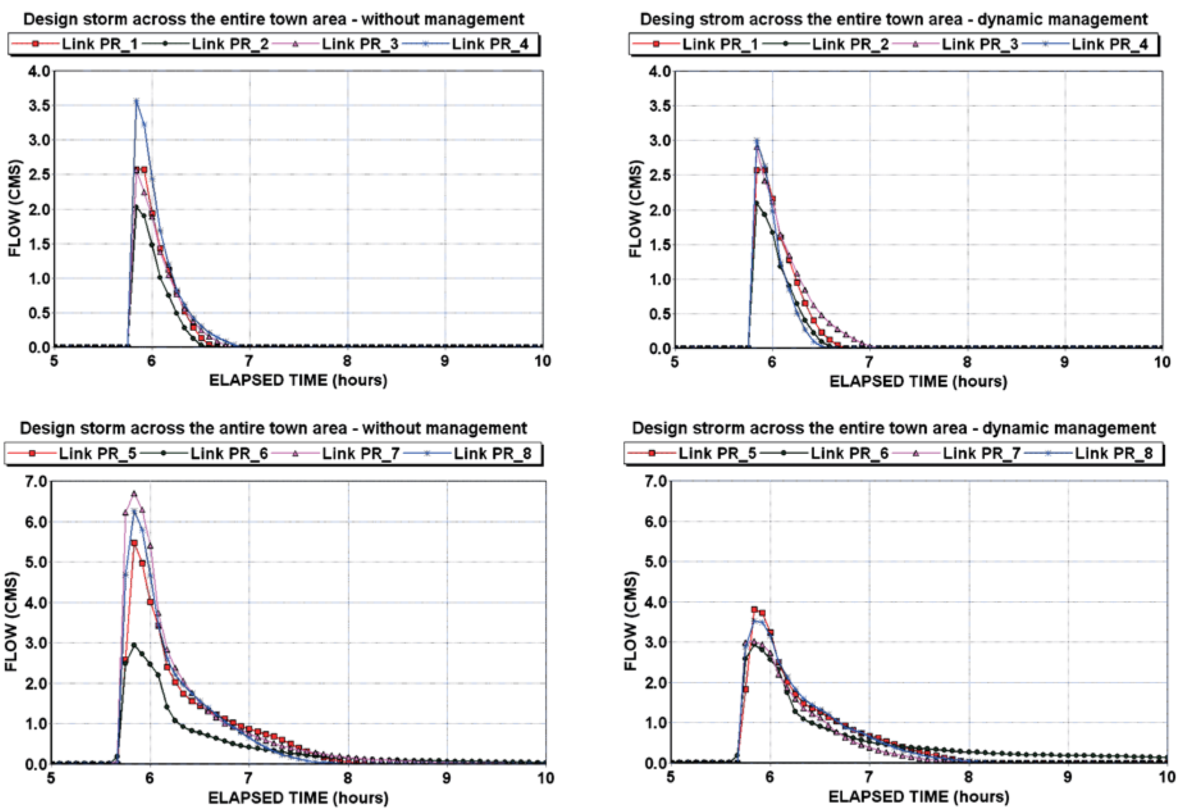

Figure 10 *Flow rate* (m^3/s) *at stormwater overflows for design storm across the town - without operating and with dynamic operating*
Slika 10. *Protok na preljevima* (m^3/s) *za projektni pljusak po cijelom gradu - bez upravljanja i s dinamičkim upravljanjem*

this problem can be, for example, re-connection of some channels; construction of a new combined sewer overflow (upstream) or a detention tank. Over the stormwater overflows, 16,5 % less water quantity is discharged into the receiving body, while at the main discharge point there is 5 % more water, and this all goes for the system operated unlike the one that is not, so the conclusion may be that some water will be retained in the sewerage system.

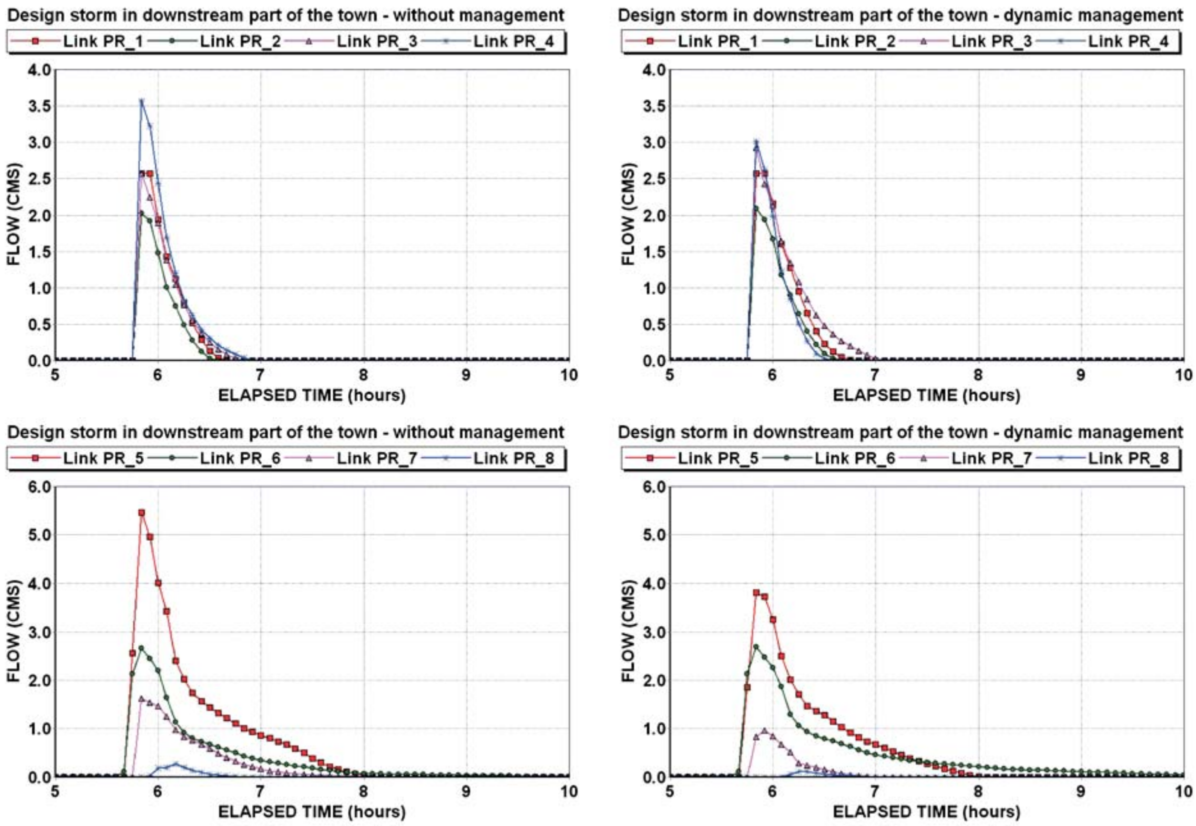

Figure 11 *Flow rate* (m³/s) *at stormwater overflows for design storm in downstream (eastern) part of the town - without and with dynamic management*
Slika 11. *Protok na preljevima* (m³/s) *za projektni pljusak u nizvodnom (istočnom) dijelu grada - bez upravljanja i s dinamičkim upravljanjem*

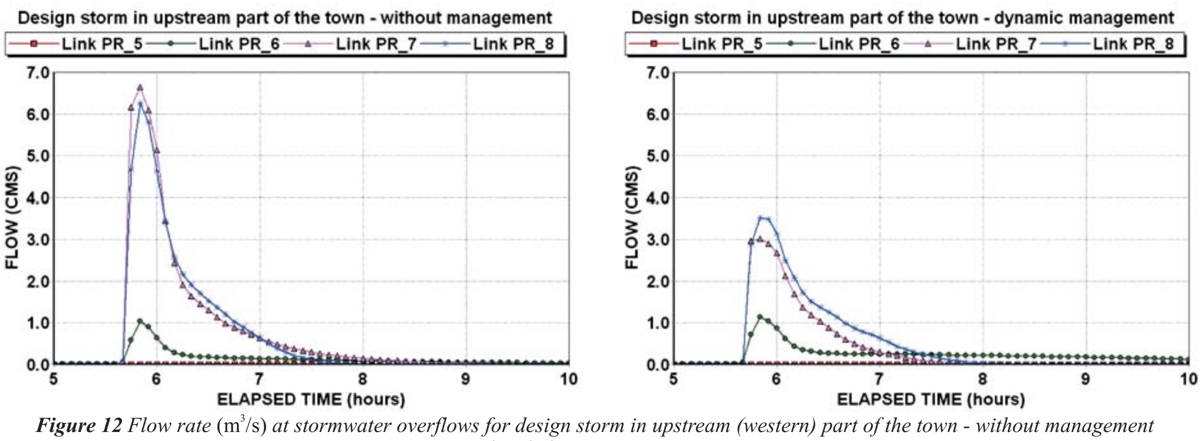

Figure 12 *Flow rate* (m³/s) *at stormwater overflows for design storm in upstream (western) part of the town - without management and with dynamic management*
Slika 12. *Protok na preljevima* (m³/s) *za projektni pljusak u uzvodnom (zapadnom) dijelu grada - bez upravljanja i s dinamičkim upravljanjem*

3 Conclusion
Zaključak

Functioning and development of the urban sewerage system is the consequence of numerous influential elements (elements of economic and social development, natural stochastic events, many local circumstances and others) that could not be considered at all or could be considered in a very limited way only.

The existing situation is described by a huge quantity of data the collection of which takes time and money, so that the actual sorting of different values for their application in modelling requires knowledge and experience.

The developed model, no matter how well calibrated, includes certain adaptations. It reflects a time limited condition of the existing system, so that its application, is limited.

By means of fine modelling and appropriate simulations, some useful information may be obtained about functioning of a system, in this case the Osijek sewerage system and the functioning of its combined sewer overflows.

Modelling supplements and extends the system management and development options, if applied adequately and on time, and gradually improved. Based on the example of adaptation of stormwater overflows, one of such options has been presented. It has to be noted that other options are possible (adaptation of parts of the sewerage system, redirection, extension, and so on).

Appropriate, recent model is applicable for management in real time. There are different operating options, but their application depends on various factors. The presented example of management of the capacity of some combined sewer overflows in accordance with the recorded water level at the closest relevant locations, indicates the simplest option for the Osijek sewer system. Management, for example, could have been based on values of recorded precipitation at established measuring stations and on simulations of the model set (including those particular results). That is of higher quality, although other options are possible, depending on particularities of the sewer system in question or on the operation criterion set. Further analysis comprising some other options will follow.

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