

Use of Historical Rainfall Series for Hydrological Modeling

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RAINFALL-RUNOFF ANALYSIS FOR THE ZAGREB SEWERAGE OPTIMISATION PROJECT

KEY - WORDS

Real-life application, Master plan, complex rainfall-runoff analyzes continuo simulation, historical rainfall data, on-line measurements, and real-time control.

ABSTRACT

The Zagreb sewerage optimization project is today one of the most comprehensive projects concerning sewage systems, undertaken in Croatia so far. The core of the project is creation of the "Master plan", but project initiates series of real world processes. The aim is to change the way sewerage system of Zagreb is being treated, operated, maintained and designed. Economical validation of short terms remedial and long-term development measures are being validated against risk criteria. Project is in coordination with other infrastructures and/or environmental protection projects underway.

The purpose of this paper is to discuss how the choice of means and ways of usage of rainfall data can influence the final result. Paper also explains the way, rainfall records and existing IDF curves were used in the project so far.

INTRODUCTION

Sewer system of the city of Zagreb serves more than one million inhabitants and large industry. The system has more than 1300 km of public sewers. No WWTP exist at the moment, but plans are set up for the nearest future for erection of a modern plant where the wastewater of Zagreb will be purified.

Sewerage system consists of two separated systems divided by the river Sava. Both systems are combined. Catchments are ranging from typical rural to predominately urban. Sewers are set up in a raster of trunks conveying water from north to south and from west to east. Sewers running from north to south are very steep in upper areas of catchments while of mild slopes at downstream part. The longest and biggest trunks convey waste water from west to east in total length of approximately 26 km. Creeks from the neighboring mountain Medvednica (also called Sljeme) north of Zagreb introduce their waters in sewer system, which is an old problem hard to solve. This is mainly since major and extremely expensive works should be appointed in order to resolve the problem. There exist no CSO's in function.

Main recipient is Sava River, which divides city, but also the sewer system as well, into two. Two separated systems are planned to be joined at the location of the future central WWTP at the Far East point on the main outlawing canal ("GOK"),

Because of its characteristics (106 years old combined system, presence of the recipient - river Sava, no CSOs in function, creeks and small rivers from the neighboring mountain Sljeme introduced in the system, huge trunks and collectors, big catchment with urbanization side effects, etc.) sewerage system of Zagreb is very much influenced on the input into the system, i.e. rainfall with all the spatial and temporal diversity, different catchments "memories" that exist in reality, etc.

In phase I, extensive analysis was performed by means of thorough mathematical modeling of the main trunks and collectors representing the present system. The aim was to recognize the pattern of the main flow characteristics within the system. GIS of the sewerage canals was initiated, as well as rainfall-runoff monitoring campaign. Calibration and verification of the model was performed on the basis of three months monitoring campaign. Analysis of all relevant model data, including available historical rainfall records was performed during phase I. Model simulations were used to analyze response of the system to different set of initial (rainfall, etc.) and boundary conditions.

In phase II modeling of relevant subsystems is being performed together with GIS of the whole system (approx. 1400 km), extreme case analyze, remedial measures and long term development plan.

The project shall in final, define how, when and why adopted concept for design of trunks and system elements shall be performed in the future. Good quality rainfall data and ways of using it are crucial for all further detailed designs and finally to the cost of the investment. Therefore special consideration is given to extensive and reliable hydrological interpretation of the problem.

Execution of the project coincides with a preparation for the WWTP for the city of Zagreb, and is in coordination with the other city plans.

The paper deals with results achieved in Phase I of the project and partly with conclusions achieved within the current phase II.

METHODOLOGY USED

Project has in the Phase I defined the present state of the system by means of the calibrated and verified mathematical model. An attempt has been made to review hydrological approaches used so far and compare it with more comprehensive approach based on continuous hydrological modeling, historical rainfall records and rainfall-runoff measuring campaign data.

All the modeling was done by means of the MOUSE package (Danish Hydraulic Institute, S.Lindberg, 1984.) including modules NAM, HD and PILOT.

AVAILABLE DATA

Variety of data was used through the project. Focus is given to relevant hydrological data.

Catchments were defined by means of existing projects, maps, and through simulation with NAM model:

Table 1. Catchments of Zagreb sewerage system

CATCHMENTS		AREA (m)
1	Left bank of the Sava river - Urbanized part	8.250
2	Mcdvcdnica rivers, entering sewerage and GOK	14.200
3	Right bank of the Sava river	1.100
	TOTAL	23.550

It was for several decades that main collectors were designed on the basis of predefined IDF curves for the city of Zagreb, and rational formula. This proved to assure adequate security for the performance of the system, for many years. Long and big trunks, no CSO's, no WWTP, recipient Sava with-autopurification effects, this all could work till the “underground system” did not start to feel changes “in the upper world”.

Increase in the number and type of area of newly connected catchments with paved surface directly contributing to the runoff heavily effected performance of the system.

It was obvious, something should be done. The project is recognized as a first step into new era of performance of the sewerage system of Zagreb.

Hydrological input is seen as a main boundary condition in definition of the system performance definition, which should be investigated and interpreted in a better way. IDF curves available for the project were published in many local projects, the most recent one in the Water Management Plan for the Zagreb catchment in 1992. 15 different IDF rains were used in the project in order to analyze effects of the wider set of rain of IDF type instead of predefined one

Available historical rainfall data for the project were mainly adopted from the National weather Service – “DHMZ”. On the area of Zagreb there were 11 rain gauges of tipping bucket type, out of which six were close enough to be

considered within the project. After data amount and quality check, it has been decided that only 3 rain gauges, i.e. Bijenik, Gric and Maksimir will be used within the project since they proved to have sufficient duration of data recordings and good quality data.

HTP curves for Zagreb IDVOGZ 1992.

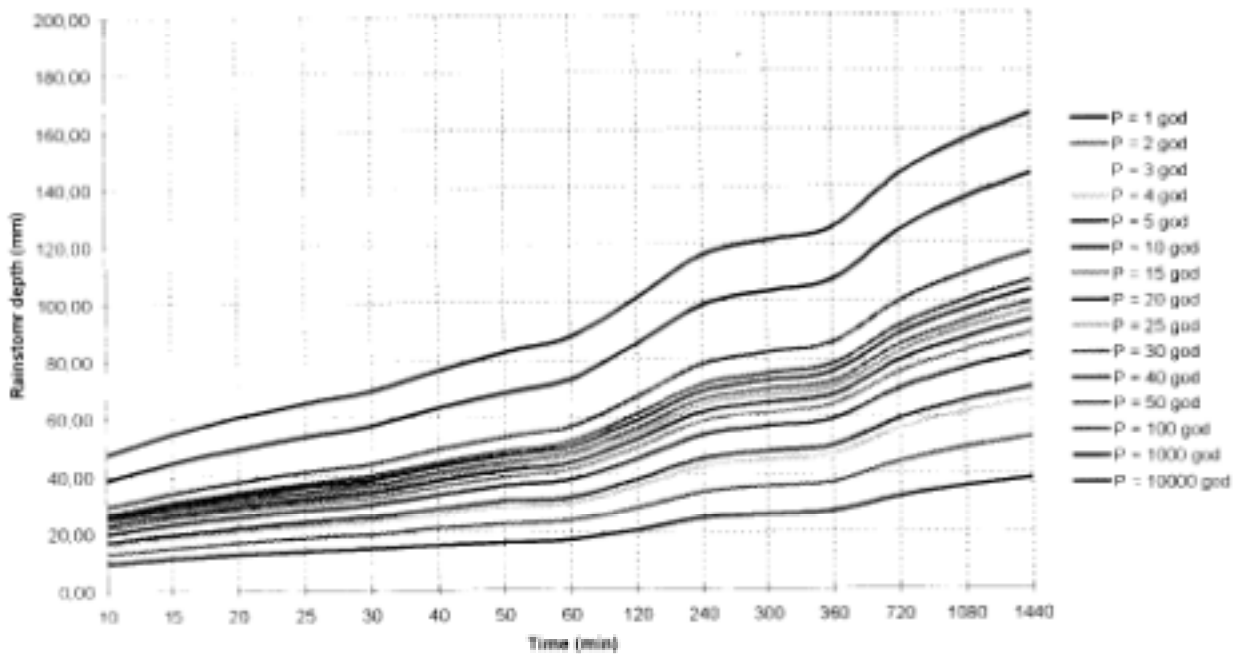


Table 2. Six rain gauges within the Zagreb area

Year/R. gauge	YEARLY AVERAGE	Bijenik	Borčec	Grič	Maksimir	Puntijar	Rim
1984	1023,0	923,0	597,8	730,7	726,2	628,5	440,1
1985	918,0	785,8	488,7	651,6	621,4	368,4	380,2
1986	896,2	822,7	564,3	825,4	736,0	539,1	419,6
1987	977,7	872,4	559,1	755,8	790,9	52,4	218,6
1988	878,2	697,3	420,6	527,9	743,6	564,5	406,0
1989	1044,4	958,1	642,7	880,1	883,4	895,0	525,9
1990	779,8	730,6	71,8	644,6	610,6	232,5	438,4

Ten historical and most severe rain events were chosen to analyze the performance of the system and compare observed/recorded information/data.

Table 3. Ten historical rain events used for HD simulation

NO.	DATE	1-HOUR PEAK RAIN VOLUME (MM)	AVERAGE RAINFALL DURATION (HOURS)	AVERAGE TOTAL RAINFALL VOLUME (MM)
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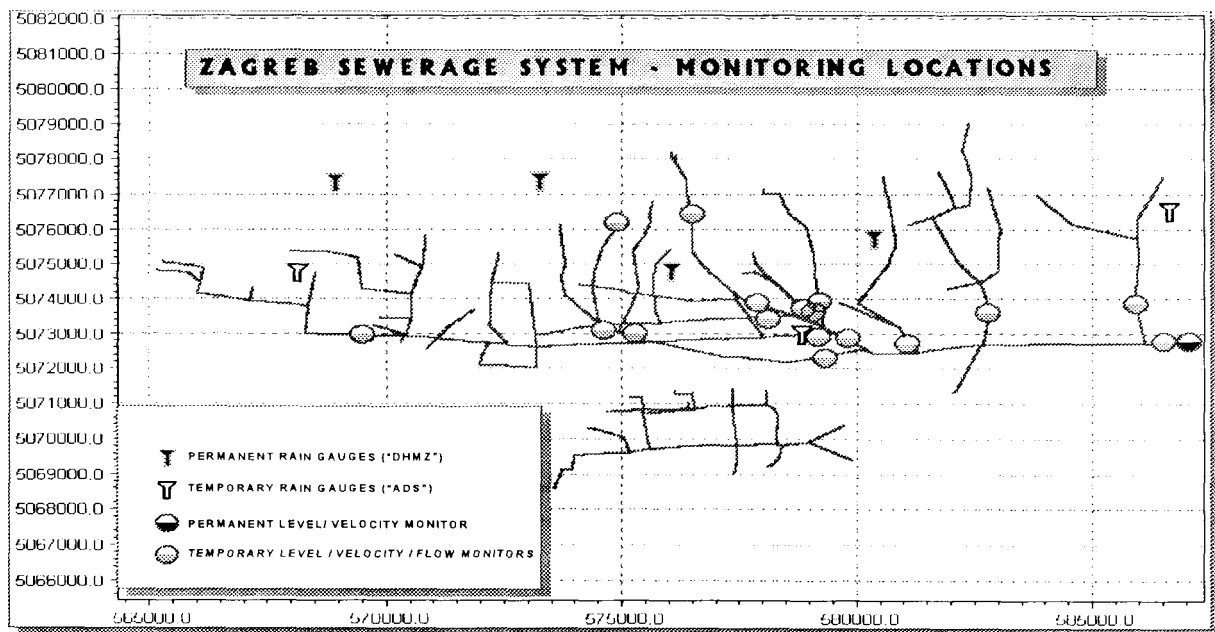
1.	03.07.1989.	27,3	10,58	96,2
2.	25.08.1989.	21,6	7,42	38,6
3.	29.05.1985.	33,7	2,05	19,8
4.	23.06.1989.	27,6	1,75	27,60
5-	08.08.1989.	39,5	10,36	65,37
6.	27.09.1987.	17,2	18,39	77,23
7.	23.09.1991.	26,5	5,81	37,37
8.	14.06.1990.	18,4	1,33	17,37
9.	14.06.1986.	31,1	6,61	40,27
10	06.08.1985.	19,1	9,22	39,07

In addition, a measuring campaign was launched aiming to get instant insight in the rainfall-runoff processes in the catchments and within the sewer system. The campaign aims also to ensure data needed for calibration and verification of the results. Initiation of a measuring campaign represents a start of a new measuring system to be conducted and performed by and for the Sewerage Department of Zagreb Water and Sewerage Company.

Table 4. Rain events from DHMZ and from measuring campaign used for calibration and verification

RAIN EVENT	2907/95	05/08/95	19/08/95	21/08/95	25/08/95
BIJENIK	48,8	16,2	21,2	19,7	13,7
BORČEC	45,4	6,6	18,8	51,9	1,4
GRIČ	58,5	14,9	22,7	20,5	10,9
MAKSIMIR	68,0	16,8	37,0	15,5	18,1
ADS RG1	94,0	36,3	56,4	22,9	15,2
ADS RG2	69,6	17,7	38,7	12,6	26,8
ADS RG3	58,2	11,6	35,2	55,9	12,7
AVERAGE	63,21	17,16	32,85	28,43	14,11

Dwg.3 monitoring locations during monitoring campaign 1995.

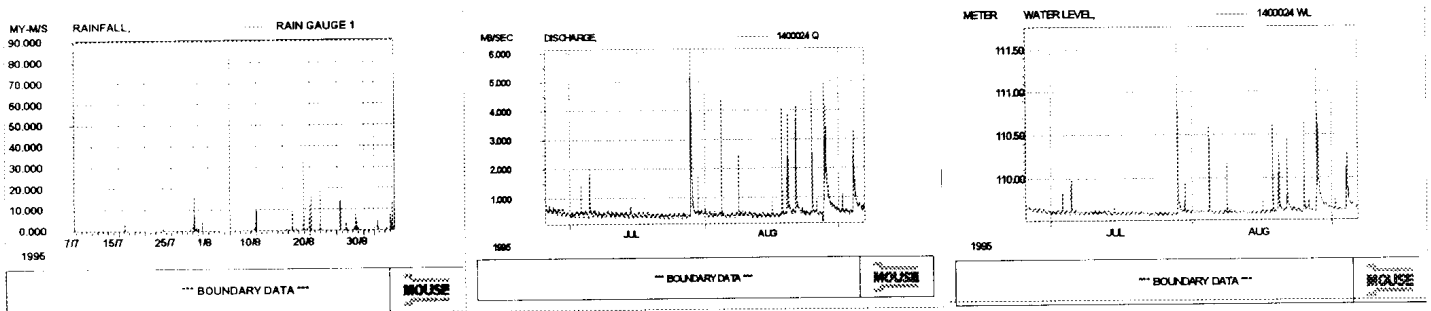


RAINFALL-RUNOFF MEASURING CAMPAIGN

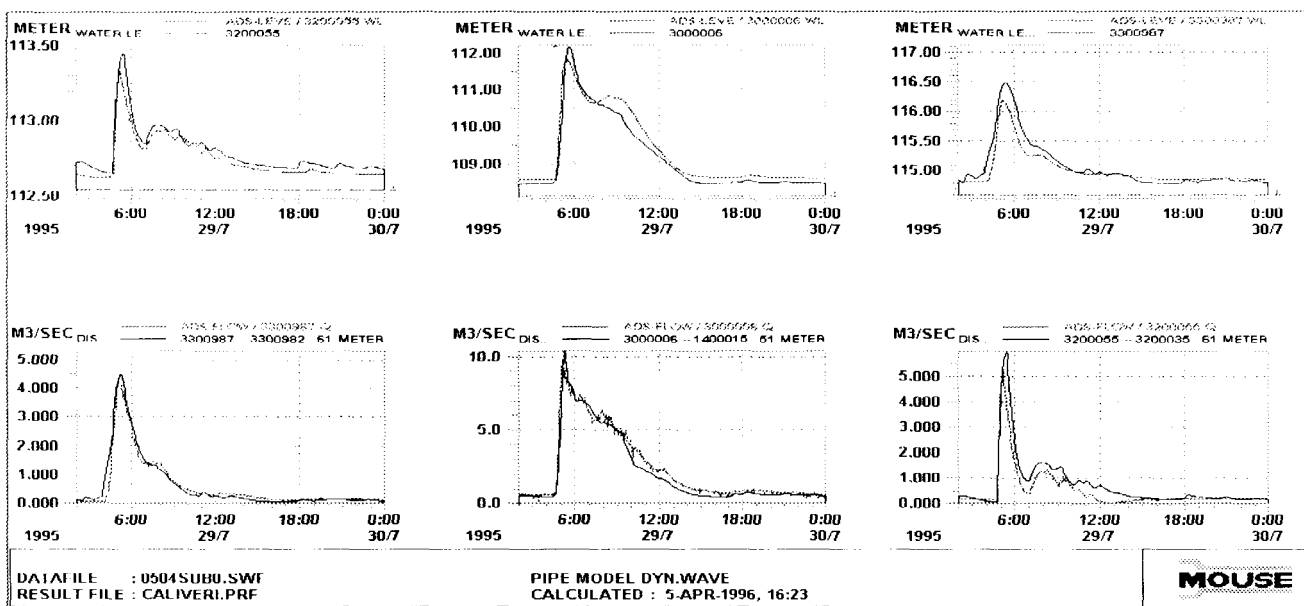
Intensive rainfall-runoff measuring campaign on 17 strategic locations on the system took place from July 1995 - October 1995. Ever since, three rain gauges and five discharge meters were set to permanent monitoring locations collecting rainfall-runoff data. In addition in 1997. Sixteen new discharge monitors were bought for new monitoring locations, which makes in total 21 discharge meters (Ultra Sonic velocity sensors, pressure sensors and Ultra Sonic level sensors) and three rain gauges.

The system will at later stage be covered by SCADA system to enable effective manipulation with waters in the system. In timethis will be extended with the real-time control system.

Dwg. 4 Data Bases of historical records and simulated results



Dwg. 5 Simulated vs. observed data in calibration process



RESULT AND DISCUSSION

In the project, comparative rainfall analysis was undertaken of both IDF synthetic / hypothetical rain events as well as historical rainfall series covering the period 1983. - 1994.

Calibration and verification was performed in order to achieve reliable model results by means of measured rainfall and subsequent run-off f data in the period of 4 months in 1995. Two main goals were set for the first phase when discussing the present state of the sewer system;

Definition of the city floods areas/maps and conveyance capabilities of the system.

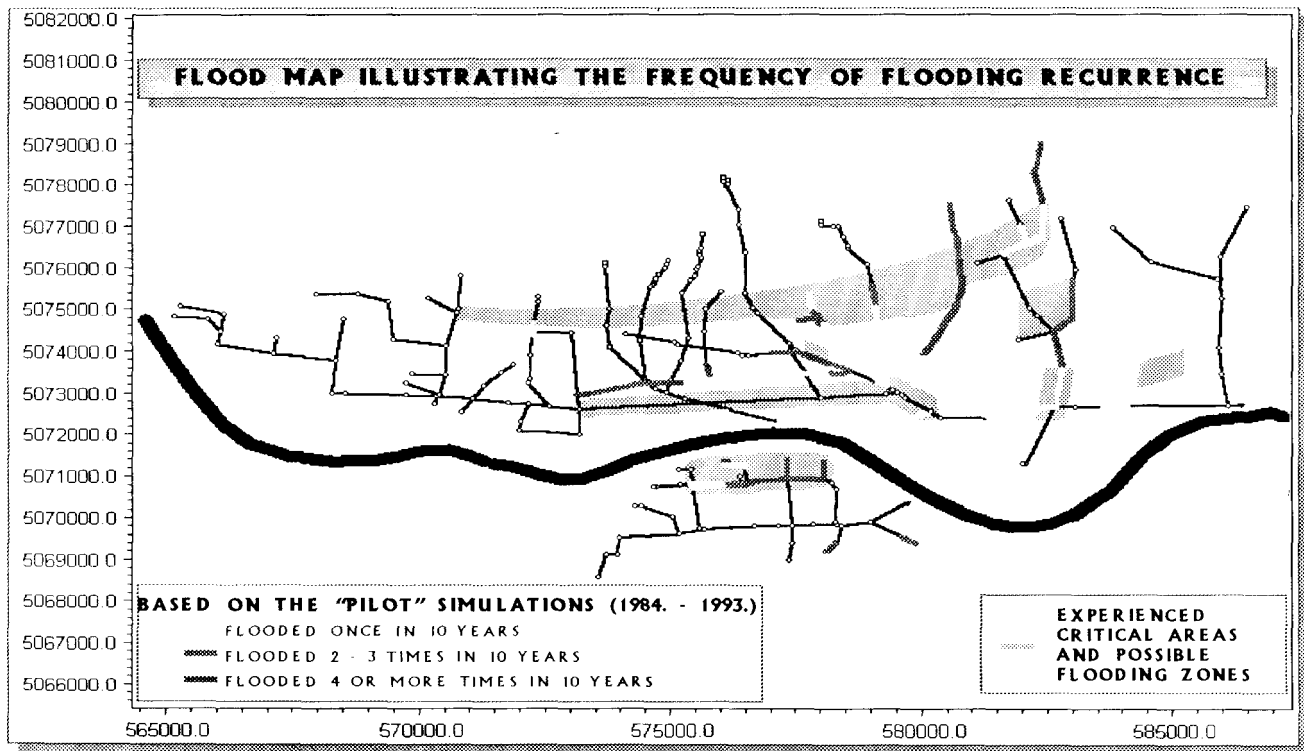
Flooding maps were generated to detect critical urban areas subject to flooding or surcharge. These were achieved by means of both IDF rains and at the later stage of the project with historical rainfall records.

Generally, activities were performed in sequence from simple methods (IDF curves, lumped hydrological models with historical records) for gaining overall data on the system and checking of alternative model results to complex methods (historical records, continuous hydrology) for final verification of results.

Such an approach proved to be adequate for majority of tasks as defined by the client. It proved that both IDF rainfall based flooding maps as well as the ones based on historical records showed high percentage of similarities as to the real world experience. Areas endangered to flooding and surcharge were more or less the same in both cases. What was not the same was occurrence of flooding. This investigation is a subject to further investigation in subsequent phases of the project.

When however analyzing in detail local conditions or sewers capacity to convey water, IDF curves proved to overdimension sewers beyond reasonable and economically acceptable profiles. This at least stands from the initial investment point of view. Such an overdosing of the sewer system resulted in the network of significant volume, capable of storing huge amounts of water. This may be beneficial from the operational point of view, but then again, where is the balance? The answer, of course, is in a long-term investment/performance cost-benefit analysis!

Dwg. 6 Flooding map



CONCLUSION

To our experience and based on project conclusions so far, one can draw following conclusions:

1. It seems a practical standpoint to use comprehensive system analysis by means of usage of historical rainfall records and adequate hydrodynamic run-off modeling, whenever more detailed insight in both hydraulic and environmental processes is required.

Apart for the Master Plan for the Sewerage system of Zagreb, such an approach will be used for definition of the close conduit profile for the main outflowing canal - GOK and design of the WWTP performance criteria. Also, this approach will be used for environmental impact assessment for the future CSO's on the Sava river and resulting influence on the groundwater recharge for the drinking water supply for the city of Zagreb.

2. Hydraulic design of the complex sewerage system based on historical rainfall records should however not be a general goal. We see it as a final step in a process, where after rough but more simple and faster Methods, initial ideas can be checked on real data, so that time for reaching final conclusion can be made Shorter.

Design of sewers within a contributing catchment shouldn't necessary follows, a complex and time

Consuming hydrological analysis, once the system's Master Plan was defined by means of such a detailed Approach.

3. For the reason that national weather services cannot, at the time, provide rain data in the real-time or at least within reasonable time, with sufficient resolution, and reasonable price, creation of the parallel measuring system, (namely rain in conjunction with run-off f) seems to be a must. Demand for on-line data of sufficient resolution will be a must as soon as a plan for the real control of the sewerage system will be in effect and WWTP operational.

4. For the reason of unification of approaches and methodologies, (also since many projects in different countries are internationally financed from just several sources, communication between investors, designers and operation engineers would be easier, etc.) a scientifically based, more detailed guidelines and recommendations, should be defined and recognized by local authorities.

Such a local project should follow similar international project.

We have just started building our models, databases, control system, experience. All in hope for environmentally friendly, economically acceptable and controllable sewer system.

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