Regional Rainfall Conference of the Balkans 2010

PROCEEDINGS

Belgrade 2010

FOREWORD

Dear Ladies and Gentlemen, colleagues and friends,

The 2nd Regional Conference has been organized in order to inform professionals from the Balkans of recent research and application results of rainfall runoff measurements, modelling and application through design procedures and projects.

The information and experience have been gained through participation at the conferences NOVATECH, that were taking place in Lyon for the last 20 years, rainfall conferences held in Switzerland that were as well, held in the last two decades, and a series of conferences organized by IRTCUD UNESCO. In addition, experience started and is based on early works during 80-ies at Balkans and worldwide.

While NOVATECH conferences cover a wide range of aspects of rainfall runoff, modelling of rainfall-runoff, quality aspects, measurements and numerous applications, what could be summarized in the movie "Water, Nature and the City" by Prof. Chocat, the modern comprehensive measurements being in progress will be presented by the president of NOVATECH and JCUSD, Jean-Luc Bertrand Krajewski. Prof. Manuela Portela will explain Portuguese results of measurements of rainfall gained as well as the impacts of climate change toward rainfall characteristics. Last but not the least, Thomas Einfalt from Lubech will present just a piece of his long term work and experience in radar applications of rainfall analysis in numerous projects worldwide. The three distinguished researches will give their Keynote lectures.

The colleagues from Rijeka, Rubinic and others have a good tradition in measurements of rainfall and runoff, which became a sample work to be copied for other professionals.

Wet weather is usually going from Croatia and Slovenia toward the South – East Balkans, and severe showers and torrent floods are occurring more frequently in the last several years. Therefore, we are in a position to have such information and analysis of heavy rainfall events, in cities and in rural areas.

At the South-Eastern part of Balkans, not much attention was paid to rainfall runoff phenomenon so far, although severe flooding has happened in the cities in Serbia, Montenegro and Bosnia.
Besides, a new Water Act in Serbia clearly defines the responsibility of protecting the flood plans by local authorities, but the storm water systems are not considered yet as "water" systems, in general.

Whether the aspects of water quality and environmental pollution will move storm water issue to a proper position, is a big question for all of us.

Thanks to all the authors and participants, colleagues, administrators and others from the institutions and companies who supported the conference, particularly the youngest ones.

On behalf of the Organizational an Scientific Committees of Regional Rainfall Conference 2010

Prof. Dr Jovan Despotovic

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RAINFALL ANALYSIS AND PREDICTION

Software for spatial interpolation of short-term rainfall in Serbia

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ABSTRACT:

For the purposes of defining the design storm of shorter duration on hydrological un-gauged catchments in Serbia, sofware for spatial interpolation of short-term rainfall was made. The software is used by user interface and consists of drop-down menus and command buttons. The software also consists of an automated spatial interpolation of daily precipitation data from 435 gauging stations and their “conversion“ to intensity of short-term rainfall, by directly using data from 30 pluviograph stations in Serbia. The software enables these intensities to be calculated at any point in the territory of the republic. There is also an option to obtain the average value in a confined space, such as hydrological un-gauged catchments, municipality, region or larger catchment area.
Key words: software, spatial interpolation, short-term rainfall

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INTRODUCTION REMARKS

In the framework of the actualization of the hydrological basis for making of Water Master Plan of Serbia, detailed analysis of pluviograph records at all stations on the territory of Serbia was carried out. Special emphasis is placed on processing the maximum intensity rain events in order to schedule of generalization of these data and allow quick calculation of probabilistic characteristics of storms of high intensity at any point in the territory of the republic. Regarding this, a software for spatial interpolation of storms of shorter duration in Serbia was developed. This software was developed as a product of research on the scientific and technological project of development TR 22005 (Ministry of Science of Serbia).

The output from this software are rainfall depth and intensities of storms for the desired duration at any point in the territory of Serbia. By using this software the average values in a confined space, such as hydrological ungauged basin, municipality, county or larger catchment areas, can be obtained.

MODEL FOR SPATIAL INTERPOLATION OF SHORT-TERM RAINFALL

Available Data

Theoretical value of maximum annual daily rainfall amount on 435 gauging stations for occurence probabilities of p = 0.1, 1, 2, 5, 10 and 50%
Theoretical values of rain depth of shorter duration at 30 pluviograph stations for different rainfall duration τ = 10, 20, 30, 60, 120, 180, 360, 720 and 1440 minutes and the probabilities of p = 0.1, 1, 2, 5, 10 and 50%.

Spatial Interpolation of Pluviograph and Gauging Stations

Each gauging station gets its ID number - IBKS
Each pluviograph station gets its ID number - IBPS
On the basis of Thiessen's polygons, an interpolation of pluviograph and gauging stsations was made.

$IBPS_i \leftrightarrow IBKS_{i,j}$

i = 1, 2, ..., 30
j = 1, 2, ..., 435

Calculation of Reduction Curves for High Intensity Storms on i-th pluviograph station

Reduction curve for high intensity storms

$$\psi^i_{\tau,p} = \frac{H^i_{\tau,p}}{H^i_{24,p}} \quad (1)$$

Reduction curve for maximum mean intensity of storms

$$\overline{\psi}^i_{\tau,p} = \frac{\psi^i_{\tau,p}}{\tau} \quad (2)$$

where:

$H^{i}_{\tau,p}$ = depth of rain on the pluviograph station for the duration of rainfall τ and the probability of occurrence p, $H^{i}_{24,p}$ = amount of rain on the pluviograph station for the24 hours duration of rain and the probability p.

Calculation of Theoretical Values of Short-Term Rainfall Depth and Intensity on Ungauged Basin for Different Probabilities of Occurence

For calculation we use the following input data: the name of the river, the corresponding catchment area, the name of the output profile and representative gauging stations – IBKSj

Identification of belonging pluviograph station - IBPS (i = 1,2 ,...., I)

Each IBKSj match any (by Thiessen-in) IBPS
Adopt one IBPS which larger number of stations IBKSj corresponds to

Calculation of the maximum amount of rain of short duration τ at each j-th gauging station for the probability of occurrence p:

$$H^{j}_{\tau,p} = \psi^{i}_{\tau,p} H^{j}_{24,p} \qquad (3)$$

where $H^{j}_{24,p}$ represents 24 hour rainfall on j-th gauging station (should be taken from input data file)

Calculation of the maximum mean intensity for different duration τ at each j-th gauging station for probability of occurrence p:

$$i^{j}_{\tau,p} = \overline{\psi}^{i}_{\tau,p} H^{j}_{24,p} \qquad (4)$$

Calculation of short duration rainfall amount τ for the probability of occurrence of p on ungauged basin:

$$H^{ns}_{\tau,p} = \frac{\sum_{j=1}^{L} H^{j}_{\tau,p}}{L} \qquad (5)$$

where L represents the number of gauging stations on ungauged catchment.

Calculation of mean maximum intensity of short duration rainfall τ for the probability of occurrence p on ungauged basin:

$$i^{ns}_{\tau,p} = \frac{\sum_{j=1}^{L} i^{j}_{\tau,p}}{L} \qquad (6)$$

Graphic and tabelar presentation of the theoretical value of the amount and intensity of storms in the function of rain duration τ and the probabilities p, $H^{nz}_{\tau,p} = f(\tau, p)$ and $I^{nz}_{\tau,p} = f(\tau, p)$, on the hydrological ungauged catchment.

GIS PROCESSING (GEOGRAPHIC INFORMATION SYSTEM)

On the basis of geographical location pluviograph stations (total 30), Thiessen's polygons for the Republic of Serbia were formed, and then the polygons were created in electronic form using the program ESRI Arc View 3.3. Figure 1 gives an overview of Thiessen's polygons for the Republic of Serbia.

Further GIS processing, creates themes which show gauging stations for which the processing was made, (a total of 435 stations) and river basins (total 184). Then, the particular sets of gauging stations which correspond to appropriate basin (Figure 2) and sets of gauging stations corresponding to the appropriate Thiessen's polygon (Figure 3) were determined.

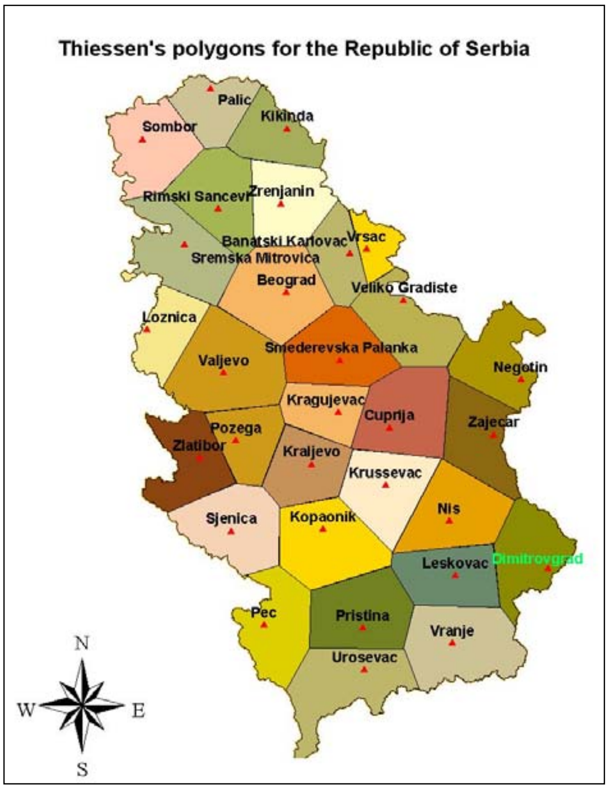

Figure 1. Thiessen's polygons for the Republic of Serbia

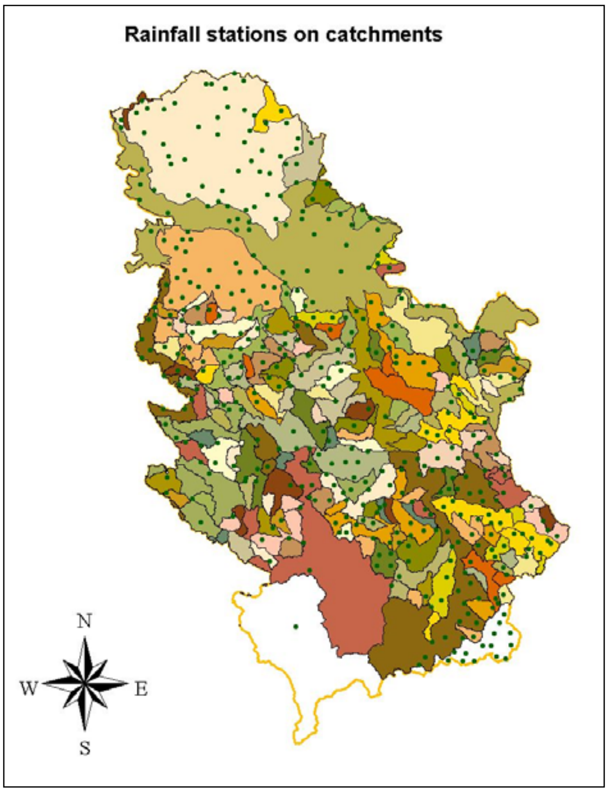

Figure 2. Gauging stations by catchment

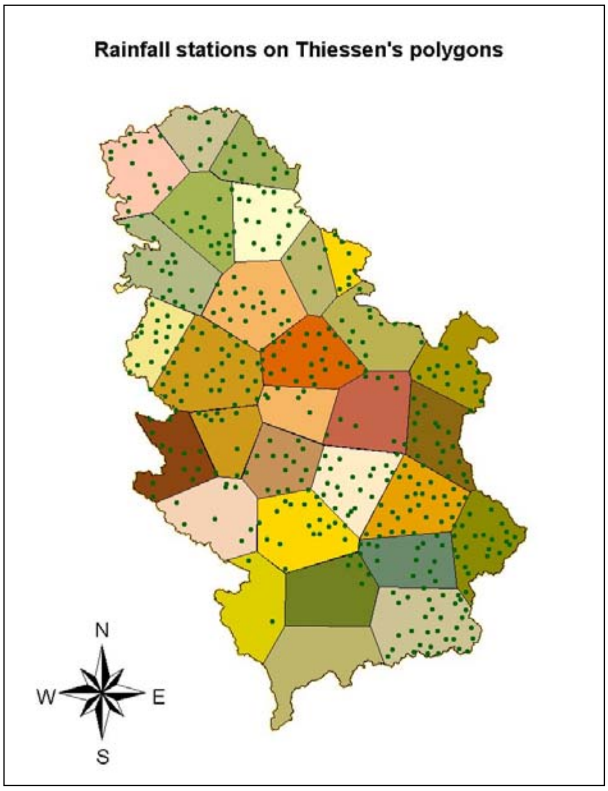

Figure 3. Rainfall gauging stations by Thiessen's polygons

COMPUTER PROGRAM FOR SPATIAL INTERPOLATION OF SHORT TERM RAINFALL

Necessary environment

A computer program was developed using Visual Basic for Applications - VBA within MS Excel files (Excel 2003). The program uses two input files: theoretical value of annual maximum daily rainfall amount on 435 stations for probabilities p = 0.1, 1, 2, 5, 10 and 50% and theoretical values of short duration rain depth on 30 pluviograph stations for different duration of rain τ = 10, 20, 30, 60, 90, 120, 180, 360, 720 and 1440 minutes and the probabilities of occurrence p = 0.1, 1, 2, 5, 10 and 50%.

User interface

The user interface consists of drop-down menus and command buttons. In the first step, from the drop-down menu we choose the catchment area, the program automatically selects rainfall station(s) at the selected basin and representative pluviograph station. Figure 4 gives an example for the selected river basin Lepenica on Kolubara. Appropriate stations are Brezdje, Mionica and Mratišići and authoritative pluviograph station is Valjevo.

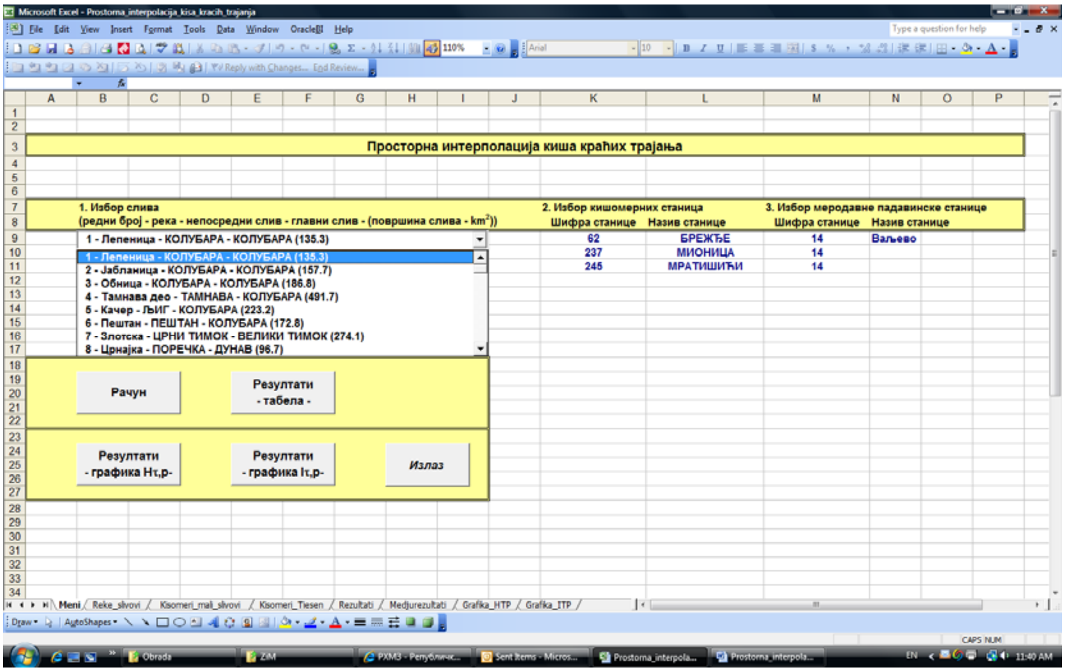

Figure 4. Computer program user interface

In the next step, by clicking on the **Calculation** button, table of calculations is shown.

Also, by clicking the Results - Standings - we get the same view.

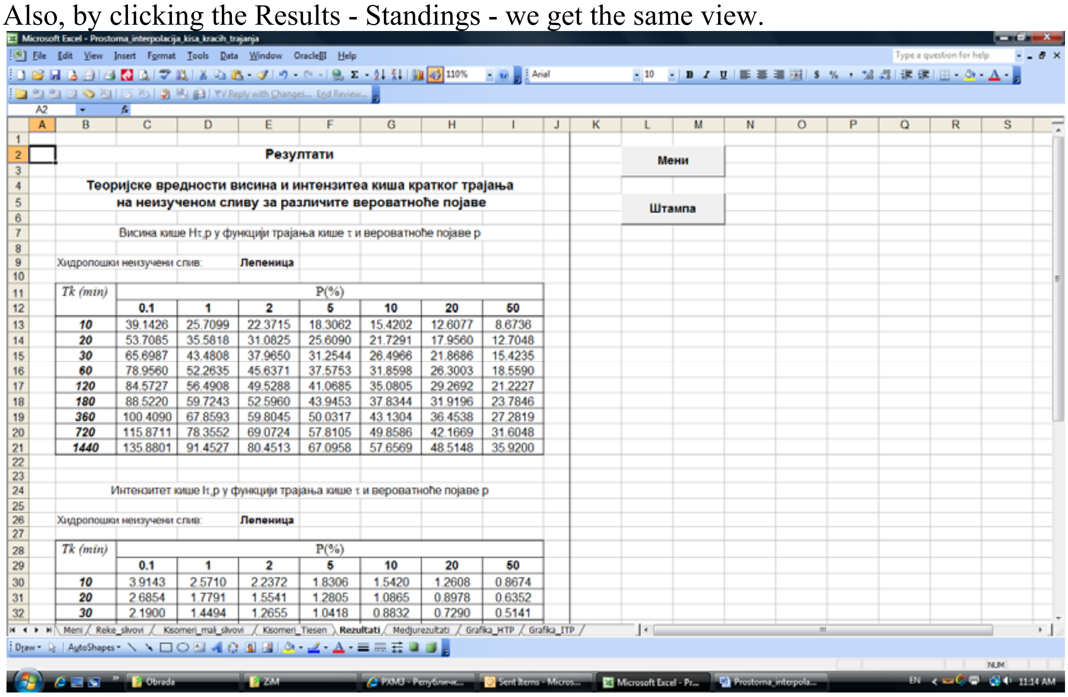

Figure 5. Computer program table calculations

By clicking the Menu button, we return to the homepage. For graphical presentation of results for rain depth H τ,p in the function of rain duration τ and probabilities p, click the button Results- H τ,p graphics - Figure 6.

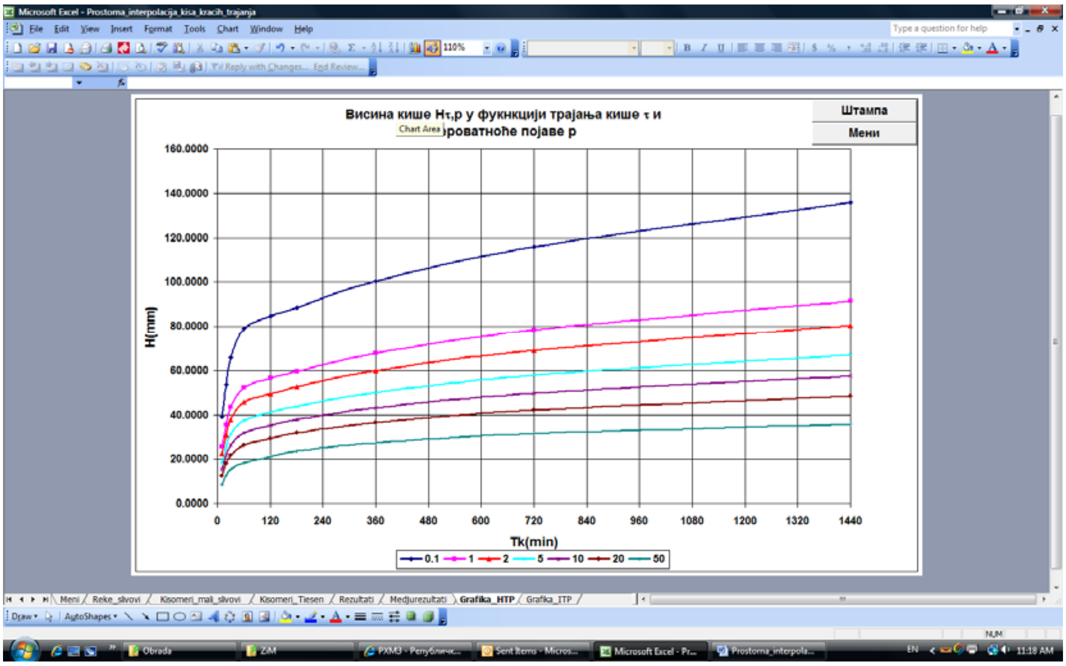

Figure 6. Graphical presentation of analysis results Hτp in the function of rainfall duration τ and probability of occcurence p

For graphical presentation of the results for the intensity of rain I τ,p in the function of rainfall τ duration and probabilities p, click the button Results - I τ,p graphics – Figure 7. In order to print these two kinds of results click the Print button.

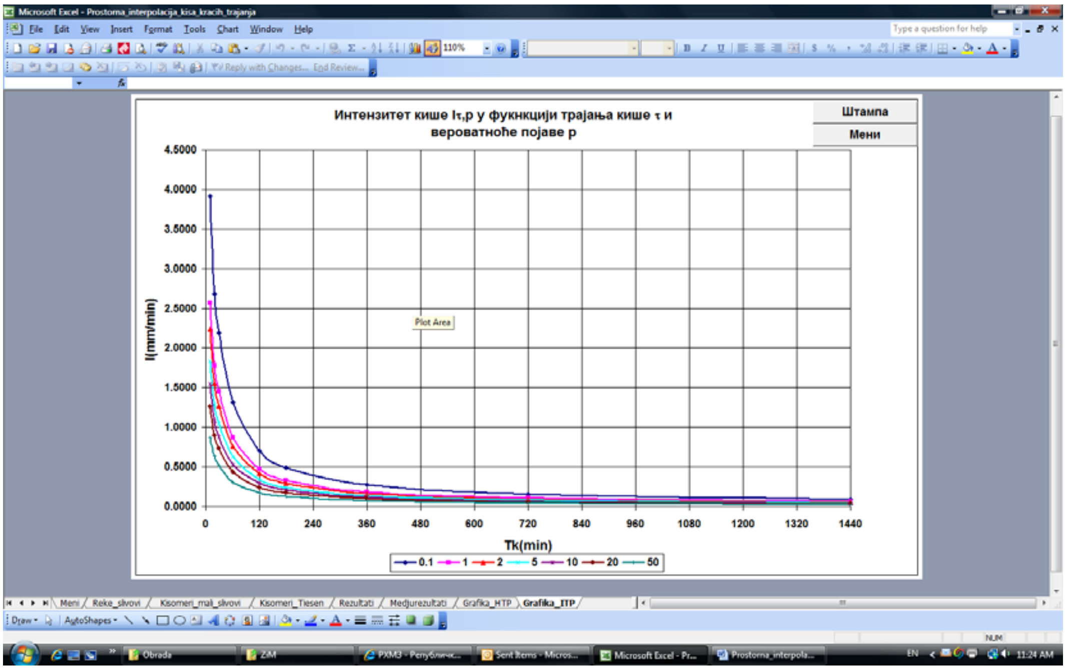

Figure 7. Graphical presentation of analysis results I τ,p in the function of rainfall duration τ and probability of occcurence p

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Results of Pluviograph Records Processing in the Republic of Serbia

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ABSTRACT: The paper outlines the results of pluviograph records processing at thirty meteorological stations of Republic Hydrometeorological Service of Serbia. Reliability of statistical parameters was assessed on all pluviograph stations which had relatively long time series. Pluviograph records were analyzed in details by calendar year, only for the recorded extreme rainfall. Rainfall intensities were calculated for different durations of 10 minutes to 1440 minutes, with the inclusion of maximum daily precipitation. In addition, processing was also done for the series of maximum daily, two-day and three-day precipitation. The practical example of the results will be illustrated for one pluviograph station.

Key words: pluviograph record, pluviograph station, rain intensity, maximum daily precipitation, two-day precipitation, three-day precipitation

INTRODUCTION REMARKS

Within the scope of upgrading of meteorological basis for the preparation of water balance of Serbia, detailed analyses of intensity of short duration of heavy rains in the entire territory of Serbia was made. The analyses encompassed all available data recorded on pluviograph stations of Republic Hydrometeorological Service of Serbia. Maximum annual storms in each calendar year were selected and analyzed in the period up to 2008. Analyses encompassed 30 pluviograph stations were selected which had a relatively satisfactory recording period of pluviograph data. Figure 1 presents an overview of the selected stations and their operation time.

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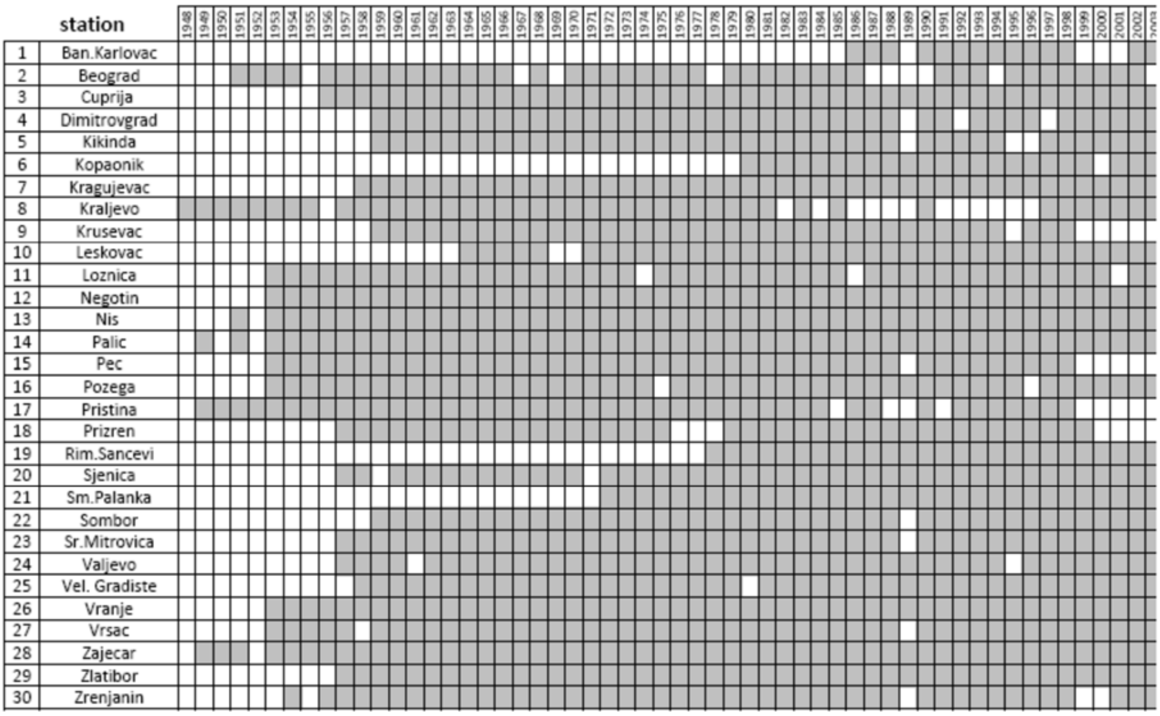

Figure 1. An overview of available pluviograph data

From Figure 1 follows that lengths of the available time series of pluviograph data are different. Basically, most of the stations have a relatively long series of records (more than 50 years). Yet, there are stations with a considerable shorter series, like Banatski Karlovac with only 17 years of observation. Interruptions in the observations appear at some stations, while data from three stations in Kosovo and Metohija were not available after 1999. It should be noted that the Hydrometeorological Service of Serbia performs continuous rainfall recording only during the warm half of the year (sometimes much longer, but not in the winter).

BASIC PROCESSING OF PLUVIOGRAPH DATA

For all considered stations basic processing of pluviograph tapes was made in the same way. First, the events with maximum amounts of rainfall during the observation period were singled out. The actual processing of pluviograph tapes was done in two ways:

For constant 1 hour period of time discretization
For moving maximum values of storms of different duration

Pluviograph tapes processing for constant periods of discretization

For all identified maximum storm events in the calendar year hyetographs were defined:

$H_{\Delta t=1hour,k,i}$

Where:
$H_{\Delta t=1hour,k,i}$ denotes amount of rainfall in 1 hour on the pluviograph station;
k- serial number of pluviograph station, k=1,2,..., 30;
i- serial number of calendar year, i = 1,2,..., N;
N-total number of calendar years on the pluviograph station.

Figure 2 illustrates the rainfall hyetograph of the maximum storm recorded in the calendar year (1962) on the pluviograph station. The cumulative curve, shown in the same figure, is defined:

$$\sum_{t=0}^{T_k} H_{\Delta t=1hour,k,i}$$

Where:

T_k – total duration of storm event
t – current time, $t = 0,1,2,\ldots T_k$

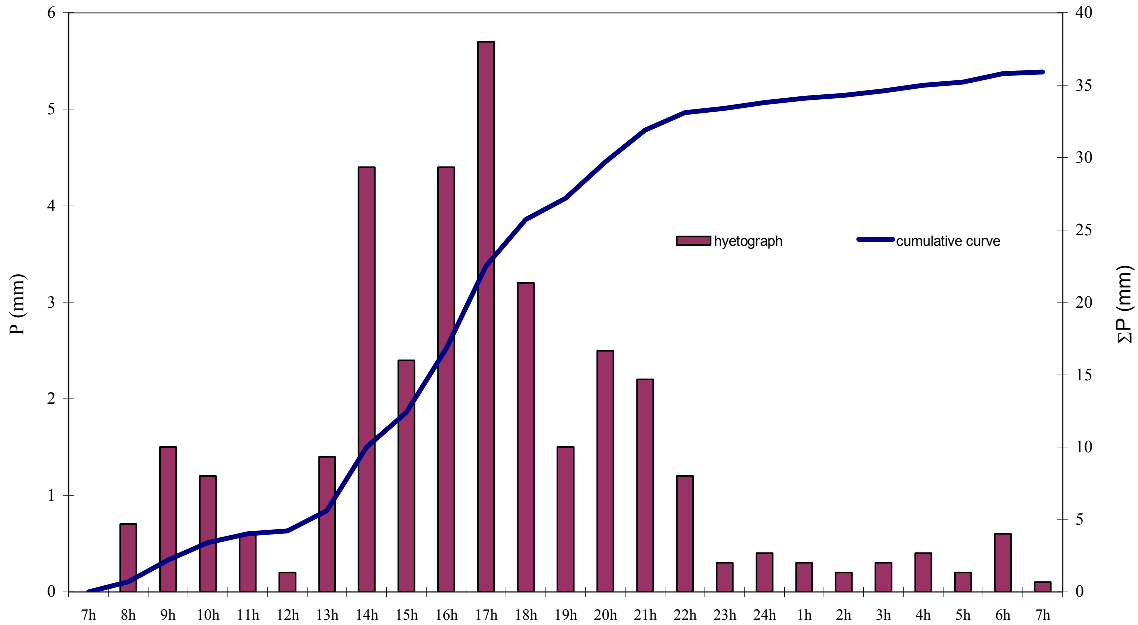

Figure 2. Hyetograph and the cumulative curve of maximum rainfall in 1962

Based on the data from cumulative curves, dimensionless curves of maximum rainfall were defined for all storm events and for all pluviograph stations in terms of depth and duration of rainfall:

$$\eta_{k,i} = \frac{H_{\Delta t=1hour,k,i}}{H_{T_k,k,i}} \quad (1)$$

$$\Theta_{k,i} = \frac{t_{k,i}}{T_{K,}k,i} \quad (2)$$

Where:
$\eta_{k,i}$ - ordinate of dimensionless curve of maximum rainfall at the considered pluviograph station
$\Theta_{k,i}$ - abscissa of dimensionless curve of maximum rainfall at the considered pluviograph station

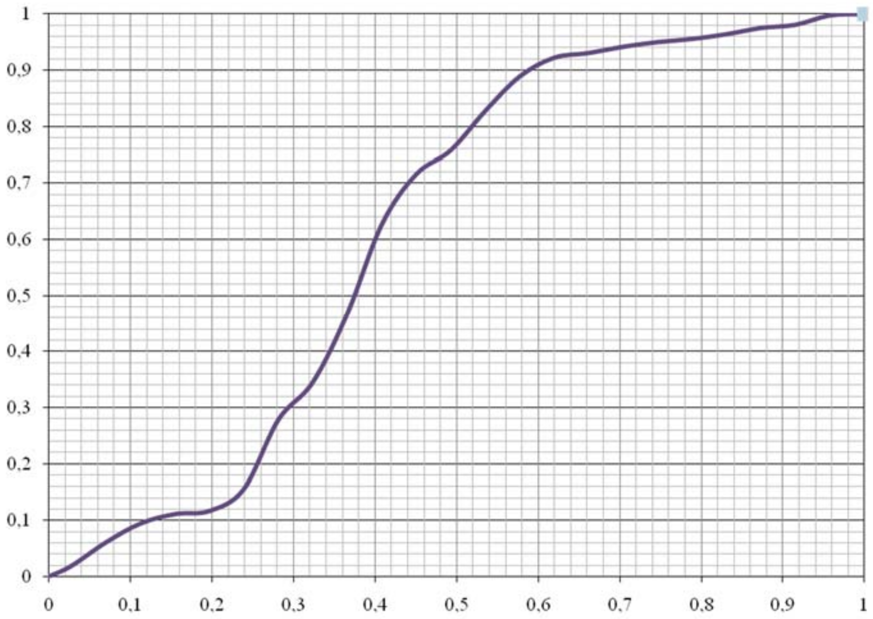

Figure 3. An example of dimensionless cumulative curve of maximum rainfall at the pluviograph station (1962).

Dimensionless cumulative curves of maximum rainfall were calculated for all rainfall events (i = 1, …, N) and all pluviograph stations (k = 1, ..., 30). Theoretical values were calculated for all (N) series of the dimensionless curves, using classical probabilistic procedure (Pearson III probability distribution), for each relative duration (θ = 0.1, 0.2,…, 1.0) for occurrence probability of 10, 20, 50 , 80 and 90 %. Figure 4 illustrates the calculated results.

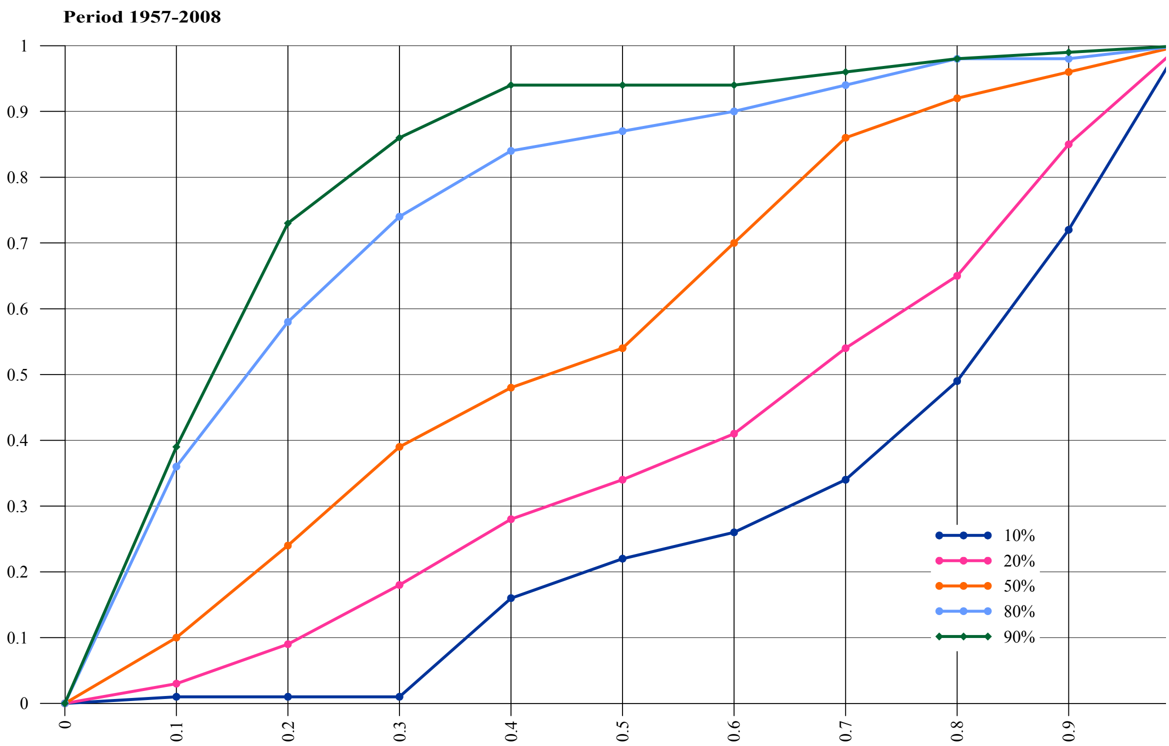

Figure 4.Dimensionless curves for different probabilities

Analyses of maximum rainfall of different duration

Identification of the maximum rainfall of short duration at all considered stations was carried out using a moving-selection procedure for the pre-selected periods of rainfall duration. The following durations of the maximum annual rainfall intensity were processed: 10, 20, 30, 60, 120, 360, 720 and 1440 minutes, as well as the recorded maxima daily rainfall during the year. In addition, one-, two- and three-days maxima were analyzed from the daily sums of precipitation**.**

Using several probabilistic models, the theoretical distribution curves were calculated for the selected rainfall duration. The statistical tests have shown that the Log-Pearson III and the Gumbel distribution laws offer best fits. Figure 5 illustrates goodness of fits of the theoretical distribution curves.

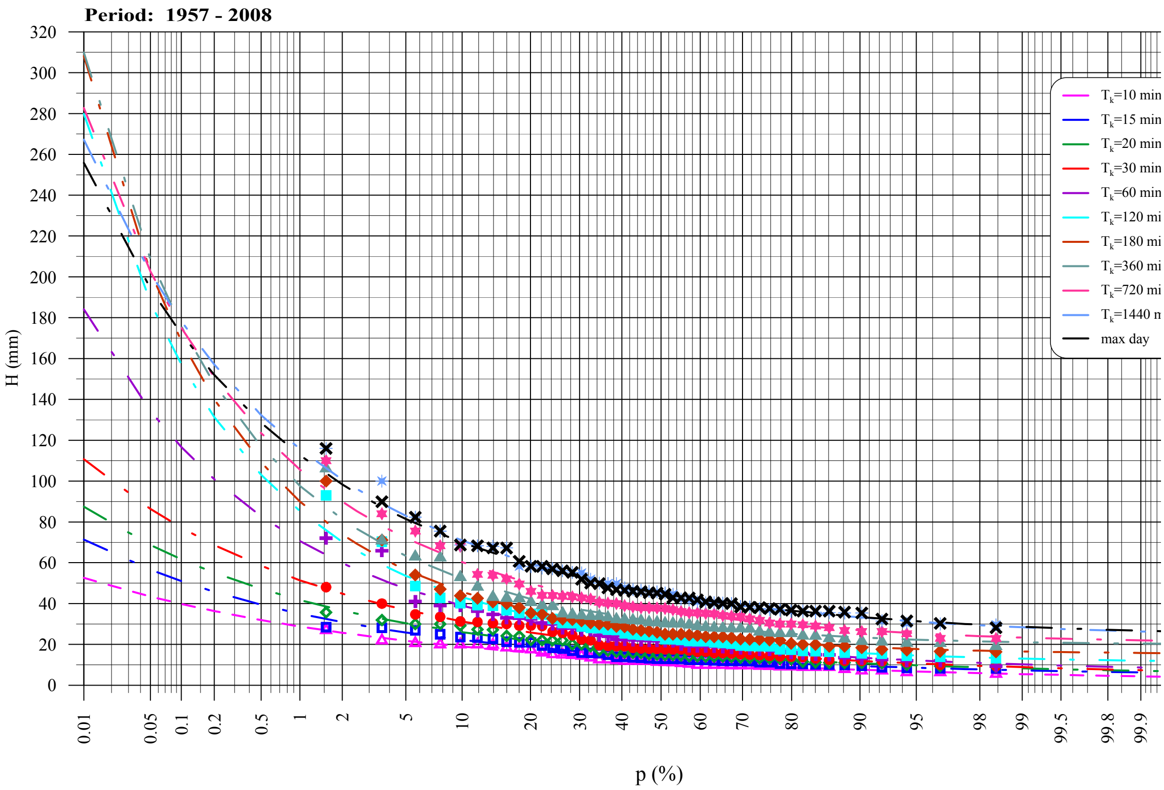

Figure 5. Exceedance probability for different rainfall durations

The dependence probabilities - rainfall depth for each analyzed duration (in literature known as the $RDDF_k$: Rainfall Depth – Duration – Frequency curves) were defined from Figure 5 for all 30 pluviograph stations. A practical example of this curve for the k-pluviograph station is shown in Figure 6.

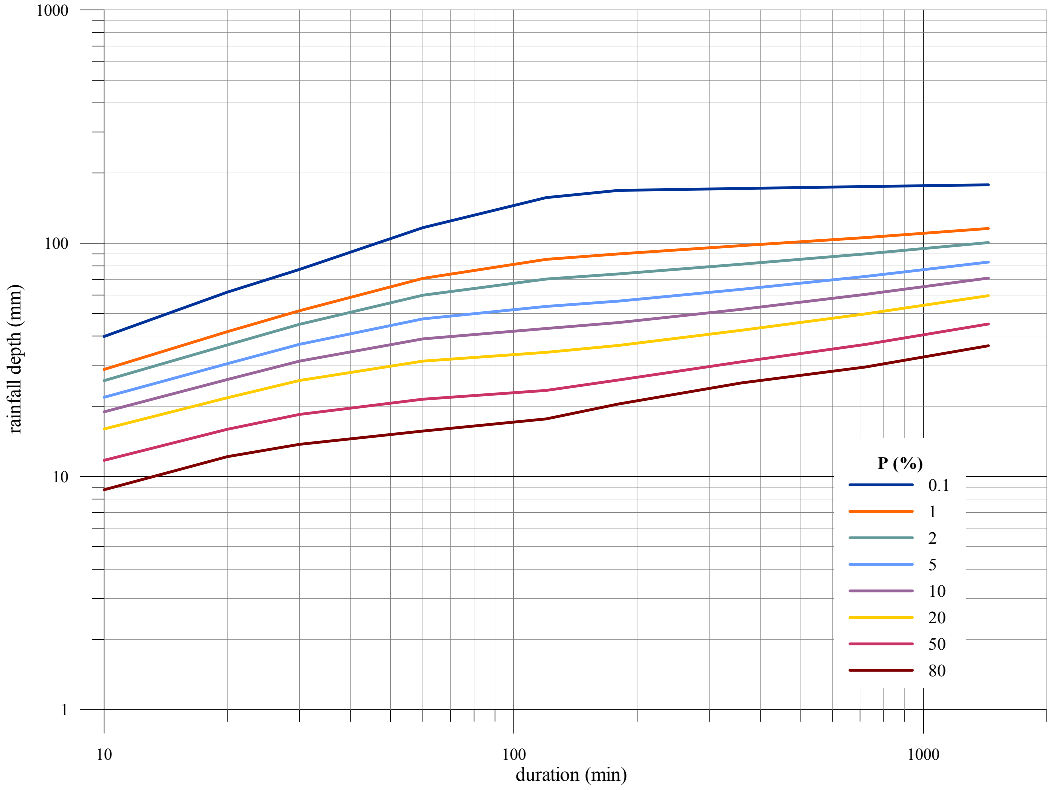

Figure 6. RDDF Curve

Corresponding curves of maximum of rainfall intensity for the selected durations and the probabilities, also known as the $\bar{i}_{\tau,p,k}$, were also calculated for all 30 pluviograph stations, as illustrated in Figure 7 for k-pluviograph station.

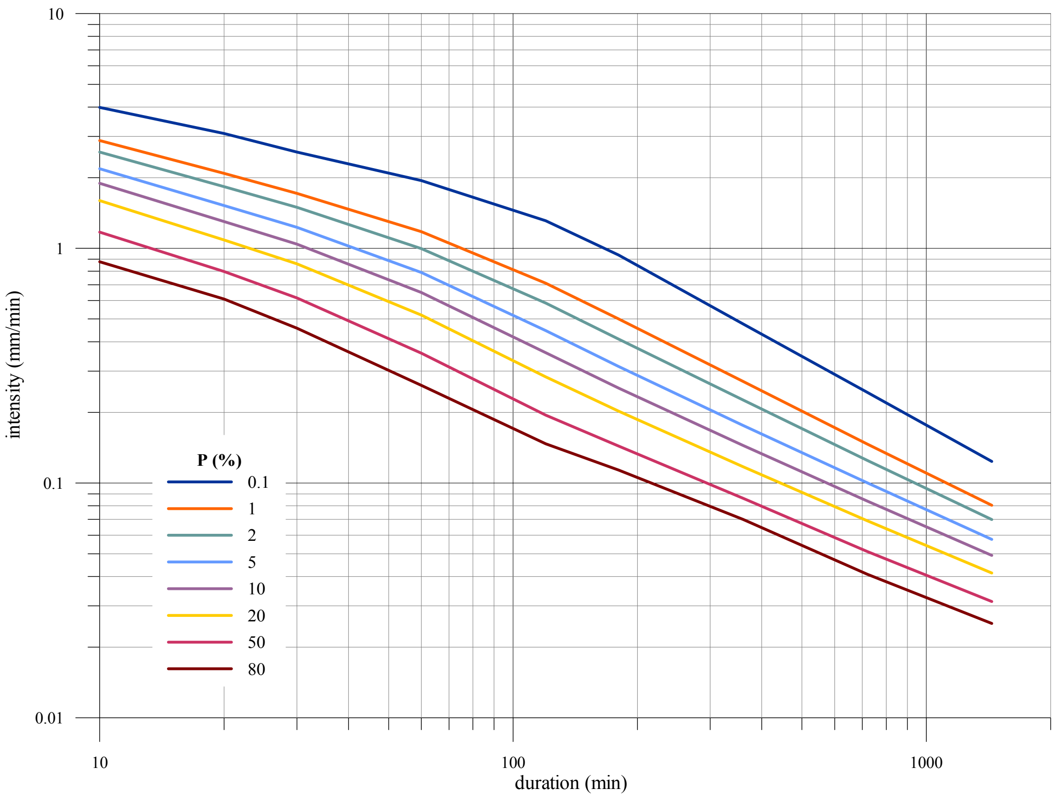

Figure 7. IDF Curve

REDUCTION CURVES OF HIGH INTENSITY RAINFALL

Reduction curves of rainfall intensity, for which the methodology was developed by G. A. Alekseev, give an opportunity to determine maximum rainfall of given duration and return period at any point. Namely, the basic idea of this approach relies on the fact that, in order to do spatial analysis of storms, one should use the data from the regular gauging network for it has greater density then the pluviograph station network. Dimensionless curves, ψ (τ), $\psi_{av}(\tau)$ and $\psi'(\tau)$, which generally represent reduction curves of maximum rainfall depth, mean and minimum intensity, are very stable, which enables their broader regionalization.

The essence of the development of reduction curves of high intensity rainfall consists of using the results of statistical analysis of time series $P\tau$ ($P\tau$ - the maximum rain depth for the selected durations τ = 10, 20, 30, 60,..., 1440 minutes), as described in section 2.2, and maximum daily rainfall on regular gauging station P_{dy} for a given return period T, i.e. exceedance probability p (%), which yields dependence:

$$\psi(\tau) = \frac{P_\tau}{P_{dy}} \qquad (3)$$

which represents the increase of rainfall depth with an enlargement of rainfall duration τ. The following equation determines the maximum mean intensity of rainfall:

$$\bar{I}_{\tau,p} = \frac{P_{\tau,p}}{\tau} = \frac{P_{dy,p}\psi_p(\tau)}{\tau} = P_{dy,p}\overline{\psi}_p(\tau) \qquad (4)$$

where dependence :

$$\overline{\psi}(\tau) = \frac{\psi(\tau)}{\tau} \qquad (5)$$

is characterized by the Law of Reduction of maximum mean rainfall intensity with increased duration of rain τ.

In hydrological practice, it is advisable to know the minimum intensity of rainfall at the end of time interval τ:

$$I_{\tau,p} = \frac{dP_{\tau,p}}{d\tau} = \frac{d\lfloor P_{dy,p}\psi_p(\tau)\rfloor}{d\psi} = P_{dy,p}\psi_p^{'}(\tau) \qquad (6)$$

This way, following curves can be defined for each pluviograph station:

Reduction curve of rainfall intensity

$$\psi_p(\tau) = \frac{P_{\tau,p}}{P_{dy,p}} \qquad (7)$$

Reduction curve of maximum mean rainfall intensity

$$\overline{\psi}_p(\tau) = \frac{\psi_p(\tau)}{\tau} = \frac{\bar{I}_{\tau,p}}{P_{dy,p}} \qquad (8)$$

Reduction curve of minimum rainfall intensity

$$\psi_p^{'}(\tau) = \frac{d\psi_p(\tau)}{d\tau} = \frac{I_{\tau,p}}{P_{dy,p}} \qquad (9)$$

All three curves which were defined above are shown on Figure 8.

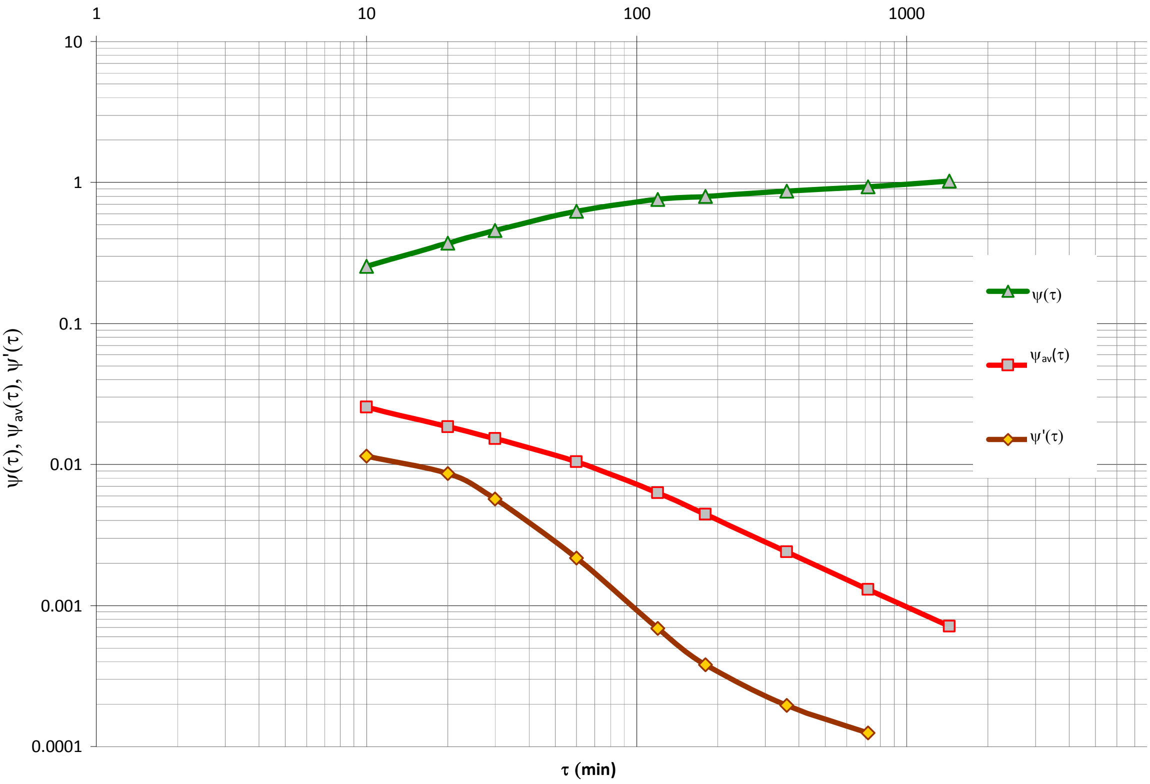

Figure 8. Reduction curve of high rainfall intensity, maximum mean rainfall intensity and minimum rainfall intensity

Research that have been carried out so far indicates that this reduction curves of high intensity (maximum depth, mean and minimum intensity), do not depend much on the exceedance probabilities of corresponding values $P_{dy,p}$ and do not vary much in space, which gives the possibility to define maximum rainfall depth, as well as mean and minimum rainfall intensity for a arbitrary location, knowing only the daily amount of rainfall.

$$P_{\tau,p} = \psi(\tau) P_{dy,p} \qquad (10)$$

$$\bar{I}_{\tau,p} = \overline{\psi}(\tau) P_{dy,p} \qquad (11)$$

$$I_{\tau,p} = \psi'(\tau) P_{dy,p} \qquad (12)$$

Finally, curves of maximum yield for heavy rainfall were defined for all duration τ at all pluviograph stations in Serbia:

$$S(\tau) = 1667\overline{\psi}(\tau) = 1667\frac{\psi(\tau)}{\tau} = 1667\frac{\bar{I}_{\tau,p}}{P_{dy,p}} \qquad (13)$$

Also, auxiliary time E is defined by formula:

$$E(\tau) = \tau\sqrt[4]{S(\tau)} \qquad (14)$$

Figure 9 shows a practical example of calculated curves of rainfall intensity for duration τ-S(τ) and auxiliary time E - S (E), for the k-pluviograph station.

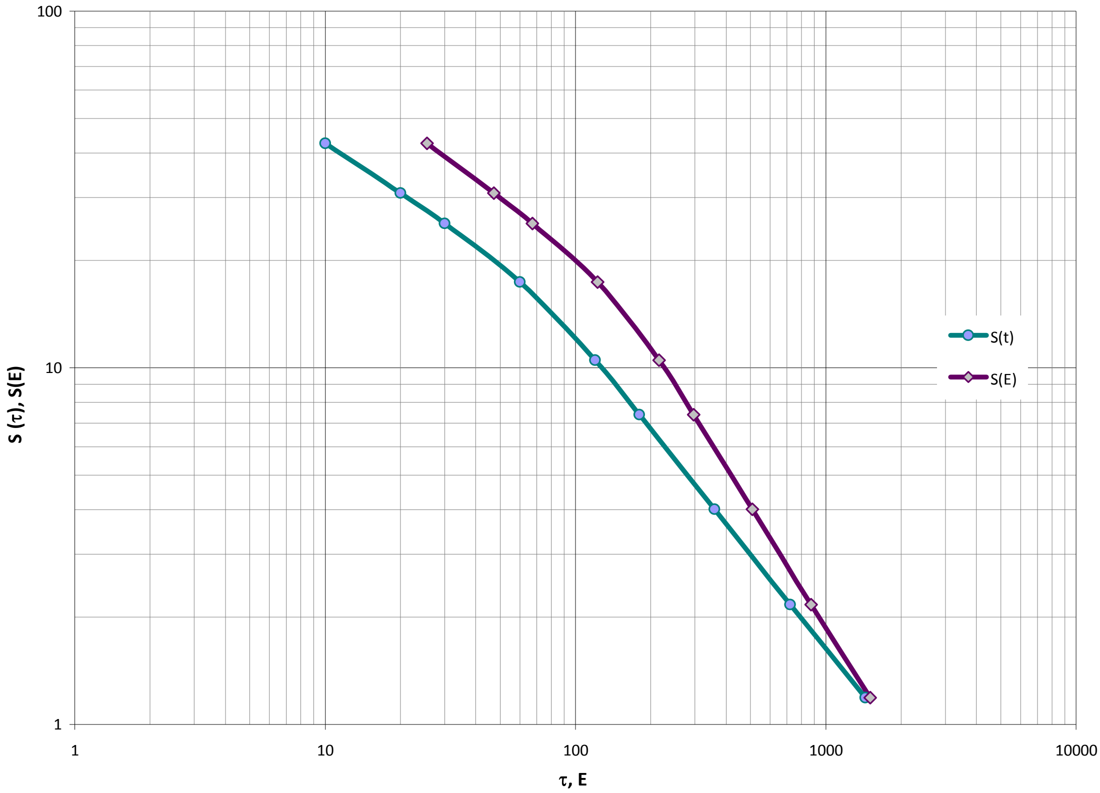

Figure 9: Calculated curves of rainfall intensity for duration τ-S(τ) and auxiliary time E - S (E), for the k-pluviograph station

CONCLUSION

Most interesting characteristics of storms were analyzed and defined for all 30 pluviograph stations in Serbia, using the maximum possible length of available data, since beginning of the station's operation until 2008. Practical examples in this paper are given only for one randomly selected k- pluviograph station, with the real values shown in the graphics. Pluviograph tapes that were processed exceeded the requirements of actualization of meteorological basis for the development of Water Management Master Plan of Serbia. Financial assistance for the implementation of the outlined detailed analyses was provided from the current research projects funded by the Ministry of Science and Technological Development of Serbia. Therefore, the results of this analysis can be found in the Institute for Development of Water Resources "Jaroslav Černi" and in the Republic Hydrometeorological Service of Serbia. They are non-public and, at this time, cannot be published, without written approval of the Ministry of Science and Technological Development of Serbia.

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Research presented in the paper is financed by the Ministry of Science and Technological Development of the Republic of Serbia as a part of scientific project no. 22005 ‘Extreme Hydrologic Features: Floods and Droughts in Serbia’.

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Heavy precipitation occurrence in Rijeka – problems, measurements and analysis over time

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ABSTRACT:
The paper deals with analysing of heavy short-term precipitation occurrence in Rijeka region. Rijeka is a town situated in the north of the Adriatic coast, the region characterized by occurrence of very heavy short-term precipitation which results in storm water drainage problems, especially in urban areas. Monitoring of short-term precipitation occurrences was started in 1954. During the past period numerous data on heavy precipitation occurrences have been registered. Maximum precipitation amounts of specific durations are practically on the upper envelope of precipitation maximum values in Croatia. As time went by, not only have the data on the registered precipitation been changing, but also the methods of their processing and so the processing results. The results of those processing are presented as standard HDF and IDF curves.

The present is characterized by the development and the application of modern approaches dealing with the storm water drainage followed with the precipitation and storm water monitoring system as one of the fundamental basics which is in the implementation stage in Rijeka and its surroundings. During 2007, a system of ten rain gauge stations was established covering the whole area of Rijeka and its surroundings with developed storm water drainage system. During 2009, the system was extended by a flow meter installed in the canal sewage network.

The paper discusses several aspects of short-term heavy precipitation data monitoring and analysis issues. The paper also deals with the variability of short-term heavy precipitation

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occurrence from two points of view – in terms of time and space. Not only were the results of the conducted HDF curve processing for Rijeka station defined by several months, but also the time and space variabilities of specific precipitation episodes characterized by heavy precipitation occurrence.

Key words: Short-term heavy precipitation, measurements, HTP curves, variability, trends
Introduction

Rijeka is a city with a relatively long tradition in the measurement and interpretation of storm features. The reason is that this is an area which is characterized by very pronounced precipitation intensities, and thus the problems of storm water drainage, particularly due to the fact that most of the municipal sewage system (85%) is mixed type. Expansion of the city caused spread of storm water drainage system, but not always in an appropriate way and which are favored by the fact that in practice often the relevant information containing background of the characteristics of precipitation weren't applied even when they existed. Joining some major urban facilities, such as drainage of city's bypass, in the city's sewage system highlighted the current problems of storm drainage in the city of Rijeka. They have greatly intensified the need for the development of contemporary approaches to the problems of storm drains, which include appropriate monitoring and analysis of precipitation data, as well as runoff data.

First rain gauge monitoring at the meteorological station Rijeka were established in the organization of the National Meteorological and hydrological institute 1954, and there are still in use. During 2006. Rijeka Water and Sewerage Company has established an additional monitoring of precipitation over a dozen internal rain gauge stations located throughout the city and suburbs of urban areas (Figure 1) on which are organized storm water drainage systems. The present paper, which is a synthesis of several previous works, contains some basic features of phenomena of current heavy precipitation in Rijeka's area, analyzed based on data from these stations, and discussions was conducted about more practical problems associated with monitoring and interpretation of precipitation data.

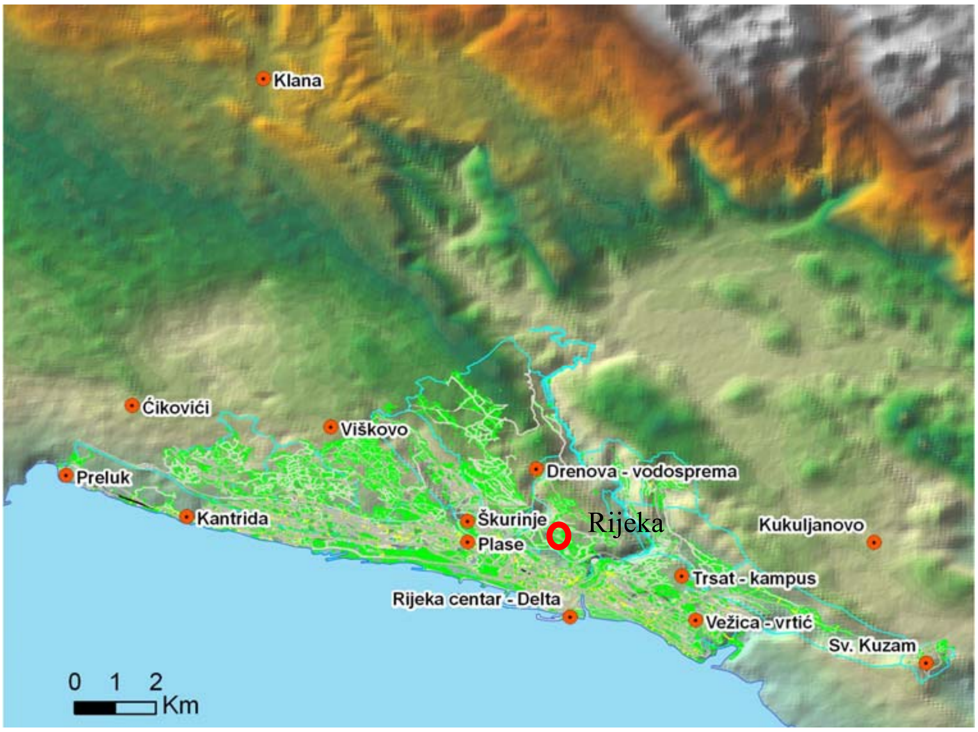

Figure 1. Positions of rain gauge stations in Rijeka and suburbs

Short-term precipitation measurement problems

Forming of rain gauge stations made only the first step toward securing information on the precipitation regime heavy short-term precipitation. It is necessary to ensure continuity of measurement, where historically, in the period of using the classic rain gauge with pots for forced discharge the most significant problem was the risk of freezing the instruments, so observations were often suspended during the cold part of the year. Sometimes the reason for suspension of monitoring was poor emptying of tie. Figure 2 shows a percentage of missing annual amount of precipitation in Rijeka during certain years, i.e. a percentage of months where monthly amount of precipitation aren't reported due to deficiencies in the work of rain gauge.

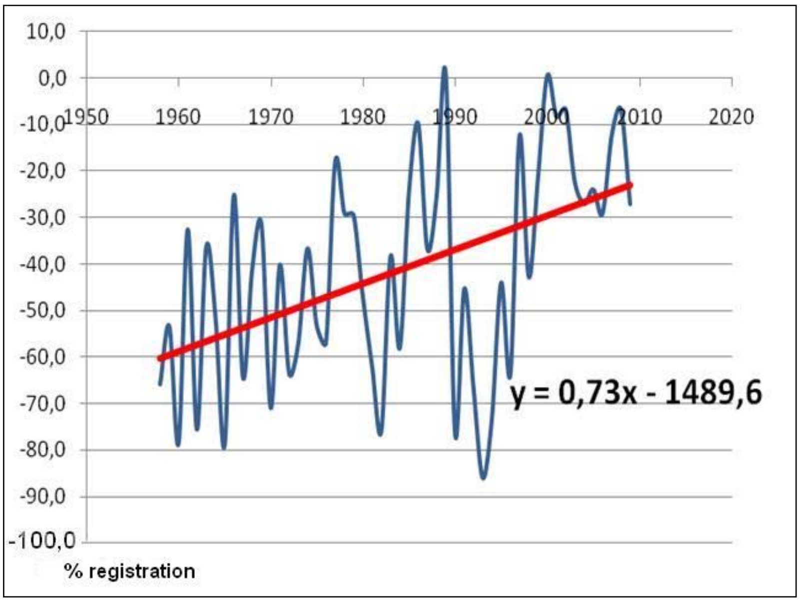

Figure 2. Percentage of registered precipitation amount in Rijeka based on monthly statement of rain gauge (1958 – 2009) compared to data from pluviometer

At the level of the entire analyzed period, during the months in which there were no problems with the work of recording rain gauge, it was registered only 57.6% of the total annual precipitation amount. It is evident that the trend of increasing registered precipitation is present for about 0.7% per year. Although most of the situation with the unregistered rainfall refers to the winter period of the year when the recorded intensity of precipitation is less, that big difference between registered and unregistered rainfall brings up the question of representativeness of input data series for further processing.

Besides ensuring the heating of the instrument, witch was done at the meteorological station Rijeka, one way to minimize periods of unregistered precipitation is a provision of new types of instruments less sensitive to such changes in the conditions of their work.

One step in this regard was made by the Rijeka Water and Sewerage Company several years ago by placing contemporary rain gauge in the monitoring system. Rain gauges made by RainWise Inc. (USA) are set in Rijeka and its surroundings. They are the electronic rain gauges working on the principle of the seesaw and they respond on the fallen precipitation by providing appropriate el. pulse when the container of seesaws is full. Seesaw container volume, which is also the accuracy of the readings, is 0.01 `` (0.254 mm). This accuracy is quite sufficient for practical engineering of processing heavy precipitation intensity as required for operational purposes in Rijeka Water and Sewerage Company, in addition to the somewhat reduced accuracy, robust and economically acceptable instruments are also provided.

Each rain gauge (Figure 3) consists of an independent collector of rain with a device for measuring and memory for data collecting. The device has a large memory capable of collecting data for an entire year in minute resolution.

a)

b)

Figure 3. Rain gauge a) rain collector, b) construction detail of seesaw instrument

Urban areas, due to the spectrum of different conditions, aren’t suitable for collecting precipitation data series. Frequent breaking of recording rain gauges and stealing of the same, forced workers of Rijeka Water and Sewerage Company to design a new way to protect them. Locations on which rain gauges will be placed were carefully observed not only in terms of catchment area but also with aspects how to disable approach to "unauthorized" persons and within the area managed by RWSC in so-called peaceful places. The original idea to set up rain gauges in accordance to Croatian standard "HRN 13798:2002 Hydrometry -- Specification for a reference rain gauge pit“ had to be modified under the conditions dictated by the urban centers.

Figure 4. Protective barrel with the instrument

Although the standard states that the rain gauges should be put in the ground, in our case, the same are set in a steel barrel with capacity of 200 liters (Figure 4). The lid of the barrel has been modified by installing a steel mesh to prevent the collection of rejected raindrops, and barrel itself is weighted, with approx. 100 kilograms of weights.

It is evident that electronic rain gauge instruments of the new generation (with seesaw) have significantly higher reliability (Figure 5).

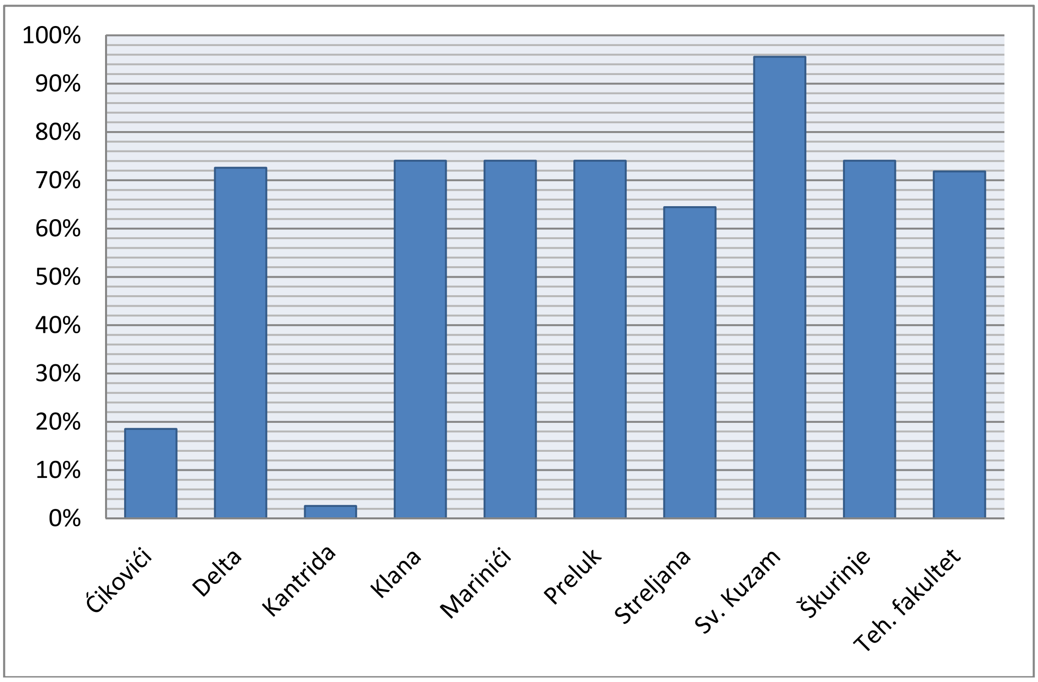

Figure 5. Percentage of time with the correct registration of precipitation amount on rain gauges of Water Supply and Sewerage Ltd. Rijeka (I-IX.2010.)

Analysis of the features of heavy short-term precipitation based on precipitation data from station Rijeka

Rijeka is a city with an average annual precipitation amount of 1533,9 mm, but very intense precipitation, where it often registers a daily amount more than 100 mm. As for heavy short-term precipitation, within Preliminary design of sewage of city Rijeka dated in the 1961st (N.Čulinović, 1961), first detailed study of such storm of the wider area of Rijeka was conducted. But because of the short data series available from station Rijeka, data from station Kraljevica were used, which has been active in the period 1926th -1940th. First data processing registered in Rijeka (from the period 1954-1965) was conducted in a manner that the observed extreme precipitation amount were equaled to the function type of Precipitation - Duration, and for which was supposed to match the 20-year return period (Bakota, 1970).

This was followed by several different methodologies, with different methodological assumptions, different periods of treatment, as well as a variety of selection of the analyzed period and return period (Rubinić, 1987 and 2002; Gajić-Čapka & Zaninović, 1999). Table 1 gives an overview of selected results of treatment carried out in that way for several characteristic values of the intensity of precipitation (for the duration of 20 min, 1 and 2 hours; the return period of 2 and 20 years). From these results it’s shown that the results of processing are stabilized around relatively close values.

Table 1. Comparison of treatment results of maximum precipitation intensity (l/s/ha) in several historical documents

Authors of interpretations	Duration 20 min		Duration 1 hour		Duration 24 hours	
	RP 2 god	RP 20 god	RP 2 god	RP 20 god	RP 2 god	RP 20 god
Čulinović N. (1961)	160					
Bakota (1970)	-	339	-	154	-	16
Vodopija (1980)	156	-	79	-	-	-
Rubinić (1987)	232	324	122	212	12	24
Gajić-Čapka & Zaninović (1999)	216	308	109	216	12	25
Rubinić (2008)	245	322	118	208	12	26

However, over time the information on the features registered in short-term precipitation and processing methodology changed. Figure 6 provides a comparative overview maximum daily amount (per rain gauge in Rijeka) and a maximum 24-hour amount (by rain gauge) for the period starting from 1958 (with omitted situations when rain gauges didn't work), and in Figures 7 and 8 views of the trend rising their characteristic values for several selected duration. It is evident that all analyzed data series, except those of longer duration of 12-24 hours, showing a slight trend of decrease in the intensity of precipitation.

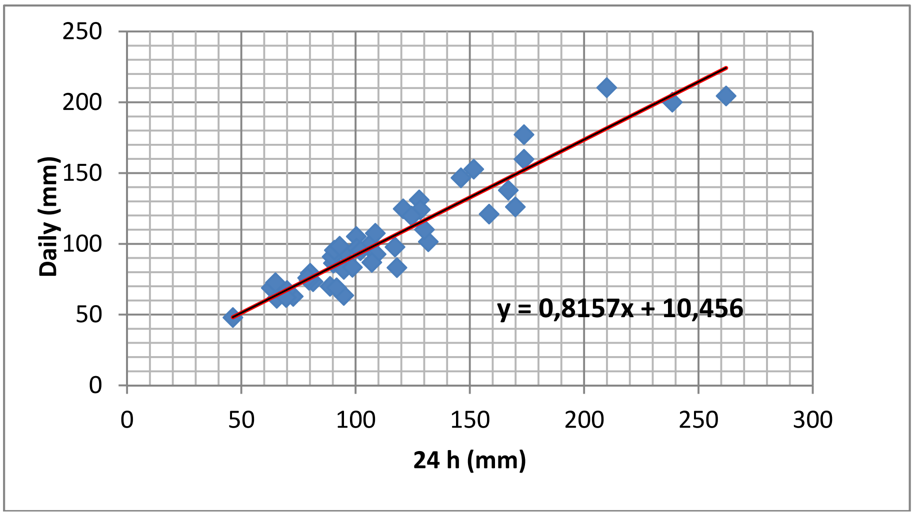

Figure 6. Comparative overview of maximum daily and maximum 24 - hour precipitation amount from station Rijeka

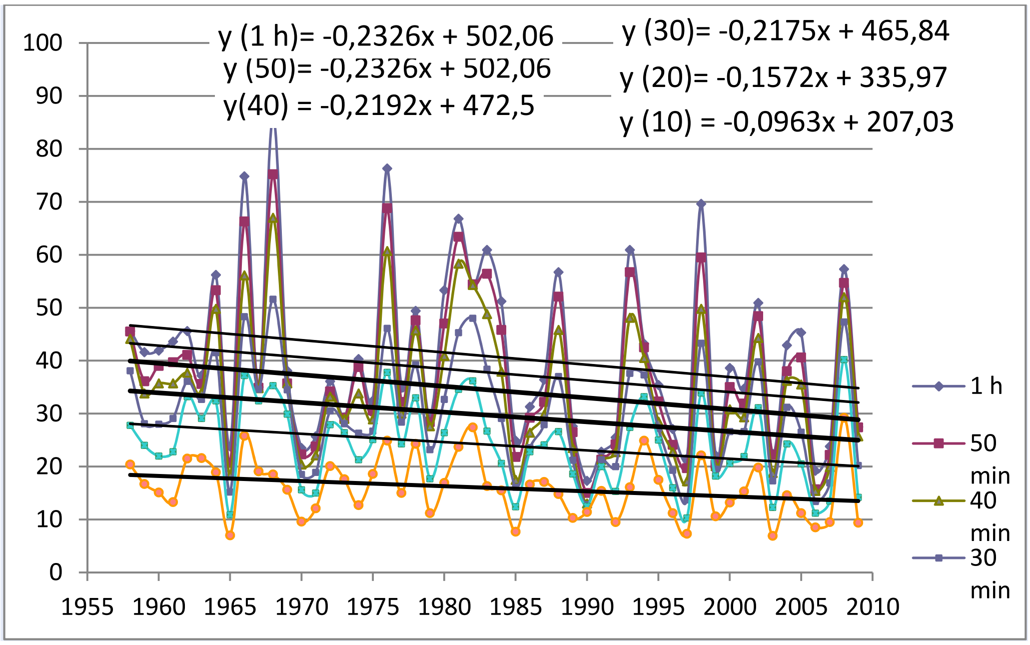

Figure 7. Comparative overview of registered data series of characteristic maximum annual precipitation amount from station Rijeka for duration of 10 minutes - 1 hour

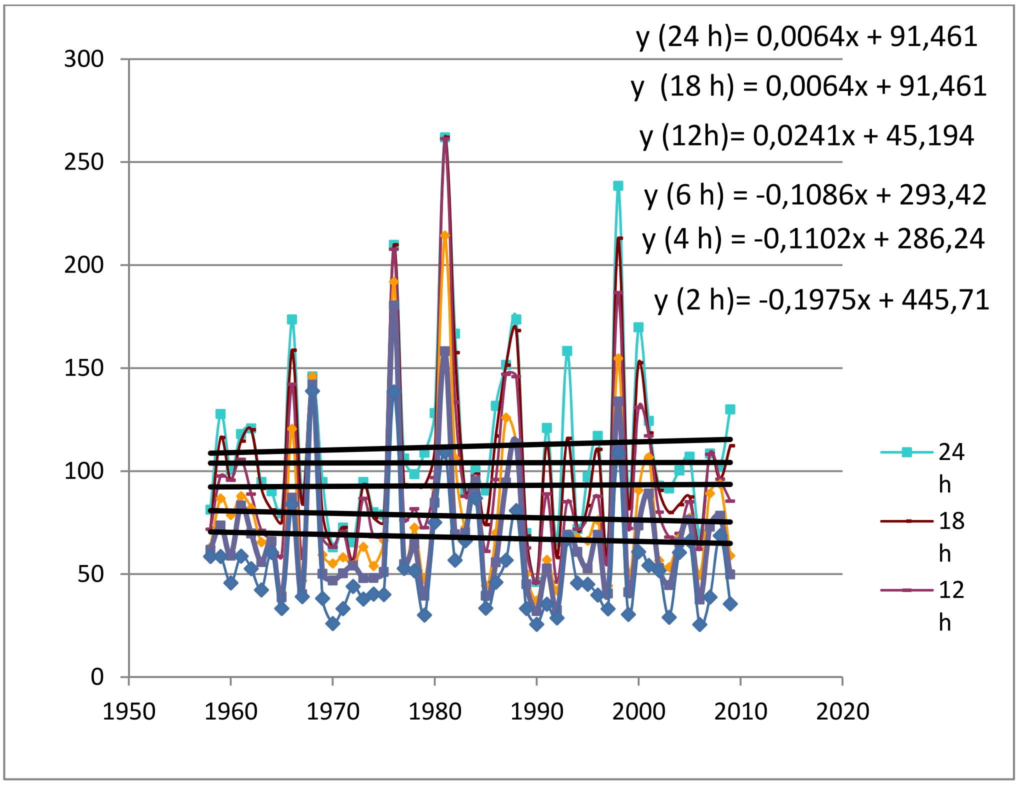

Figure 8 - Comparative overview of registered data series of characteristic maximum annual precipitation amount from station Rijeka for duration of 2-18 hours

It is interesting to see annual distribution of maximum short-term precipitation of different duration and return period (10min – 24 h). It is noted that during the short period the maximum monthly precipitation occurs during warm season (June – September). With increasing of duration precipitation intensity increases in the second half of the year (Figure 9).

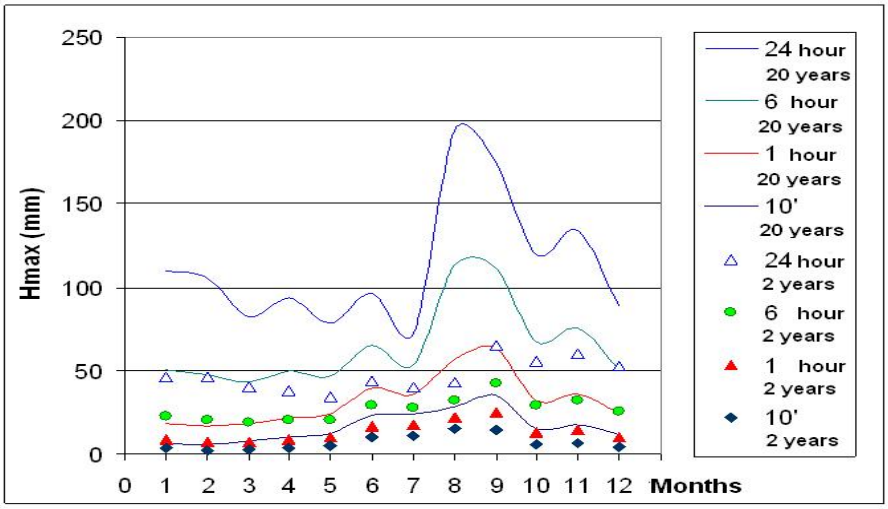

Figure 9. Seasonal distribution of the maximum monthly precipitation for 2 and 20 years return period – Rijeka (1957– 1984) (Rubinić et all, 2009)

The results show relatively high differentiation of HDF curves for each month (Figure 10). It is shown that August and September are characterized by maximum intensity throughout the amplitude of durability. Intensities which are more pronounced with increasing duration appear during November and October.

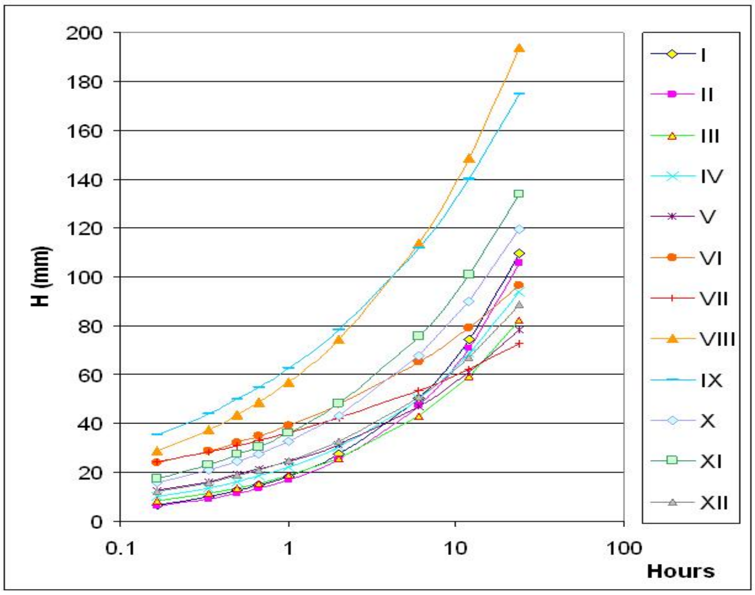

Figure 10 – Monthly HDF curves for 20th years return period – Rijeka (1957 – 1984) (Rubinić, 1987)

Analysis of the features of heavy short-term precipitation from the rain gauge stations network of Water Supply Rijeka

The establishment of a relatively dense network of rain gauge stations on area of Rijeka Water and Sewerage Company also enabled the monitoring of their spatial-temporal variations in some selected situations, as well as over a longer period of time. Software has been developed for processing such registration data with which it is very easy to browse and compare the information contained in the Rijeka Water and Sewerage Company precipitation database, as well as for a longer period, and for each storm event.

What is amount of the spatial-temporal variability of the collected data is evident in Figures 11-13. Figure 11 shows how data on maximal intensity differ, although collected at relatively close locations, during one, selected year (2007), and Figure 12 and 13 shows the differences in rainfall registered during a selected storm event.

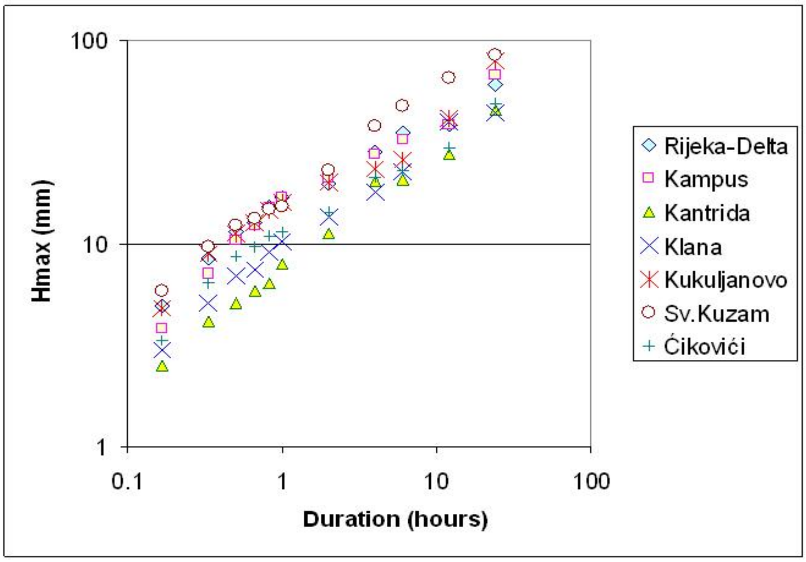

Figure 11 - Overview maximum intensity/amount of precipitation for selected duration of 10 minutes - 24 hours for the analyzed rain gauge stations at the area of Rijeka and suburbs in 2007 (Rubinić et all, 2009)

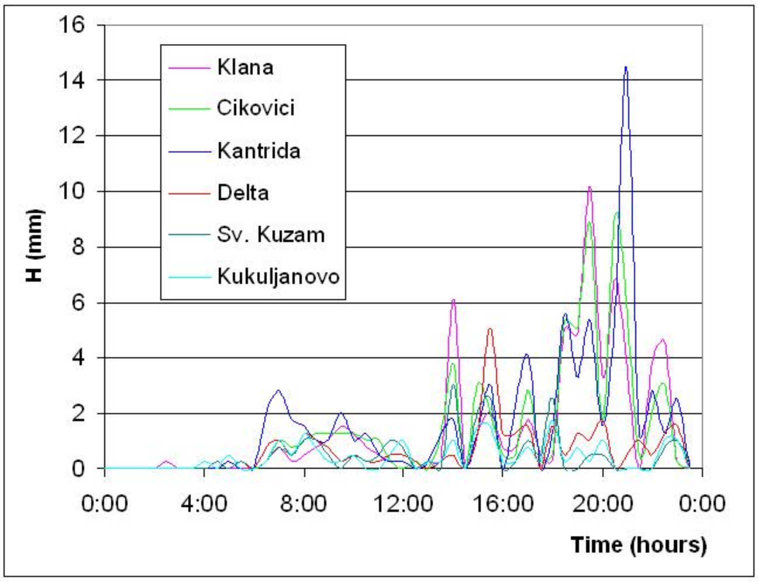

Figure 12 – Rise of half-hour precipitation on October 26, 2007.

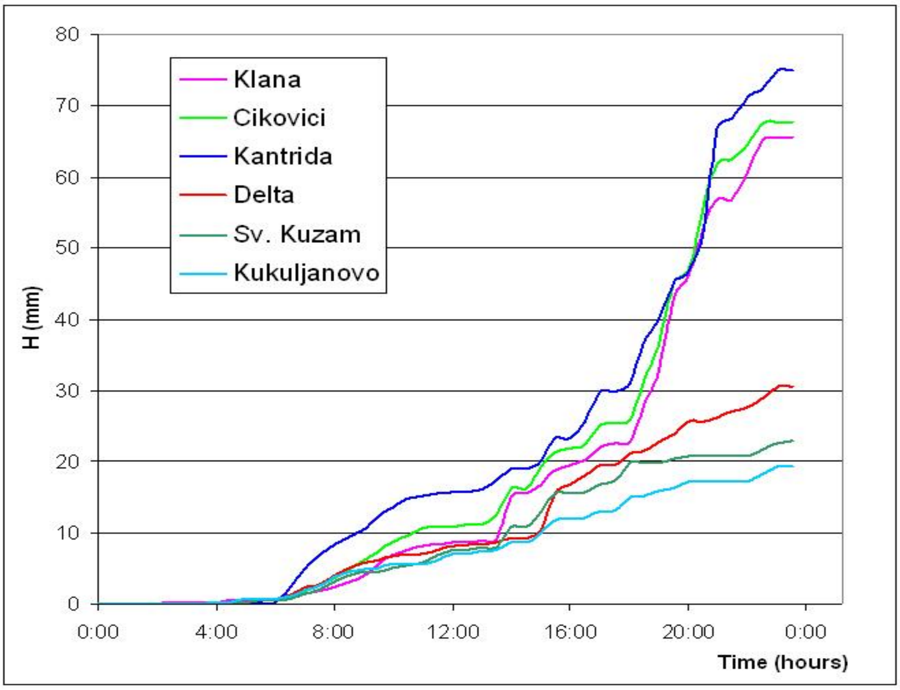

Figure 13 – Time rise of precipitation amount on October 26, 2007.

Conclusion

In a given work, for city of Rijeka, is shown obvious complexity of monitoring and interpretation data for heavy short-term intensity precipitation, and ability of new systematic approaches. During the development of rain gauge monitoring the available information about registered precipitation and methodological approaches, were changing. Shown results of rarely conducted year analysis of distribution heavy short-term rainfall shows that it is also possible to provide basis for hydrological calculations take into account the seasonal changes of the system. The results of the analysis of annual variation of typical duration of heavy short-term precipitation indicate that their trend for short-term rainfall (up to 6 hours) in a slight decline, and longer in slightly growing.

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Prediction of heavy rain using WRF-NMM mesoscale model, case studies

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ABSTRACT: Nonhydrostatic Mesoscale Model (NMM) core of the Weather Research and Forecasting (WRF) system is flexible state-of-the-art numerical weather prediction model suitable for use in various applications with horizontal resolution ranging from few kilometers to several hundreds of kilometers. This system is capable of describing and estimating powerful nonhydrostatic mechanism in convective clouds that cause heavy rain. Model is running in Republic Hydrometeorological Service of Serbia from August 2007 in operational short range weather forecast. Boundary conditions are taken from European Centre for Medium Range Weather Forecast (ECMWF) global model. Experience in everyday work convinces us that WRF-NMM model is applicable and reliable for forecasting most important meteorological parameters, including precipitation. In this study, three days forecast outputs are evaluated in order to examing capability of timely prediction of heavy rain. For case studies we focused on recent rainy episodes that caused floods and flash floods in Balkan region. Precipitation amount and spatial distribution are analyzed and verified against observations. Short description of WRF-NMM model with summary of particular version used is presented as an introduction. Synoptic analysis precedes forecast model output plotted with available precipitation observation in the region of interest. The results are encouraging in terms of timing, location and amount of precipitation. Forecasted WRF-NMM precipitation indicated very good agreement with observations.

Introduction

Current horizontal resolution in numerical weather prediction models is reaching the limits of hydrostatic approximation validity. Nonhydrostatic processes in the atmosphere are the most responsible for extreme precipitation occurrence. Treating of nonhydrostatic atmospheric processes in numerical models requires new, sophisticated approach and high horizontal resolution. In accordance to this, computation demands are huge.

Weather Research and Forecasting system is numerical weather prediction system developed in cooperation of National Center for Atmospheric Research (NCAR) and National Centers for Environmental Prediction (NCEP) in USA. WRF provides a operational forecasting model that is flexible and efficient computationally, while offering the advances in physics and numerics contributed by the researchers.

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This system is installed and is running in Republic Hydrometeorological Service of Serbia, twice a day on HP XC 128 processors cluster.

Model description

Core of WRF system is NMM, Nonhydrostatic Mesoscale Model, an alternative approach to nonhydrostatic modeling. Instead of extending mesoscale nonhydrostatic modeling concepts to the synoptic scales, hydrostatic model has been extended to include the nonhydrostatic motions, preserving the favorable features of the hydrostatic formulation. NMM uses full compressible equations split into hydrostatic and nonhydrostatic part. Hydrostatic part is responsible for traditional meteorological parameters where hydrostatic approximation is sufficient. This means also significant reduction of computational requirements at lower resolutions. The nonhydrostatic module can be turned on and off depending on resolution, so that the model can be run in the hydrostatic mode at lower resolutions with no extra cost. Very high horizontal resolutions of about kilometer or less introduce the importance of vertical motion and the nonhydrostatic dynamics has been included through an add-on nonhydrostatic module. Extra computational effort needed due to the nonhydrostatic extension is of the order of 20% of that required by the hydrostatic dynamics.
Vertical coordinate in NMM model is the terrain following hybrid pressure-sigma coordinate. Sigma is vertical mass (hydrostatic pressure) based coordinate defined as:

$$\sigma = \frac{p - p_T}{p_s - p_T} \qquad (1)$$

Where p_T is the hydrostatic pressure on the top of the model and p_S is hydrostatic pressure on the surface. With the hybrid coordinate lower coordinate surfaces follow the terrain while they are flat above and far from mountains. Over the mountains hybrid coordinate increases vertical resolution and equations are continuous. Hydrostatic pressure is used as the vertical coordinate above 420hPa so that the most serious problem with sigma - sloping coordinate surfaces are restricted to the lower half of the atmosphere.

The full system of governing equations in inviscid adiabatic form (Janjić at al. 2001) is analogous to a hydrostatic except for nonhydrostatic pressure and ε, parameter defined bellow. The nonhydrostatic continuity equation can be written as:

$$w = \frac{1}{g}\left(\frac{\partial \Phi}{\partial t} + V \bullet \nabla_\sigma \Phi + \dot{\sigma}\frac{\partial \Phi}{\partial \sigma}\right) = \frac{dz}{dt} \qquad (2)$$

Here, w is vertical velocity, g is gravity acceleration, Φ is geopotential, V is the horizontal wind vector, $\dot{\sigma}$ is the vertical velocity in the sigma coordinate and z is the height of the coordinate surfaces. The ratio of vertical acceleration to gravity has the form:

$$\varepsilon \equiv \frac{1}{g}\frac{dw}{dt} \qquad (3)$$

Since the geopotential is computed from hydrostatic pressure, temperature and nonhydrostatic pressure, Φ, w and ε are not independent variables. The main consequence is that independent equations for calculating vertical velocity should not be used. In the discrete systems, the same variable would be computed in different, inconsistent way at different places. This inconsistence could induce numerical noise.
Value of ε is much less than one in meso and large scale atmospheric flows and impact of nonhydrostatic dynamics becomes detectable at horizontal resolution less than 10 km, important at 1 km.

Map projection in the NMM model is latitude-longitude coordinates rotated in a way that the coordinate origin is located in the centre of the integration domain and translated in the intersection of the equator and prime meridian. The rotation minimizes convergence of meridians over the domain and maintains more uniform earth-relative grid spacing than for a regular latitude-longitude grid. The grid staggering is the semi staggered Arakawa E-grid.

The discretization applied in NMM model is tested in earlier hydrostatic model Eta. The model uses a forward-backward scheme for horizontally propagating gravity-inertia fast waves, implicit scheme for vertically propagating sound waves, Adams-Bashforth scheme for horizontal advection terms, and Crank-Nicholson scheme for vertical advection. The same time step is used for all terms. A number of first and second order quantities, including energy and enstrophy, is conserved.

Several physical options are applicable in the NMM model, accessible through the namelist. They contain full physics for land-surface and planetary boundary layer. Atmospheric and surface radiation, microphysics, and cumulus convection are treated in separate modules. This comprehensive package, together with the nonhydrostatic dynamical option is crucial in computation of the large scale and convective precipitation.

Operational application

Operational use of WRF NMM system in Republic Hydrometeorological Service of Serbia started in August 2007. Model domain covers Balkan region and Adriatic Sea.

Horizontal resolution is 4 km, number of numerical points is 220 in west-east and 290 in south-north direction. Vertical resolution is 45 vertical levels from the surface to 50 hPa where the model top is. Time step is 10 s, forecast period 72 hours. Twice a day, with the start in 00 UTC and 12 UTC, the model runs on boundary conditions from European Centre for Medium range Weather Forecast global model. Three days forecast are available at 07 UTC, morning run and 19 UTC for afternoon run.

Development and moving of the frontal areas causes vigorous vertical movement and flux of the humidity from the surface in turbulent mixing. Such processes are meso scale, usually about 1 km horizontal radius, very fast and momentary with large time and space variability. These facts make forecasting the small scale weather phenomena difficult and computationally demanding. Most of the weather prediction models have problems and poor verification scores when cloud scale processes that produce extreme convective precipitation are resolved.

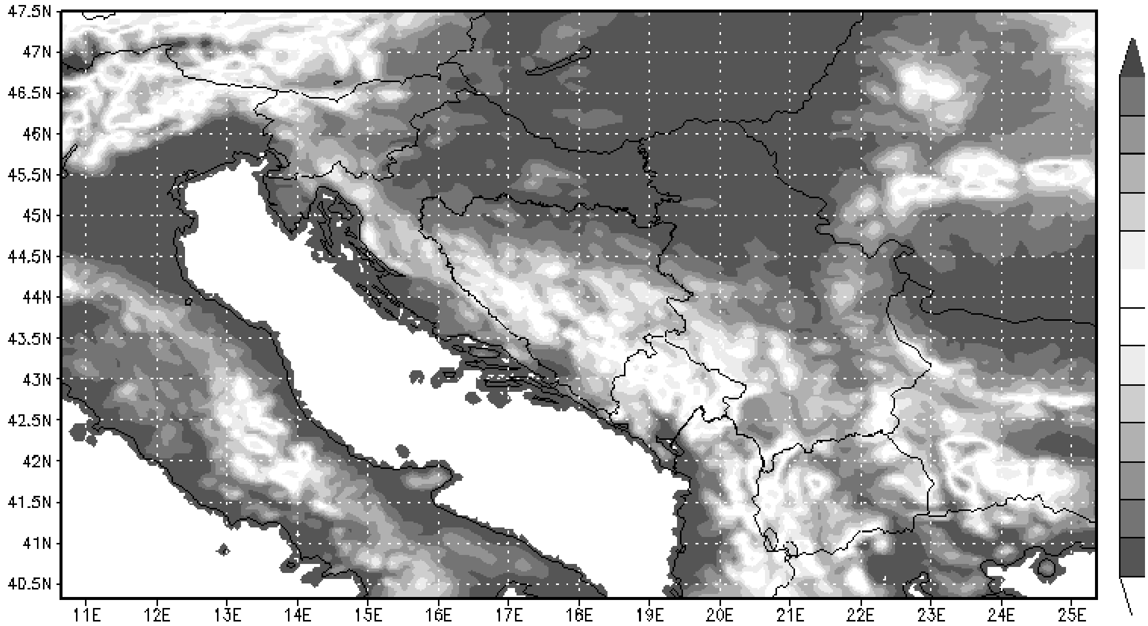

Fig.1 Operational model domain and orography

NMM model outputs show very good agreement in comparison with the observations during past three years of everyday exploitation. Temperature and wind verification scores are extremely good. Precipitation verification for the first nine months in 2010 is presented. Mean absolute error of 24 hour precipitation is calculated separately for every forecast day against conventional observations from the ground meteorological stations in Serbia. Contribution of the precipitation forecast for dry days is included.

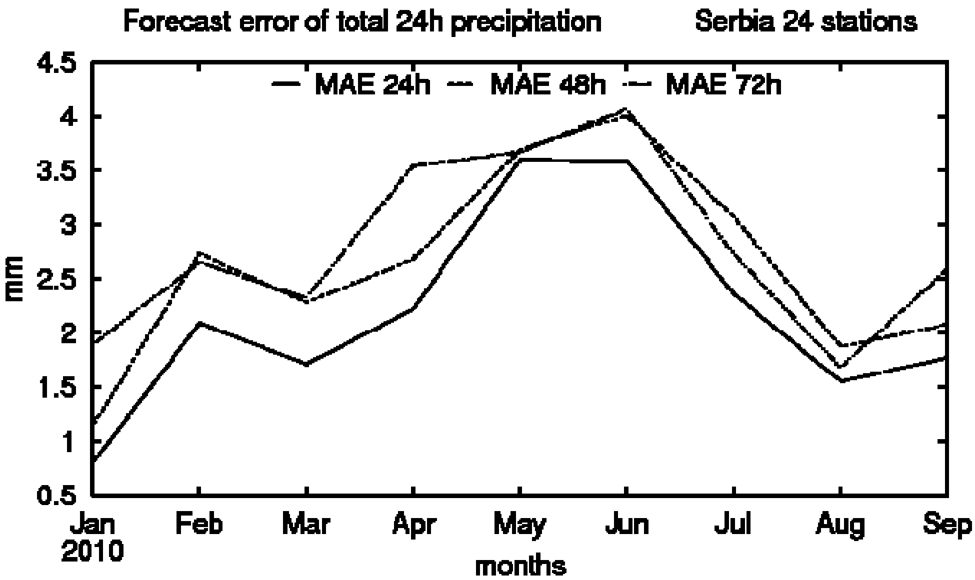

Fig. 2 Monthly forecast error of 24 h accumulated precipitation

Mean absolute error of 24 hour precipitation for each day of the forecast are quite satisfying during the whole period, except in May and June when frequent small scale instability and convection with precipitation were occurred.

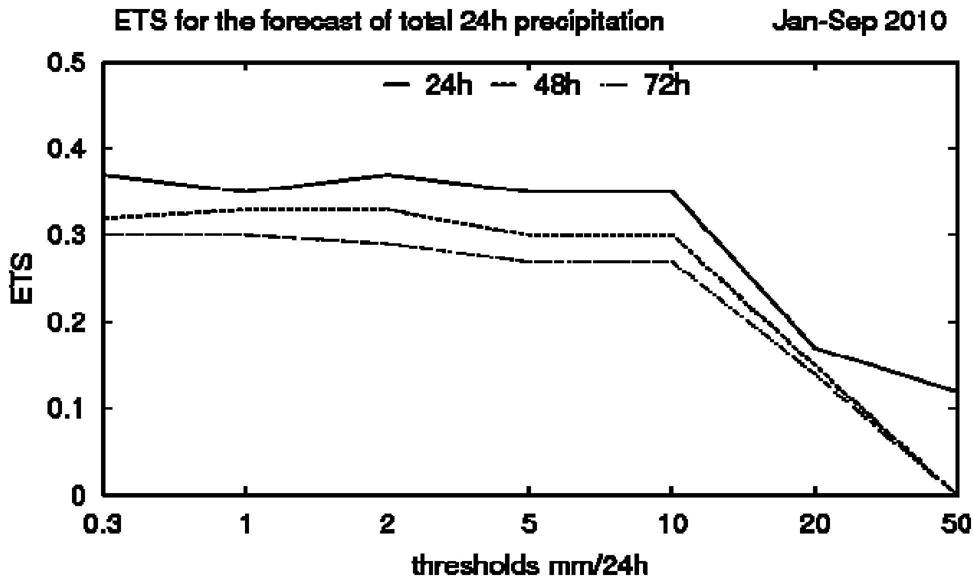

Fig.3 Equitable threat score for 24 hours precipitation

Equitable threat score measures the fraction of observed and/or forecast events that were correctly predicted, penalizing both misses and false alarms in the same way. Perfect score is 1, -1/3 indicates no skill. Observed rain was stratified by the rainfall intensity thresholds in order to give better insight in the model behavior. It can be noticed that ETS score is moderately good to intensity of 10 mm/24h and worse for the amounts exceeding 20 mm per 24 hours. The result is expected having in mind the nature of the processes and the fact that the model can extremely overpredict the amount of precipitation in the single numerical point in these situations. It should be emphasized that the events with 24 hours rain amount over 50 mm are very rare. In our set of data covering first nine months of 2010, it happened only 8 times on 24 observation points.

Case studies

Successful and timely forecast of the flood events during summer and fall 2010 on the Balkan and reliable verification scores gave us an idea for this study. Operational outputs available in the weather forecast department without any additional correction or adjustment were compared with conventional observation to give an insight in accessible background for severe rainfall warnings.

On September 16th deep, spacious low pressure with the centre over Scandinavia induced advection of the cold northern air to the west coast of Europe. Warm and humid air mass on the south was moving towards north east maintaining almost stationary front over the Alpine region. This front remained in place throughout the forecast. Permanent flow of the moist air from the south west and low level wind shear provided conditions for the heavy rain during the next few days.

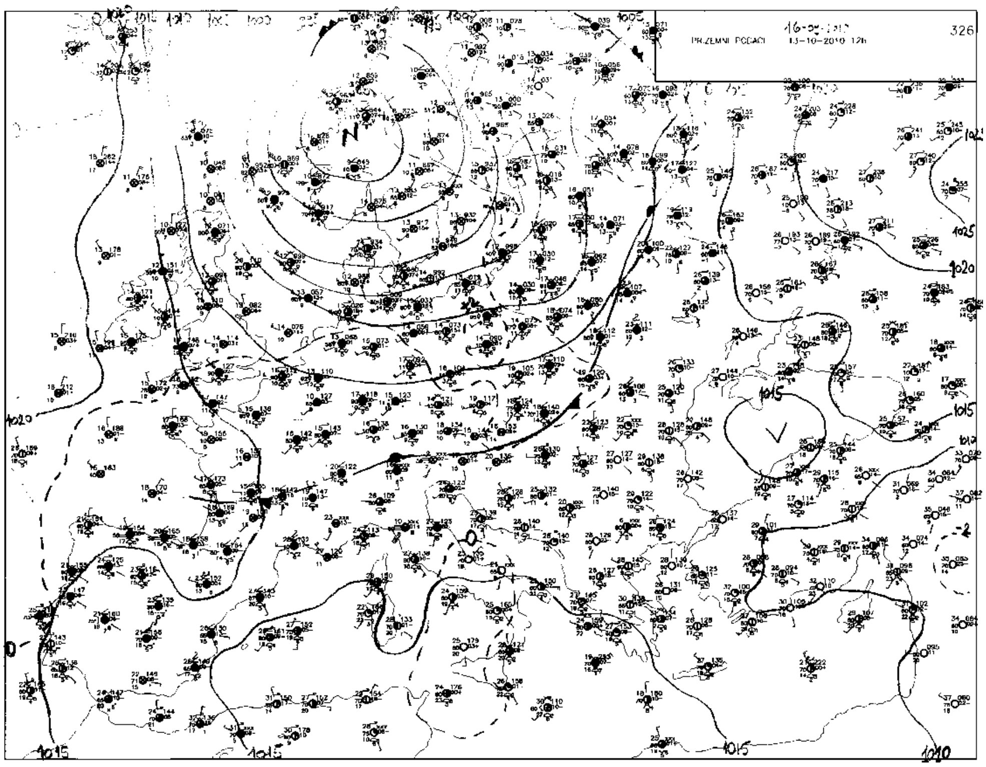

Fig.4 Surface analysis, 12 UTC 16th September 2010

Distribution of 24 hour forecast precipitation on the part of the domain, zoomed area of interest where heavy rain was observed, is presented on the next plots. Figure 5 presents outputs from the run started two days before the actual event. In Figure 6 precipitation forecast from the run twelve hours after is plotted. Ground station reports from regular GTS dissemination are considered.

It could be visually noticed that model predicted rain over west parts of Slovenia and Croatia precisely in terms of location of maxima within them. Forecasted quantities correspond very well to the observed values. Matching with observation is better later in the forecast. Possible explanation could be that model physics needs time to adjust moisture content and rain production that leads to the consequence that forecast after two days is more realistic.

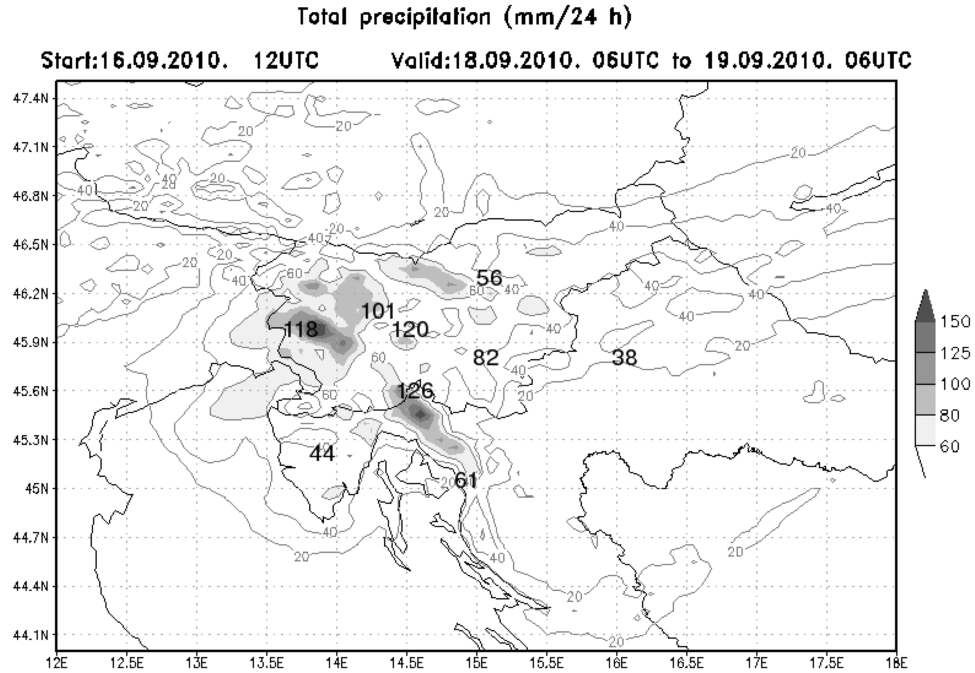

Fig.5 WRF-NMM 24 hour precipitation forecast, 42-66 hour

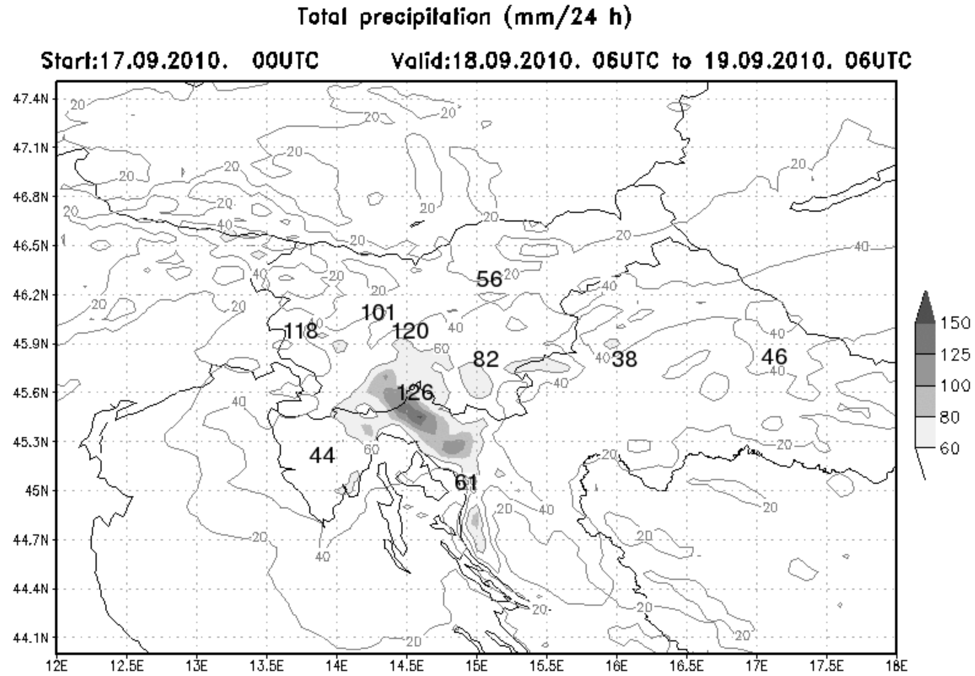

Fig.6 WRF-NMM 24 hour precipitation forecast, 30-54 hour

Extreme precipitation that exceeded hundred year maximum was observed from 20th to 22nd June 2010. Starting on 20th June closed low pressure over the Gulf of Genoa was moving towards east Balkan. Large amount of moist air was dragged into circulation forming rain zone with heavy precipitation next few days over Bosnia. 48 hour precipitation is presented to cover the whole rain event.

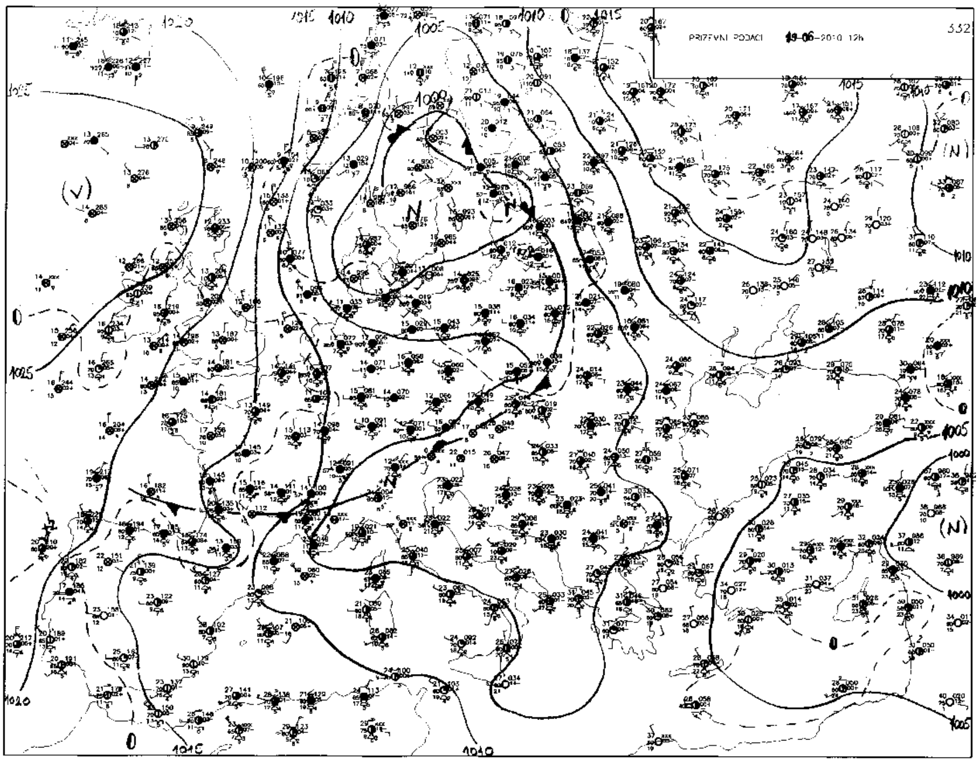

Fig.7 Surface analysis, 12 UTC 19th June 2010

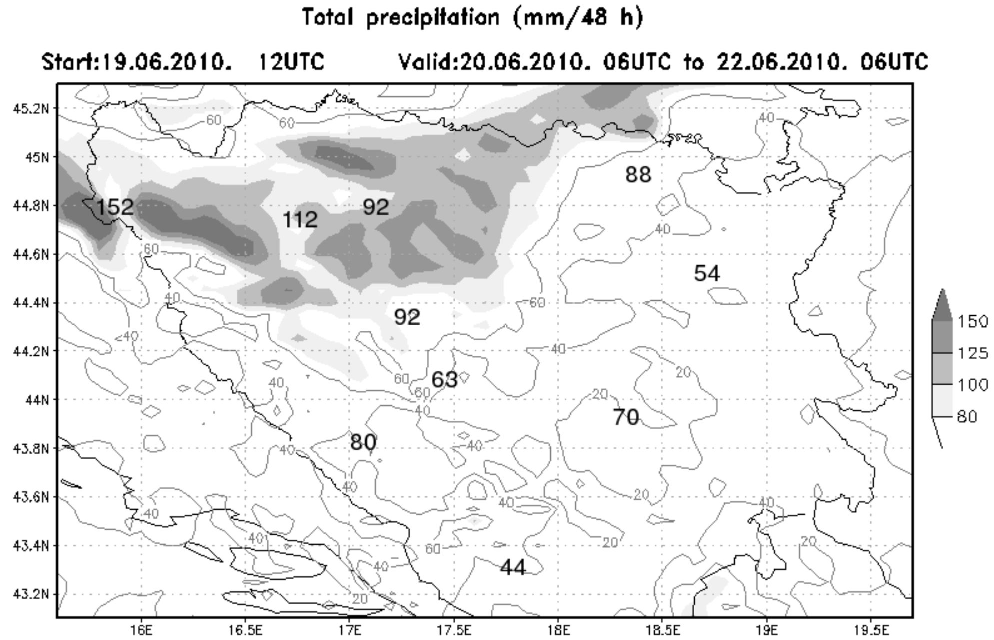

Fig.8 WRF-NMM 48 hour precipitation forecast, 18-66 hour

Small closed area of maximum precipitation in the northwest Bosnia is almost on the place where the maximum occurred. Indication of expected region with rain is given correctly except for the south Bosnia where less precipitation was observed.

Recent extreme precipitation occurence in southern part of Montenegro happened on 5th and 6th October 2010. A cut-off low pressure formed over western Europe was moving towards southern Adriatic sea across the Alpine region. A frontal system was accompanied with that upper low and warm and moist air in southwesterly flow.

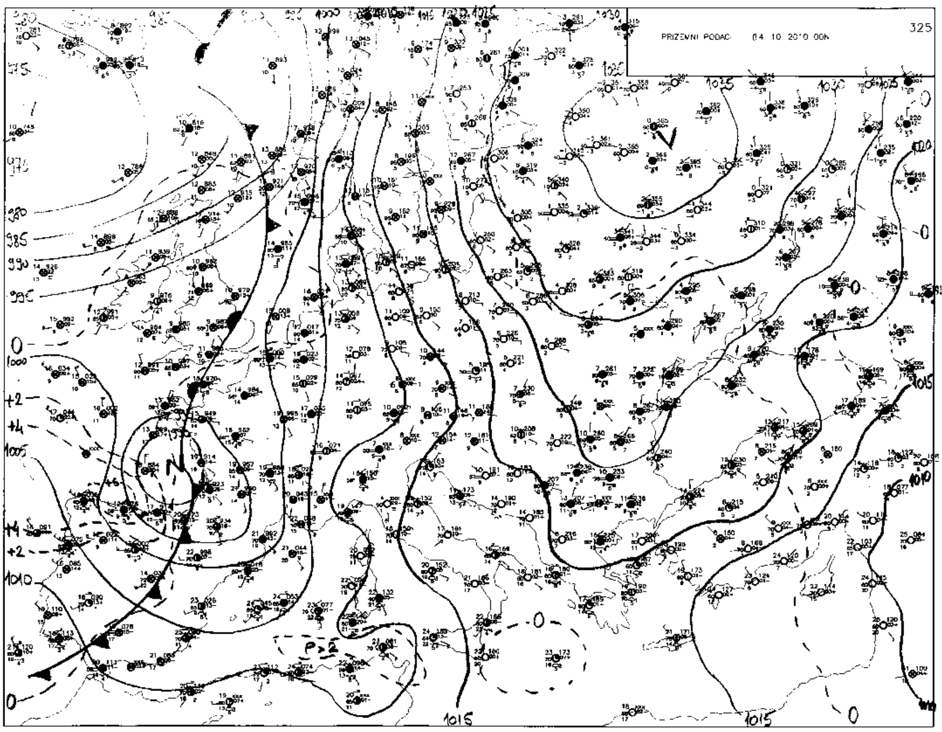

Fig.9 Surface analysis, 00 UTC 4th October 2010

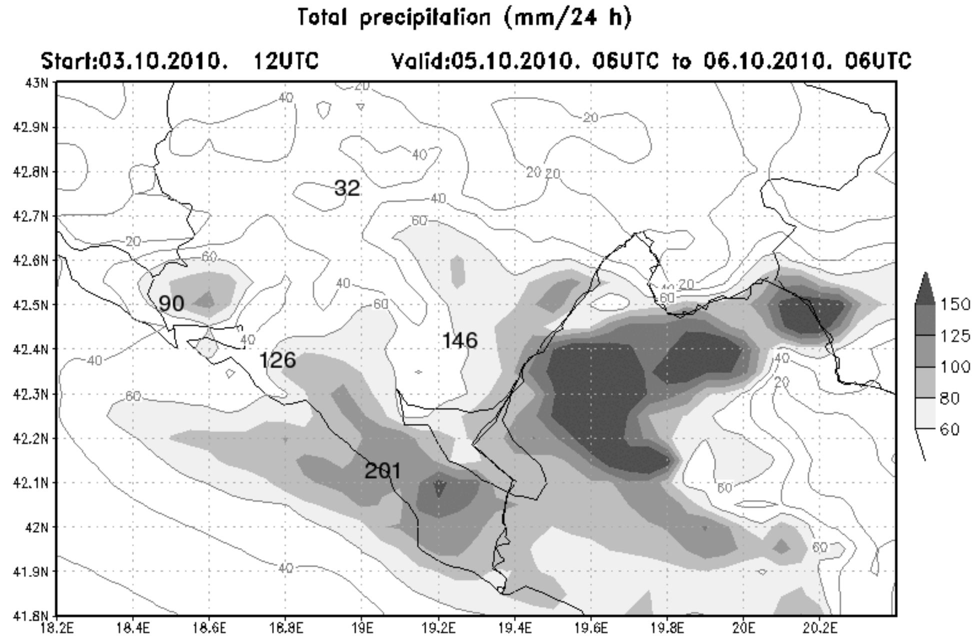

Fig.10 WRF-NMM 24 hour precipitation forecast, 42-66 hour

This rapid rainy situation lasted only several hours in the afternoon afternoon on 5th October. Distribution of precipitation forecast is in a very good agreement with the observed values, particularly on the narrow pattern along the south Adriatic coast where maximum was identified. Model also indicated the time when the rain stopped, on the third day of forecast.

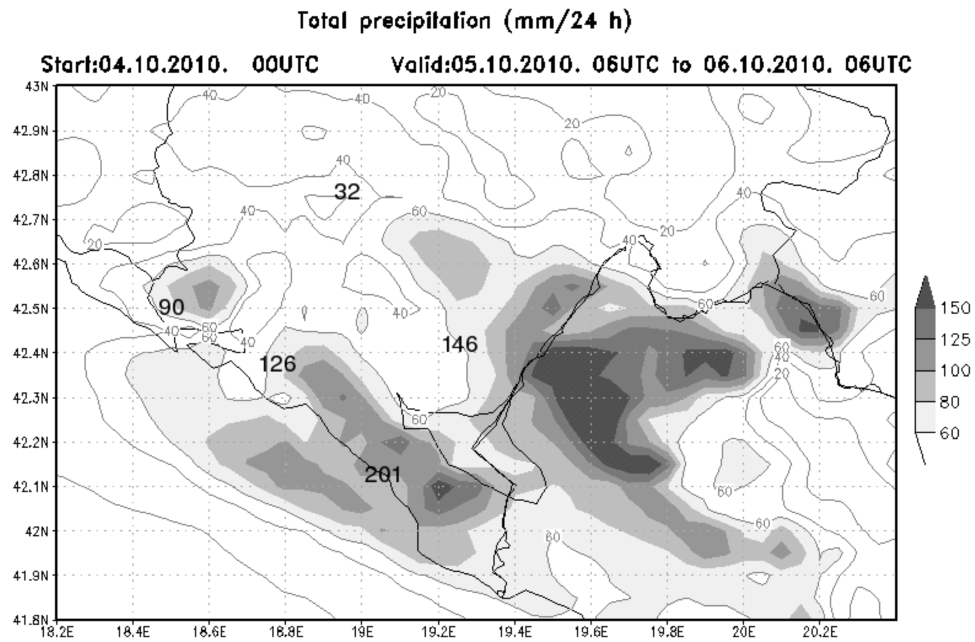

Fig.11 WRF-NMM 24 hour precipitation forecast, 30-54 hour

Both forecasts missed maximum over continental southeast part of Montenegro and predicted extreme precipitation over northwest Albania, roughly 20 km on the east. Lack of observation reduces assurance but it can be assumed that heavy rain occurred in Albania also. Shifting in forecast is probably a consequence of steep slopes and high mountains around flat surface of the lake Scadar. This rapid change of elevation on sub scale distances enters imprecision and uncertainties in the model computation.

Conclusions

Principally, model is better in forecasting large scale precipitation since dynamics of these processes is well known. NMM model is very successful in prediction of precipitation events and less successful in precise spatial positioning of the maxima. Forecasted spots with maximum precipitation are usually placed in the 20 km radius within observed maximum. It can be considered as satisfactory forecast in terms of timely severe weather warnings. Recommendation should be to follow the signal, indication of predicted extreme amount of precipitation in space and time that the forecast for the third day gives.

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RADAR OSERVATION AND DATA PROCESSING

Radar rainfall measurement and nowcasting – high resolution data for hydrological application

Thomas Einfalt[1]

ABSTRACT: Distributed and realiable rainfall data are required for hydrological applications such as flood warning, urban sewer layout, dam design and reservoir operation. Such rainfall data are traditionally won through a network of raingauge stations, but in recent times also by radar. For both kinds of measurements, a thorough analysis of their quality is indispensible, regardless of the application. However, remaining uncertainties in the data may be considerable – but they need to be known and quantified. For real-time applications, spatially detailed nowcasting based on radar is a major advantage of radar over raingauges. Different approaches are being presented.

Key words: weather radar, radar rainfall, rainfall nowcasting, data quality control

INTRODUCTION

Rainfall measurement

Raingauges are the traditional devices to measure rainfall. Main deficiencies of raingauges are their limited density and hence lacking spatial coverage as well as measurement problems in presence of strong wind or frost.

Rainfall measurements by radar are subject to uncertainties, due to measurement errors and due to the indirect measurement by the radar as an instrument. These uncertainties and their consequences for further applications have not yet been systematically evaluated. The main reason for it is that it is difficult to assess the many different uncertainties which are partly dependent on the radar location and on the rainfall situation. Inspite of this, approaches to assure data quality for known problems (Michelson et al., 2005; Golz et al., 2006) are available and should be used when applying radar data.

Rainfall measurement by radar

Radar measurement is a key source of information on rainfall. Details on the technique (see Meischner, 2003) and the necessary quality control (see Einfalt et al., 2004; Golz et al., 2006) are briefly presented here. Weather radar measures rainfall by using remote sensing technology: a rotating emitter sends out a focussed electromagnetic beam, typically with a width of 1°. Obstacles reflecting the beam are then captured by the radar antenna and their signal is evaluated.

The beam captures all obstacles in its path, such as aircraft, birds, insects and precipitation. Precipitation, and more specifically liquid precipitation (rainfall), is the primary focus of

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weather radar measurements. A major challenge in this respect is the transformation of reflectivity values into rainfall intensity. This is because there is no straightforward and linear relationship between these two parameters: a raindrop of 1 mm diameter inside a volume of 1 m^3 produces a reflectivity signal of 1 Z. The same reflectivity is produced by 1 million raindrops with a diameter of 0.1 mm.

When the raindrop size distribution is known, the summation of the raindrops with diameter D over a unit volume is given by:

$$Z = \int_0^\infty D^6 N(D)\,\mathrm{d}D \qquad (1)$$

When the vertical airspeed is zero, the rainfall rate, R, is given by:

$$R = \frac{\pi\rho}{6}\int_0^\infty D^3 v_t(D) N(D)\,\mathrm{d}D \qquad (2)$$

where: R: rainfall rate
D^3: raindrop volume that is proportional to Z
$v_t(D)$: terminal velocity of a raindrop having a diameter D
ρ: density of water.

As a mean empirical formula, the so-called Z-R relationship has become established:

$$Z = aR^b \qquad (3)$$

Z and R are expressed in mm^6/mm^3 and in mm/h, respectively. Values for a and b are always empirical averages and may differ greatly within one radar volume. The Z-R relationship, however, is the pragmatic way that appears to be the best compromise for the usual uni-polar weather radars. High values of reflectivity and intensity are considered to be much more uncertain than small values. This is due to the non-linearity of the relationship. Figure 1 presents the relationship for a = 200, b = 1.6 (Marshall and Palmer, 1948) and for a = 256, b = 1.42 (DWD - German Weather Service).

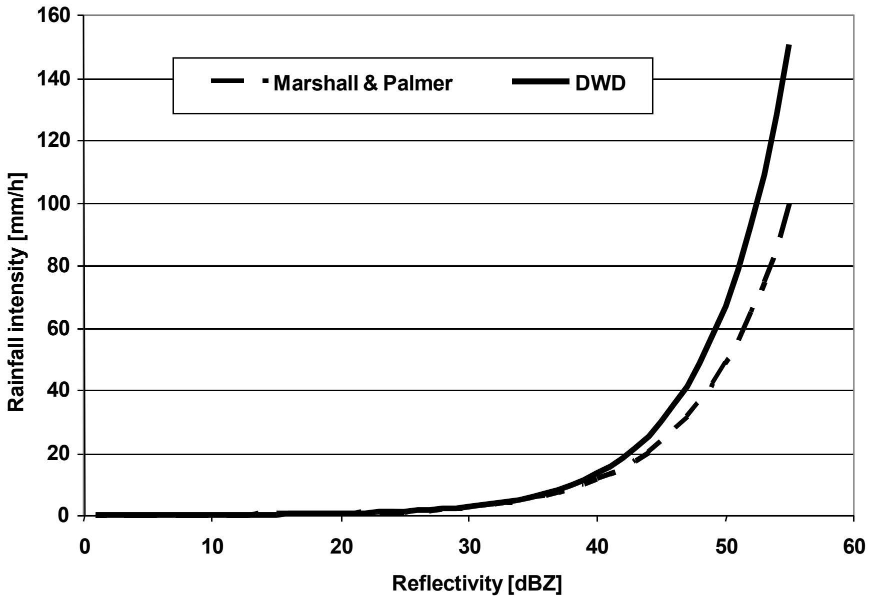

Fig. 1: Z-R relationship following Marshall and Palmer (1948) and DWD approaches

Radar generally measures with a beam width of 1° and with a range step of e.g. 1 km, thus creating a polar coordinate system. This means that, close to the radar, the measurement volume is small, covering a small area above the ground. Whereas far from the radar emitter the volume and area covered is large.

The implications of this are that small scale high resolution precipitation can only be captured close to the radar, while such rainfall peaks are averaged far from the radar.

With distance from the radar, the beam which usually is inclined by 0.5° to 1° relative to the earth at the radar site gains height in the atmosphere (Fig. 2): at a distance of 100 km from the radar, the measurement takes place at 1.5 km height or more, making the use of radar measurements for small scale hydrology a highly uncertain venture. Beyond this distance, the hydrological value appears to be prohibited due to the height of precipitation systems which in Europe may be completely below 2 km.

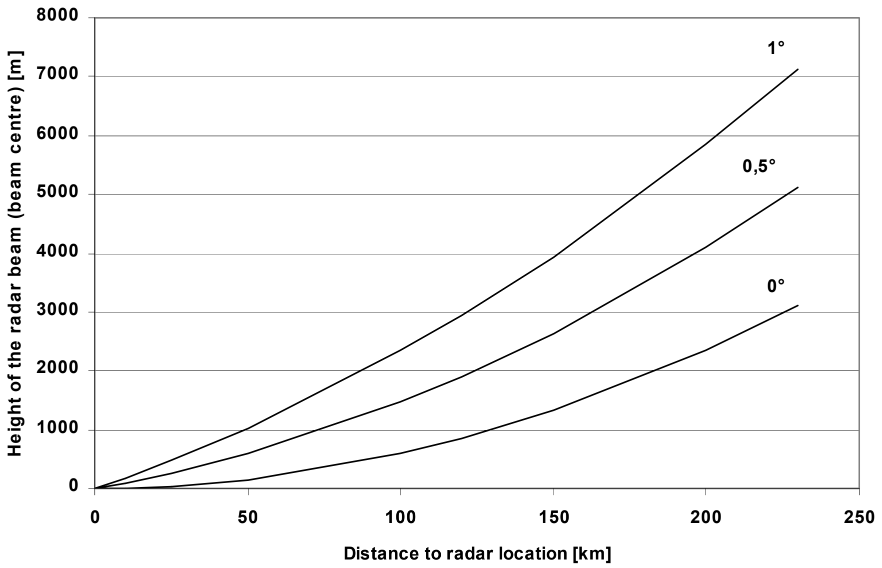

Fig. 2: Height of radar measurement with distance from the radar

The time step of the radar measurement plays a major role in the precision of precipitation determinations. This is because radar provides an instantaneous measurement. Put simply, this means that there is no information on rainfall between radar measurements. In reality, rain fields do not change so rapidly, in most cases, that a 5 minute time step would not be sufficient. With convective storms, however, such a time step may produce a lot of uncertainty in the measurements.

Radar rainfall quality assurance

Rainfall measurements by radar are subject to uncertainties, due to measurement errors and the indirect measurement by the radar as an instrument. The COST 717 Action "Use of Radar Observations in Hydrological and Numerical Weather Prediction Models" (http://www.smhi.se/cost717) has been active in three working groups, organised along the application fields of radar data. A cross cutting activity in this context was the production of a status report on “Radar Data Quality in Europe” (Michelson et al., 2005).

The report summarised, for the first time, activities in Europe related to radar data quality, both country-wise and project-wise. It commenced by defining objectives and error sources, and concluded by presenting ways to formulate radar data quality, as well as, open issues and forthcoming challenges for radar data providers and users.

The most relevant and frequent obstacles that may occur during rainfall measurement by weather radar are:

Clutter: Ground clutter is the reflectivity of fixed targets such as buildings or mountains. Ground clutter can be minimised through intelligent radar sighting, Doppler suppression, and through the use of post-processing methods such as static clutter maps.

Shielding: If the sighting of the radar is of poor, nearby objects like trees, topography, and buildings and other structures can block the radar beam in whole or in part causing shielding of sectors of interest. Corrections may improve the data in case of partly shielded radar beams.

Attenuation by precipitation: Heavy rain, graupel and hail can attenuate beam energy, leading to strong underestimation of precipitation intensities. Especially in hail the scattered energy can be attenuated to the point of virtual extinction over the return path. Shorter wavelengths (X and C bands) are more seriously affected.

The melting layer: This factor is specific to the region where snow melts to rain. The extremities of a snowflake melt first, causing a film of water to coat the particle before it implodes into a raindrop. Since water is a much more conductive medium than ice, this causes strong reflectivities in radar data and an effect known as the Bright Band where this region is found at more-or-less uniform heights/ranges. The Bright Band is often absent or very close to the surface during the winter in northern Europe, and seldom reaches above three km during summer.

Inhomogeneous beam filling and overshoot: These two problems increase in severity with distance from the radar, as the beam width increases. Inhomogeneous beam filling occurs where the scale of precipitation is small relative to the pulse volume, for example with convective events. Overshoot, in whole or part, occurs where the precipitation is shallow in relation to the pulse volume, and is a greater problem in cold climates, where winter snow is usually considerably shallower than summer rain.

The proper consideration of these effects by a data quality control scheme is essential to ensure a good data quality. On the other side, only a small number of the above mentioned effects will be present on a measurement image at the same time. So a qualified data screening can rapidly tell whether the data can be used with or without a lot of additional effort.

A Quality Index may help to recognise the quality of radar data which have undergone a quality control scheme. An example for such a quality index is given in figure 3.

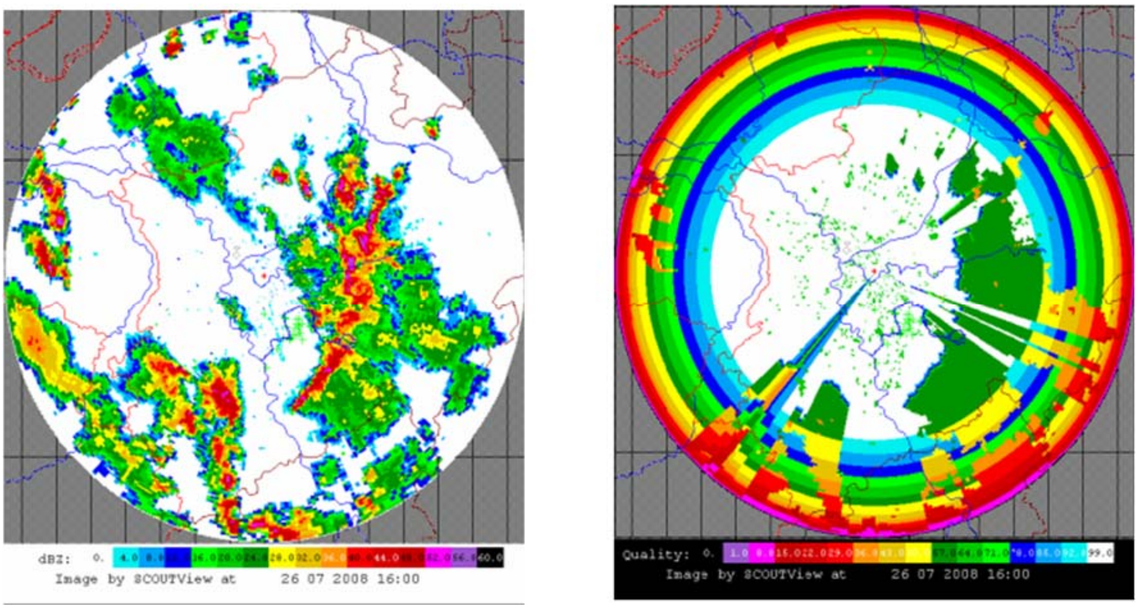

Figure 3: Quality index for DWD Essen radar measurement on 26 July 2008, 16:00 UTC (reflectivity left, quality index right)

Radar nowcasting

Methods

Radar “images” present highly dense data which can be appreciated by the human eye, and a succession of such images facilitates prediction of where the observed rain fields will move. Fuelled by these findings, short-term rainfall forecasting had already become an important issue by the 1970s. As for general rainfall nowcasting (see grey box) methodologies, the basic approaches developed more than 30 years ago have not changed. Due to limited storage capacity, "area tracking" forecasting approaches were initially based on the comparison of whole radar images (e.g. Austin and Bellon, 1974; Collier, 1978; Browning et al., 1982). The evolution of computational capacity has since led to more sophisticated real-time "cell tracking" approaches.

In order to produce a nowcast based on radar rainfall measurements, many different models have been created during the last 30 years. Initially, they were based on the concept of a software program that imitated human viewing of the image, i.e. to look at radar images as a trained observer and estimating the future location of rain cells. The main methods have remained the same: the “area tracking” and the “cell tracking” approaches (Fig. 4 and 5). The range of methods and their details have evolved, and now include wavelet based methods, spectral analysis etc. The objective of providing nowcasts for longer time intervals and convective events required additional information. Hybrid models linked with numerical weather prediction (NWP) model output have been developed, and ensemble extensions were added to existing models (e.g. NIMROD, STEPS).

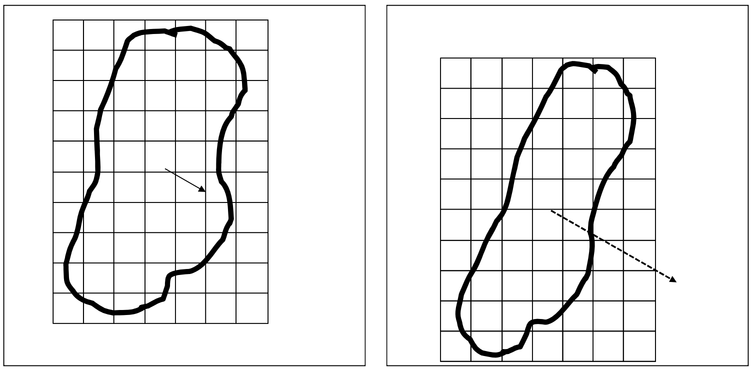

Fig. 4: Principle of “area tracking”

The "area tracking" approach is based on the statistical comparison of the rain fields in two successive radar images, using, for example, the cross correlation function. The function is calculated for different displaced super-positions of the two images (Fig. 4). The maximum of the function indicates the most probable displacement. The forecast is obtained simply by extrapolating the displacement vector, applied to the whole or parts of an image (“areas”).

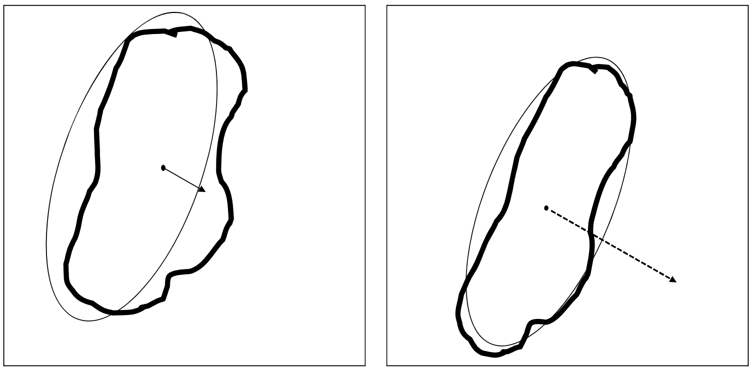

Fig. 5: Principle of “cell tracking”

Since 1978, early "cell tracking" approaches, i.e. those that are pattern recognition oriented (Blackmer et al., 1973), have been improved upon. Methodological work (Bjerkaas and Forsyth, 1980; Einfalt and Schilling, 1984), including that on satellite images (Wolf et al., 1977), led to the incorporation of more advanced image processing techniques. In essence, cells from each image are characterised, and are subsequently recognised (“matched”) based on their characteristics. The movement of each cell is then extrapolated linearly.

The shortcoming of these basic nowcast approaches is their implicit assumption of the stability of the rainfall field, its direction and speed of movement. Both limit the accuracy of nowcasts far into the future, and a potential forecast of variable rain fields or movements requires knowledge of processes that are not yet fully understood or cannot be supported by measurements.

In a very dynamic convective situation, the use of radar alone for a nowcast may lead to a forecast horizon of less than 30 minutes for small catchments.
In recent years, many more models have been developed and are being successfully applied.
Conclusions

A rainfall forecast is always a qualified guess about a future situation: it is therefore imprecise, and its value for an application depends on the application itself and its requirements. A thorough analysis of these requirements is necessary for the definition of the best possible forecast strategy. The following points are crucial when working with rainfall radar forecasts:

- Never expect a perfect forecast;
- Forecasts based on radar do not reach beyond a lead time of two to three hours for quantitative hydrological applications;
- A radar based nowcast can be supplemented by a numerical forecast for the long range (lead times > 3 hours);
- For any forecast it is important to know the requirements of the application(s), since these determine the type of forecast needed. These requirements have to be formulated with respect to:
    - Forecast horizon;
    - Forecast time step;
    - Forecast accuracy in space and time;
    - Type of forecast required (warning or forecast).

A forecast is a technical result of computations which has to be “translated” to useful information for end users, e.g. through the formulation of a well-defined and well-focused warning;
A forecast application is only as good as the combination of forecast quality and the skill and competency of the forecasting team.

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Serbian Radar Network - possible applications for Quantitative Precipitation Estimation

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Zoran Babic [1]

ABSTRACT: Thirteen S band automated radar systems operate in Serbia at present. Ten of them are radar systems Mitsubishi RC 34A, 3 Gematronik Meteor 400S, one of them is polarimetric radar (Meteor 500S). All Mitsubishi RC 34A radars are automated with software package HASIS (Hail Suppression Information System) developed for use in hail suppression. Radar systems Gematronik are based on “Rainbow” software package and HASIS-3D software package for 3 dimensional visualization of radar data. Mitsubishi RC 34A radars cover south and central parts of Serbia, and have only reflectivity data. North and central parts of Serbia are covered with Radar systems Gematronik; reflectivity, radial velocity, spectral width and differential reflectivity data are available.
On the other hand, by its nature, precipitation is very variable meteorological element concerning spatial and time distribution. In a meteorological and hydrological observing system, the biggest problem is the lack of information concerning the precipitation intensity and quantity in real time. Researches connected to the application of weather radars in meteorology have shown that they could be used to estimate with high accuracy the intensities and quantities of precipitation over a certain area.
Using Rainbow5 software additional radar products such as hydrological products SRI and PAC can be generated and used in hydrological forecasts and analysis. These products can give fast information about precipitation on territories where rain gages do not exist.
Software packages HASIS and HASIS-3D are developed in corporation with Faculty of Electronic Engineering, Nis. Now is in progress the 2 year project “Integration of HASIS – HASIS 3DI”. As the result of this project, radar composite for whole radar network will be available.

Key words: radar network; radar product; precipitation estimation.

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INTRODUCTION

Weather radars - Quantitative precipitation estimation

By its nature, precipitation is very variable meteorological element concerning spatial and time distribution. This fact requires a very dense station network and short observation intervals. Such a network exists (network of precipitation stations), but it is inaccurate, unreliable and limited. In a meteorological and hydrological observing system, the biggest actual problem is the lack of information concerning the precipitation intensity and quantity in real time.

Radar meteorology have tried for years to find a useful formula concerning the relation between R and reflectivity factor Z. Unfortunately, there is no an universal relation concerning these parameters, although there is a common practice that higher precipitation quantities produce more intense echoes. By analyzing the necessary equations, we can see that it isn't enough to measure only one parameter in order to get the R-value for the purpose of exponential distribution of a raindrop size. It may also be stated that the characterization of a real distribution of a drop size requires an endless number of parameters and thus, a certain value of a reflectivity factor Z determined by the radar cannot provide a unique precipitation quantity measurement, R. There were significant efforts to find out whether some of the parameters of drop size distribution can be known for a certain type of rain (stratus, thunderstorm, etc.). Measurements of drop size distribution were made in different parts of the world under different weather conditions and Battan (1973) gave a list of about 69 different R – Z relations.There are also problems with clutters, noise, biological reflectors etc. Nowadays, radars with dual polarization give us a set of new type of radar data (Differential Reflectivity, Specific Differential Phase, etc.) that can help to improve the quantitative precipitation measurements. New software for radar data acquisition and visualisation can generate different radar products such as surface rainfall intensity, precipitation accumulation, etc, which can be a useful tool for precipitation estimation.

RADAR NETWORK IN SERBIA

Radar network in Serbia consists of 10 radars Mitsubishi, and 3 Doppler radars Gematronik. All of them are S-band radars, and that network cover hole territory of Serbia in mode for measuring radar parameters and quantitative precipitation estimation (Figure 1.) and in observing mode each of radars can cover up to 250 km range, so we have useful information about cloud systems that approaching to our territory. Radar observations and measurements are primarily used for observing and measuring characteristics of convective clouds in hail suppression activities in period from 15. April to 15. October, we also use them for now-casting, warnings and hydrological forecasts.

Hardware and software

Ten non-Doppler radars made by Mitsubishi in period 1978 to 1984 are all automated by DSP cards and Hail Suppression Information system (HASIS) since 2004. They cover south part of Serbia. In Vojvodina, there are 3 Doppler Gematronik radars made in period from 2000 to 2002. Location of the radars and their characteristics are shown in Table 1.

In case of Mitsubishi RC 34A radars, PPI and RHI products are made which have been generated by HASIS software ever since 2004. These products have a good resolution so they give us good information about clouds and precipitation on one single elevation or one azimuth angle.

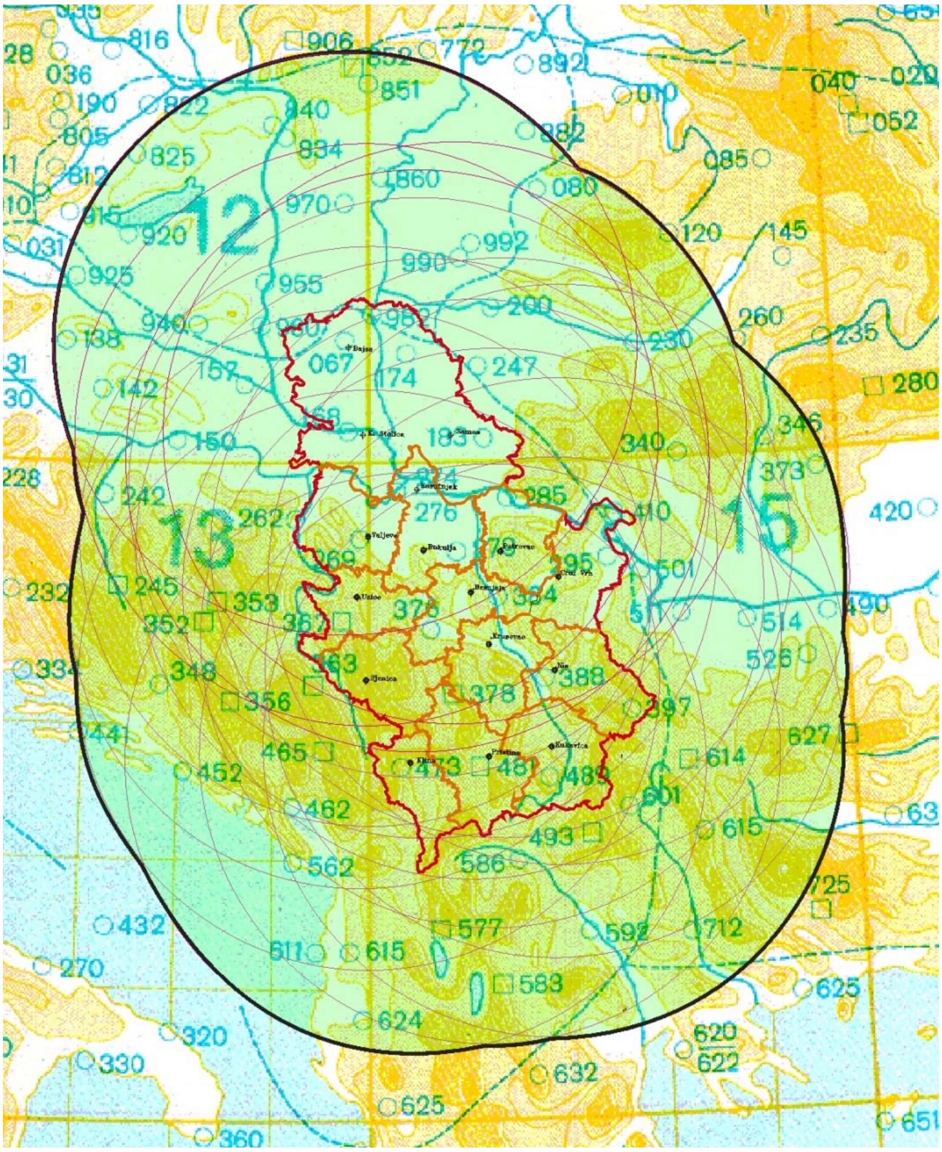

Figure 1. Covered territory in measuring mode

Gematronik radars perform volume scans about every 4 to 15 minutes for the use in hail suppression, as well as in forecasting and warnings. They collect radar reflectivity, radial velocity and spectra with data (good information about turbulence), and radar on Radar center Fruska gora also collect differential reflectivity data, which give us information about hydrometeors in the cloud. Operations of Gemtronik radars are controlled by Ravis (Radar Visualisation) and Rainbow software. The second one is used also for acquisition and archiving of radar data and generation of different meteorological, hydrological and aviation products.

For hydrological purposes we can use products such as Vertical integrated liquid (VIL), Surface rain intensity (SRI), Precipitation accumulation (PAC), River Subcatchment Accumulation (RSA) and Rainfall intensity histogram (RIH).

Table 1. Weather radars in Serbia

Radar center	Latitude	Longitude	Height	Doppler.	Dual pol	band	range	Starting year	Antenna diameter	Beam width
Fruska Gora	45.157	19.816	504	Y	Y	C	400	2002	6.1	1.3
Bajsa	45.786	19.601	105	Y	N	C	400	2001	6.1	1.3
Samos	45.189	20.777	105	Y	N	C	400	2000	6.1	1.3
Valjevo	44.374	19.924	387	N	N	C	250	1979	4	2
Bukulja	44.298	20.534	695	N	N	C	250	1979	4	2
Petrovac	44.326	21.342	280	N	N	C	250	1982	4	2
Crni Vrh	44.130	21.970	1027	N	N	C	250	1980	4	2
Uzice	43.887	19.846	832	N	N	C	250	1979	4	2
Besnjaja	43.997	21.053	559	N	N	C	250	1979	4	2
Krusevac	43.262	19.978	1244	N	N	C	250	1984	4	2
Sjenica	43.621	21.259	406	N	N	C	250	1979	4	2
Nis	43.405	21.952	813	N	N	C	250	1982	4	2
Kukavica	42.791	21.952	1438	N	N	C	250	1985	4	2

The aim of the VIL product is to give an instantaneous estimate of the water content residing in a user-defined atmospheric layer in the atmosphere. For this reason, the VIL product will need volume scan reflectivity data. These reflectivity data are converted into liquid water content data. For each vertical column the liquid water content is integrated within the user-defined boundaries of the atmospheric layer. The resultant vertically integrated liquid water VIL in [mm] is displayed in a PPI type image.

The SRI generates an image of the rainfall intensity in a user selectable surface layer with constant height above ground (Figure 2.). A user definable topographical map is used to find the coordinates of this surface layer relative to the position of the radar. This map is also used to check for regions, where the user selected surface layer is not accessible to the radar. These parts of the image will be filled with the NO_DATA value.

The PAC product is a second level product. It takes SRI products of the same type as input. The PAC product accumulates the rainfall rates of the selected SRI product. The timely accumulation is done according to a user-definable time period (look back time). Every time a new SRI product is generated, the PAC generation starts again. The display shows the colour coded rainfall amount in [mm] for the defined time period (Figure 3.).

The RIH product is a second level product. It takes SRI products of the same type as input. The RIH product provides information about the rainfall intensity at selectable locations within the radar coverage during a user-definable time period. The user can define various locations by mouse click in the SRI product display. The rainfall intensity versus time for the selected locations is displayed in multiple histogram style. Additionally, the accumulated rainfall rate in [mm] for the time period is indicated.

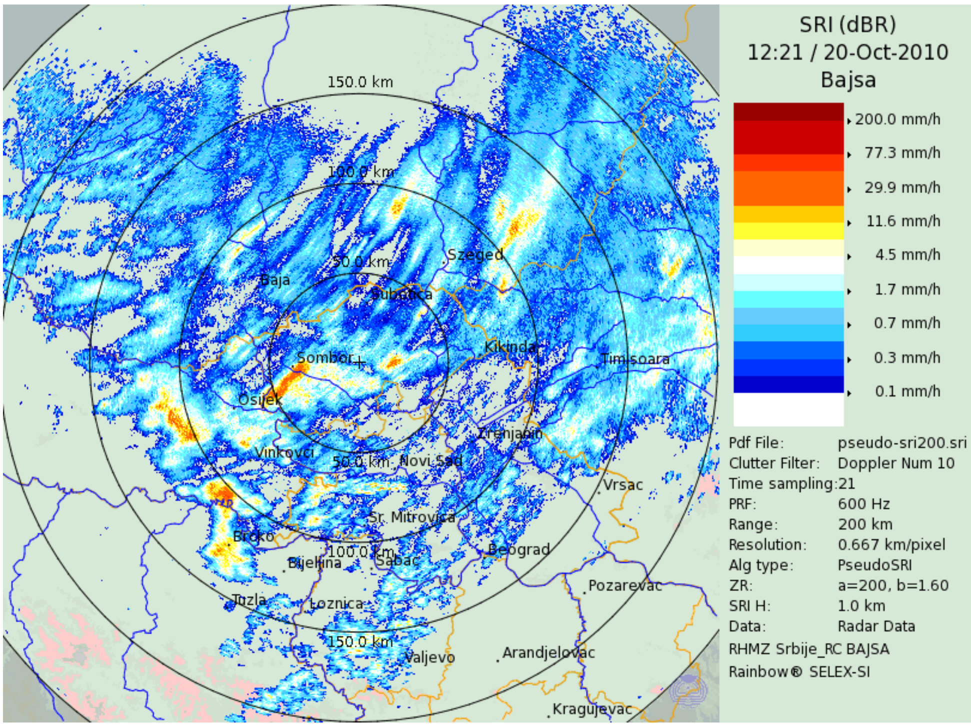

Figure 2. SRI (Surface Rain Intensity) product

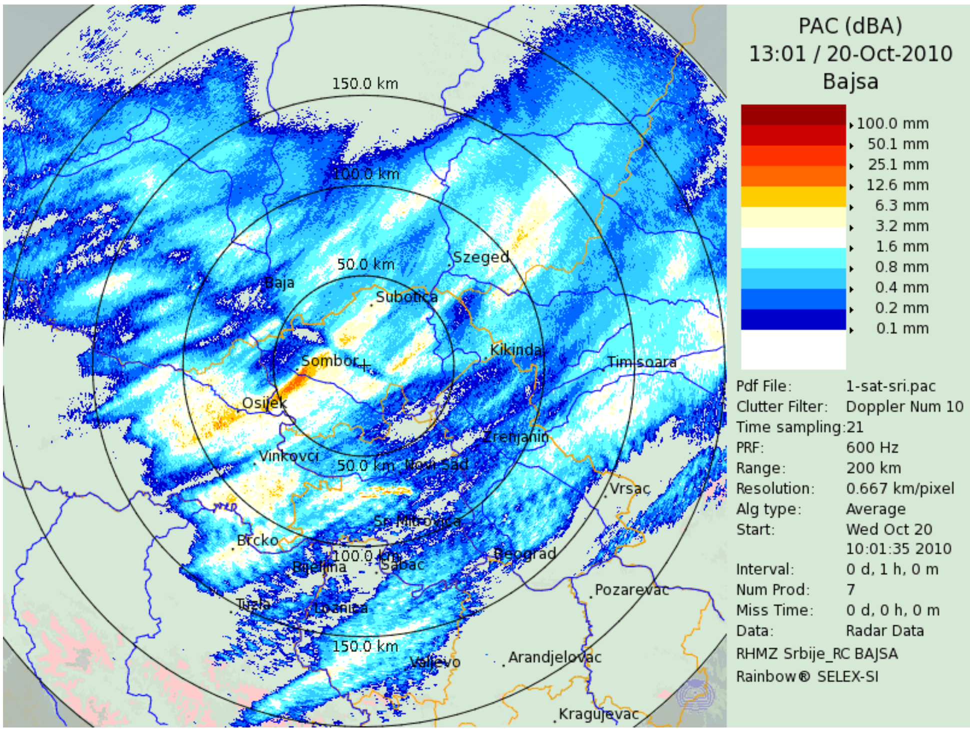

Figure 3. PAC (Precipitation Accumulation) product

The RSA product is a second level product. It takes SRI products of the same type as input. The RSA product provides information about the amount of rain in user-defined basins (typically river subcatchments). Additionally, it calculates the sliding average over the rainfall in a configurable time span for each region. The results are presented as a text table in the Display Manager.

Using volume scans and HASIS software, we can see and study characteristics of convective cells in three dimensions by means of CAPPI, MAX and vertical cut products

- Monitoring clouds motion and changes in 2D and 3D view
- Cloud parameters measurement (reflectivity, heights, distances, etc.)
- Automatic cloud shape extraction and hail potential size estimation
- Detection of cloud with hail potential
- Transforming raw radar data in geographic coordinate system using GIS to locate cloudiness and precipitation very accurately (Figure 4.)

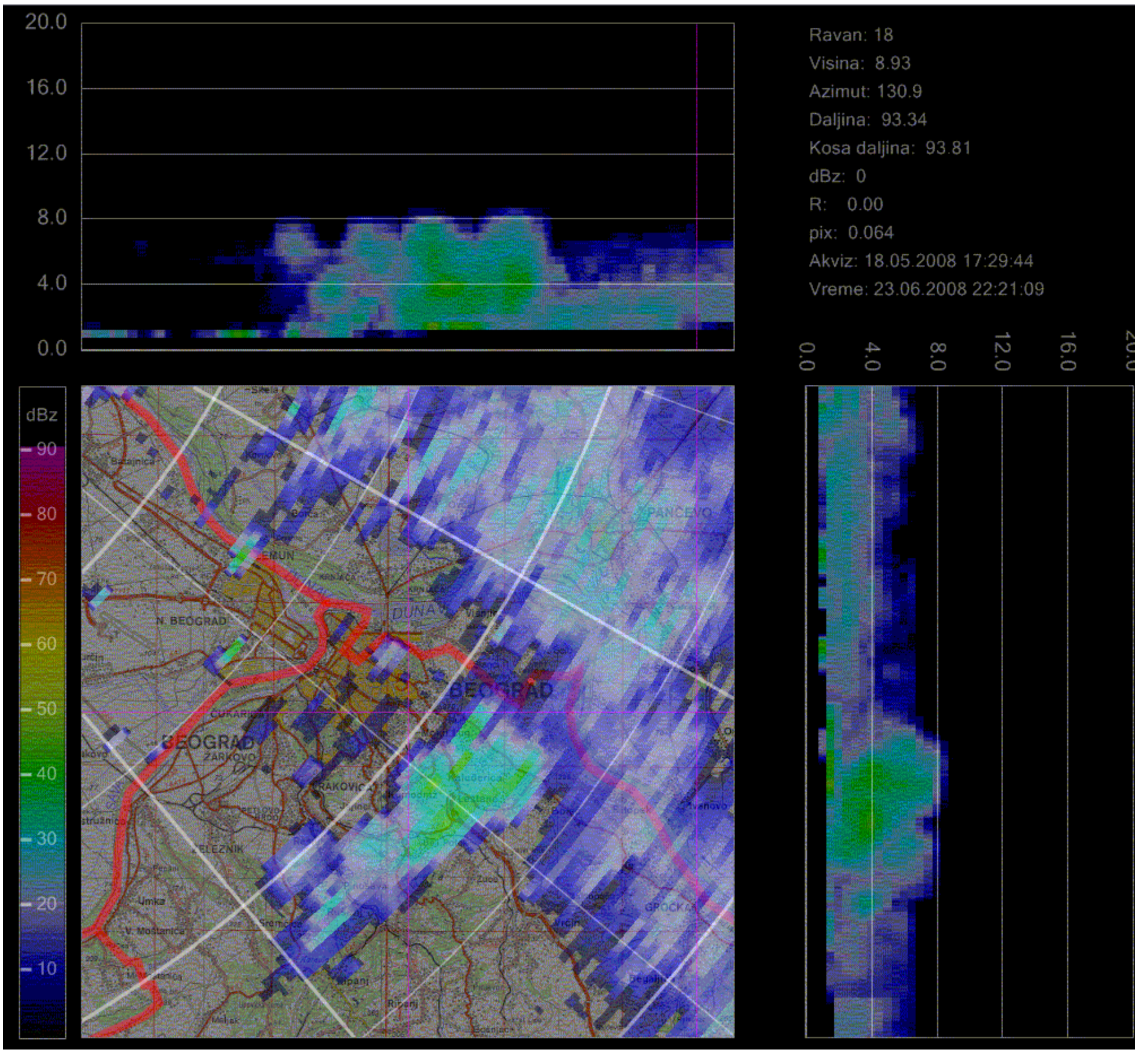

Figure 4. Locating the cloudiness using GIS

Modes of working

In period 15. October to 15. April, when there are not hail suppression activities radar measurements are done by radar centers Fruska gora, Samos, Nis and Sjenica. They are working in pairs alternately by 24 hours shifts and they collect volume data every 60, 30 or 15 minutes, depending on the cloudiness observed by radar. Generated radar product (CAPPI at 2 km height) has to be updated on the Internet site of RHMSS (Figure 5.).

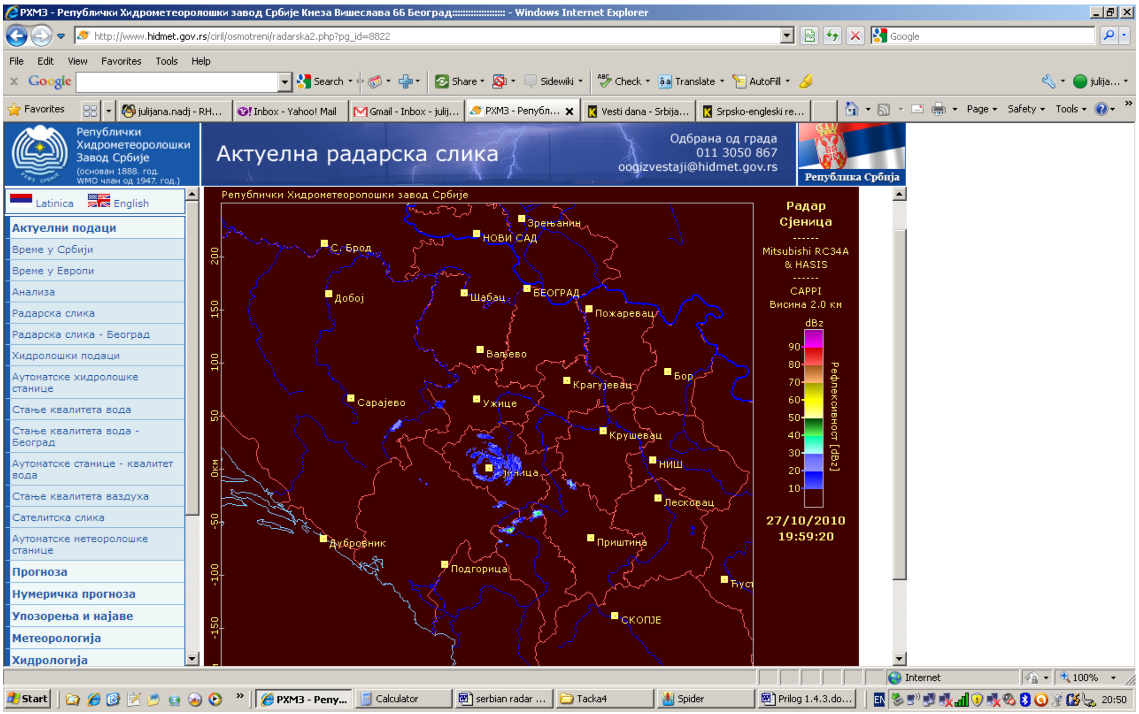

Figure 5. CAPPI product of Radar Sjenica on the Internet site of RHMSS

Working of the network in period of hail suppression activities (from 15. April to 15. October) is proposed by set of Instructions. In case of clear weather three of radars are covering the whole territory, but in case of convective clouds the defined radar centers (or all of them) are included in the process of the observing. Orderly centers collect volume data every 15, 30 or 60 minutes, and update the CAPPI products on the Internet site of RHMSS, and radar centers that have convective development on it's own territory made volume scans every 4 minutes, or PPI and RHI scans almost every minute, measure the characteristics of convective cells permanently and do the cloud seeding if it is necessary for hail suppression purpose.

This means that the whole territory of Serbia (and parts of surrounding countries) is covered by radar observations. Different radar products can be easily transferred by ftp to defined users depending on the customers need.

Future development

By installing the Rainbow 5 software on Gematronik radars we will have spectra of new radar products and also radar composite which will cover the north and central parts of Serbia.

By finishing the developing project HASIS 3DI (funded by Ministry of Science as all projects for radar automation and Hail Suppression Informative System finished up to now) will have composite radar images for Mitsubishi radars. Combined images of few radar parameters will be enable which is very important for hydrometeor classification and quantitative radar estimation.

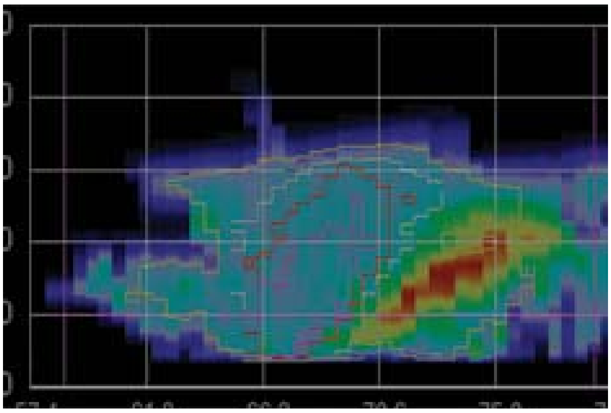

Figure 6. Combined view - VCUT – reflectivity and differential reflectivity

On the Jastrebac Mountain in next year there will be installed new radar with dual polarization, founded by World Bank credit for purposes of waterpower engineering. This radar will cover the south part of Serbia with dual-pol radar measurements and improve the quality of precipitation estimation and flood warning.

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Vertically Integrated Liquid (VIL) as an indicator of heavy rainfall and hail: case study of June the 19th 2010

Vesna Ivkov[1]

ABSTRACT:
On 19 June 2010 west parts of Serbia was covered by large thunderstorm with hail, heavy rainfall and strong wind. There was registered 37,5 l /m^2 precipitation amount in short period in the town Valjevo. This thunderstorms were studied across Serbia in order to determine the relationship between Vertically Integrated Liquid (VIL) and heavy rainfall evolution. The vertically integrated liquid (VIL) which is the sum of all radar reflectivity (converted to liquid water content) in a vertical column above a level can be a sensitive indicator to the potential of heavy rainfall and hail.

According to synoptic situation for that day, territory of Serbia was influenced by cyclone. The energy of instability by Belgrade's emagram was very strong. During the day, southwest flow and strong convective activity were distinctive.

Thunderstorm analysis is done by using radar data obtained by Doppler S-band radar on Fruska Gora. This was a Gematronic radar running RAINBOW software. Reflectivity volume data were collected every 4 minutes. The occurrence of precipitation and hail is observed by synoptic station and automatic rain gauge situated in the Valjevo.

Key words: large thunderstorm with hail and heavy rainfall; precipitation amount; vertically integrated liquid (VIL); radar reflectivity; Doppler radar

Introduction

Large thunderstorms were studied across Serbia in order to determine the relationship between Vertically Integrated Liquid (VIL) and heavy rainfall evolution, and Vertically Integrated Liquid (VIL) and hail occurrence.

During the afternoon hours on 19th of June 2010, a thunderstorm developed in district of river Drina. The storm grown and moved from southwest direction and very quickly, it enters the territory of town Valjevo and by moving from southwest transferred across west parts of Serbia. On the path across territory of town Valjevo, it stays about 1 hour, producing wind, heavy rain and hail. After that, mass of stratiform clouds reached territory of town Valjevo at about 1100 UTC, producing wind and rain. By synoptic station in Valjevo there was registered 33.7 l /m^2 precipitation amount in 3 hours period. On the location of synoptic station Valjevo, hail was registered betwen 1052-1058 UTC.

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According to synoptic situation for that day, territory of Serbia was influenced by cyclone. The energy of instability by Belgrade's emagram was very strong. During the day, southwest flow and strong convective activity were distinctive.

Vertically Integrated Liquid (VIL)

VIL is a function of reflectivity, and converts reflectivity data into an equivalent liquid water content value based on drop-size distribution and a reflectivity factor. This factor is proportional to the total number of targets within a measured volume and to the target diameters taken to the sixth power. Thus, target diameter has a much greater effect on reflectivity than does the number of targets. Reflectivity increases exponentially as target diameter increases. Thus, VIL increases exponentially with reflectivity, so high VIL values require high reflectivity values, usually implying the presence of large targets (hail) aloft. As a result, VIL is used to identify thunderstorms that likely contain large hail and/or a deep layer of large drop sizes.

The aim of the VIL product is to give an instantaneous estimate of the water content residing in a user-defined atmospheric layer in the atmosphere.

Method

Thunderstorm analysis is done by using radar data obtained by Doppler S-band radar on Fruska Gora. This was a Gematronic radar running RAINBOW software.

The storm evolution was analyzed by reflectivity volume data collected every 4 minutes from 1000 to 1300 UTC.

At first it will be shown how the algorithm for VIL calculation within RAINBOW is working, and then the produced results.

The selected layer is analysed by use of the polar volume raw data of Log (Z). The Log (Z) data should have been already corrected for clutter, signal quality improvements, atmospheric attenuation, earth curvature etc. before, as for any other Rainbow product. First the Log (Z) [dBZ] data are converted into Z [mm^6/m^3].

In the next step, the Z data are converted into M [g/m^3], liquid water content according to a selectable exponential relationship:

$$Z = C \cdot M^d$$

The choice of the parameters C and D has to take into account that the liquid water content differs significantly between the various classes of precipitation (rain, snow, and ice) that influence the choice of C, and d parameters.

According to rain, values used for C and d parameters were C=24000, d=1.82.

Finally, the water content is integrated over the atmospheric layer selected as minimum height and maximum height in the VIL product definition worksheet. Minimum height was the height of the cloud base and the maximum height was the height of the cloud top.

The resultant is vertically integrated liquid water in millimetre [mm].

The occurrence of precipitation and hail is observed by synoptic station and automatic rain gauge situated in Valjevo.

Results

On its path over territory of town Valjevo, this thunderstorm had high values for VIL. Values ranged from 37 to 61 mm, falling to about 5 to 10 mm, due to brief cloud weakness. That thunderstorm with larger VIL values generally produces larger precipitation amount and hail.

Values for VIL, precipitation amount and hail are shown on figure 1.

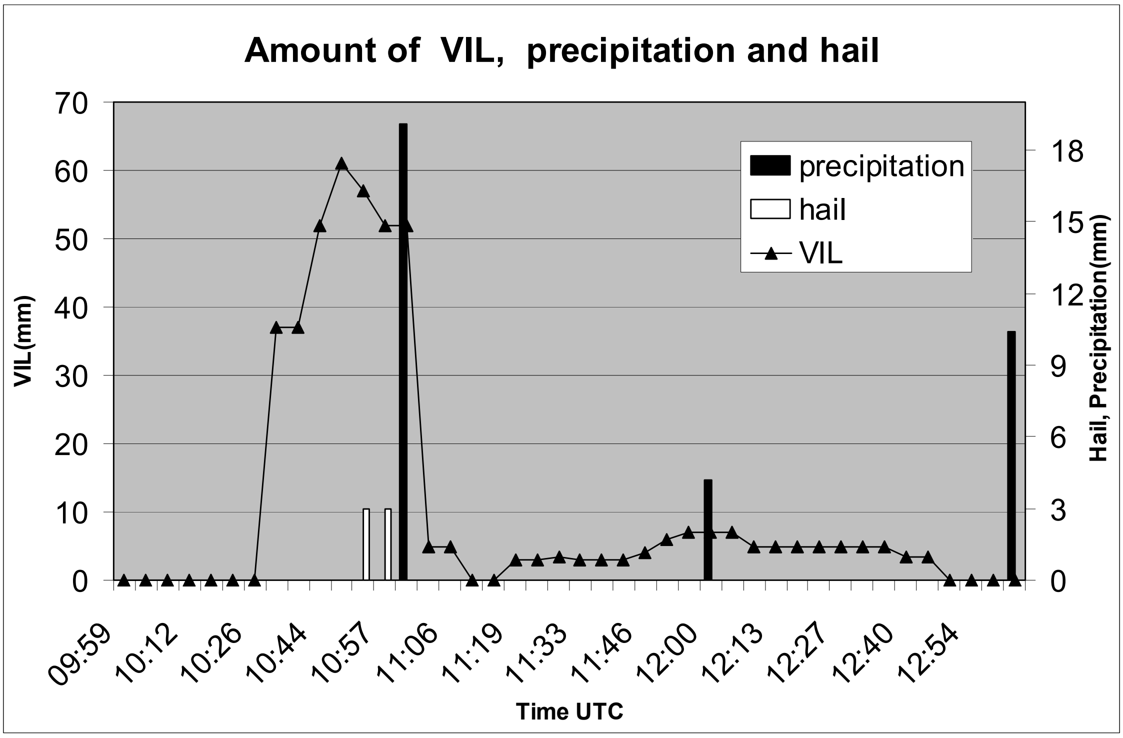

Figure 1.Amount of VIL, precipitation and hail

We can see that high values for VIL from 50 to 60 mm coincide with hail occurrence. Lover values of VIL are related with rain at the surface.

The movement and intensity of convective storm are main factors for the amount and location of heavy rainfall event.

At about 1030 UTC territory of town Valjevo was covered by thunderstorm with hail, heavy shower and strong wind. On the path across Valjevo, it stays about 30 minutes. By synoptic station in Valjevo there was registered 19.1 l /m^2 precipitation amount in 30 minutes period. In that period we can see high values for VIL from 37 to 61 mm.

After that, mass of stratiform clouds reached territory of town Valjevo at about 1100 UTC and stays about 2 hours producing rain and wind. Values for VIL in that period are lower and they ranged from 5 to 10 mm. By synoptic station in Valjevo there was registered 14.6 l /m^2 precipitation amount in that 2 hours period.

Like we said, VIL increases exponentially with reflectivity, and target diameter has a much greater effect on reflectivity than does the number of targets. As a result, high values for VIL coincide with hail and rain occurrence, and lover values coincide only with rain.

Values for reflectivity, VIL and precipitation amount are shown on figure 2.

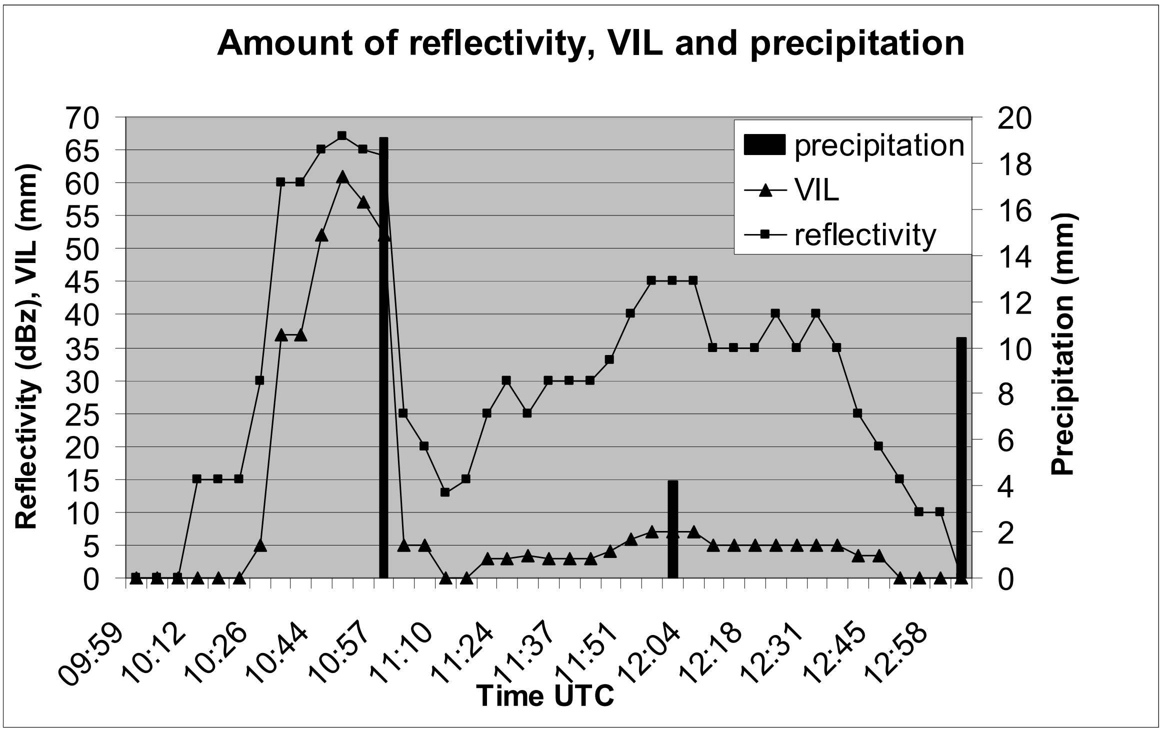

Figure 2.Amount of reflectivity, VIL and precipitation

Conclusions

This thunderstorm analysis shows connection between VIL and heavy rainfall evolution and hail occurrence, and confirms the results obtained by other studies. A high value of VIL correlates well with the occurrence of severe thunderstorms and hail. In stratiform situations VIL rarely exceeds a value of 10 mm.

VIL is an excellent tool to indicate the rainfall potential of a severe storm. It gives a short-term forecast of precipitation to be expected soon. However, VIL data must be used in conjunction with the other radar products and weather data.

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Belgrade hailstorm on 18. May 2008

Svetlana Sevanovic[1]

Julijana Nadj [1]

Mira Stepanovic-Nikolic [1]

ABSTRACT: About 18 hour on 18 May 2008 center of Belgrade was covered by thunderstorm with hail, heavy shower and strong wind. There was registered 22.6 l/m^2 precipitation amount in short period. In some regions of the city this caused pluvial flood. Hailstones were up to 4 cm and the wind crashed the threes. The storm was developed in the middle of the line of predominantly stratiform clouds which passed territory of Serbia in southwest direction. It was locally storm, the only one with high intensity that day.

The storm was observed by S band radars on Fruska gora and Bukulja. Doppler radar on Fruska gora with dual polarization (only ZDR is available) performed volume scans. Reflectivity, radial velocity, spectrum with and differential reflectivity volume data were collected every 4 minutes. Using Radar on Bukulja RHI and PPI scans were performed all the time when the hailstorm existed. Using HASIS 3D software we extract the Belgrade hailstorm from volume data, and analyzed them during its life-time. Maximum intensity, CAPPI on different height and different AB cuts were generated and analyzed for all parameters. Using Rainbow software additional radar products such as extended meteorological product VIL and hydrological products SRI and PAC were generated and analyzed. This product can give fast information about precipitation where rain gages do not exist.

Key words: hailstorm; pluvial flood; radar products.

INTRODUCTION

About 18 hour (16 UTC) on 18 May 2008 centre of Belgrade was covered by thunderstorm with hail, heavy shower and strong wind that crashed the threes. On the location of Meteorological Observatory, hail was registered between 17:52 – 17:58; hailstones were up to 4 cm and the wind velocity maximum was 15.7 m/s. There was registered 22.6 l/m^2 precipitation amount in 23 minutes period on the same location, but the network of automatic rain gauges that cover territory of Belgrade weren't registered any precipitation.
The storm was developed in the middle of the line of predominantly stratiform clouds which passed territory of Serbia in southwest direction. It was locally storm, the only one with high intensity that day.

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Figure 1. Center of Belgrade, 18. 05. 2008. at 18:00 (16 UTC)

Synoptic situation

Influence on weather in great part of Europe take the cyclonic activity over Baltic Sea. In the area of Balkan Peninsula and Pannonia plate two secondary low pressure centers over Genova and southwest Hungary take a dominant influence with occluded front between. Over area of our county air mass is warm and unstable, and a according to soundings moisture increase, with presents of moderate shear in low levels. In front of the occluded front in term 12UTC and 18 UTC thunderstorm activity is observed.

During the day heating over city area effect of the termic island and influence of instability caused with occluded front produced the severe thunderstorms over the city area. In this case, conditions favorable for severe thunderstorms developed rapidly, over a period of a few hours.

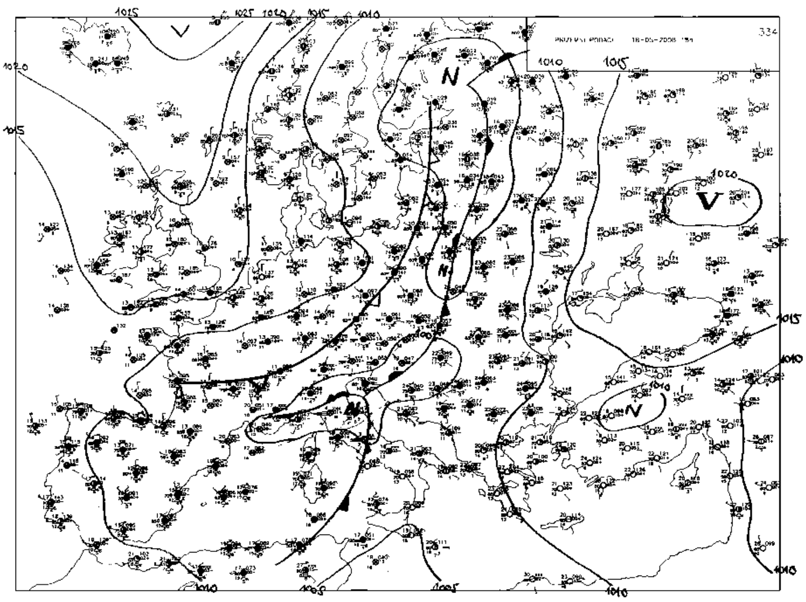

Figure 2. Synoptic situation at 18:00 UTC

Radar observations

Data collection and radar products

The storm was observed by S band radars on Fruska gora and Bukulja. Doppler radar on Fruska gora with dual polarization performed volume scans. Reflectivity, radial velocity, spectrum with and differential reflectivity volume data were collected every 4 minutes using the scan with 12 elevations (starting elevation 0.5 and final 25.5 degrees) and Doppler filter 15. Using Radar on Bukulja RHI and PPI scans were performed all the time when the hailstorm existed. Using HASIS 3D software we extract the Belgrade hailstorm from volume data, and analyzed them during its life-time. Maximum intensity, CAPPI on different height and different AB cuts were generated and analyzed for all parameters. Using radar software package Rainbow 3.4 additional radar products were generated such as extended meteorological product VIL (vertical integrated liquid) and hydrological products SRI (surface rainfall intensity) and PAC (precipitation accumulation).

VIL (vertical integrated liquid) is a radar product which gives us information about water content existing in an atmospheric layer defined by user. Relationship between reflectivity and liquid water content is:

$$Z=CM^{D} \qquad (1)$$

Where C, D are parameters for the certain type of precipitation, for our rain case the values are C=24000, D=1.82. VIL is excellent tool to indicate the rainfall potential of severe storms. In our case, vertical extent is from 0 to 12 km, the displayed range is 75 km and the display resolution is 0.214 km.

SRI (surface rainfall intensity) informs us about rainfall intensity in an atmospheric layer defined by user with constant height above ground (1.5 km in our case). SRI use relationship between reflectivity Z and rainfall intensity R:

$$Z=aR^{b} \qquad (2)$$

Where a, b are parameters given by Marshal-Palmer relation; a=200 and b=1.6.

PAC (precipitation accumulation) informs us about rainfall amount for the defined time period (defined by user). Product accumulates the rainfall rates of the selected SRI products i.e. for the chosen time period. For the better overlook at time on precipitation produced by this storm PAC was taken for 10 minutes period, and also for one hour interval, which coincide with interval of storm existence.
Overlay for the all hydrological product contain the net of automatic rain gauges on Belgrade city area, in which the real position of gauge is given by doth in certain circle. Neither of rain gauges has recorded any rainfall for this date (rain gauges 2 and 5 were out of function).
Radar data analysis

The line of predominantly stratiform clouds reached territory of Serbia at about 13:00 (11:00 UTC), and it moved to north-east slowly. Between 15:30 and 18:00 about 100km far ahead of that line, on territory of Romania, a few strong convective cells was developed, but the line was still weak, with maximum reflectivity about 40 dBz, and echo top height 8 km. (Figure 3.)

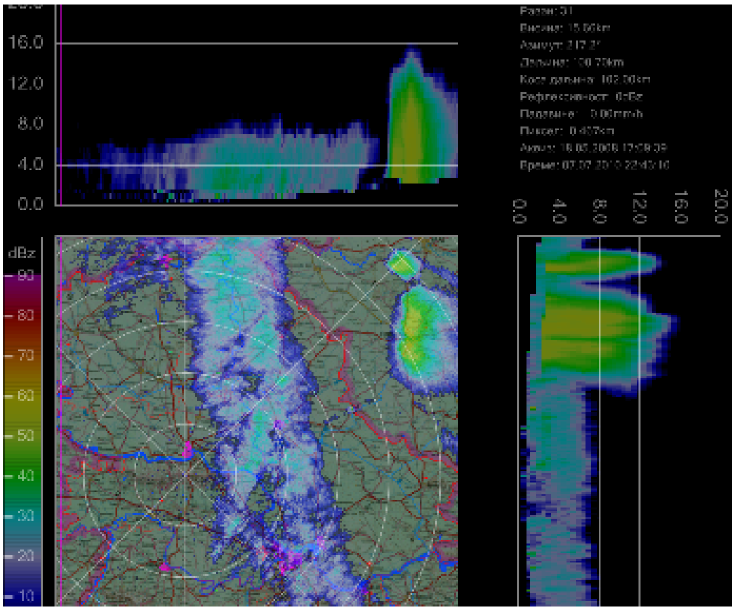

Figure 3. Max product of radar reflectivity at 17:21

At 17:29, (15:29 UTC) when the central part of this line was passed Belgrade, on the product of maximum reflectivity we can find a developing convection behind the line of clouds. On the product extracted from the volume scan that was performed 4 minutes later south from Belgrade, the second cell appeared, which was became a large hailstorm in a short period. Maximum reflectivity of that cell was 32 dBz on height at about 5 km. Value of differential reflectivity was from -1 to 3 dB, radial velocity -5m/s.

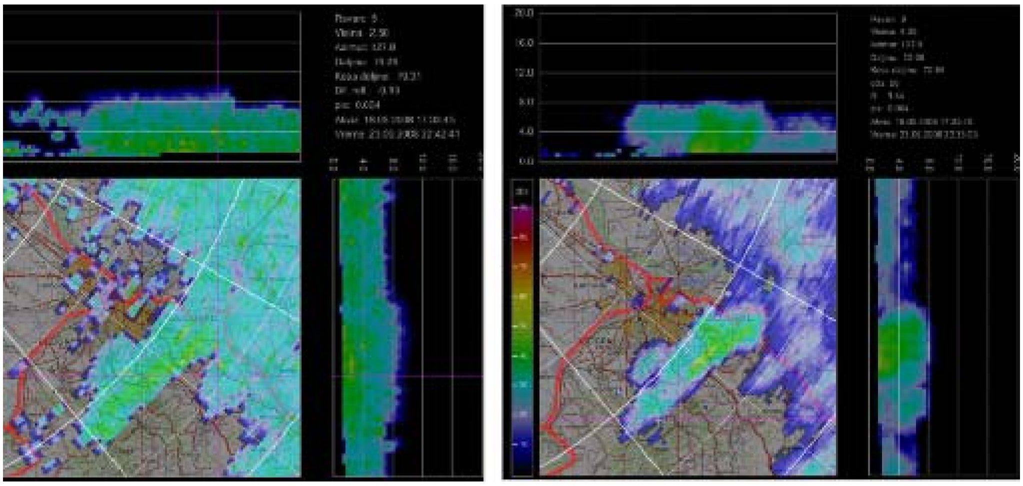

Figure 4. Max product of differential reflectivity (left) and reflectivity at 17:33

At 17:41 (Figure 5.) the height of cell was up to 10 km with maximum of reflectivity about 50 dBz. A narrow Zdr column was observed on the right side of the storm just above the 0º C level, and the idea was to analyse them, and also to correct the precipitation data using values of Zdr, but on the next image (Figure 6.) the data artefact was appeared, caused by three-body scatter spike (TBSS), and it became stronger, because of the large hail produced by the storm.

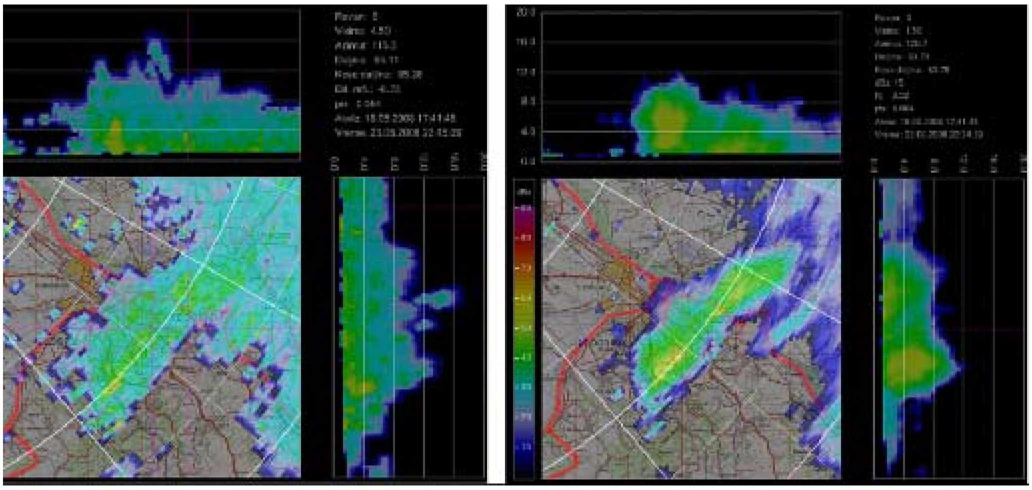

Figure 5. Max product of differential reflectivity (left) and reflectivity at 17:41

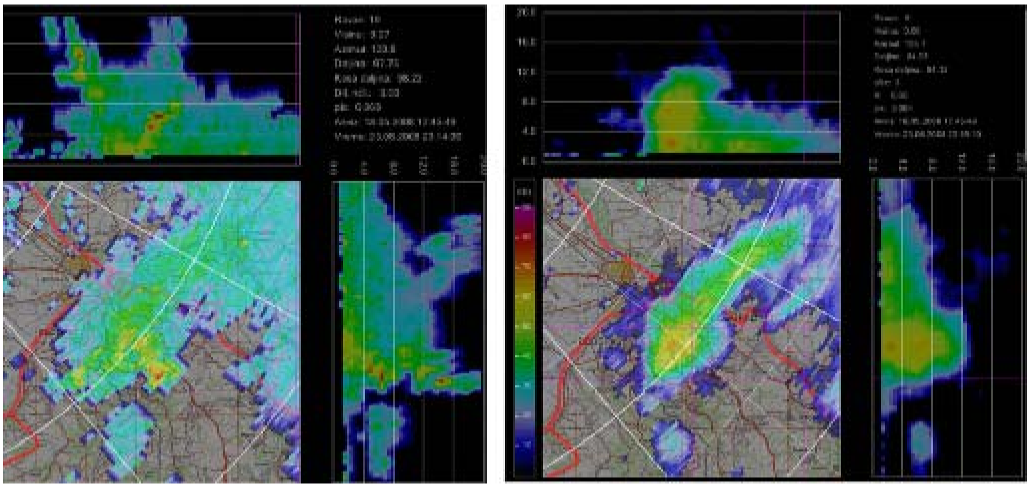

Figure 6. Max product of differential reflectivity (left) and reflectivity at 17:45

At 17:53 maximum reflectivity of the convective cell was 68 dBz, and in the same region near the ground differential reflectivity was 0 dB. Corresponding to the radar data of reflectivity and differential reflectivity, large hail started to fall on the location of the Meteorological Observatory in center of Belgrade at 17:52 (15:52 UTC).

On the Figures 8. to 12. VIL, SRI and PAC product are shown for the same time stamp as the products above. During the observation time of this thunderstorm the cloud mass overtake only the position of rain gauges number 5, 6 and 10. West from the rain gauge number 5 is the Meteorological observatory which only have recorded rainfall.

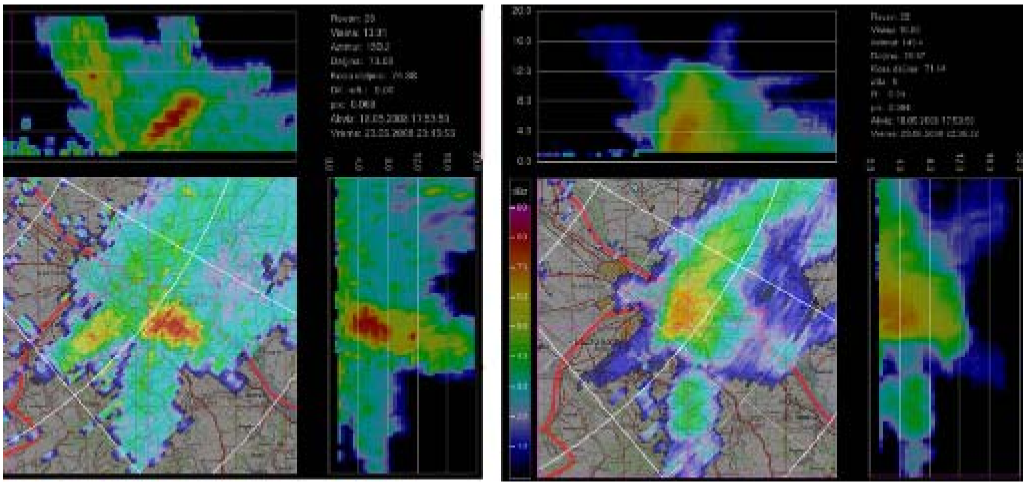

Figure 7. Max product of differential reflectivity (left) and reflectivity at 17:53

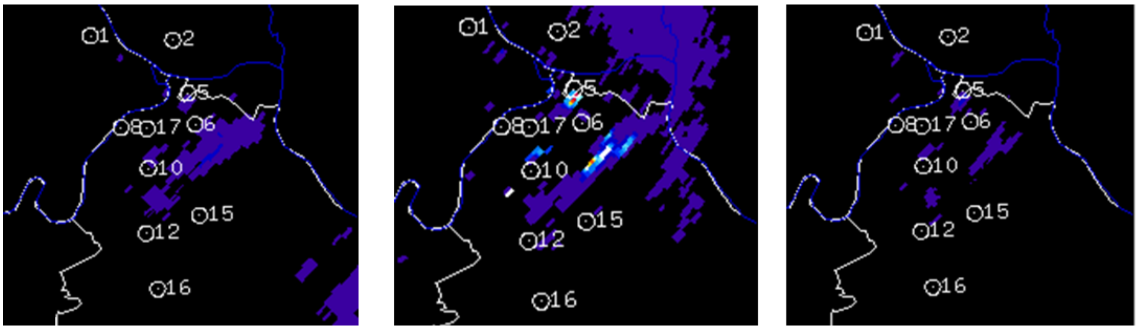

Figure 8. VIL, SRI and PAC product at 17:33

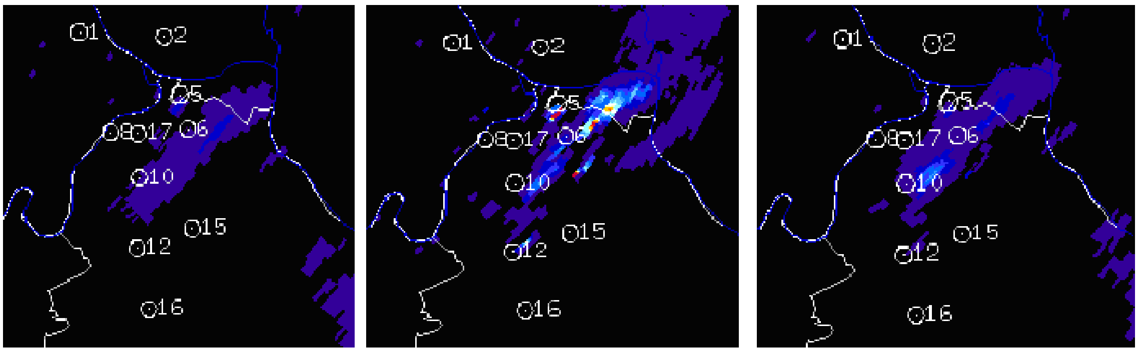

Figure 9. VIL, SRI and PAC product at 17:41

The VIL product above the position of the rain gauge 10 in time 17:41 shows values of vertical integrated water in the lowest interval of scale which indicates low rainfall potential. According to the values on SRI and PAC product, there weren't expected precipitations corresponding to the measured amount for this rain gauge with absence of recorded precipitation.

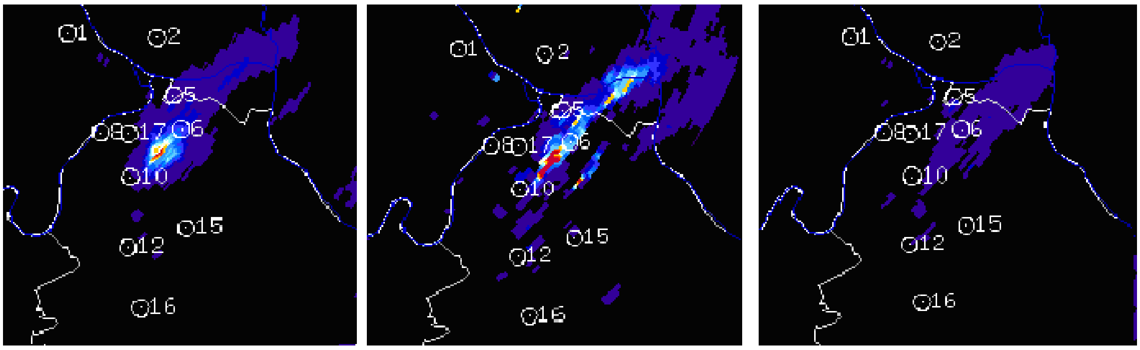

Figure 10. VIL, SRI and PAC product at 17:45

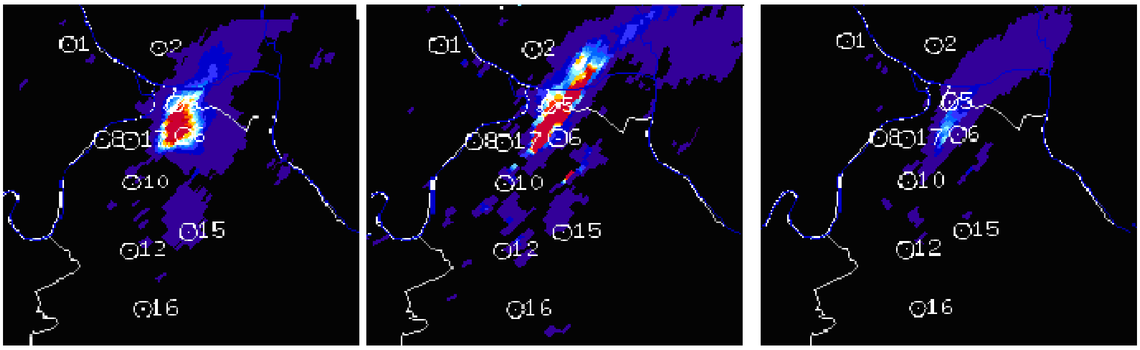

Figure 11. VIL, SRI and PAC product at 17:53

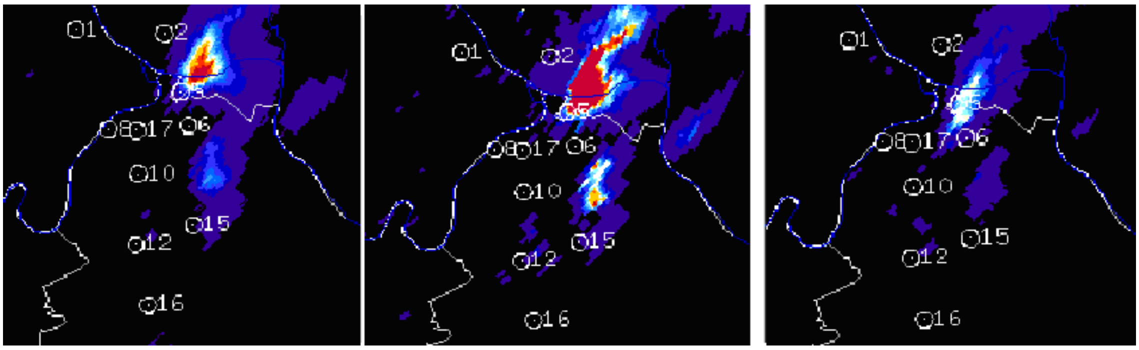

Figure 12. VIL, SRI and PAC product at 18:01

Above the rain gauge number 6 in the period from 17:41 to17:53 we have VIL values from lowest interval of scale to 52.0 -56.3 mm at 17:53; for same interval SRI values show rainfall intensity from lowest interval (0.1 -4.4 mm/h) to 21.7-26.1 mm/h at 17:45 and PAC values of accumulated rainfall are 0.1-4.4 mm in period from17:45 do17:53 (Figures 10. and 11). Only the values of PAC product with its minimum can be considered to compare for this rain gauge, because the recorded precipitation amount is 0 mm. Values of other two products, do not coincide with measured precipitation amount, but we can interpret this like possibility of storm too produce precipitation.

Rain gauge number 5 is in the best position relative to the storm movement, according to all shown products (VIL, SRI, and PAC, Figures 10. to 12.). In period from 17:45 to 18:01 products VIL and SRI obtain fast maximum values both at 17:57 (56.3-60.7 mm for VIL and 60.7-65 mm/h for SRI) and PAC product also rapidly take maximum but at 18:01 (maximum value is 21.1-26.1mm, Figure 12.). Unfortunately, we don't have data recorded by this rain gauge, because it was out of function.

On the location of Belgrade meteorological observatory (marked as green point on Figure 13.) there was registered 22.6 l/m^2 precipitation amount in period from 1652 to 1800 (with abruption and variation in intensity) which is considerably similar to the value of PAC product at 18:01. This fact can be taken in to consideration especially in case that we do not have measuring at the ground.

According to these, the existing rain gauges net was not suitable to get information about analysed thunderstorm. Flood caused by maximum rainfall intensity and hail appearance was happened between rain gauges position. Radar estimation of precipitation in case like this can help us to have useful data and to fill missing of ground measurements.

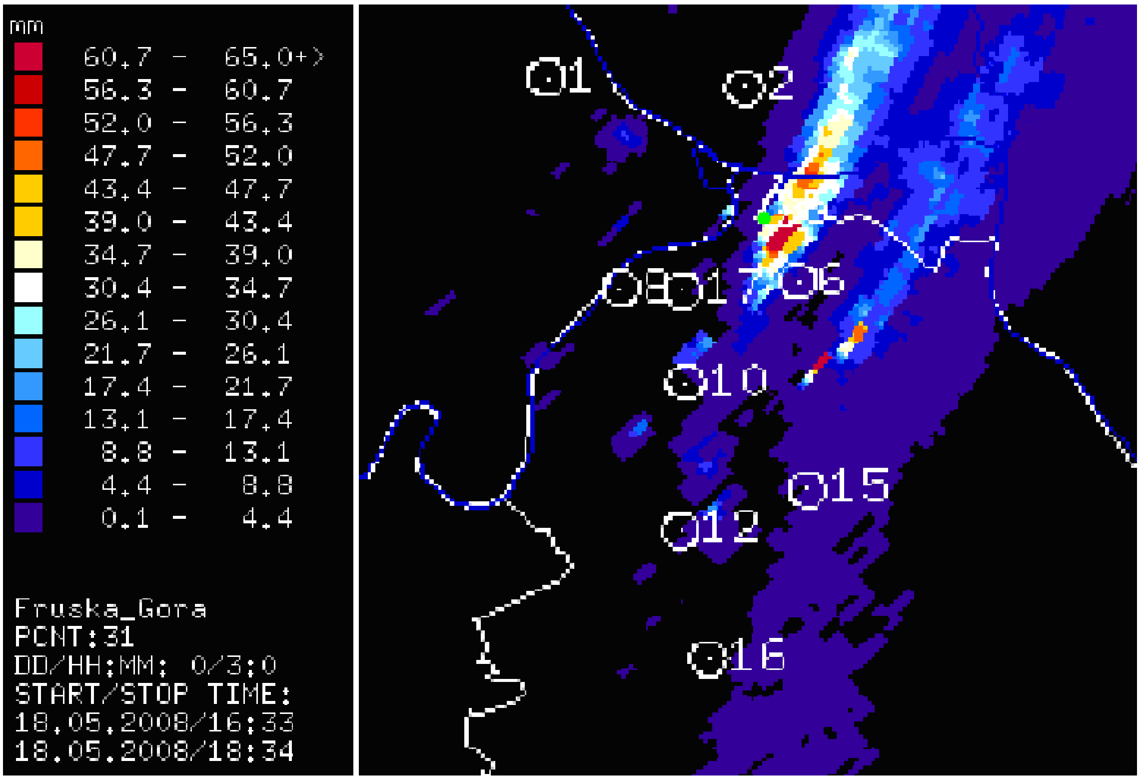

Figure 13. PAC product for the storm life-time

CONCLUSIONS

The thunderstorm that covered the center of Belgrade on 18 May 2008 was developed behind the central part of stratiform cloud line and caused hail, heavy shower and strong wind was reached its maximum intensity in very short period. Time between the Zdr column appearance and the hail observed on the location of Meteorological Observatory was about 10 minutes. First indication of a large hail in center of Belgrade was values of reflectivity and differential reflectivity. This kind of information is very important for these atmospheric processes, because infrequent rain gauge net is problem which can be partially mitigated by radar observation, but it is necessary to take correction for the both data radar and rain gauge. Also we must take care about errors that exist in radar estimation of rainfall intensity. Today we have programs that consider many uncertainties which appear during the precipitation estimation. However, radar products shown in this paper, can give us important information for fast reaction in jeopardized from flood area (urban and rural) and for critical traffic point. Warning about this kind of meteorological event can be provided by radar observation.

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Rainbow operator manuel Volume 2, Extended meteorological products, hydrological products

Hydrological applications of weather radar – case study July 08th 2009

Olga Brujić[1]

ABSTRACT: Rainfall is spatial and temporal meteorological variable element. If reliable information about intensity or amount of rainfall in certain area has to be collected, network with close rain gauges arrangement and short intervals of observation are required. That kind of network exists, but it can be unreliable if the rain gauges don't maintain properly.
Radar can provide rainfall measurement, also. Simultaneously it can track development and relocation of cloudiness. The main advantage of using radar for precipitation estimation is that radars can obtain measurement over large areas with fairly high temporal and spatial resolution. Another advantage is that measurement results are sent to the central location in a very short time, so it can be issued a proper warning about possibility of the occurrence of heavy rainfall.
Various researches indicate that rain rates can be estimated in every time instant using values of radar reflectivity, differential reflectivity, and some empirical equations. Calculated values can be compared with values of rain gauges.
The idea of this work is to present values of radar reflectivity and some hydrological products (surface rainfall intensity - SRI, precipitation accumulation – PAC) in the case of convective rainfall which occurred July 08th 2009 in Belgrade. Some rain gauges recorded above 30 l/m^2 of rainfall in just 30 minutes.
Radar data are provided using volume scanning at METEOR 500 S-band radar. Scanning is done in the range of 250 km, with 12 elevations, starting from 0.5 degrees, up to 25.5 degrees. Pulse duration was 0.83 μs and pulse length was 250 m. Radar products are collected from scanning which last four minutes.

INTRODUCTION

In order to issue proper warnings of possible flash floods and mitigate material damage it becomes necessary to have a rainfall field in almost real time that covers all the area being considered. That is why there is increasing interest in getting good estimates of precipitation at a ground level by using remote sensing tools.

Although rain gauges are characteristic instruments for measuring precipitation, they are inadequate for hydrometeorological purposes. Since they are measuring only isolated precipitation values, it is difficult to obtain a continuous field of measurements covering the whole observed territory, especially in areas of complex topography. On the other hand, radar can obtain measurement over large areas with fairly high temporal and spatial resolution. Another advantage is that measurement results are sent to the central location in a very short time, so that proper warning about the occurrence of heavy rainfall can be issued at the time.

The meteorological radar can cover the area up to 250 km of radius, although at the distance further than 100 km, quality of the rainfall estimate is usually much reduced. However, it is important to know that various errors can occur when the radar rainfall estimation is done. These can be grouped into three categories:

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- Errors caused by the radar system itself (bad electronic calibration),
- Errors related to the interaction between the radar wave and the environment (ground clutter, animals, airplanes, orographic blocking, rain attenuation),
- Errors in converting the reflectivity measurements to the precipitation intensity values on the ground (Z-R relations).

During selection of the level on which precipitation will be observed, the level of bright band has to be avoided. The bright band is a layer where the radar reflectivity strongly increases. This phenomenon occurs when the solid hydrometeors particles cross the melting layer they begin to melt, and are covered by a thin film of liquid water. The radar interprets them as very large drops of liquid precipitate and reflectivity values suddenly increase. The solid and liquid precipitation has different dielectric constants and different speed of falling, which makes the reflectivity values detected by the radar different depending on the stage of precipitation.

This paper contains analysis of two hydrological radar products (Surface Rainfall Intensity-SRI and Precipitation Accumulation-PAC) in the case of convective rainfalls which occurs on July 08th, 2009 in Belgrade. Some rain gauges recorded above 30 l/m^2 of rainfall in just 30 minutes. Simultaneously, wind with speed up to 70km/h crashed the trees. The great material damage was done.

RADAR PRODUCTS

Two hydrological products of Doppler weather radar are described in this paper: Surface Rainfall Intensity (SRI) and Precipitation Accumulation (PAC).
The SRI generates an image of the rainfall intensity in a user selectable surface layer. The SRI data are processed on this terrain-following layer, i.e. at a constant height above ground. The ground heights are usually calculated from orographical map (DEM model). This map is also used to check for regions, where the user-selected surface layer is not accessible to the radar.

The SRI worksheet contains parameters for a conversion from reflectivity (Z=10^dBZ/10) to rainfall rate. Usually, this conversion is performed by a Z-R relation of the form

$$Z = a \cdot R^b \qquad (1)$$

where Z in [mm6/m3] is the reflectivity and R in[mm/h] is the rainfall rate. In all cases the relation Z-R is the one use by Marshall and Palmer:

$$Z = 200 \cdot R^{1.6} \qquad (2)$$

The precipitation falling during a specified period of time is permanently processed, with scheduler repetition time. The PAC is a second-level product, which can be applied on different input products. Every time a new input product is available an updated PAC product is calculated.

First, the input products are sorted by their Scan Date and Time (oldest first, latest last). For each image pixel, N-1 accumulation steps are performed (having N products P_0, P_1,…,P_{N-1} in total):

$$A = \sum_{i=1}^{N-1} A_i \qquad (3)$$

where A_i is the accumulated rain of the i^{th} accumulation step. A_i is the accumulation for the two products P_i-1 and P_i and is calculated as follows:

$$A_i = (t_i - t_{i-1}) \cdot \frac{(R_i - R_{i-1})}{2} \tag{4}$$

where R_i is rainfall intensity.

SYNOPTIC SITUATION

One low pressure system, with centre over Scandinavia, was present. It influenced the weather across Central Europe that day. As a part of the cyclone, a deep trough extended up to Alps region, with cold front moving to the east. Southwest flow was present over the Balkans, bringing hot and moist air mass to the region. Strong cold front speeded up to the east, in reaction to the strengthening of the surface low. High values of CAPE index (>2000 J/kg), and strong vertical shear were allow for well-organized thunderstorms, including a supercell. Large hail and severe wind gusts are related to the appearance of the supercell.

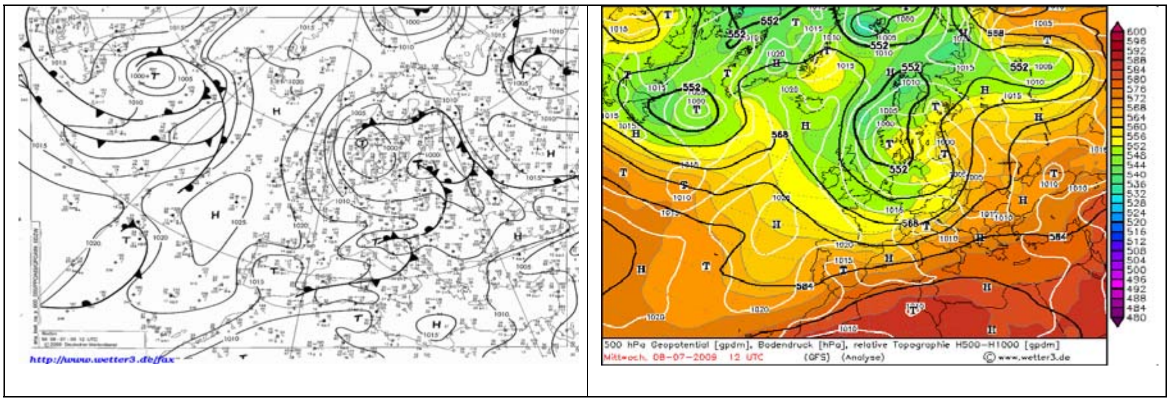

Figure 1. DWD surface analysis (left) and 500 hPa Geopotential, Relative Topography H500-H1000gpm (right)

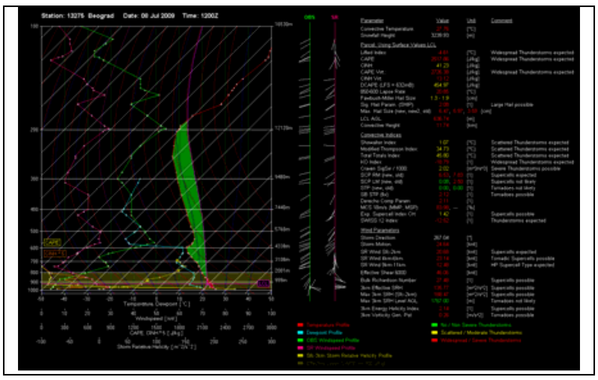

Figure 2. 12 UTC sounding for the Belgrade station

RADAR OBSERVATION AND RAIN GAUGE MEASUREMENTS

A couple of convective storms developed immediately in front of the cold front on that day. About 14:00 CET two convective cells developed above the Bosnia's territory. In the western-southwestern flow they propagated over the Drina River. They became stronger and developed into supercell thunderstorms above the territory of Serbia with values of radar reflectivity up to

70dBZ. One of them crossed southwards, and the other one above territory of Belgrade city. The storm produced large hailstones, great amounts of rainfall and strong winds.

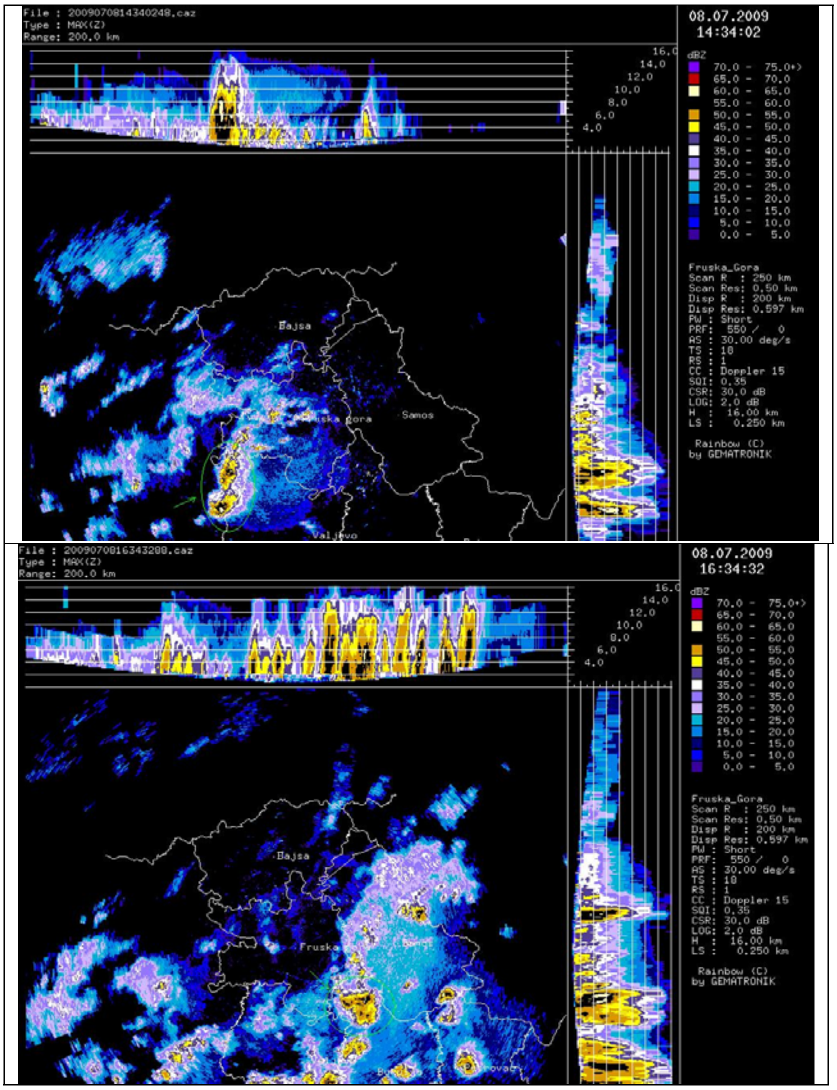

Figure 3. Max product of radar reflectivity at 14:34CET (above) and at 16:34CET (bottom)

The storm was observed with Doppler weather radar sited on Fruska gora. This is dual-polarized radar that operates in S band. This radar performs 12 scans between 0.5° and 25.5° per 4 minutes, and a Doppler filter is applied to remove fixed echoes. Rain rates obtained from radar reflectivity are compared with data measured by tipping buckets which are installed on territory of Belgrade. Reading from the tipping-bucket is recorded in the moment when the bucket is filled to the value of 0.2 mm (in this case every minute).

Between 16:25 and 16:58 CET tipping bucket on Kosutnjak registered 33.8 l/m2 of rainfall.

SRI product was measuring rainfall rate 1.5 km above the ground level, below level of freezing. This product is collected from scanning which last four minutes. The measurements are compared with data of four tipping buckets (Kosutnjak, Kumodraz, Dusanovac and Pionir) installed on territory of Belgrade. Readings from the tipping bucket is recorded every minute, so that certain adjustment of rain gauges data to radar data is undertaken. In that respect four samples of the rain gauge data is considered for averaging. Taking into account each fourth sample together with last three samples, and averaging the sum provides common mm/minute average rainfall rate.

$$AS_i = \frac{1}{4}(S_i + S_{i-1} + S_{i-2} + S_{i-3})$$
$$AS_i = \frac{1}{4}\sum_{j=i-3}^{i} S_j \qquad (5)$$

While S_i is rain gauge sample and AS_i is averaged value.

To convert the unit it is enough to multiply AS_i to 60, to have rainfall rate in unit of mm/h.

$$TS_i = 60 \times AS_i$$
$$TS_i = 60 \times (\frac{1}{4}\sum_{j=i-3}^{i} S_j) \qquad (6)$$

While TS_i is treated sample and presents rainfall rate every minute with unit of mm/h.

Results of analysis indicate that rain rates determined by radar observation, follow the trend of intensity obtained by rain gauges. Radar observations generally underestimate the values of intensity. For rain gauges Kosutnjak and Kumodraz, which recorded the strongest rainfall, matching radar measurement data with common rain gauges values are very good.

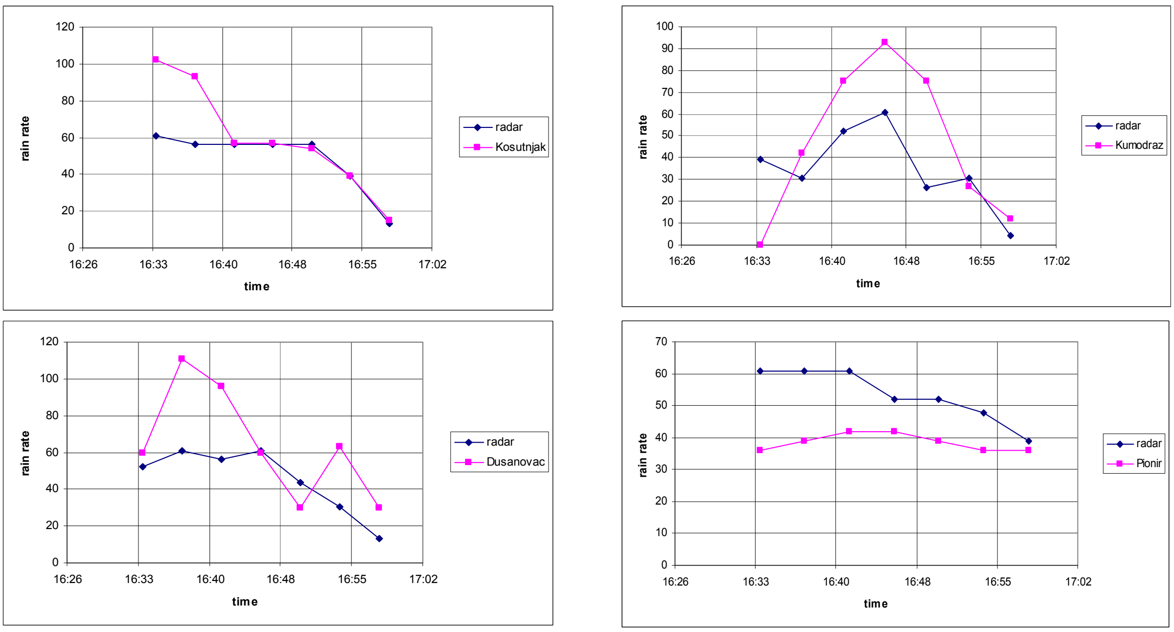

Figure 4. Rain gauges rainfall intensity vs. radar SRI values

PAC product, which calculates accumulation for time interval of 30 minutes (16:30-16:58) gave values between 21.7 mm and 26.1 mm for location that match with location of Kosutnjak rain gauge. In the observed period rain gauge registered 29.4 l/m2 of rainfall. Table 1 shows the comparison of 30 minutes precipitation values measured by the other rain gauges with the corresponding values of PAC product.

Table 1. Rain gauges precipitation amounts vs. radar PAC values

Rain gauge	30 min. precipitation amounts (mm)	PAC values (mm)
Dusanovac	29.6	21.7-26.1
Kumodraz	23.4	21.7-26.1
Pionir	31.0	30.4-34.7

The phenomenon was analyzed only at representative set of rain gauges. The other rain gauges provide unreliable measurement data during observed time interval.

The analysed period is a short data sample. That is the reason why significant conclusions in respect to considered phenomena cannot be provided. So, this research must be continued in the future.

CONCLUSIONS

The research must be continued on a larger number of rainy days, what will enable to make significant conclusions of considered issue. Statistical methods can be used to determine deviation of radar data in comparison to the rain gauge data. Values of coefficients for Z-R relation can be varied with aim to determine which values describe the precipitation in the region at the best possible way.

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STORM RUNOFF QUANTITY AND QUALITY

Continuous monitoring of storm runoff quality: recent results on two experimental urban catchments

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Marjolaine Métadier [2]

ABSTRACT: Since the late 1960s, monitoring campaigns based on sampling collection have been carried out to identify and quantify the presence of various pollutants (mainly TSS, COD, N, P, metals and PAHs) in storm runoff, in both combined and separate sewer systems. More recently, similar campaigns have been devoted to priority and emerging pollutants (European Water Framework Directive priority substances, organic pollutants, pesticides, pharmaceuticals, etc.). These campaigns have been very useful to progress in knowledge (concentrations and loads of pollutants), modelling and management of urban stormwater, but present some critical limitations, especially regarding their representativeness at short time scale, their ability to fully account for the very significant variability of pollutants concentrations and loads, and their cost. Since the late 1990s, continuous on-line monitoring of storm runoff quality has been developed, aiming to propose solutions to the above limitations. It is frequently based on turbidity or UV-visible spectrophotometry measurements, to estimate e.g. TSS and COD loads. The paper presents the metrological and monitoring methods and results obtained for two experimental urban catchments in Lyon (Ecully 245 ha residential area with a combined system, Chassieu 185 ha industrial area with a stormwater separate system), with more than 230 events recorded on each catchment in the period 2004-2008 with a 2 minute time step. The variability of the concentrations, loads and pollutographs is highlighted. The variable contribution of the dry weather effluents in case of a combined system is evaluated.

Keywords: Sewer systems, urban drainage, stormwater, dry weather, monitoring, sensors, continuous monitoring, data processing, data validation, uncertainties.

Introduction

Since the late 1960s, monitoring campaigns based on sampling collection have been carried out to identify and quantify the presence of various pollutants (mainly TSS, COD, N, P, metals and PAHs) in storm runoff, in both combined and separate sewer systems. More recently, similar campaigns have been devoted to priority and emerging pollutants (European Water Framework Directive priority substances, organic pollutants, pesticides, pharmaceuticals, etc.). Data sets and data bases have been established and used in several countries (USA, Canada, France, Germany, Australia, etc.). These campaigns have been very useful to progress in knowledge (concentrations and loads of pollutants), modelling and management of urban stormwater, but present some critical limitations, especially regarding their representativeness at short time scale, their ability to fully account for the very significant variability of pollutants concentrations and loads, and their cost.

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Since the late 1990s, continuous on-line monitoring of storm runoff quality has been developed, aiming to propose solutions to the above limitations and to build large data bases that can be used for various purposes, including estimation of pollutant loads for regulatory requirements, operation, planning and rehabilitation of sewer systems, real time control and modelling. For Total Suspended Solids (TSS) and Chemical Oxygen Demand (COD), surrogate measurements of turbidity can be used to overcome the limitations of traditional sampling and analyses methods. Several research groups are working on that field worldwide (e.g. Gruber et al., 2005; Fletcher & Deletic, 2007; Muschalla et al., 2008; Ruban et al., 2008; Lacour, 2009; Schilperoort et al, 2009; Francey, 2010). Bertrand-Krajewski et al. (2007) proposed an initial set of methods for estimating TSS and COD concentrations and their uncertainties from turbidity. Event and annual pollutant loads can then be calculated. The proper application of these methods strongly depends on two main considerations as follows. Firstly, sensors may be affected by various functional, technical and operational constraints, thus requiring careful data validation. Raw data must be corrected and their uncertainties evaluated according to adequate calibrated relations for a sensor. Given the large amount of data typically collected with continuous monitoring, software tools have to be used to ensure the quality of data without the need to resort to an unnecessarily time-consuming manual process. Examples of such tools designed for urban drainage specific needs have been presented in the literature. They are applicable to both small (Mourad and Bertrand-Krajewski, 2002) and large catchments (van Bijnen and Korving, 2008). These tools include rules to detect doubtful and/or unreliable data, using different parametric tests which have been developed from previous knowledge and experience. Secondly, the determination of correlation functions between continuously measured turbidity and sampled TSS and COD concentrations. These correlation functions are both site and sensor specific. To ensure their reliability, outliers in calibration data sets must be detected and specific regression methods which account for uncertainties in all variables need to be applied.

This paper presents some key methodological aspects for continuous data acquisition and data processing. Their application is illustrated with examples of results for two experimental urban catchments in Lyon, France: i) Chassieu, 185 ha, industrial area with a stormwater separate system, ii) Ecully, 245 ha, residential area with a combined system, respectively with 263 and 239 storm events recorded (rainfall, discharge, turbidity time series) in the period 2004-2008 with a 2 minute time step.

METHODOLOGY

The methodology includes the following main steps:

- calibration of sensors and determination of calibration functions
- data correction and estimation of uncertainties in corrected data
- automated data pre-validation by application of a set of parametric tests
- final data validation by an operator
- calculation of discharge, TSS and COD concentrations, and their uncertainties
- calculation of storm event TSS and COD loads and of their uncertainties, including the dry weather contributions in case of a combined sewer system.

Steps 1 to 4 have been previously described in other papers (see Métadier and Bertrand-Krajewski, 2009). Steps 5 and 6 are briefly presented in the following paragraphs.

Calculation of discharge and concentrations of TSS and COD

Various methods can be used to calculate discharge including: (i) Manning-Strickler applied to water level, (ii) a water level-velocity relationship in cases where it is locally known, (iii) a locally established rating curve or (iv) a combination of water level and flow velocity measurements. Standard uncertainties in discharge can be calculated by means of the Law of Propagation of Uncertainties - LPU (ENV, 1999; ISO, 2009). TSS and COD concentrations are calculated from correlation functions for turbidity, for both dry and wet weather periods. Correlation functions are determined either by the ordinary least squares regression or the Williamson regression, preferably. Details are given in Bertrand-Krajewski et al. (2007) and Torres (2008).

Event load calculation

TSS and COD event loads are calculated with their standard uncertainties. This includes two sub-steps which are described hereafter: (i) the automated determination of the duration of the hydrologic event and (ii) the calculation of the event load itself between the determined storm event limits.

The duration of the hydrologic event comprises (i) the storm event duration itself, i.e. the time between the beginning and the end of the rainfall event as measured with the rain gauge and ii) the time needed for a set of variables (discharge, conductivity, turbidity) to reach again the values they had before the storm event started. A software tool has been created to facilitate the automatic identification of the beginning and the end of hydrologic events in sewer systems (Métadier and Bertrand-Krajewski, 2010a). The identification of the beginning t_d and the end t_f of hydrologic events is based on 3 criteria: (i) discharge threshold, (ii) minimum period between 2 successive independent events and (iii) the maximum duration between the beginning of the storm event and the rising of the discharge in the sewer. The identification of the end of hydrologic events is more complex than the identification of the beginning as, in some cases, pre-event dry weather values of conductivity and/or turbidity are not reached again even many hours after the end of the rainfall event. This is why the expertise of the operator remains necessary for final validation of the beginning and the end of hydrologic events.

Event loads are calculated by integration over the storm event duration of the continuous discharge and TSS or COD concentration time series:

$$M_X = \left(\sum_{i=1}^{N} C_{Xi} Q_i \right) \Delta t \qquad (1)$$

where M_X is the event load of pollutant X (kg), C_{Xi} is the concentration of pollutant X (kg/m^3) at time step i, Q_i is the discharge (m^3/s) at time step i, Δt is the duration (s) of the time step, i is the index, and N is the number of time steps corresponding to the duration of the hydrologic event: $N = (t_f - t_d)/\Delta t$.

Standard uncertainties in TSS and COD pollutant loads are calculated by means of the LPU taking into account discharge and concentration uncertainties.

Determination of dry weather contribution during storm events

Most models of storm weather pollutant loads in combined sewer systems are based on the assumption that the total storm event load is the sum of i) the DW (dry weather) contribution that would have been observed during the event duration if no event had occurred and ii) the WW (wet weather) contribution including surface runoff + possible erosion of deposits accumulated in the sewers. The DW contribution during a storm event can be estimated from turbidity time series.

In addition to Equation 1, it is assumed that:

$$M_X = M_{X\_DW} + M_{X\_WW} \tag{2}$$

$$V = V_{DW} + V_{WW} \tag{3}$$

with M_{X_DW} the DW contribution, M_{X_WW} the WW contribution to the total mass M_X, V the total event volume, V_{DW} the DW volume during the storm event and V_{WW} the WW volume generated by the storm event.

M_{X_DW} is the pollutant load that would have been measured if no storm event had occurred: by definition, it cannot be measured and should be estimated. The proposed method to estimate M_{X_DW} consists to determine the most likely DW discharge and turbidity time series (i.e. DW signals) compatible with the DW time series measured after and before the observed storm event. This most likely DW signal, named hereafter the reference signal, is chosen among available measured DW days which are close to the day during which the storm event occurs. The two steps are the following ones: i) test of several DW signals by juxtaposing them to the storm event signal and ii) comparing the values and the dynamics of the two signals on common DW periods of some hours on both sides (before and after) of the storm event limits: these periods are named the fitting periods. The DW signal having the most similar dynamics over the fitting periods is selected to estimate M_{X_DW}. In other words, it is assumed that if a tested DW signal is similar to the DW signal measured before and after the considered storm event, it is also an appropriate estimation of the un–measurable DW signal during the storm event. The method is illustrated Figure 1. The DW signals to be tested are not chosen randomly but according to a pre-established DW days classification (see paragraph 0). The selected reference signal shall satisfy the following criteria: i) both discharge and turbidity series are available without any gaps, ii) it must be long enough over the fitting periods to ensure a reliable comparison, iii) it is not necessarily an entire DW day as long as the fitting periods are fully covered and iv) it can be composed of several DW days in case the storm event is occurring over more than one day (e.g. weekdays and weekends.

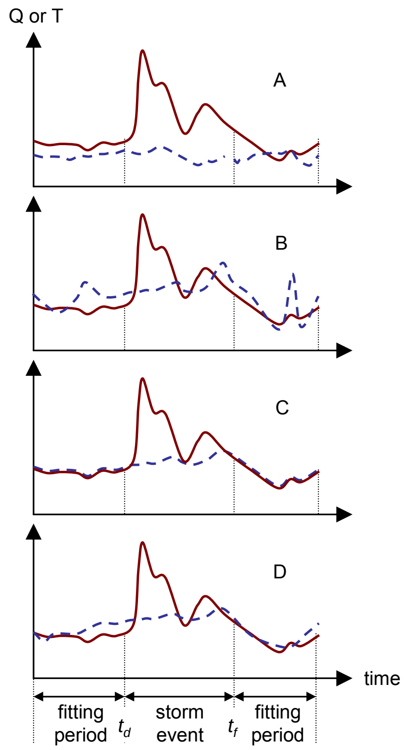

Figure 1. During a storm event, the un-measurable DW contribution is estimated by comparing a set of a priori similar dry day signals. In this figure, four signals A to D (dotted line) are compared with the dry periods before and after the storm event, named fitting periods. The most similar signal over the fitting periods is signal C. Consequently, signal C is applied to estimate the DW signal during the storm event. The above approach is used for both discharge Q and turbidity T signals.

In case reference and measured signals are comparable over the fitting periods in terms of dynamics but not in terms of absolute values, the reference signal can be translated by applying a simple mathematical signal fitting, independently for discharge and turbidity. It is based on a least squares minimization of the distance between the two signals, by ignoring extreme distances that correspond to random peaks (especially for turbidity). As for dynamics comparison over the fitting periods, the need for translation is visually evaluated by the operator, with some possible degree of subjectivity. However, based on our experience with long continuous time series, the reference signal translation is rarely required, given measurements from rather close DWDs are usually available. The fitting may be necessary in case of long term gaps in the continuous series or long rain periods, for which no adequate DW periods are available.

M_{X_DW} is then calculated from the reference signal at each time step i during the storm event duration:

$$M_{X\_DW} = \Delta t \cdot \sum_{i=t_{d\_DW}}^{t_{f\_DW}} C_{Xi\_DW} \cdot Q_{i\_DW} \qquad (4)$$

with Q_{i_DW} the reference signal discharge, C_{Xi_DW} the reference signal concentration of pollutant X computed from the signal reference turbidity $Turb_{i\_DW}$, and t_{d_DW} and t_{f_DW} the reference signal starting and ending times corresponding to the storm event limits t_d and t_f.

The standard uncertainty $u(M_{X\_DW})$ is then calculated by means of the LPU:

$$u(M_{X\_DW})^2 = \Delta t^2 \left(\sum_{i=t_{d\_DW}}^{t_{f\_DW}} Q_{i\_DW}{}^2 \cdot u(C_{Xi\_DW})^2 + C_{Xi\_DW}{}^2 \cdot u(Q_{i\_DW})^2 \right) \qquad (5)$$

with $u(C_{Qi\_DW})$ and $u(C_{Xi\_DW})$ the standard uncertainties at time step i resp. for discharge and concentration of pollutant X of the reference signal. Compared to total event load uncertainty, the DW contribution uncertainty includes an additional source of uncertainty which is related to the DW contribution estimation method itself, i.e. the error due to the fact that the reference signal is substituted to the true but unknown DW signal. Thus, the uncertainty of the substituted discharge and turbidity signals at each time step i of the signal reference include both the measurement uncertainty $u(Q_{i\_DW\_m})$ and $u(Turb_{i\_DW\_m})$ and a substitution uncertainty $u(Q_{i\_DW\_subs})$ and $u(Turb_{i\_DW\_subs})$. Under the assumption that substitution uncertainties are normally distributed:

$$u(Q_{i\_DW})^2 = u(Q_{i\_DW\_m})^2 + u(Q_{i\_DW\_subs})^2 \quad (6)$$

$$u(Turb_{i\_DW})^2 = u(Turb_{i\_DW\_m})^2 + u(Turb_{i\_DW\_subs})^2 \quad (7)$$

More details about uncertainties in substituted values are given in Métadier and Bertrand-Krajewski (2010b).

EXAMPLES OF APPLICATION

Chassieu catchment with a separate sewer system

The above methodology has been applied to the 185 ha Chassieu catchment. It is drained by a separate stormwater sewer system which has sensors at its outfall sewer to continuously monitor water level and water quality indicators (turbidity, conductivity, pH and temperature) with a 2 minutes time step. Water quality indicators are not measured directly in the sewer but in a monitoring flume continuously supplied by a 1 L/s peristaltic pump. Five years of data have been collected for the period 2004 -2008. All sensors are calibrated twice in a year. A variable variance was applied to turbidimeters because calibration tests revealed that the variance is significantly higher beyond 1000 NTU. In situ standard uncertainties have been estimated to be equal to 7.5 mm and 10 % of the measured value respectively for water level and turbidity values. For automatic event identification, data from the nearest rain gauge were used. Other criteria were set as follows: discharge threshold = 4 L/s, minimum duration between 2 successive events = 4 hours, maximum duration between beginning of storm event and rising discharge = 6 hours.

Figures 2a and 2b shows respectively the Turbidity-TSS (left figure) and Turbidity-COD (right figure) correlation functions for wet weather conditions. Both are second order polynomial functions determined by means of Williamson regression to account for uncertainties in both variables (turbidity and TSS or COD). Grey areas correspond to 95 % confidence intervals in estimated TSS or COD concentrations. It is important to note that both functions have been established with samples collected during various storm events covering a large measurement range (respectively 0 - 680 NTU corresponding to 0 - 1000 mg/L of TSS and 0 - 800 NTU corresponding to 0 - 800 mg/L of COD). This is important to ensure that the correlation functions are applicable for various conditions and without undue extrapolation.

In 2005, 33 storm events have been monitored in Chassieu. For each event, TSS and COD event loads have been calculated, with their 95 % confidence intervals. The results are shown in Figure 2c: black and white thick bars represent respectively the TSS and COD loads for the 33 events. Each thick bar is completed with a vertical thin bar segment representing the 95 % confidence interval of the event load. The variability of the event loads is very significant, with values ranging typically from a few to 400-500 kg of TSS or COD per event. The event number 25 shows extremely high loads compared to all the other ones. A further analysis of these 33 events loads (results not shown here) has indicated that there was no correlation between events loads and basic event characteristics like rainfall duration, intensity, and antecedent dry weather period or rainfall return period.

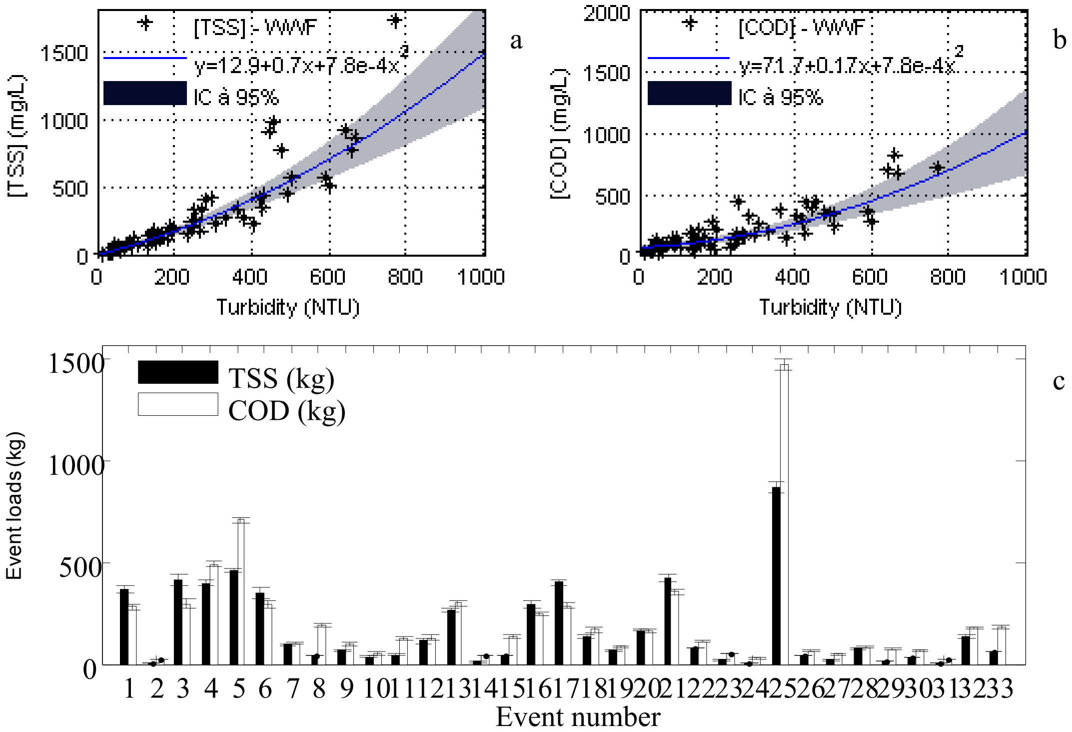

Figure 2. Example of results for the Chassieu catchment: (a) Turbidity-TSS and (b) Turbidity-COD correlation functions, (c) TSS (in black) and COD (in white) event loads in 2005 with 95 % confidence intervals.

Ecully catchment with a combined sewer system

The methodology has also been applied to the 245 ha Ecully catchment drained by a combined sewer system. Three clearly distinct DW daily pattern classes were identified among the available 180 DW days recorded in 2007-2008: i) class 1: weekdays (Monday to Friday) without school holidays, ii) class 2: weekends (Saturday and Sunday) and weekdays with general public holidays and iii) class 3: weekdays (Monday to Friday) with school holidays. The three classes represent respectively 55 %, 22 % and 23 % of the 180 DW days (resp. 99, 40 and 41 DW days). The three classes correspond to calendar percentages over the period 2007-2008 of 41, 32 and 32 %, evidencing a satisfactory representativeness of the available DW data. In order to analyse the DW pattern variability, mean discharge and turbidity profiles for the period 2007-2008 were computed for each class and for all classes together, with standard deviations and coefficients of variation computed at each time step of the profiles (720 values per day). 5 % - 95 % percentile intervals and distributions of residuals (distances from the each DW day value to the mean profile) were also computed. Results are summarised in Table 2 and illustrated in Figure 3and Figure 4 resp. for class 2 and for all classes together (named hereafter class 4).

Table 2. Mean standard deviations and mean coefficients of variation of the mean discharge and turbidity along the DW profiles for classes 1 to 4.

Class	Mean standard deviation		Mean coefficient of variation	
	Discharge (L/s)	Turbidity (NTU)	Discharge (%)	Turbidity (%)
Class 1	7.05	55.23	21.86	31.80
Class 2	6.52	51.31	22.69	29.25
Class 3	9.46	59.33	28.6	36.39
Class 4	7.91	60.18	23.75	34.66

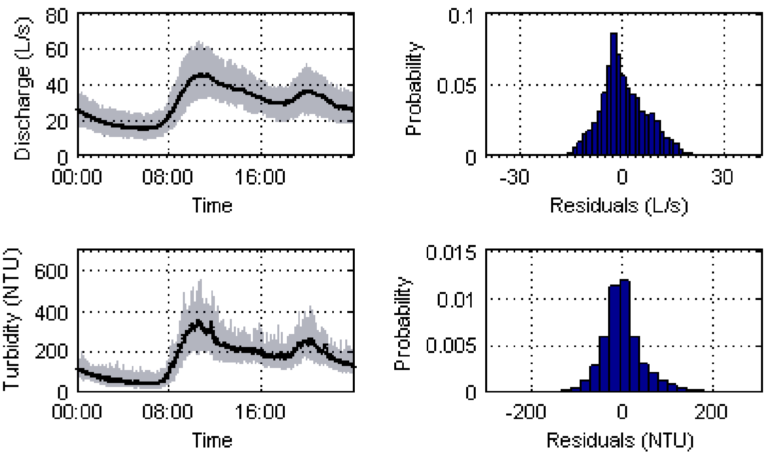

Figure 3. Class 2 mean DW discharge and turbidity patterns, with 5 % - 95 % percentiles interval (left) and residuals distribution (right).

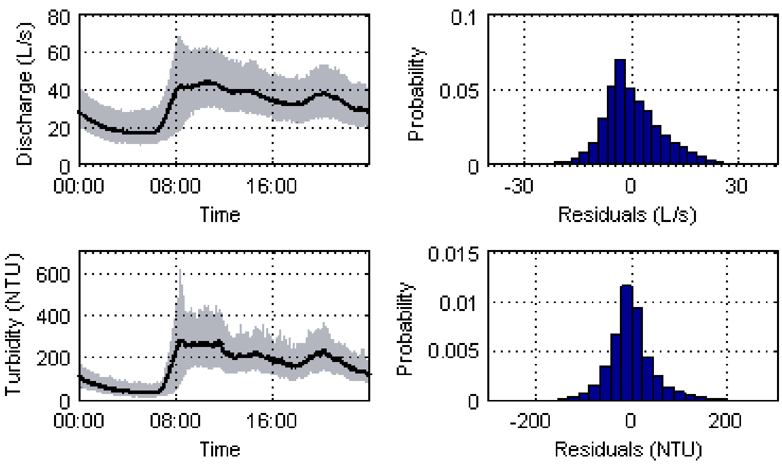

Figure 4. Class 4 mean DW discharge and turbidity patterns, with 5 % - 95 % percentiles interval (left) and residuals distribution (right).

The results are rather similar for all classes. Residuals are approximately log-normally distributed. The computed 5 % - 95 % percentile intervals are comparable for the four classes, with larger values for high flow periods around 10:00-12:00. Dispersion is significantly higher for turbidity with mean coefficients of variation around 30-35 % compared to 20-25 % for discharge. Moreover 5 % - 95 % percentile intervals are less smoothed for turbidity, which is explained by the random turbidity peaks observed during the day especially during high flow period at the end of morning and evening peaks. This trend is even more pronounced when results are analysed at 2 min time step. Comparable orders of magnitude of the variability for both discharge and turbidity signals have been observed by Lacour (2009) in two urban combined catchments in Paris, France.

TSS and COD event loads calculation have been calculated for the 239 storm events measured in Ecully in 2007-2008. Constant substitution uncertainties were applied, respectively equal to 3.33 L/s and 47.0 NTU for discharge and turbidity. As an example, Figure 5 illustrates the storm event dated Friday 31 October 2008, which is a class 3 DW day. The rainfall depth is 10.7 mm. Event starting and ending times are respectively 12:28 and 20:28. The selected reference signal corresponds to Tuesday 4 December 2008, which is available in the DW data base. The left graphs represent, from top to bottom, the rainfall intensity, the conductivity, the discharge and turbidity reference signals measured on Tuesday 4 December 2008, and the measured discharge and turbidity signals measured on Friday 31 October 2008. The right graphs represent, from bottom to top, COD and TSS mass fluxes (in kg/s) computed from the TSS-turbidity and COD-turbidity correlations, and event pollutant loads (in kg). For discharge, turbidity, fluxes and event loads, 95 % confidence intervals are computed with the LPU. Event runoff volume, TSS and COD loads with WW and DW contributions and their 95 % confidence intervals are summarized in Table 3. Results for the storm event dated Friday 31 October 2008.

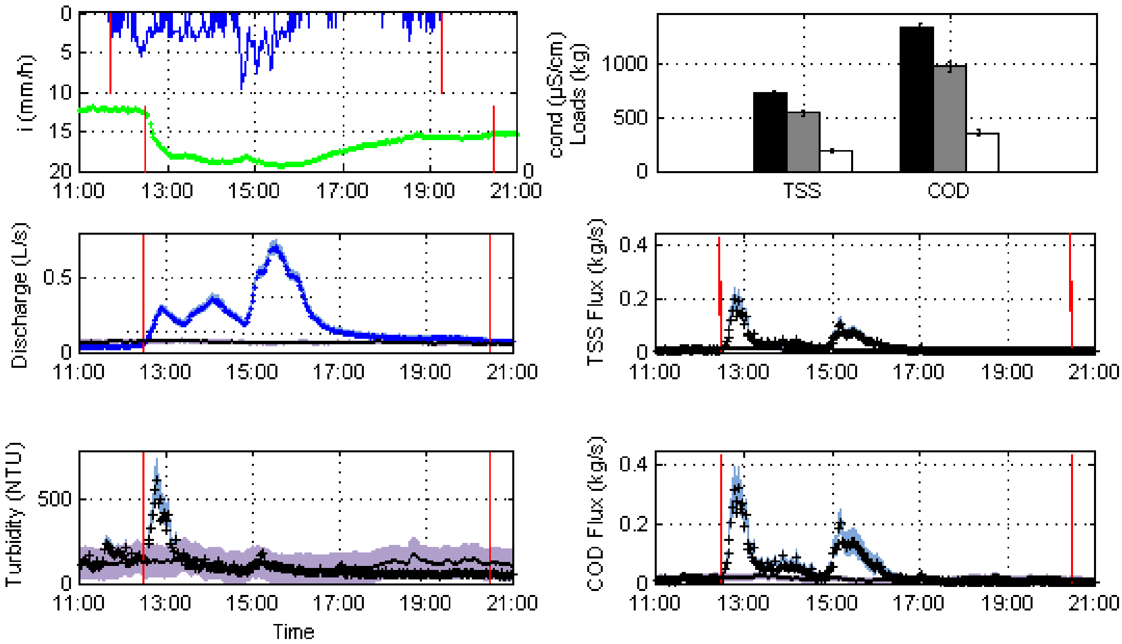

Figure 5. Illustration of the methodology for the storm event dated 31 October 2008.

Table 3. Results for the storm event dated Friday 31 October 2008.

Friday 31 Oct. 2008	Total	WW contribution	DW contribution
Runoff	6323 +/- 26 m^3	4645 +/- 62 m^3	1718 +/- 32 m^3
TSS load	729 +/- 22 kg	540 +/- 26 kg	189 +/- 13 kg
COD load	1324 +/- 42 kg	967 +/- 46 kg	356 +/- 20 kg

M(V) curves for both catchments

The dimensionless M(V) curves (Bertrand-Krajewski et al., 1998) have been determined and analysed for all events in Chassieu and Ecully experimental catchments, to analyse the distribution of pollutant loads within storm events. In order to facilitate the comparison with other authors, the classification proposed by Lacour (2009) has been used, distinguishing three groups of M(V) curves (Figure 6): i) group A with M(V) curves significantly above the bisector line, ii) group B with M(V) curves very close to the bisector line, and iii) group C with M(V) curves either significantly below the bisector line or meandering around it. The results, given in Table 4 and in Figure 7, clearly indicate that M(V) curves of type A are rare (less than 10 %) while the great majority are of type C (more than 70 %). They corroborate those obtained by Lacour (2009). More details are available in Métadier (2011).

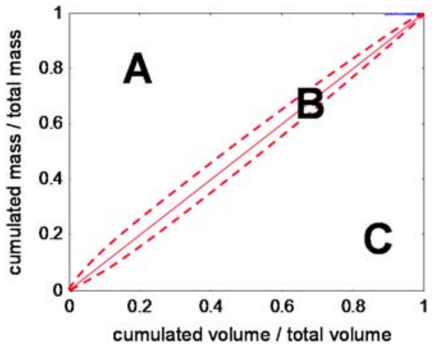

Figure 6. Classification of M(V) curves in three groups.

Table 4. Distribution of M(V) curves in Chassieu (263 curves) and Ecully (239 curves)

	Group A	Group B	Group C
Chassieu (263 events)	8 %	13 %	79 %
Ecully (239 events)	7 %	21 %	72 %

CONCLUSION

With the increasing implementation of continuous monitoring of both discharge and water quality in sewer systems, large data bases are now available. In order to manage large amount of data and calculate various variables and indicators of interest, it is necessary to apply automated methods for data processing. A complete methodology, described and illustrated in this paper, has been implemented in a prototype software tool to validate raw measurements of turbidity and water level and to calculate event and annual loads of TSS and COD and their uncertainties, for both separate and combined sewer systems contexts.

ACKNOWLEDGEMENTS

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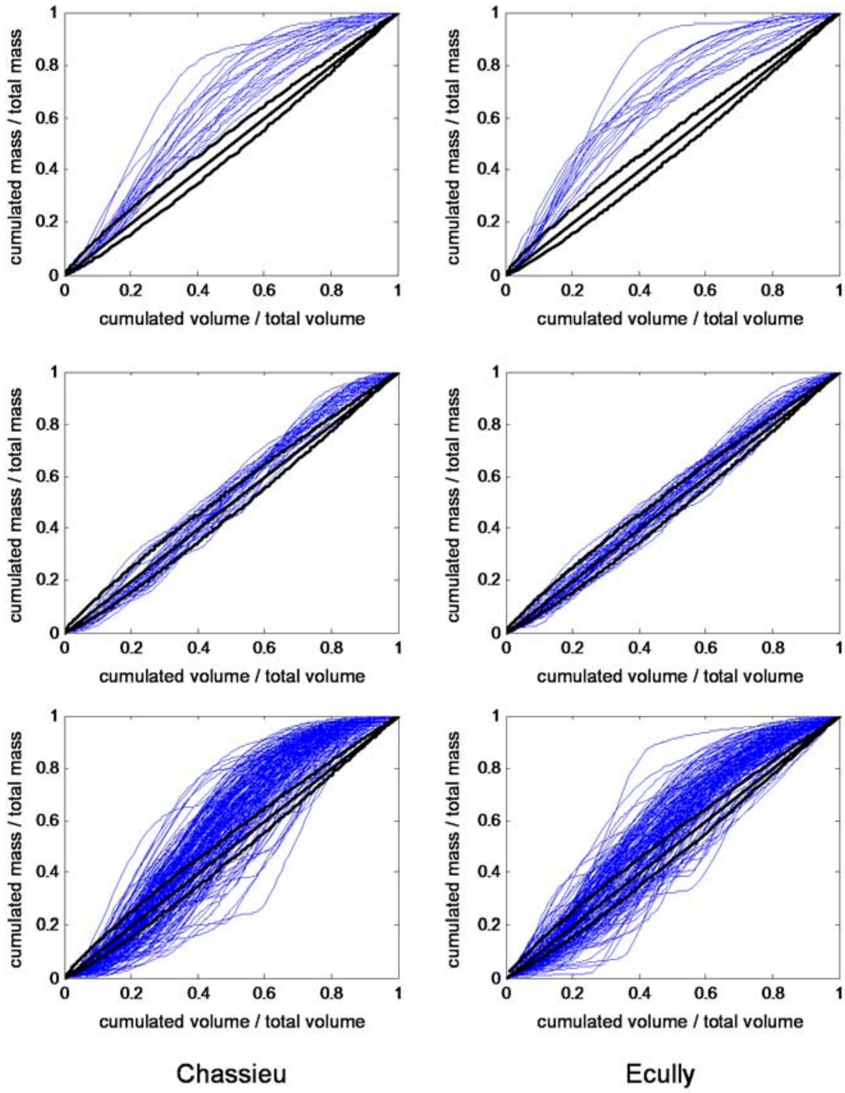

Figure 7. M(V) curves in Chassieu (left, 263 curves) and Ecully (right, 239 curves). Top: group A, middle: group B and bottom: group C.

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Measurement of waste water quantity and quality at Belgrade sewerage and stormwater system

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Abstract
At the fall of 2006, Belgrade Sewerage started the operation of the first part of the system for the continuous measurement of water quantity and water quality parameters of discharged water from the BS system into the Danube and Sava rivers. Only simultaneous measurement of water quantity and quality together with appropriate data processing may provide reliable information on quantities of harmful materials that enter the recipient from the waste water. Flow measurement at Belgrade Sewerage is performed continually with suitable probes, while the laboratory investigations of physical, chemical and biological parameters are performed on composite samples taken by automatic samplers within 24 hours.
Until recently, storm waters were considered relatively pure and the problems of storm water discharge were observed only from the aspect of flood protection. But, due to increased pollution introduced by these water, it is necessary to treat not only the water waters, but also a part of the storm water collected along with waste waters in general sewerage systems.

KEY WORDS: waste water, storm water, load, sewerage system

Introduction

Within its regular activities of system operation monitoring, Belgrade Sewerage System (BSS) has been working in classical manner for many years, only by recording the total operation time of certain pumping stations and consumed electricity. Also, the waste water discharged is monitored by sampling two representative outflows every day, taking four composite samples, and analyzed chemically and bacteriological (according to the Regulations for waste water discharge into the sewage). In the cases when the accidental pollution occurs, BSS team also samples water within the sewage system in order to determine the pollution source [Andrić et al. 2007].
During 2006 and 2007, the sewerage operation monitoring system was modernized by placing the first 8 measuring points at the largest outflows from BSS. These are (Fig. 1): Sajmište, Ušće at gravitation outflow, Lasta, Dorćol, Istovarište, Ada Huja 1 and 2 and Višnjica. It is estimated that these 8 measuring points encompass about 80% of water quantities discharged into the Sava and Danube [Prodanović et al. 2007-2008].
All measuring points are equipped with devices for continual flow and water level measurement and with sensors for continual measurement of water quality parameters. Measured data are sent

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via GPRS connection to the SCADA (Supervisory Control And Data Acquisition) system, installed at one PC of standard performances, which records current data and print daily and weekly reports.
Each measuring point contains also one automatic sampler, that may take 6-hour composite sample. The chemical analysis of the sample is performed at the existing laboratory of the Sewerage system. Due to large scope of work, two measuring points are sampled at the same time, for a whole week. Water quality data are processed and stored at the Department for ecology, control and protection, in the form of Excel tables.

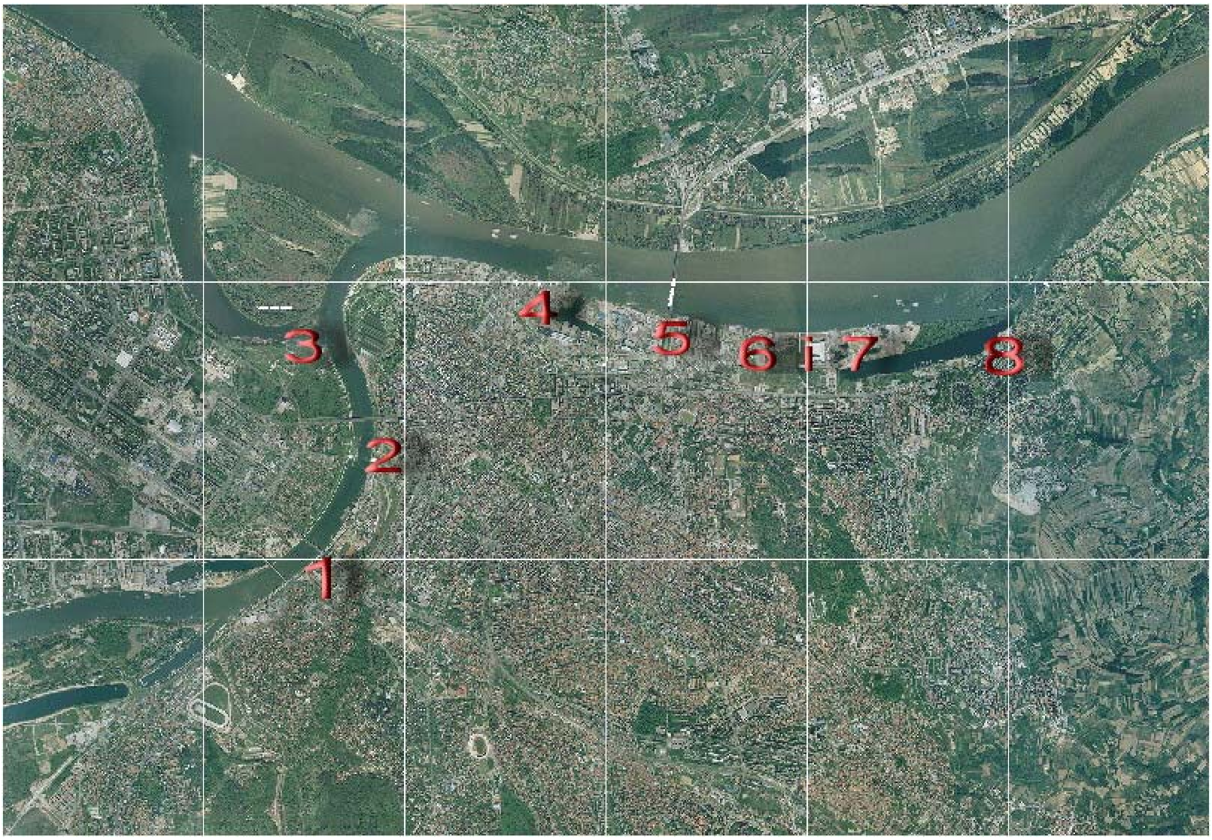

Figure 1. Locations of 8 measuring points at the outflows of the Belgrade Sewerage

This paper presents a short description of the equipment placed at 8 measuring points and the results of the outflow measurements and water quality parameters for two rain episodes. The paper emphasize the importance of continual measurement of outflow and water quality, especially because of the considerable storm water impact onto the quality parameters. These data are necessary for the appropriate dimensioning of the future waste water treatment system.

Flow measurement at the collector outflows

It is usual in the river hydrometry to calculate the flow using the measured depth and flow curve (Q/H diagram). Unfortunately, flow in sewage collectors is most often under the considerable influence of downstream recipients or under the influence of pumping station operation, so the method for flow measurement using the one depth is inadequate.
For reliable flow measurement, it is necessary to know the water velocity in cross-section and depth. For measurements at outflows, it was decided to use ultrasonic Doppler (USD) sensors for velocity (robust and appropriate for dirty water) and contactless ultrasound (US) sensors for water level.

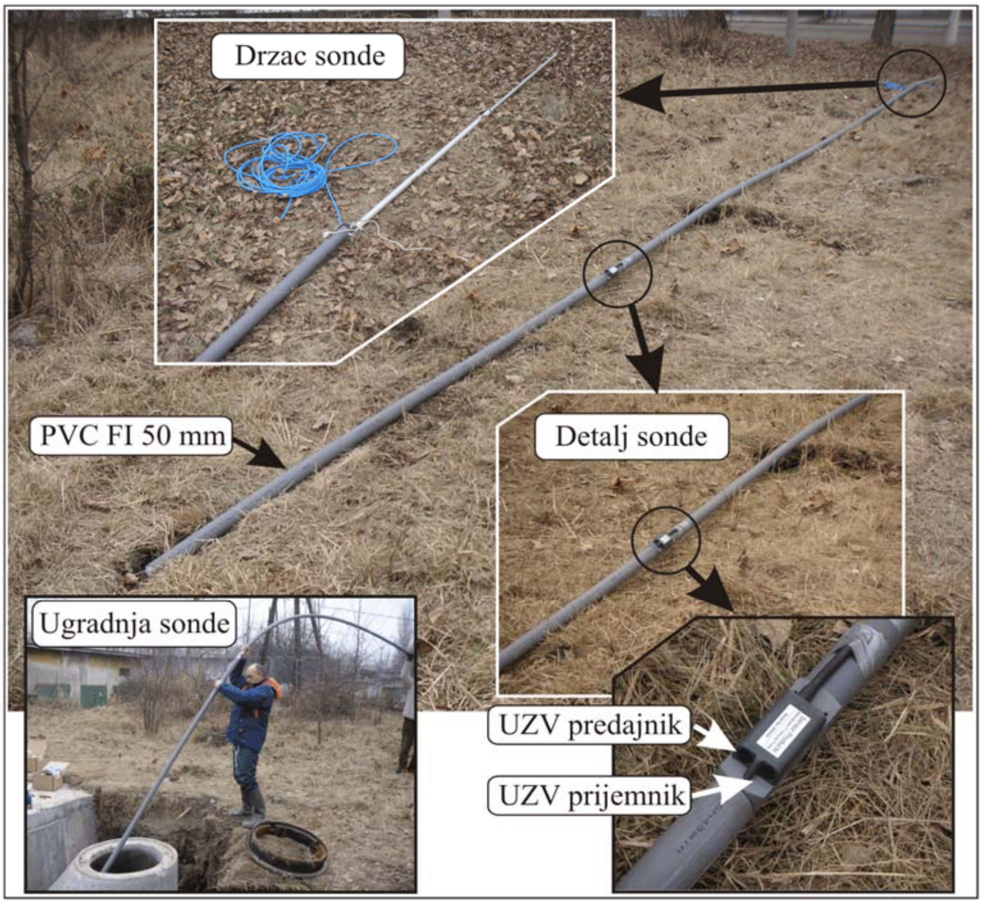

Figure 2: US sensor for velocity on a floating PVC pipe F150 mm, with bearing detail (upper figure) and installation detail (down left)

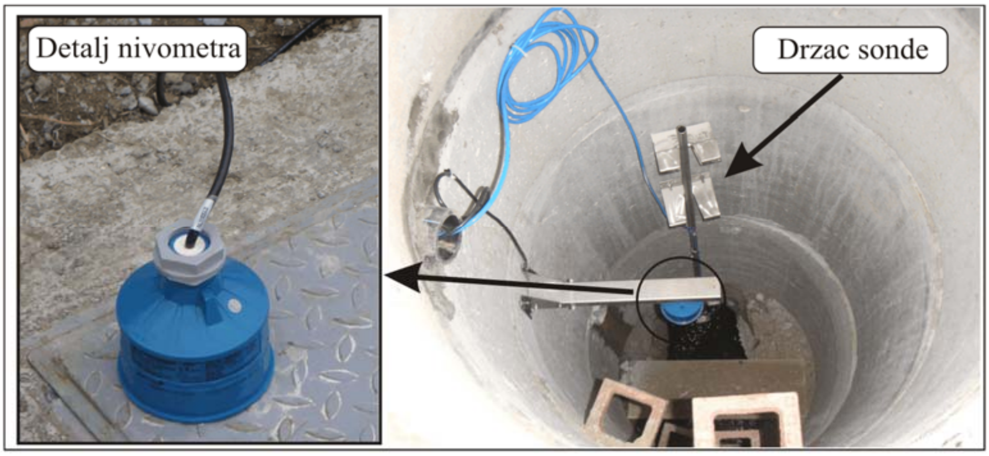

Figure 3: US water level sensor and velocity probe bearing placed inside the manhole

Obtained USD equipment for velocity is reliably measuring in the water velocity range of 5cm/s to 5 m/s. USD mount as floating sensor (right part of the Figure 3) are used in collectors of larger diameters, and for collectors of smaller diameters, they are placed on inox strips of the collector laterals, above the maximal expected level of deposits (left part of the Figure 4).

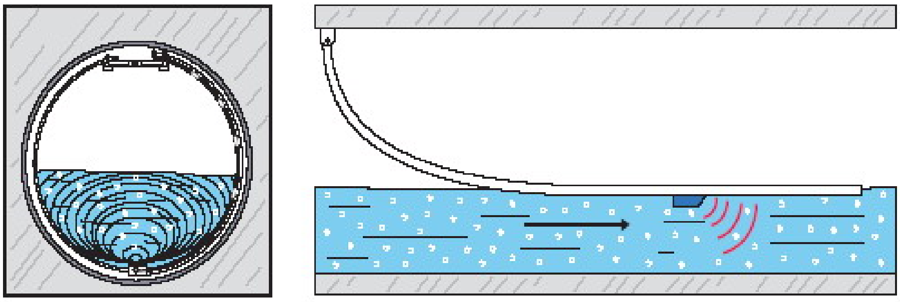

Figure 4: US Doppler velocity sensor placed at the bottom of the collector (left part of the Figure) or floating (right part of the Figure)

The applied method of velocity measurement is robust and operates very well in dirty waters. The floating bearings enable occasional sensor extraction and their cleaning. The basic flaw of the method is the fact that the velocity is measured in relatively small volume, so a long straight section with developed velocity profile is necessary, which is mostly unaccomplished in sewer systems. Also, USDr system is sensitive to small velocities, so that velocity measurement is not reliable during the periods of small flows with considerable downstream backwater.
As already noted, water level in the collector is measured using contactless ultrasonic sensor. US sensors are, by rule, sensitive to moisture and dirt, so it is necessary to be cleaned occasionally. For flow calculation, it is necessary to obtain water depth, not water level, so the deposit in the collector is one of the main sources of errors. If the deposit is fixed, motionless, then the bottom level represents the deposit level. But, if the deposit is formed during small waters, which is later washed out during larger flows, it is questionable how to determine the real water depth. It is necessary to visit measuring points often and check the state of the deposits [Jauković et al. 2007].

Measurement of quality parameters

Laboratory investigations of physical, chemical and biological parameters are performed on composite samples collected by automatic samplers within 24 hours. Although the continuous water quality measurement probes were used (Figure 5 shows the look and placement of probe for continual measurement) they were useless due to necessity to perform cleaning on the daily basis (Figure 6).

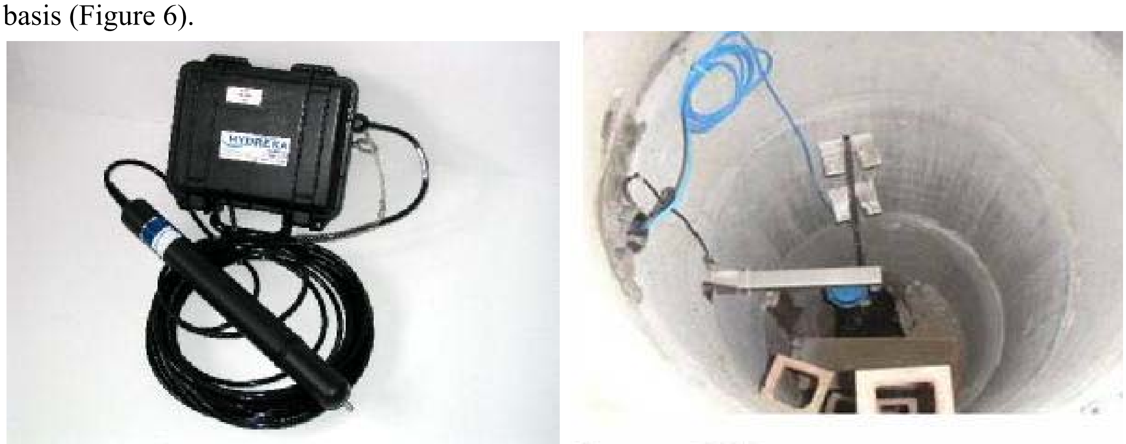

Figure 5. Probe for continuous measurement of water quality

Figure 6. Probe for continuous measurement – before cleaning (left) and after cleaning (right)

The used automatic sampler is presented on Figure 7. Flow measurement data in relation to measurement data of waste water quality parameters give mass flow of polluting substances, i.e. load that is brought into the recipient. Obtained mass flows are one of the basic parameters for designing future waste water treatment plant and managing the treatment process, and also necessary input data for the environmental analysis of waste water impact.

Figure 7. Automatic sampler

In the sewage systems with considerable inflow of additional waters it is difficult to assess the participation of each flow component in the total measured hydrograph, and hence it is hard to analyze and interpret obtained flow and water quality measurements. Additional water quantities (inflows, infiltration, and so) are considerably different both in intensity and dynamics. Flow measurements during the period without precipitation determine “base flow” that consists of used water flow and water infiltrated into collectors, while in the periods with precipitation, in the used water systems or sewerage of generally type, additional storm water quantities may be measured and evaluated [Mihajlović et al. 2009].

Figure 8. Diagram of precipitation intensity, flow and load of the measuring point “Ušće”

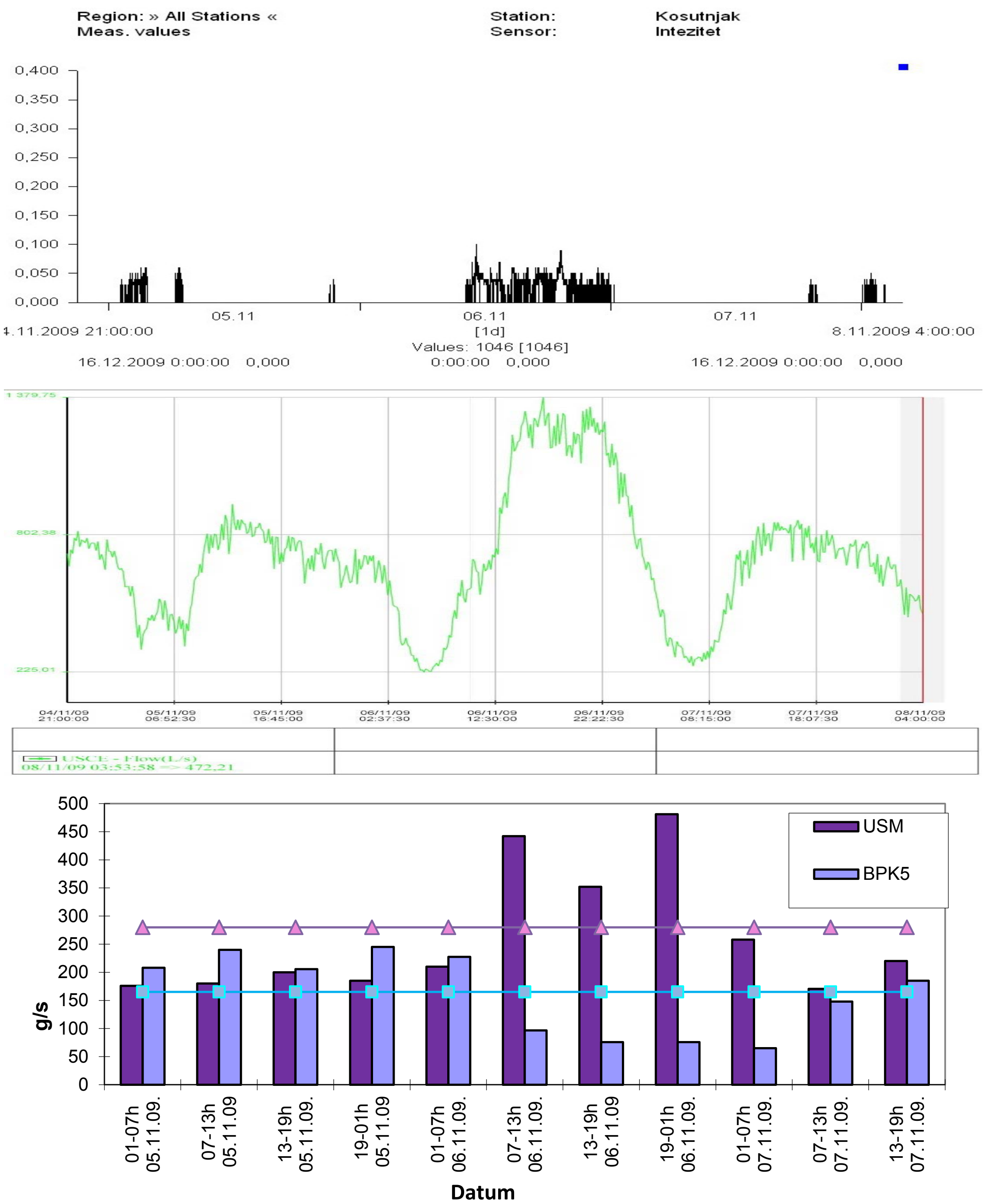

Figure 9. Diagram of precipitation intensity, flow and load of the measuring point "Istovarište"

Result interpretation

In order to investigate the storm water impact onto the waste water quality in the sewerage system, measurement of polluting substances, that are introduced into the recipients via sewerage system during the period without precipitation and in the period after precipitation, was performed. This paper presents measurement results during two events, when considerable precipitation quantities were recorded.

Measuring points "Istovarište" (near Pančevo bridge, measuring point 5 in Fig. 1) and "Ušće" (measuring point 3 in Fig. 1) were chosen for the result presentation, as two largest sewage outflows on the left and right Danube river bank. Diagrams in Figures 8 and 9 give comparative

presentation of precipitation intensity, flow (l/s) and quantity of certain polluting substances, expressed using mass flow (g/s) that are introduced into the recipient.
The obtained results were basis for determination of a load, which occurred under the influence of storm water, that is total suspended material (USM) and biological oxygen consumption after 5 days (BPK5). In order to consider the storm water impact, Figures 8 and 9 present loads with comparative presentation of load with named parameters at the period of investigations and mean annual load.
Presented measurement results show that immediately after the beginning of precipitations there is a considerable increase of inorganic substance emission (expressed using USM) due to rise of the previously deposited sludge in collectors and due to inflow of polluting substances from urban surfaces, while the organic component (expressed using BPK5) decreases, due to storm water dilution, and at the end of the outflow a decrease occurs in relation to average values. Considerably smaller part of biological oxygen consumption in relation to total suspended substances shows that the storm waters that enter into the sewerage system are considerably more loaded with inorganic then organic pollution.
Due to the manner of composite sample formation, presented results relate to the averaged 6-hour sample. Because of that, it is impossible to see the effects of the first outflow onto the water quality. Maximal concentrations recorded during the period of precipitation would certainly be higher than the measured averaged concentrations.

Conclusion

From the result of precipitation, waste water quality and quantity measurement at the Belgrade Sewerage, it may be concluded that the storm water impact onto the physical, chemical and hydraulic load is considerable. For the observed general sewage system, during the period of precipitation, there is an increase of pollutant concentration in the waste water which results in polluting substance load. By analyzing the obtained results it may be concluded that the contamination with pollutants of inorganic origin, which enter the sewage system via storm water, is dominant. The increased concentrations of examined substances in the storm water impose the conclusion that these waters should, at least partially, be treated in appropriate manner.

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The impact of stormwater pollution in the Venice lagoon: the actions for its safeguard taken by the Italian Government

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ABSTRACT: The present paper reports the results of the monitoring campaign conducted during 2007 in 30 different site in the Venice area in order to evaluate the characteristics of stormwater from impermeable surfaces not subjected to industrial activities. The results indicated that stormwater characteristics are related to the type of activity of the different areas. Another interesting result is that no substantial differences have been detected between first flush and second flush. I order to reduce and control the stormwater pollution the Magistrato alle Acque, the Venice Water Authority, is issuing technical and guidelines in order to reduce and control stormwater pollution in the Venice area, by the implementation of both Best Management Practice (BMP) and structural treatments.

INTRODUCTION

The Venice Lagoon is characterized by a water basin of 540 km^2, with an average depth ranging between 0.6-0.7 m and is crossed by a closed network of more or less deep channels branching from the lagoon inlets of Malamocco, Lido and Chioggia toward the mainland interface; it is the largest lagoon area in the Mediterranean Sea. (Figure 1).

The daily exchange between the lagoon water and the Adriatic Sea, whose volume is about 400 million of m3, is assured by its tides that enter and exit the lagoon twice a day thorough the lagoon inlets, reaching two maximum and two minimum (semi-diurnal tides). Such a hydrodynamic system has favoured the development of the lagoon ecosystem, an environment of transition between land and water, rivers and sea which is undergoing a continuous evolution and is characterized by an extreme fragility and by a wide range of organisms typical of that environment.

The exchange of water has represented the most important element for the building and the development of Venice. The city, built in the centre of the lagoon on 119 islands separated from each other by 160 canals, due to these peculiarities, lacks a dynamic sewerage network able to

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collect the water discharge, but has a very modern system of water treatment which consists of thousands of septic tanks and hundreds of most advance individual treatment plants (SBR and MBR). The water running off the roofs and the streets of the city flow into a close network of underground sewers placed at a height next to or lower than the average sea level and connected to the inner canal network. The city of Venice is characterized by absence of traffic and industrial activities, but the severe pollution of the Venice Lagoon's water and sediments is caused by industrial activities, including petrochemicals, shipping, power plants and refineries based on the drainage basins.

The areas which make up the drainage basin are: islands of the open lagoon, banks and internal islands of the fish farms, hinterland draining into the lagoon, coastal strip areas draining into the lagoon.

Italian Government issued more severe standards for the Venice Lagoon itself with the aim of regulating all the wastewater discharges into the lagoon, including stormwaters: 1) Ministry of the Environment, Decree of July 30, 1999 and 2) the more recent law n.192/2004, which regulates stormwaters from impermeable surfaces that are not used as industrial sites (public and private roads, parking place also of industrial sites), which states areas subjected to permission to direct discharge but requires attenuation and BMP measures for non authorized areas, this is the first example in Italy. This special Regulation specifically issued for these areas, is promulgate by the Magistrato alle Acque of Venice.

The Magistrato alle Acque, a branch of the Ministry of Infrastructure and Transport, today plays an important role in protecting hydraulic and environmental aspects of the lagoon and is the Water Authority of the Venice Lagoon. The Venice Water Authority acts through its contract-holder Consorzio Venezia Nuova, as per Law n. 798/84, which is its concessionary and is made up of big national companies, cooperatives and local enterprises.

Figure 1. The Venice Lagoon and the drainage basin.

In order to draw the guidelines of the special Regulation on stormwater and to estimate the level of the pollution produced by stormwater discharges from different sources, the Venice Water Authority carried out a monitoring survey during 2007.

MONITORING

The monitoring survey was performed during 2007 in 30 different sites which were considered a potential source of pollution for the lagoon.

These sites included industrial sites, roads characterized by high, medium and low traffic level, highways, parking areas of industries, commercial stores and residential buildings, airport areas, car wrecking centers, waste treatment plants, glass factories and the city of Venice, which is characterized by the lack of car traffic. The objective of the study was to detect the contamination levels discharging into the lagoon. Each site was monitored four times during one year, in order to verify the seasonal influence on the transport of pollutants by stormwater, the samplings were taken in the collecting traps. The samples were collected by refrigerated automated sampling systems operated by rain-gauges. (Figures 2-3).

Each sampling system was equipped with two set of bottles (each set consisted of four different samplers for different types of contaminants analysis) in order to collect separately the first flush and the following runoff (second flush), according to Italian standard which considers the "first flush" as the first 5 mm of each rainfall event. For convenience in this study we refer to the term "first" and the following "second flush" according to the Italian Regulation, even though the uncertain nature of first flush in the U.S. definition suggests that it should not be the basis for design treatment criteria.

The automated sample collector was able to store the samples in the refrigerated compartment at a constant temperature of 4°C and is completely automated, can be operated via the use of a remote control and a supervisory software system which allows distant programming and parameters settings of the unit.

Figure 2. Monitoring station at the Murano glass factory and automated sample collector.

By this way, 240 samples were collected and more than 32.000 data were analyzed. The parameters which were taken into account in this study are: suspended solids TSS, nutrients (nitrogen and phosphorus in the different forms, both organic and inorganic), organic matter as

COD and BOD5, inorganic contaminants and metals (arsenic, mercury, cadmium, antimony, lead, nickel, manganese, iron, chromium, copper and zinc), volatile organic compounds VOC, including aromatic and halogenated hydrocarbons, semi-volatile compounds SVOC, including phtalates, phenols, pesticides, polynuclear aromatic hydrocarbons (PAH), total hydrocarbons, dioxins (PCDD), furans (PCDF) and polychlorobiphenyls (PCB). The parameters include 126 pollutants, considering the sum of PCDD/F, IPA and PCB as a single compound. The values were related to the limits of industrial and civil discharges entering the Venice Lagoon, Decree of July 30, 1999. In the monitoring stations was included the reference station n. 30 characterized by absence of car traffic and far from industrial activities (city of Venice, S. Giobbe). In addition 4 samples of rain events in different seasons were analyzed as background control.

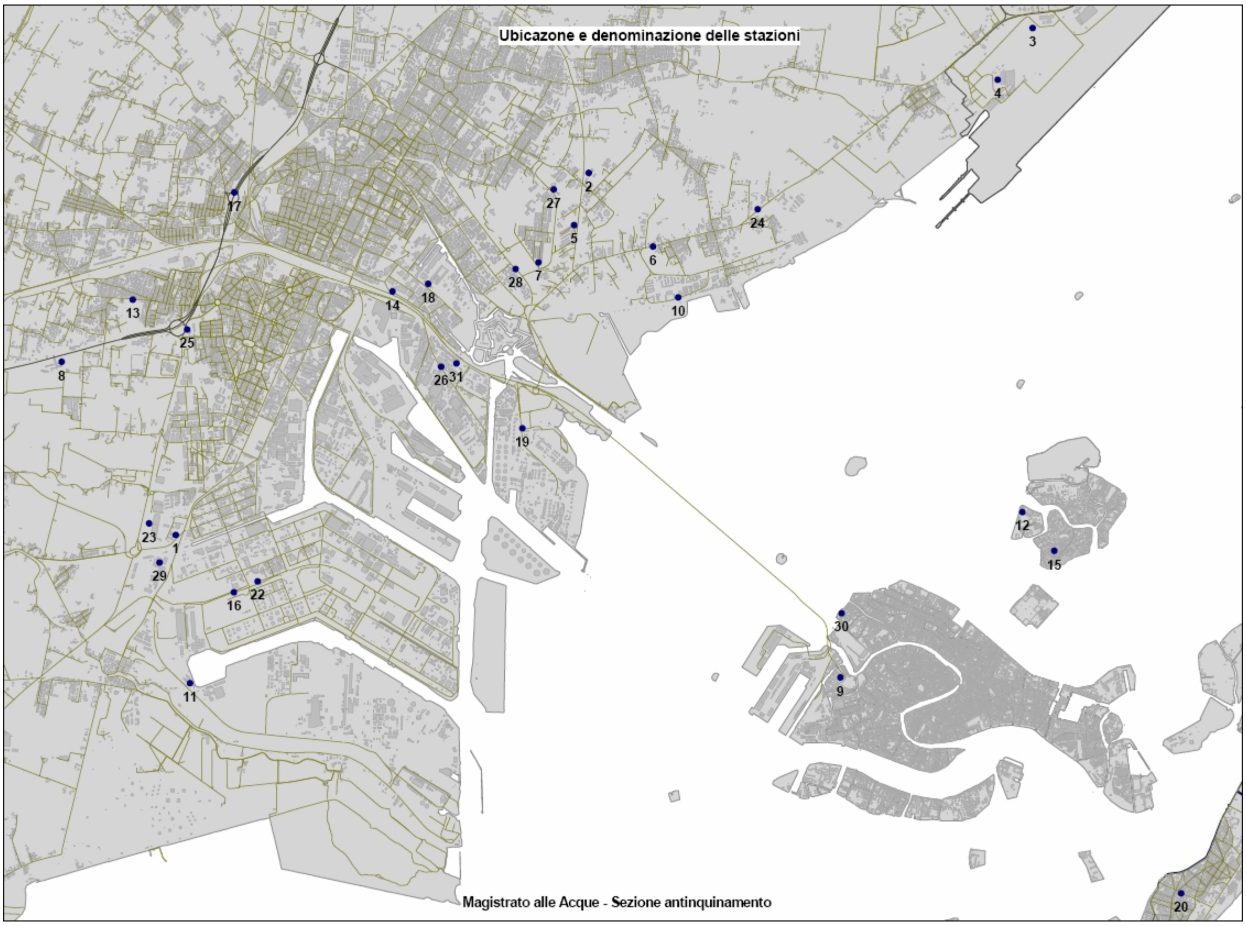

Figure 3. Monitoring stations.

RESULTS AND DISCUSSION

The analytical results have been statistically processed in order to assess the characteristics and the effects of stormwater runoff in the Venice Lagoon area. The results of the different parameters measured in each station clearly indicate that the quality of runoff, in many cases, did not comply with the quality standards issued for the industrial discharges for the Venice Lagoon (Decree, 1999). Not all the contaminants are able to fulfill the quality standards for the industrial discharges (Table 1). The mean values in each site has been calculated as the average of 8 measurements during one year of campaign (4 samples of first flush and 4 samples of second flush).

Table 1. Stormwater runoff contamination level fulfillment the quality standards for industrial discharges in the Venice Lagoon.

Contaminant	Frequency group	Quality standards fulfillment
Chromium Cr	1	100
Manganese Mn		100
Nickel Ni		100
Vanadium V	2	97
Total hydrocarbon THC		96
Antimonium Sb		93
BOD5		93
Mercury Hg		93
Ammonia $N\text{-}NH_4$		90
Total Nitrogen TN		90
COD	3	87
Total Phosphorus TP		87
Nitrous Nitrogen $N\text{-}NO_2$		83
Cadmium Cd		80
Poly Aromatic Hydrocarbon		77
Copper Cu		60
Zinc Zn		57
Arsenic As	4	47
Lead Pb		30
Dioxins/Furans		23
Total Suspended Solids TSS		17
Iron Fe		10
Hexachlorobenzene HCB	5	0
Polychlorinatedbiphenyls		0

Table 1 shows that only for few contaminants (Cr, Mn Ni) stormwater runoff fulfilled the limits of discharge in all sampling sites (Group 1). The second group includes contaminants (V, THC, Sb, BOD5, Hg, N-NH4, TN, COD, TP, N-NO2, Cd) which exceeded the quality standard for the industrial discharges only in a reduced percentage of the sampling sites (from 97 to 80% of compliance). In the third group are included PAH, Cu and Zn, which showed a moderate frequency of non–fulfillment (from 77 to 57% of compliance). In the fourth group are included contaminants (As, Pb, PCDD/F, TSS, Fe) which exceeded the standard limits in most of the sampling sites (from 47 to 10% compliance). Finally, there is the group consisting of HCB and PCB (Group 5) which exceeded the limits of discharge in all the sampling sites. It is important to notice that in Groups 4 and 5, beside TSS and Fe, are included the most toxic and dangerous contaminants, such as As, Pb, PCDD/F, HCB and PCB.

In the present work, four samples of first and second flush were collected and analyzed in each sampling sites during one year of survey. The correlation of the average concentration of the different contaminants of first and second flush samples indicated that there is not a substantial difference, in terms of water quality, between the first and the second flush samples collected in each sampling site and, in many cases, the second flush exceeded the quality standard for the Venice Lagoon. The relationship between the concentration of first and second flush for TSS, Pb and PCDD/F is shown in Fig. 4.

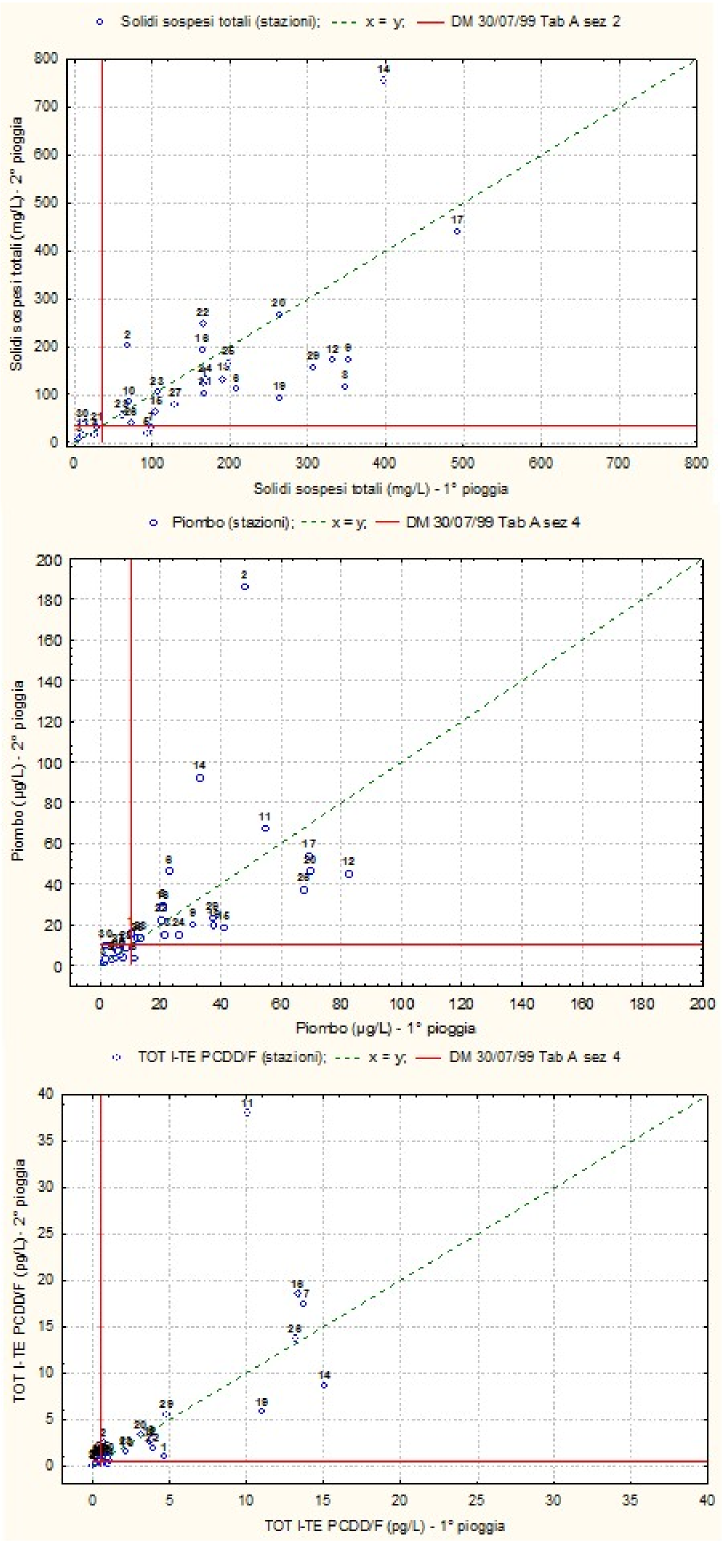

Figure 4. Comparison between the contamination of first and second flush for TSS, Pb and PCDD/F (the red lines represent the quality standards for the Venice Lagoon).

These results show that the first flush catch basins which are required by the Italian Regulation cannot guarantee the compliance with the quality standards of the discharges in the Venice Lagoon. Therefore, the main function of these catch basins is to collect limited volumes of contaminated water during the rainy events in order to preserve the efficiency of centralized treatment plants. At the end of the rainy event, the volumes of runoff can be pumped to the centralized treatment systems with flows which are compatible with the hydraulic plant capacity.

The correlation among the different contaminants indicated that TSS is the parameter which showed high correlations with most of the other contaminants, particularly with metals and organics micro-contaminants (PCDD/F, PCB, PAH, HCB). This aspect is quite important for the selection of additional measures to reduce the impact of heavy metals and the other persistent organic pollutants (POP), including PCDD/F and PCB, concerning the second flush event in the lagoon of Venice. In fact, the effective abatement of TSS from the second flush could substantially reduce also the contamination due to the more toxic heavy metals and POPs. On the other hand, treatments based on passive filtration/adsorption and grease traps showed only a limited efficiency in removing these contaminants (maximum 30% of abatement) and therefore do not seem useful to protect the Venice Lagoon from the pollution of stormwater runoff (first and second flush) according to Italian Regulation.

Runoff contamination is related both to type and location of sampling sites. For example, highest concentration of Cu, Cr, Sb, Zn, Fe, Mn, PAH were found in the stormwater runoff from highways, while aromatic and chlorinated hydrocarbons (including PCDD/F and PCB), V, Ni and Hg characterized the runoff from the petrochemical area. Hydrocarbon and Pb characterized car wrecking centers and As and Cd are the typical contaminant of the Murano island where are located most of the factories for the production of artistic glass. The spatial distribution characterizing the maximum concentrations of the different contaminants is shown in Figure 5.

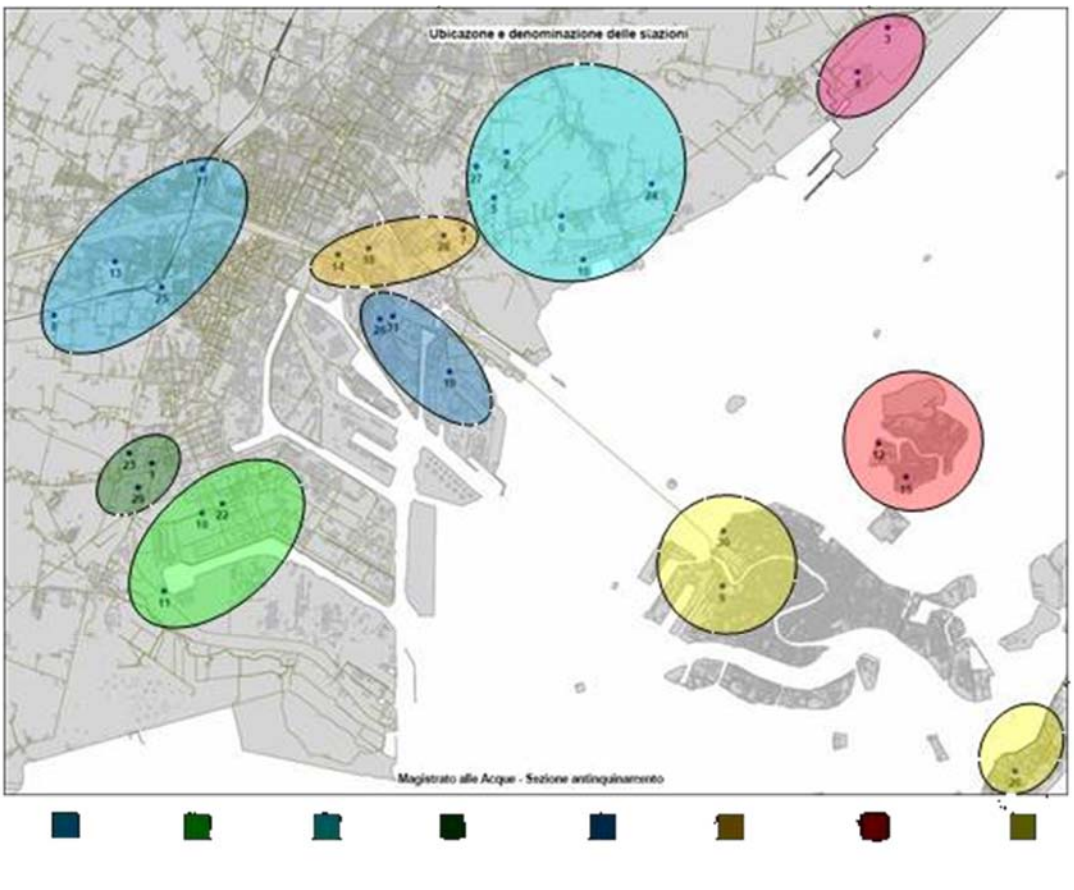

Figure 5. Spatial distribution of the monitoring sites and maximum level of the contamination.

The specific load of the contaminants which are the most critical to fulfill the quality standards of the industrial discharges in the Venice Lagoon, expressed in μg/m2/year, are shown in Table 2. These are mean values concentrations in different sites considering an area of major impact in the drainage basins of 10 km width. These results show that the runoff contamination is quite different according to the sampling sites and the risk is much higher in highways and petrochemical areas, with the exception of As, which prevails in the glass factory areas of Murano island. Therefore, in these areas should be primarily improved the implementation of additional measures to reduce the stormwater runoff pollution of the Venice Lagoon.

Table 2 – Specific load of stormwater runoff in the different areas for the main contaminants.

Contaminant	**Highways**	**Motorways**	**Parking areas**	**Industrial area**	**Glass factories**	**Petrochemical area**
	$g/m^2/year$					
As	3300	1100	1000	4900	7800	2300
Pb	43900	25500	4000	5200	38800	30700
PCDD/Fs	0.011	0.004	0	0	0.002	0.012
HCB	3.27	0.38	0.13	0.18	0.24	2.47
PCB	45	9	1	3	5	38

CONCLUSIONS

The study shows that a strong treatment program of stormwater runoff within the Venice Lagoon is needed, including impermeable surface that are not used as industrial sites, according to Italian regulation. The calculation of pollutant loads concentration in the area of major impact is based on mean values concentrations in different homogenous areas such as: high traffic roads, parking areas, car wrecking sites, etc., taking into account the size of the impermeable surface areas.

These values show that the problem of stormwater discharge from non-industrial areas is quite relevant and not completely solved. It means that the today's treatment systems which are adopted such as passive filtration/adsorption, grease traps need to be improved as well as maintenance operations. It is also demonstrated that the pollution is not only related to the pollutants load itself but it depends on the characteristics of the site and, in addition, there is no difference in terms of water quality between first and second flush, according to Italian Regulation definition.

This problem needs to be solved with advanced solutions and BMP. These solutions must consider areas and sewage systems management of stormwater, and in the sites of major contamination impact, must take into account the adoption of systems which remove specific pollutants (we have clearly demonstrated, once again, that TSS are mostly correlated to some pollutants, especially total Cr and Fe and POP's) and which enhance drainage, taking into account the peculiar characteristics of the Venice Lagoon.

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DESIGN OF STROM DRAINAGE SYSTEMS. STANDARDS AND LEGAL ISSUES

Advanced rainfall data processing for Urban Pluvial Floods

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Introduction

Flooding in urban areas is occurring with increasing frequency all over the world and is causing repeated damage that calls for improved management of floods from all sources. According to the UK Government's Independent Review into the Summer 2007 Flood Event (Pitt Review), about two thirds of flood damage in urban areas was caused by surface water (pluvial) flooding. While fluvial and coastal floods are well documented with extensive fluvial flood mapping and fluvial flood warning systems in place, this is not the case for pluvial (surface water) flooding. Furthermore, the time scales of fluvial and coastal flooding allow for timely flood warning issuing and response. As opposed to this, surface water (pluvial) flooding–caused by intense local storms during which the capacity of the sewer network and of the surface drainage system is often exceeded– takes place at smaller temporal and spatial scales and has, until now, not been given appropriate attention.

The UK Pitt Review (2007) as well as governmental and environmental regulations of other countries around the world call for integrated solutions to the problem, addressing both technical and socio-economic issues in Integrated Urban Flood Management (IUFM) and highlighting the importance of tackling the surface water (pluvial) flooding. Furthermore, in the recently held ICUD (International Conference on Urban Drainage, Edinburgh, 2008) and the UDM (Urban Drainage Modelling, Tokyo, 2009) it was stated that there is now scientific/professional and (in many cases) governmental consensus on the importance and need to accurately model and forecast short term pluvial/surface flooding.

Because urban surface water flooding occurs at a smaller scale and is affected by the local topography, the drainage infrastructure and the built urban environment, and given that the events that cause this type of flooding are characterised by rapid onset and high intensity precipitation, a new approach for urban surface water flood modelling and prediction (and warning) is required. This new approach has to include two main modules: (1) short term rainfall analysis and prediction and (2) short term flood prediction. Afterwards, these two

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modules must be coupled together, so that surface water flooding can be accurately and timely modelled and predicted.

Regarding the first module, it has to be taken into account that modelling of urban pluvial flooding requires short term rainfall prediction with high spatial and temporal resolution. The state-of-the-art methods for high-resolution rainfall prediction/modelling are mainly based upon radar nowcasting techniques; however, the lead time of these methods (approximately 45 – 60 minutes) is insufficient for the corresponding surface flood models to carry out an accurate and timely estimation. To overcome these shortcomings, an integrated methodology consisting of rainfall models and observation techniques over multiple spatial and temporal scales is currently under development at the Urban Water Research Group (UWRG) of Imperial College London. The aim of the techniques that are being developed is to increase the lead-time of the rainfall forecast as well as to improve its resolution and accuracy/reliability in order to enable inputs to the pluvial flood modelling and prediction based on the concept developed also at UWRG (Maksimović et al (2009). Furthermore, techniques for predicting rainfall based upon rain gauge information only are also being developed at the UWRG; these techniques are necessary for catchments where no radar data is available. The rainfall modelling and forecasting techniques that are under development at the UWRG will be detailed in Section 2.

Short term rainfall analysis and prediction

The existing short-term surface flood modelling requires at least a couple of hours lead time to provide reliable estimates of the distribution of floods over urban scales; however, the associated achievable lead time of high-resolution rainfall prediction is usually up to 45 - 60 minutes (Sokol, 2006). This predictability is limited mainly due to the deficient capabilities of existing short-term rainfall forecast models, which generally rely on extrapolating the precipitation measured by the networks of raingauges and meteorological radars. Although these models are able to carry out spatially and temporally high-resolution rainfall forecasts (or nowcasts), the lead time is however too short as compared to the reasonable response time of an urban catchment to extreme floods.

It is therefore crucial to improve the state-of-the-art methods of rainfall modelling, aiming to provide high-resolution rainfall forecasts with longer lead time. In this section, the concept of integrated rainfall modelling, which has been widely applied to operational weather forecasting systems worldwide, is firstly explained; then, the possible technical improvements are detailed, particularly focusing on the production of urban/street scale rainfall information based upon statistically-based downscaling techniques.

Moreover, this work proposes a methodology to carry out short-term rainfall prediction for the areas unable to afford radar observation networks. The idea is to generate the spatial distribution of rainfall based upon a dense network of raingauges. The associated techniques and some preliminary results are described.

Concept of Integrated Space-Time Rainfall Modelling

Numerical Weather Prediction (NWP) models, which are generally implemented by solving a set of equations of fluid dynamics and thermodynamics to estimate the future state of the atmosphere in synoptic scale ($\geq$ 1000 km grid) or mesoscale (~ 5 to several hundred km grid), may be the solution to providing longer lead-time prediction. The operational NWP model over the UK, named Unified Model (MetUM), has been substantially developed and used at the Met Office to help predict future weather. Constrained by computer power availability, this model currently undertakes $\approx$ 4 km grid and up to 6 hour lead-time forecasts over urban areas. Although NWP models are able to provide longer lead-time forecast, the achievable spatial resolution of NWP forecast is insufficient for hydrological modelling, let alone the surface flooding modelling over urban/street scales, which approximately range from 100 to 500m grid (Fabry et al., 1994). Moreover, the behaviour of precipitation is very stochastic/non-linear at smaller scales, which are generally modelled by statistical methods. The outputs of NWP models thus are expected to be very fluctuant/noisy, which substantialy increases the difficulty in providing satisfactorily accurate rainfall forecasts over urban scales. Rico-Ramirez et al. (2009), for example, applied high-resolution NWP precipitation ensemble forecasts (the smallest spatial resolution ≈ 3.3 km grid) to flood modelling over a small urban area in Yorkshire, UK; the predicted precipitation, however, is of insufficient accuracy as compared to that obtained from ground raingauge stations. This result suggests that it may be inappropriate to use merely the NWP forecasts to conduct quantitative rainfall and flood prediction over urban areas.

The method of integrating rainfall models over multiple scale ranges has been widely developed as the solution to carrying out high-resolution rainfall prediction with longer lead time; two examples of this are the operational STEPS and Nimrod systems in the UK Met Office (Pierce, 2009; Bowler et al., 2006; Sokol, 2006; Golding, 1998). The common idea is to blend NWP forecasts with Nowcasting and Downscaling techniques (shown in Figure 1). In operation, the Nowcasting usually plays the major role to predict precipitation (e.g., 1 – 10 km grid), based upon real-time radar-raingauge-calibrated observations (radar reflections calibrated by ground raingauge data), using for example linear extrapolation or auto-regression (AR) methods. The nowcasts then are merged (or blended) with the coarser weather information predicted by NWP models (≥10 km grid) to implement longer lead-time forecasts. This merge may increase the predictability of nowcasting; for example, in STEPS, the forecast lead time is up to 6 hours in the 15 min time interval and 2 km grids. Finally, statistically-based space-time downscaling techniques are employed and expcted to generate the details (e.g., 5 min time interval and 100 m grid) of these forecasts for local urban pluvial flood prediction uses. These may include 1D-1D surface runoff models such as (Maksimović et al., 2009 in the future 1D-2D (allitt et al., 2009)
Improvements therefore could be made in several aspects. The first is to enhance the spatial resolution of the operational radar observations. This enhancement may be implemented by upgrading the operational radar networks using Local Area Weather Radars (LAWRs, also known as X-band radars) to provide finer-resolution rainfall observations (Jensen & Pedersen, 2005; Gerstner & Heinemann, 2008); or by employing enhanced image post-processing techniques, e.g., the super-resolution image reconstruction (Park et al., 2003) or range oversampling techniques (Yu et al., 2006; Zhang et al., 2005). The second is to improve the technique of merging (or blending) downscaled NWP forecasts and radar-based nowcasts, based upon applying reasonable weights obtained by optimising specific forecasts skills (Mason, 2002; Bowler et al., 2006). The third is to improve statistically-based space-time downscaling techniques, which play a key role in resolving the difficulty in modelling the high non-linearity of precipitation at urban/street scales and are further discussed in Section 2.2.

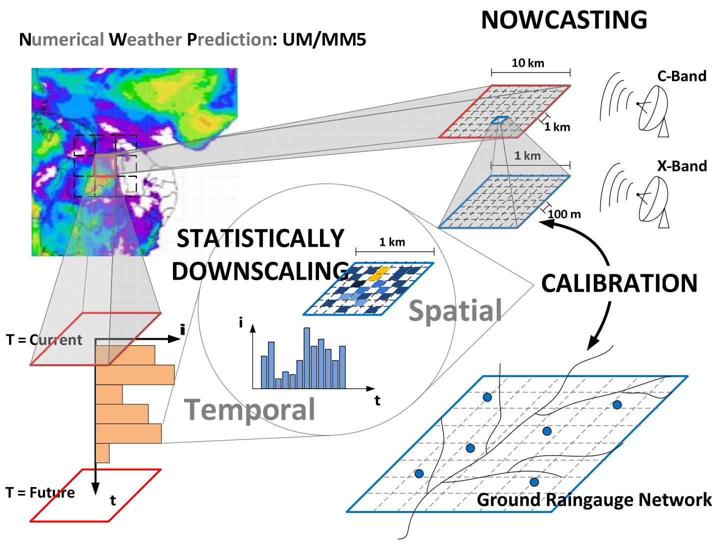


Fig. 1 - The conceptual scheme of the idea that integrates rainfall/weather models over multiple spatial and temporal scales

Statistically-based space-time downscaling

There are a multitude of statistically-based downscaling models in the literature which can be classified into three categories, based upon the theories respectively used: Generalised Linear Models (GLMs), Poisson-cluster, and cascade-based models. The first two categories are respectively based upon the pure statistical theory and the theory of stochastic point processes. Both of them have been successfully applied to the studies of disaggregation processes of rainfall, respectively at daily (Segond et al., 2006; Yang et al., 2005; Chandler & Wheater 2002; Stern & Coe, 1984) and hourly (Koutsoyiannis, 2003; Koutsoyiannis & Onof, 2001; Onof et al., 2000; Onof & Wheater, 1994) time scales. However, concerning the scales of interest (sub-hourly and urban scales) in this work, the third category (the cascade-based model), developed through investigation of the scaling behaviour of complex nonlinear processes, has the most feasible ability to handle the corresponding nonlinearity of rainfall at smaller scales.

The (multiplicative) cascade is a single process to generate fine-scale data by subdividing a unit set into smaller and smaller subsets according to a fixed set of contracting (fragmentation) ratios (**S** in Figure 2) and at the same time subdividing the associated unit measure by another set of contracting ratios (**P** in Figure 2). Many efforts have been made to characterise these ratios and to apply them to spatially- or temporally-distributed rainfall modelling (Lovejoy & Schertzer, 1990; Deidda et al., 1999; Onof et al., 2005; Pathirana et al., 2003; Onof & Arnbjerg-Nielsen, 2009; Wang et al., 2009, 2010a, 2010b). However, due to the anisotropic space and time scaling behaviour, the complexity substantially increases when extending the temporal- or spatial- only cascade models to space-time models.

Two schemes are in general used to simulate this complex anisotropic scaling: 3D and 2D+Time schemes. In the 3D scheme (Figure 3(a)), the original spatial and temporal scales (two in space and one in time) are subdivided into smaller scales at the same time respectively according to specific fragmentation ratios. Meanwhile, the associated rainfall volume within the given 3D cube is subdivided into several sub-volumes according to a certain set of fragmentation ratios. The key issue to apply this schem to the real world is to determine the anisotropic relation between the spatial and temporal scales; and once this relation is identified, the 3D downscaling process can be simply modelled via the self-similar process (Deidda, 2000; Gires et al., 2010). The advantage of this scheme is that the self-similar downscaling process

could be simply and efficiently implemented. However, the drawback is that the spatial and temporal scales that can be generated are fixed and limited.
A more flexible approach is to apply the 2D+time scheme (Figure 3(b)), also known as the string of beads method proposed by Pegram & Clothier (2001), to space-time rainfall downscaling. The idea is to carry out the temporal downscaling first using the coarser spatial- and temporal-scale forecasts as inputs, and then to conduct the spatial downscaling at each time step (Over & Gupta, 1996; Pegram & Clothier, 2001; Lovejoy & Schertzer, 2010a, 2010b; Wang et al., 2010c). At each time step, the spatial downscaling is independently carried out; however, the parameters of spatial downscaling will evolve with time due to the causality. This means that the past rainfall field will influence the formation of the future one. The key issue when implementing this scheme is thus to model the temporal evolution of the spatial rainfall structure/pattern. For example, in STEPS, the rainfall field evolution is modelled using an AR-2 model. The advantage of this scheme is that the downscaling model can be implemented by easily integrating several different methods, and the scales that can be generated are relatively flexible. However, the evolution of rainfall field is difficult to be modelled particularly at smaller scales, and many further works are necessarily to be applied in this issue.

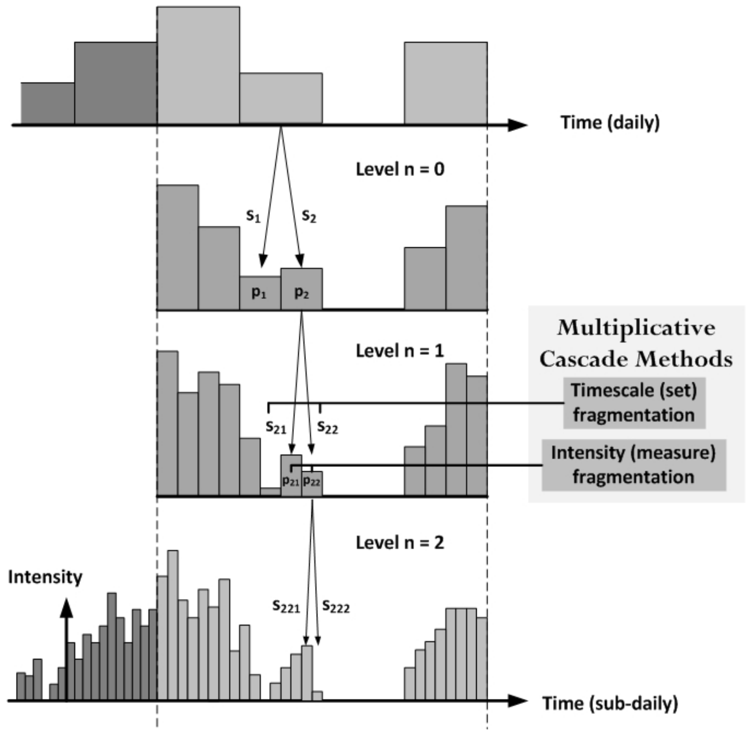
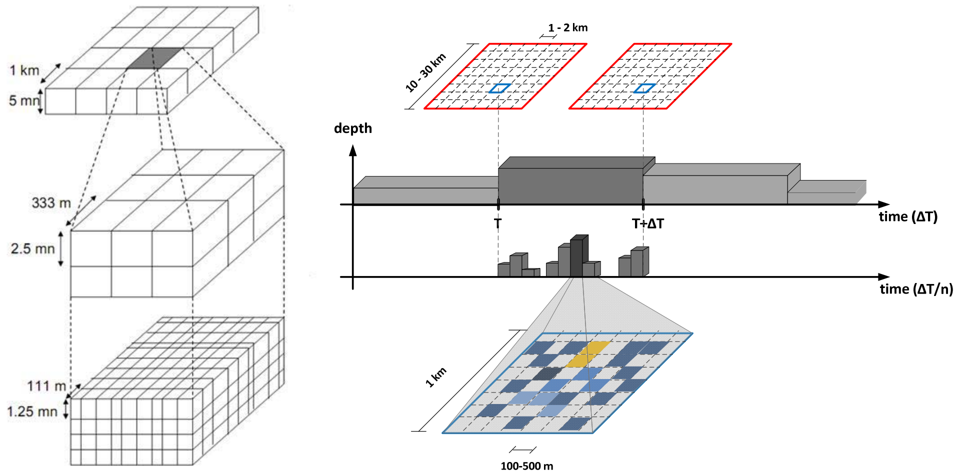


Fig. 2 - The diagram for a multiplicative cascade process



(a) (b)

Fig. 3 – Schematics of cascade-based space-time downscaling models: **(a)** 3D, and **(b)** 2D+Time schemes.

Space-Time Rainfall Modelling based upon A Dense Network of Raingauges

In urban catchments the lead time between the rainfall measurement and the flood peak time is normally just a few minutes (in most of the cases it is less than 30 min). The use of radar data is becoming common but most places are still unable to access this type of data; thus, merely raingauges are used. However, the major disadvantage of raingauge measurements is the lack of spatial information of rainfall. It is therefore essential to reproduce the spatial variation of rainfields.

The idea to carry out space-time rainfall prediction based upon merely raingauge sites is shown in Figure 6. For each snapshot, the rainfield (termed ‘‘virtual’’ radar image in this work) is generated from a dense network of synchronised raingauges laid out over the area of interest using interpolation techniques. Then, using the previously observed and current rainfall data or weather factors as inputs, rainfall forecasts can be obtained in each raingauge site and further used to generate the virtual radar images (by means of interpolation) for the following snapshots. Some preliminary results are shown in Figures 4, 5 and 7.

Interpolation techniques play the key role in the proposed idea for reproducing rainfields. Some breakthroughs have been made to improve the conventionally widely-used interpolation methods, such as, Inverse Distance Weight, Kriging and Cubic splines. Bárdossy & Pegram (2010), for example, used the mathematical technique Copulas and the Circulation Patterns to help charaterise spatial structure of rainfall and link coarser weather information to refine the Kriging interpolation method. Vischel et al. (2010) developed a simple dynamical interpolation technique that incorporates the kinematics of the rainy systems, and the results demonstrated the ability to produce more feasible spatial distribution of rainfall.

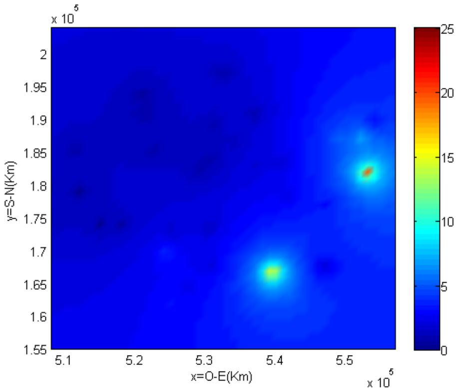


Fig. 4 - Inverse distance weight interpolation

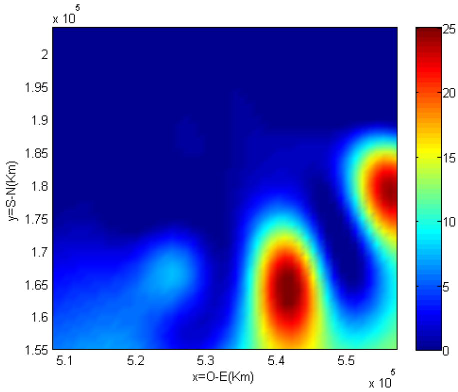


Fig. 5 - Kriging interpolation

As for radar, for very short lead times, quantitative precipitation forecasting can be achieved using extrapolation of consecutive images (e.g. using Support Vector Machines (SVM) (Gupta et al., 2009), Artificial Neural Networks (ANN) (Hung et al., 2009), Auto-Regressive Moving Average (ARMA) models (Burlando et al., 1993)). Behind the idea of ANN and SVM stands the idea of learning data. Several authors obtained good results with the application of SVM. Dibike et al. (2001) demonstrated the capability of SVM in hydrological prediction for modelling rainfall-runoff process and found that the SVM gave better prediction of runoff on test data as compared to the ANN model. Gupta et al. (2009) applied the use of support vector machine to forecast rainfall with a lead time from 15-min to 30-min by integrating and analysing three consecutive years in Mumbay.

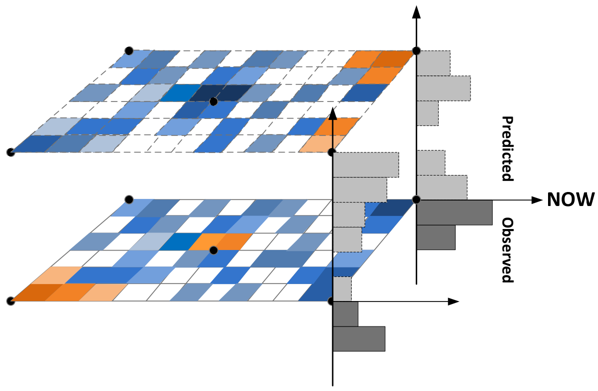


Fig. 6 – Schematic of the space-time rainfall modelling based upon a dense network of raingauges, where the black dots individually represent raingauge sites.

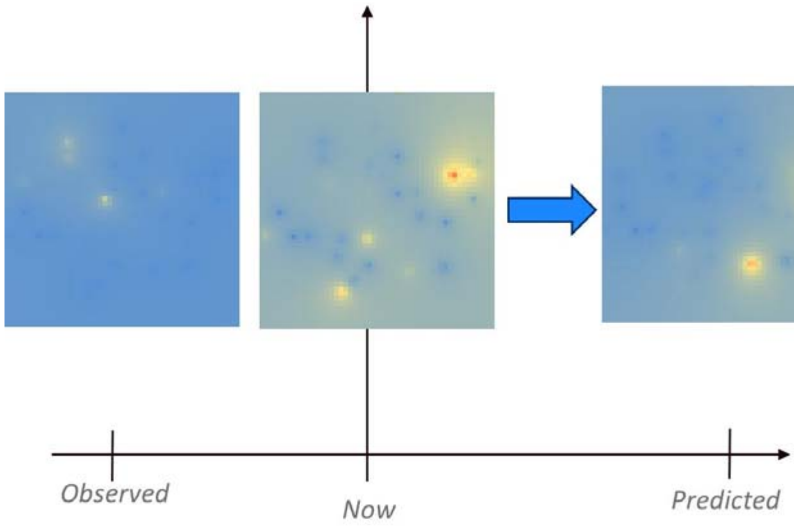


Fig. 7 – An example of 3 consecutive images using interpolation of the network of 31 raingauges (London 07/07/2009).

Case study

All methodologies will be testes in a case study in Redbridge, London, United Kingdom.

Redbridge case study

An experimental site located in the London, borough of Redbridge, is being monitored. The monitoring programme includes rainfall measurements using a raingauge network and C-band radar network (operated by the UK Met office), open channel, sewer and receiving river level measurements and wireless data communication in real time (shown in Figure 8).

The improved composite signal acquired from radar measurements by the (single-polarisation) Chenies radar and the new (dual-polarisation) Thurnham radar will be used to improve rainfall forecast under regular and (of special interest) under extreme conditions.

River Roding Catchment:

The river Roding starts at Molehill Green surrounded by the Stansted Airport at West and Great Dunmow at East (Figure 9). The river runs through the Essex districts of Epping and Uttlesford and the London Boroughs of Redbridge, Newham and Barking, before discharging into the Thames at Barking Creek (Environment Agency, 2006). The River Roding has several tributaries entering it, and two of them are the Cranbrook and Seven Kings, situated in the Redbridge area, northeast of London.

According to the Environment Agency (2006), the Roding has a rapid response to rainfall, which is typical of a densely urbanised catchment overlying London clay. Flood events have been recorded in the Roding catchment since 1926, with the most recent event being in 2000 and 2009, when several properties were flooded.

Cranbrook Catchment:

The drainage area is approximately 910 hectares. The main watercourse is approximately 5.75 km long, of which 5.69 km is culverted.

The catchment is predominantly urban with several parks, playing fields and a golf course. This area has a history of local flooding and was the worst affected area during the heavy rainfall event of 30-31 October of 2000.

Monitoring Deployment:

The monitoring campaign includes (Figure 10 and 11):
a) Three real-time accessible tipping bucket raingauges
b) One sensor for water depth measurement in open channels (frequency: 5-10 min)
c) Two sensors for water depth measurement in sewers (frequency: 5/10 min)
d) One depth sensor for Roding river (frequency: 5-10 min)
e) Over 40 weather monitoring systems in the Greater London (frequency: 1 min)

Sources of Radar Data:

The radar data used in this work are mainly provided by the UK Met Office, including:
a) Composite Nimrod modelling data (5 min and 1 km)
b) Composite Nimrod modelling data (5 min and 500m)
c) STEPS forecasting data (5 min and 2 km, 1 hour lead time)
d) STEPS forecasting data (15 min and 2 km, 6 hour lead time)

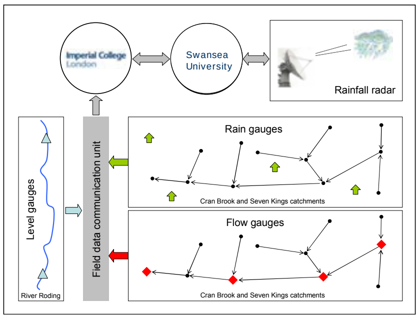


Fig. 8 – Links with Swansea University and Met Office

Fig. 9 – River Roding

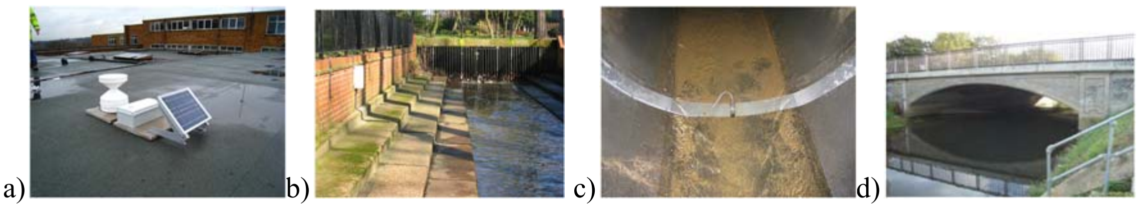


Fig. 10 – Monitoring equipment:(a) the raingauge, (b) the level gauge for the open channel in valentine park, (c) the level gauge in the sewer system, and (d) the level gauge for Roding river

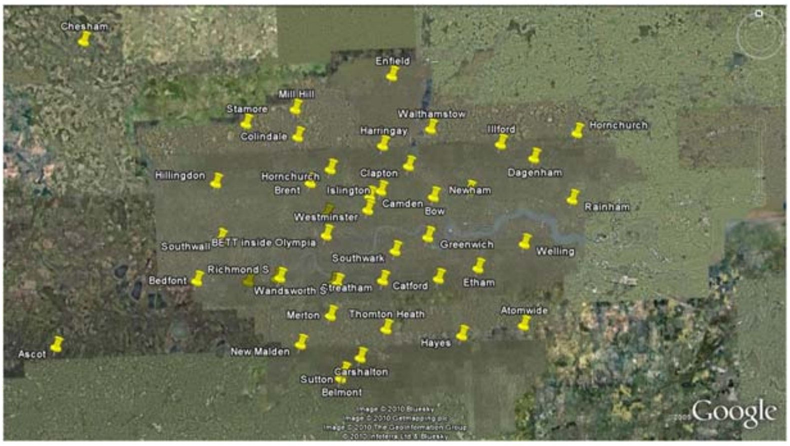


Fig. 11 – Totally 42 weather monitoring systems in the Greater London (provided by the London Grid for Learning, LGL)

Conclusions

An idea of integrated space-time rainfall modelling is explained and some remarks are given on the state-of-the-art techniques. An improved cascade-based method is being developed for carrying out high-resolution (sub-daily) rainfall downscaling, and some preliminary analyses of short-term rainfall prediction based upon raingauge network only are summarised.

We believe that a dense network of raingauges can be a cheap alternative to know the spatial distribution of rainfall in places with no radar. Enhanced interpolation methods are being developed and validated using radar data and larger-scale weather variables for "Raingauge network only".

Full-scale test on our experimental site in London will be carried out to assess the proposed integrated rainfall modelling with/without radar observations.

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Simulation of flood flows in the absence of boundary conditions

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ABSTRACT: In this paper, a method for reconstruction of flood hydrograph is described in the cases where the water levels are measured somewhere in the middle of the water course, while upstream and downstream data are missing. Utilizing the method of characteristics, it is possible to show theoretically that unsteady flow during the flood event can be reconstructed along the water course utilizing the hydrograph data at one, middle section. This approach may be utilized in reconstruction of unknown hydrograph data at the section of interest. The method is verified by application on several flood flow examples.
Key words: flood flow simulation, method of characteristics

Introduction

It is a quite common case of hydrograph data lack during flood events at locations of interest. These hydrographs are valuable for many reasons, from engineering point of view to problems where numerical simulations are required. In the case of numerical flow simulations, according to traditional approach it is required to apply boundary conditions at both, upstream and downstream boundaries (e.g. Abbot, 1979; Chaudry, 1979) .
In this paper, however, we propose the technique for numerical simulation of flood events along the water course in the case of lack of the boundary conditions, utilizing single observed hydrograph at the "middle" section. Firstly, based on method of characteristics (MOC), theoretical considerations are shown which clearly reveal that it is possible to numerically reproduce unsteady flow for the whole water course by using single hydrograph at the middle section. In the second part, several examples are shown where proposed technique is applied and verified.
Theoretical considerations

For the sake of simplicity, one dimensional open channel flow is described by the following set of equations (Hosoda, et. al., 2008):

[continuity equation]
$$\frac{\partial h}{\partial t} + \frac{\partial hu}{\partial x} = 0 \qquad (1)$$
[momentum equation]
$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial h}{\partial x} = \sin\theta - \frac{\tau_{bx}}{\rho h} \qquad (2)$$

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where x is the spatial coordinate, t :is the time, h the water depth. u the depth averaged velocity, g is the gravitational acceleration, θ the bottom slope, ρ the water density, and τ_{bx} is the bottom shear stress.
Here, the bottom shear stress is evaluated by using the friction coefficient c_f :

$$\frac{\tau_{bx}}{\rho} = c_f u|u| \tag{3}$$

Since the time derivatives are also calculated, the equation on the time derivative of h and u are also shown in the following equations.

[Time derivative of depth]

$$\frac{\partial h_1}{\partial t} + u\frac{\partial h_1}{\partial x} + h\frac{\partial u_1}{\partial x} + u_1\frac{\partial h}{\partial x} + h_1\frac{\partial u}{\partial x} = 0 \tag{4}$$

[Time derivative of velocity]

$$\frac{\partial u_1}{\partial t} + u_1\frac{\partial u}{\partial x} + u\frac{\partial u_1}{\partial x} + g\frac{\partial h_1}{\partial x} = c_f\frac{u^2}{h^2}h_1 - 2c_f\frac{u}{h}u_1 \tag{5}$$

where h_1 and u_1 are defined as follows:

$$h_1 \equiv \frac{\partial h}{\partial t},\ u_1 \equiv \frac{\partial u}{\partial t} \tag{6}$$

Equations (2), (3), (5) and (6) can be expressed in the matrix form (Eqs.(8) and (9)).

$$\frac{\partial}{\partial t}\begin{bmatrix} h \\ u \end{bmatrix} + \begin{bmatrix} u & h \\ g & u \end{bmatrix}\frac{\partial}{\partial x}\begin{bmatrix} h \\ u \end{bmatrix} = \begin{bmatrix} 0 \\ g\sin\theta - \dfrac{\tau_{bx}}{\rho h} \end{bmatrix} \tag{7}$$

$$\frac{\partial}{\partial t}\begin{bmatrix} h_1 \\ u_1 \end{bmatrix} + \begin{bmatrix} u & h \\ g & u \end{bmatrix}\frac{\partial}{\partial x}\begin{bmatrix} h_1 \\ u_1 \end{bmatrix} = \begin{bmatrix} -\dfrac{\partial u}{\partial x} & -\dfrac{\partial h}{\partial x} \\ c_f\dfrac{u^2}{h^2} & -\left(\dfrac{\partial u}{\partial x} + 2c_f\dfrac{u}{h}\right) \end{bmatrix}\begin{bmatrix} h_1 \\ u_1 \end{bmatrix} \tag{8}$$

When Eqs.(7) and (8) are multiplied by the eigen vectors of the matrix $\begin{bmatrix} u & h \\ g & u \end{bmatrix}$, $\left(1 \quad \pm\sqrt{h/g}\right)$, the relations satisfied along the characteristic lines can be derived as shown in the following equations:

$$\frac{\partial h}{\partial t} + \left(u \pm \sqrt{gh}\right)\frac{\partial h}{\partial x} \pm \sqrt{\frac{h}{g}}\left\{\frac{\partial u}{\partial t} + \left(u \pm \sqrt{gh}\right)\frac{\partial u}{\partial x}\right\} = \pm\sqrt{\frac{h}{g}}\left(g\sin\theta - \frac{\tau_{bx}}{\rho h}\right) \tag{9}$$

$$\begin{aligned}\frac{\partial h_1}{\partial t} + \left(u \pm \sqrt{gh}\right)\frac{\partial h_1}{\partial x} \pm \sqrt{\frac{h}{g}}\left\{\frac{\partial u_1}{\partial t} + \left(u \pm \sqrt{gh}\right)\frac{\partial u_1}{\partial x}\right\} &= \left(-\frac{\partial u}{\partial x} \pm \sqrt{\frac{h}{g}}c_f\frac{u^2}{h^2}\right)h_1 \\ &\quad + \left\{-\frac{\partial h}{\partial x} \mp \sqrt{\frac{h}{g}}\left(\frac{\partial u}{\partial x} + 2c_f\frac{u}{h}\right)\right\}u_1\end{aligned} \tag{10}$$

Equation (10) indicates that the disturbances of the time derivative of depth also propagate with the velocity of the positive and negative characteristic lines. Moreover, if it is necessary to use the equations of the higher time derivatives of depth and velocity, one can derive equations using the same mathematical procedure.
Now, it is possible to apply the common method of calculation which is referred to as the method of calculation in a fixed grid system to solve Eqs.(9) and (10) numerically.

Methodology application

Figure 1 shows the mesh of characteristic lines along the water course assuming subcritical flow conditions. As it can be seen, if boundary conditions are assumed and initial condition is known, hydraulic variables at the observation site can be calculated. Boundary depths may be assumed as linear functions of time, in which case only first time derivatives equations are required to solve, in order to obtain unknown coefficients at the boundaries.
Here, the following equation is utilized to describe temporal change of depth at the upstream and downstream boundary:

$$h(t) = h(t = t_0) + \alpha_1 (t - t_0) + \alpha_2 (t - t_0)^2 \tag{11}$$

where α_1 and α_2 are unknown coefficients.
Firstly, the methodology is applied on simple, numerically produced flood flow in an unit width channel. A simple depth hydrograph is applied at the upstream boundary (Figure 2a) in order to numerically produce the hydrograph at the middle section, which represents the observation site for the methodology test. For the sake of simplicity, the depth at the downstream boundary is set to be constant. The length of the channel is 20km, and the length of spatial discretization is 50m. The bottom slope and the friction factors are assumed to be 1/2000 and 0.01, respectively. Calculated hydrograph at the middle section (x=10km) is shown in Figure 2b.
In the first step, we assume the depth hydrograph at the upstream boundary according to Equation (11), and compare calculated depth and its time derivative at the observation section (x=10km). Based on comparison, coefficients $\square_1$ and $\square_2$ are adjusted in order to fit observed data at the middle section.
Figure 3a and 3b show obtained hydrograph at the upstream boundary after tuning coefficients in Eq. (11) in different time intervals.

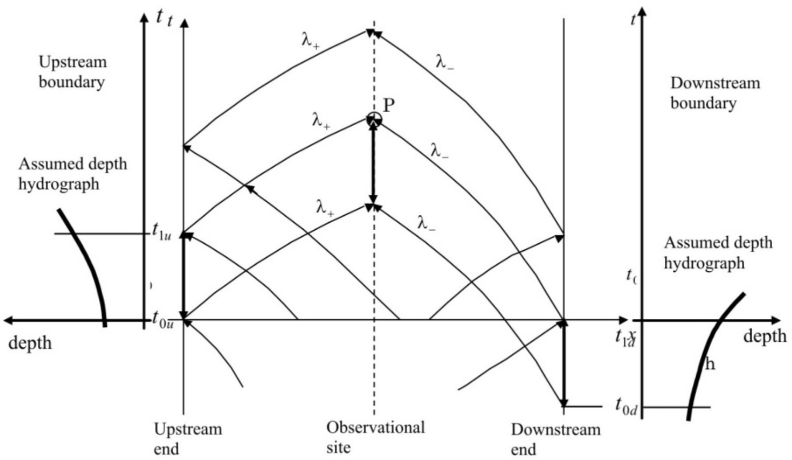

Figure 1: Computational method for calculation of flood flow in the absence of boundary condition

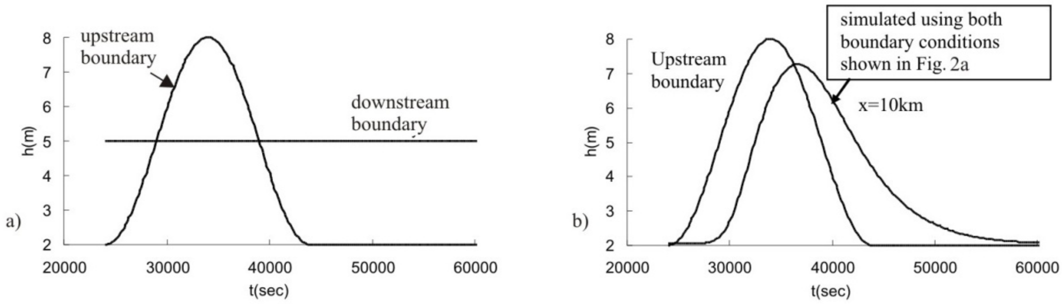

Figure 2: a) Boundary condition for calculation of hydrograph at the middle section, b) calculated hydrograph at the middle section (x=10km). Calculated hydrograph represents the observational section for methodology application.

In order to reconstruct the whole upstream hydrograph at the upstream boundary, the procedure should be repeated for several time intervals. Naturally, the decrease of the time interval length results in better agreement of reconstructed and actual hydrograph. Figure 4 shows the whole hydrograph, reconstructed for the whole period of the flood. The result indicates that the flood flow may be reconstructed along the water course by utilization of single depth hydrograph at one observation point.

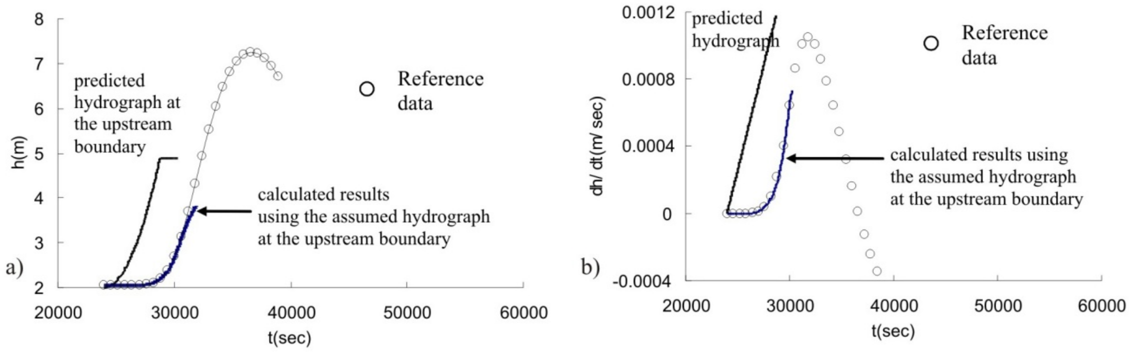

Figure 3: a) Comparison of calculated and observed hydrograph for the first time interval and reconstructed upstream hydrograph b) comparison of calculated and observed depth time derivatives

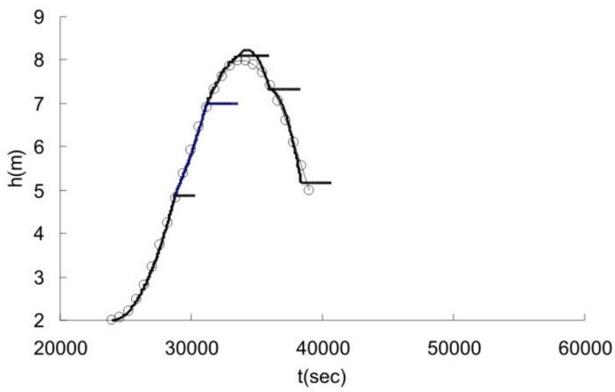

Figure 4: Reproduction of the whole hydrograph at the upstream boundary utilizing the hydrograph data from the middle section only (Comparison of the actual hydrograph and the reproduced one).

In the second example, the methodology is applied on the real problem. Namely, a flood wave at Uji river is reconstructed according to proposed methodology. Simulated river course is nearly 16km long (Figure 5). The upstream boundary represents the Amagase dam (53.2 km), while downstream end is at 37.2km . Nearly at 8.4km from the upstream boundary, there is an observation point (Mukaijima - 44.8km), which is utilized for reconstruction of the hydrographs at both boundaries.

In the first step, the steady flow is simulated by using two dimensional, depth averaged flow model, based on observations in the period before the flood wave occurrence. The model discretization for numerical simulation is obtained by 81 finite volumes in longitudinal, and 31 in lateral direction. Figure 6 shows calculated water depths along the river course for steady conditions.

In this case, upstream boundary condition represents assumed discharge and water level at the downstream boundary, according to following equations:

$$q_{up} = A_1 t + A_2 t^2 + q_0 \qquad (12)$$

$$h_{down} = B_1 t + B_2 t^2 + h_0 \qquad (13)$$

where A1, A2, B1 and B2 are unknown coefficients.

Figure 5: Uji river, the computational flow domain

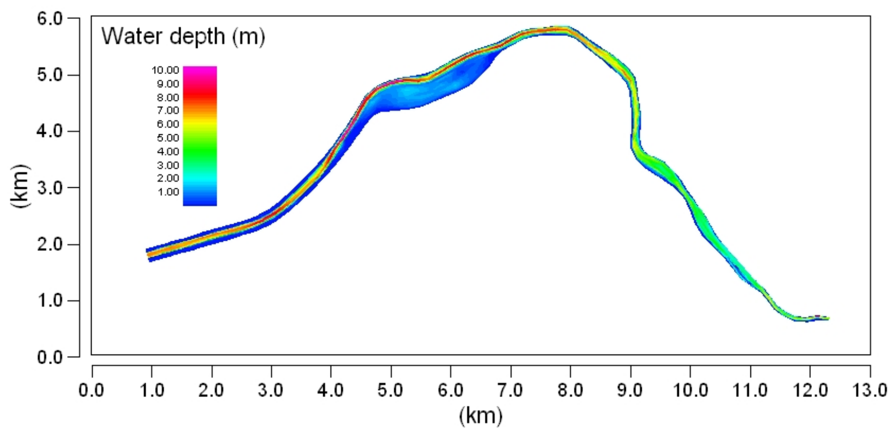

Figure 6: Calculated water depths for steady conditions, which is utilized as initial condition for methodology application

Time intervals for hydrograph reconstruction are adopted as 7200 sec. During this period, coefficients in equations (12) and (13) are considered as constant. These coefficients are estimated by comparison of calculated and measured hydrograph data at the Mukaijima observation point for each time interval. Described procedure is successively repeated for the whole flood wave hydrograph. Comparison of reconstructed of the upstream discharge hydrograph and the downstream depth hydrograph with observed ones are shown in Figure 7. Figure 8 shows comparison of simulated and observed hydrograph at the Mukaijima observation point.

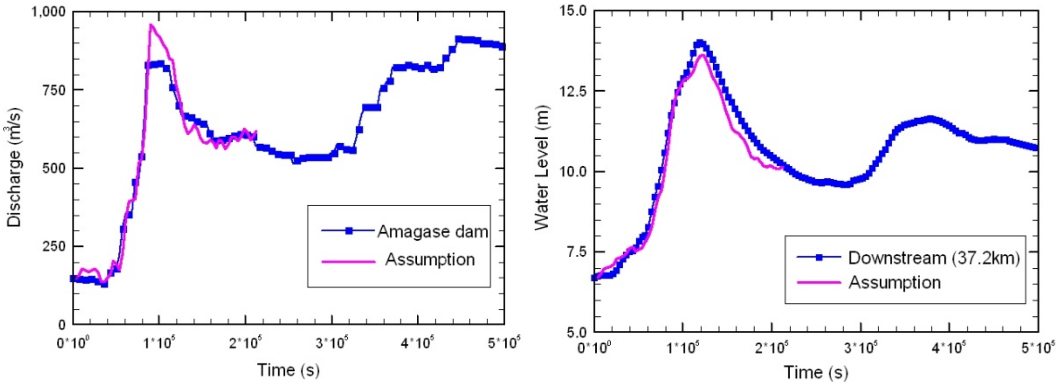

Figure 7: Comparison of reconstructed discharge hydrograph at the upstream and the depth hydrograph at the downstream boundary with observation data

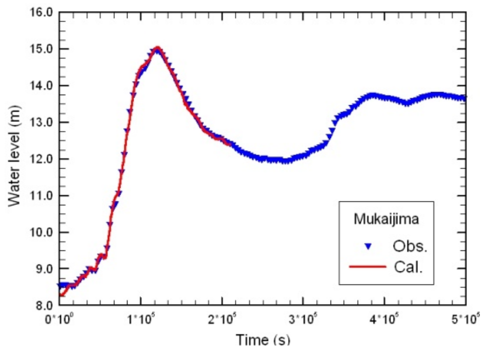

Figure 8: Comparison of simulated and observed hydrograph at the Mukaijima observation point

Conclusions

The methodology for simulation of flood flows, in the case of deficiency of boundary conditions, is proposed base on single hydrograph record at the “middle” section. The method is applied on two flood flow cases, producing reasonable agreement in reconstruction of hydrographs at the boundaries of the flow domain.

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Combined sewer overflow (CSO): possible approach to the problem

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ABSTRACT

Mixed sewerage, are systems that collect both civil and stormwater waters; during heavy events, they may be overloaded then it is necessary to adopt combined sewer overflow that avoid congestion receptor water going to unload sewage directly into a river, lake or sea. Such systems may however create serious pollution problems expecially for the fact that coarse materials go directly to surface waters, with consequent impacts on environment and on landscapes. The Veneto region is characterized by the presence of historic towns with combined sewer, is therefore subject to pollution problems of surface water due to many overflow that occur during rainfall events. The Veneto region considering the issues related to water management rule the CSO, has defined that, by 2014, all the CSO must be equipped, before the overflow itself, at least of a grid for coarse solids and, if possible, also of a section for the knocking down of settleable suspended solids. The objective is to ensure that operators of the drainage system adapt existing overflows in order to ensure a correct and functional management of hydraulic risk and problems related to water pollution. This objective can be accomplished through the use of best technologies that need to be managed and maintained effectively to guarantee their continuous and efficient operation. Particularly, for the management of these problems, it must be researched some technical solution that can fit as a retrofitting in existing infrastructures, as overflows are usually positioned in existing and old net, where can be difficult put new big structures. Thus, in these work are presented some possible solutions, different for the technologies applied, that can work either with pumping system, or without electricity, simply with the power by the water itself, than can be installed directly inside the CSO structures without significant civil works.

Presentation

Veneto is one of the 20 regions in Italy which has a population of about 4.8 million persons. It has been a land of mass emigration for a long period in history and is now one of the greatest immigrant receiving regions in the country.
The Veneto region, as elsewhere in Italy, has a very high urban density and small old towns. This explains the significant presence of combined sewer in our region. Another problem in Italy is the increase of rainfall in years. The stormwater enter in the combined sewer with all solid pollutants and create many cleaning and environmental problem. The cleaning operations are further complicated because they are usually located underground.

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Another problem is related to insufficient maintenances done during the years that has changed the hydraulic profile of the sewers. The incomplete knowledge of the sewers at least don't help their efficiency.

Many CSOs to carry away solid pollution and other pollutants in Venetian Lagoon, a particular eco-system.

The Venetian Lagoon is the enclosed bay of the Adriatic Sea in which the city of Venice is situated. The Lagoon was formed about six to seven thousand years ago, when the marine transgression following the Ice Age flooded the upper Adriatic coastal plain. Deposition of river sediments compensated for the sinking coastal plain, and coastwise drift from the mouth of the Po tended to close tidal inlets with sand bars.

For help this ecosystem "we" must find a solution!

Other peculiarity of the Veneto Region are the historical centers like Venice, Padova and Verona, where are impossible to change the sewer system without damaging any historical buildings, squares or churches. For example Venice was built on many islands, and the canals of the Lagoon are a big sewer and while Padova and Verona, were built near Bacchiglione River and Adige River, wherefore discharged their sewers in these rivers.
"New sewers" began to be built in XIX Century and the simplest solution was to adapt new sewers on old ones. These cities have had rapid expansion and these growths caused a new problem, water pollution.

To solve this trouble the best solution is a sewer separation projects-building with a second piping system for these cities, but this kind of project is very expensive and there are physical limitations may preclude building a completely separate system.

It's clear that the overflow of the CSO in a very urbanized area like is our Region have a big impact on the environment and in the quality of the surface water that is getting also the pressure from the other sources of pollutant.

This is why is necessary to find an integrated approach to try to solve the problem.

Everything has to start from the knowledge , that isn't complete at the moment of the systems of the sewers and their impacts.

The second step is the definition of a strategy with a very complete mix of actions that are going to give results in medium period and also the solutions in the short time of the peaks event with all the help that we can have from engineering and technologies.

Another big problem is how and where is possible find the money that are necessary to develop the program.

Therefore the State must find a valid solution for water pollution, which doesn't require big alteration in the sewer system.

Combined sewer overflow: characteristics and pollutant loads

A mixed sewer serves the dual purpose in the same network to collect and transport both the wastewater and water derived from surface runoff of urban catchment. Corresponding high flow rates must therefore be managed during rain events. When the hydraulic capacity of an interceptor or a trunk sewer is exceeded during a runoff event, overflow of excess water from the network into adjacent receiving water must take place upstream of this point. Combined sewer networks are therefore equipped with structures where overflow can take place. Such overflow, combined sewer overflow (CSO), mean that a mixture of untreated wastewater, runoff water from the catchment, and materials eroded from deposit in the network itself is discharged. The consequence of CSOs is a potential pollution and deterioration of downstream receiving water system.

Overflow structures

An overflow structure in a combined sewer network serves the purpose of reducing the flow rate into a downstream network during an extreme runoff event. The capacity of the downstream system in terms of premium, flooding, or overloading of a sewage treatment plant thus determines which part of the flow can be routed in the interceptor and thus defines the amount of the flow must be discharged as CSO. Figure 1 shows the principle of a simple overflow structure. The capacity of the interceptor can simply be determined by a reduced pipe diameter compared with the size of the inflow pipe or a device that regulates the outflow from the overflow structure. When the capacity of the interceptor is exceeded, the mixed wastewater and runoff water will pass the overflow weir and be discharged as CSO.

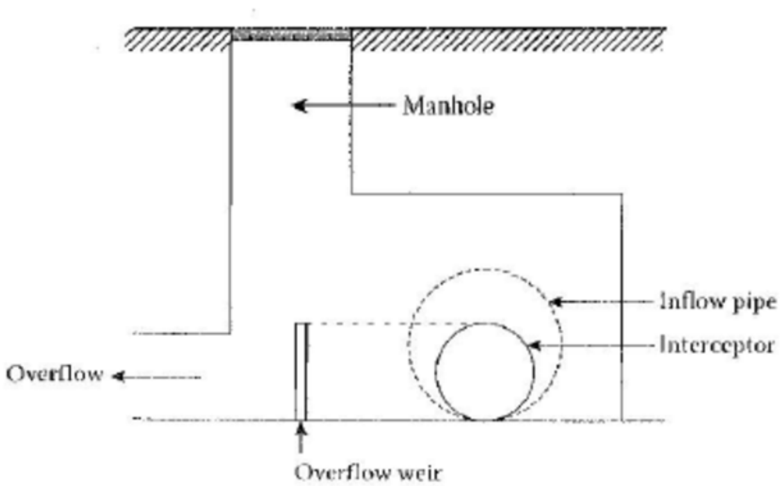


Figure 1. Schematic of a simple overflow structure

The detail of construction of an overflow structure are legion and depend on the specific objective, the local tradition, and the possibility and requirements for implementation in the entire sewer network.

CSO pollutant source

The pollutant discharged from CSOs originate from the following three major types of source (Figure 2):
The urban surface
The daily flow of wastewater
Eroded sewer solids (originated from deposits and biofilms in the sewer network)
Discharges from CSOs, known as intermittent discharges, contain both foul sewage and storm water and therefore contain large amounts of pollutants, including gross solids and finely suspended solids in solution. These pollutants can have a significant aesthetic, oxygen demand or toxic impact on the quality of the receiving water.

The relative importance of these pollutant source for the quality of CSOs depends on a large number of basin characteristics and how the sewer system is designed and managed. The degree of dilution of the daily flow of wastewater before the hydraulic capacity of the interceptor is exceeded is another important factor for the amount of pollutants discharged. The real value of the dry weather flow during a runoff event on the carrying capacity of the interceptor is therefore central. This value is not solely determined by constructive design parameters of the network but will also change with time.

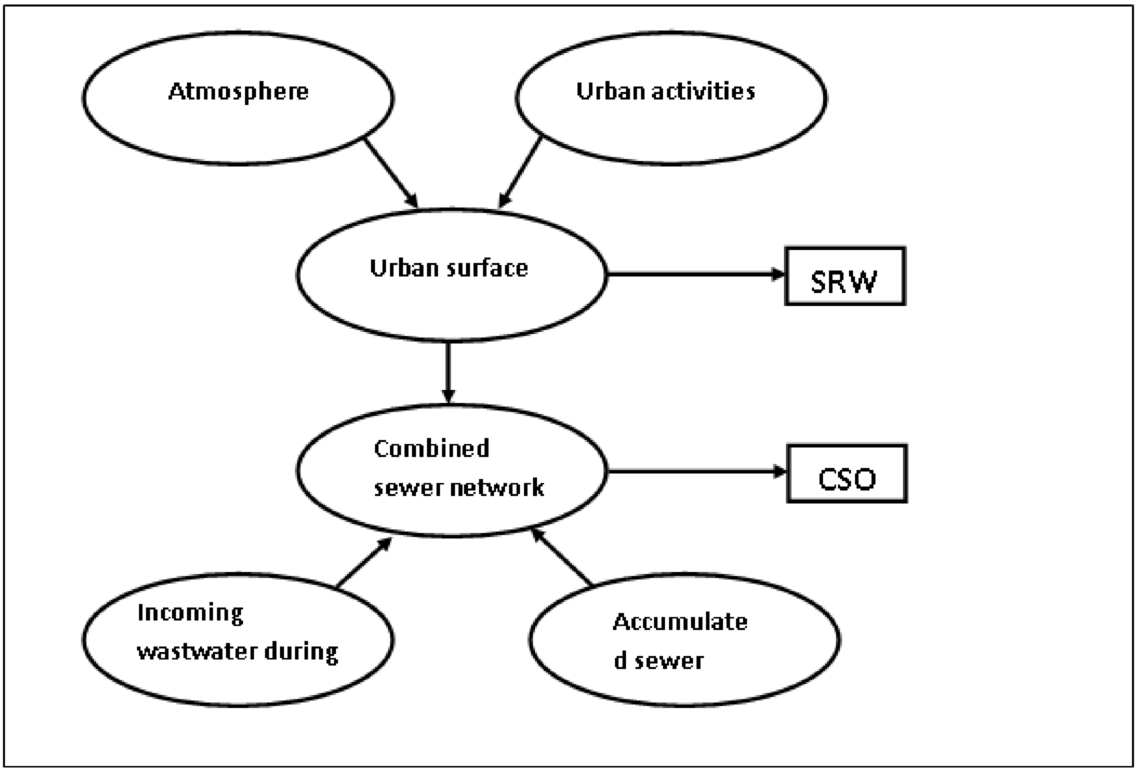


Figure 2. Overview of the pollutant sources and pathways for combined sewer Overflows

Surface runoff

In principle there is no difference in the inflow of the surface runoff into a combined sewer system compared with a storm sewer in a separate sewer network. However, often a combined sewer catchment is older and in several countries also typically found in a city centre (densely populated and with a relatively high traffic loads).

Wastewater

Wastewater in combined sewers will contribute of pollutants in CSOs. It does so in two way: directly by mixing the inflow of runoff water to the sewer with the wastewater flow and indirectly by erosion and resuspension of sewer solids that have been temporarily accumulated during preceding dry periods.

Sewer sediment and biofilms

In general, it is the magnitude and the dynamics of deposition of solids, biofilms growth, and sediment erosion in a drainage system, the extent to which sewer solids contribute to levels of pollutants in CSOs. These in – sewer processes refer to both dry weather periods where deposition and biofilms growth take place and the wet weather periods where erosion and resuspension of the deposits dominates. Into sewage systems, particularly those where sewer solids accumulate, the pollutant contribution from eroded materials is often more important for the pollutant contents of the CSOs than the contribution from both the urban areas and the wastewater. This fact makes it very important to construct self - cleansing sewers as a means, in addition to the capacity of the network, to reduce the pollutant impacts from CSOs.

Since sewer sediments have been subject to deposition, there is a potential risk for resettlement in the receiving water after discharge of CSOs. The same potential for settlement also exist for detached biofilms. The performance of the overflow structure is therefore crucial in terms of its ability to divert as much as possible of the sewer solids to the wastewater treatment plant and not into the overflow.

The solids in sewer play a specific and central role in the performance of a combined sewer network and therefore also for the pollution from CSOs. These solids are defined as follows:

- Solids in the water phase
- Sewer sediments
- Biofilms

The suspended solids that are transported in a combined sewer during both dry and wet weather flows consists of inorganic particles like sand and different fraction of organic materials. The different size and density of the particles result in corresponding different transport characteristics.

It is interesting to compare the C_{CSO} concentrations that include contribution of pollutant from both urban surfaces and eroded sewer solids with the corresponding C_{SWR} concentrations that only include pollutants from urban surfaces runoff and C_{sewer} concentration that include contribution from the daily wastewater flow, as shown in Table 2.

Table 2. Average Pollutant Concentrations in CSOs Based on a Summary Data from Several Studies

Pollutant (unit)	C_{CSO*}	C_{SWR}	C_{sewage}
BOD_5 (g m^{-3})	115	20	200
COD (g m^{-3})	365	115	500
TSS (g m^{-3})	370	415	200
Total Kjekdahl Nitrogen, TKN (g m^{-3})	3.8	1.4	40
Total N (g m^{-3})	9	3	40
PO_4-P (g m^{-3})	1.9	0.6	10
Total Pb (mg m^{-3})	370	350	-

.

Note: Data from stormwater runoff and sanitary sewage are included for comparison.
*The concentration values include contributions from the daily flow of municipal wastewater. These concentrations are therefore referred to as C_{CSO} and not $C_{runoff.}$

A Possible approach

Control of CSOs can be done through measures that provide volume control or concentration control, the first leads to a volume reduction through the overflow detention in accumulation basins, the second is accomplished by both treatment and flow control. Choosing the most appropriate solution must considered geological and hydrological features of the site as well as the availability of spaces in the area subject to overflow. In the Veneto region, where urbanization is very extensive and there are very limited space, the solutions that provide volume reduction of overflow are difficult to implement. So control of CSOs must consider measures to control pollution loads and flows reduction.
The Veneto Region is trying an integrated approach to solve the problem of the overflow of the CSO:

A THE KNOWLEDGE PROCESS

The Government of the Veneto Region, that has the competence in this field, wont conduct a census to increase the knowledge about the CSOs using the sewer fee fund that in Italy is going to be paid in the cost of the drinking water that anyone is using.
The regional government has created the PTA (Piano di tutela delle acque) "Water Protection Plan" which also legislate on combined sewer.

This Regional plan is born under a national law, made in consequence of an EU Directive that delegate to the Regions this matter under objectives and strategy that are coming from higher levels of law: National and EU.
The Regione Veneto s going to involve the Provinces, in Veneto we have seven of that and the ATO (Ambito territoriale Ottimale) that is a water authority to build the complete the census of the CSO in the Region.

This activity is necessary to be completed before the 2012.

B- ALL NEW SEWERS SEPARETED AND STORM WATER ARE NECESSERY TO BE TREATED

All the new urbanization infrastructures are going to be built with a separate sewers system between civil water and storm water.
In this way we can reduce the future impact of CSO that are never been higher of today.
The Piano regionale delle Acque has also a part about the Stormwater treatment starting from the concept that this kind of water can be source of big impact in the environment if is coming from areas interested in human activity.

C-REDUCTION OF PRESSURE IN THE COMBINED SEWERS

Starting a plan of disconnession of big areas, like parking lots, roofs , streets and reduction of impervious surface to reduce the curve numbers and the quantity of water present in the combined sewers.
Another activity is the study of presence of what we call "parassite water" in the sewer coming from the ground water or from mistake in the construction of the net of sewers.

Al these action are going to reduce in the mid period the quantity of storm water, or non civil water in the combined and other from the combined sewers.

D-POSSIBLE TRETMENTE FOR THE CSO

It' clear that is also necessary provide with some kind of solution that can't solve all the problems but that can be acceptable from environmental point of view with a reasonable investment of money and a technical feasibility.

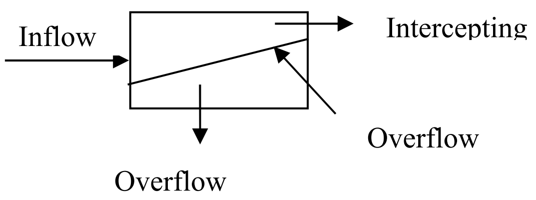
The Veneto Region Piano delle Acque said that the overflow must be provided at least a section of removal of coarse solids and, if possible, a section of remove suspended solids. Managers of the drainage system must provide a program to prepare for the adaptation of existing touches that must be approved by the ATO (Ambito Territoriale Ottimale) (The Authority over the Water process) and reported to the Province within two years from the publication Plane date. By 2014 all spillways shall be provided with a section for remove rough solids.

The overflow must be provided at least a section of removal of coarse solids and, if possible, a section of remove suspended solids.

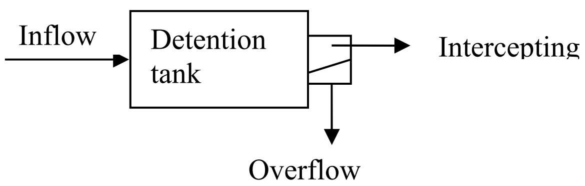
Detention basins

Below are represented three examples that illustrate the possibility of detention as a part of overflow structure, a temporary accumulation of the inflow in case the flow rate exceeds the capacity of the wastewater collection or treatment system located downstream. When the incoming flow rate is reduced to a value lower then this capacity, the wastewater in the detention basin can be diverted to the interceptor. The following figure shows the concept of both in – line and off- line detention.

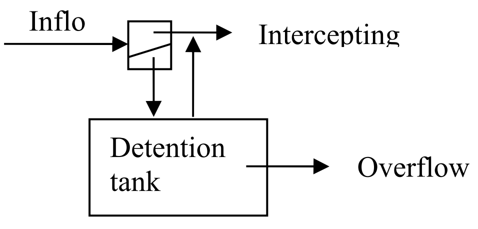
1. Simple overflow structure



2. Overflow structure with in – line detention tank



3. Overflow structure with off – line detention tank



The performance of overflow structure during a runoff or a overflow event can therefore be illustrated by comparison of inflow and outflow hydrographs. Figure 3 shows this principle in the case of an overflow structure with and without a detention tank. Figure 1.3 shows that the flow capacity of the interceptor located downstream and the detention tank volume will influence the magnitude of the CSO volume that is discharged. It is evident that a detention tank extends the time a wastewater treatment plant is exposed to high flow rates from the runoff event and also increases the volume of wastewater that must be treated.

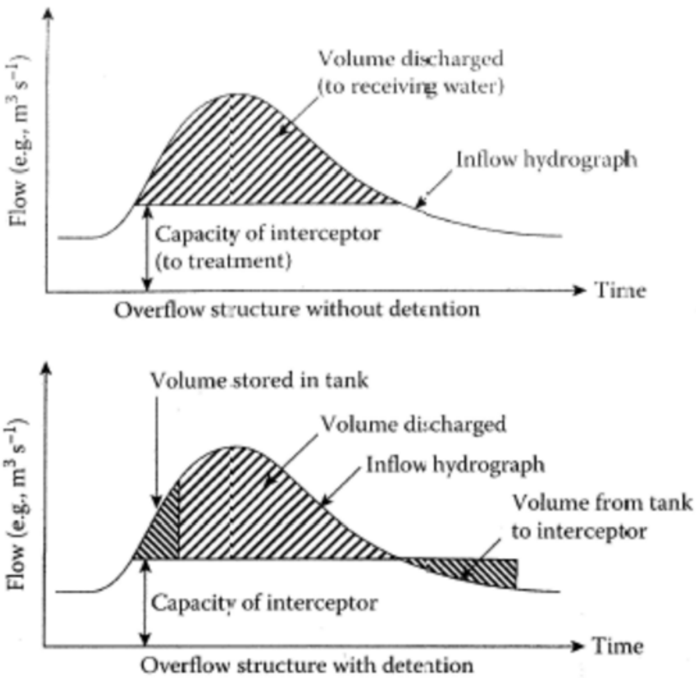


Figure 3. The Principle of inflow and outflow hydrographs during a runoff event for an overflow structure without a detention tank.

Racked bar screen

The solutions for the combined sewer in the Veneto and similar cases are find a product that is suitable for these situations and observe the law. The solution for removal the coarse solids is insert a raked bar screen that stop these pollutants in the combined sewer overflow. This product manufactured in modules is a raked bar storm screen's simple frame structure houses the drive mechanism, screen bars and rake mechanism.

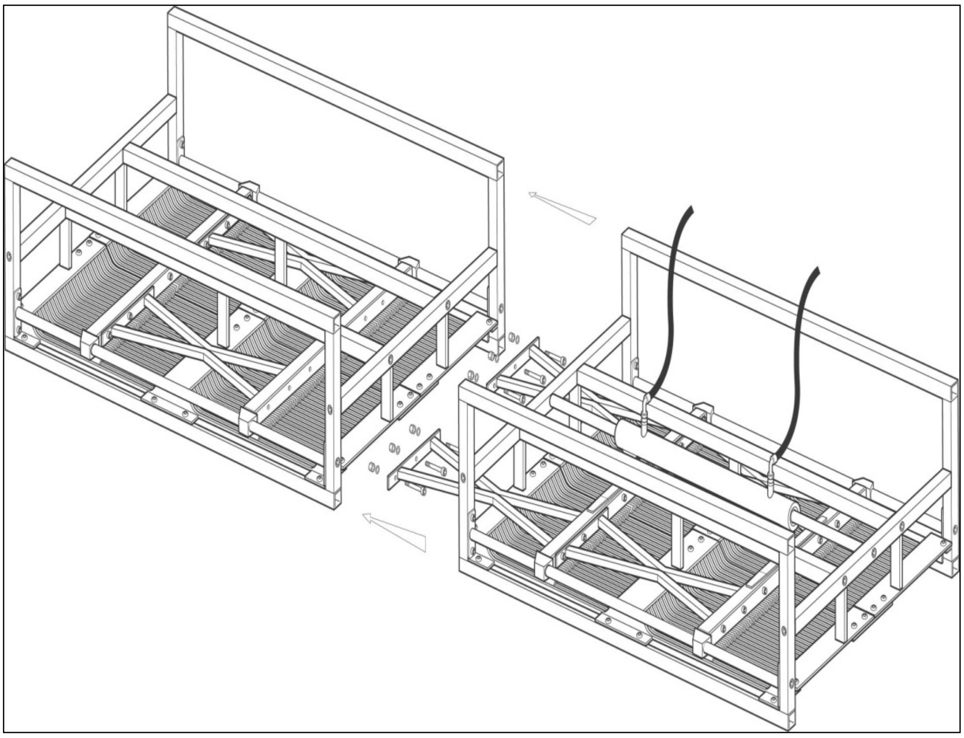


Figure 4. Racked bar screen

It is constructed from stainless steel with the screen comb fabricated in Tivar. Drive is achieved via a hydraulic power pack located remote from the screening chamber, operating a double acting cylinder. Bi-directional control is achieved with timer operated solenoid switches. The screen modules are mounted horizontally along the storm discharge weir. An ultrasonic control system monitors the upstream water level. The screen bars are set to the same level as the overflow weir and the signal to start the screen occurs just before the water level spills. Screens can be assembled below ground, through 600mm diameter manholes and can be delivered to site in complete sections or in modular form for ease of transportation. This technology requires low operation and maintenance and all All maintenance may be carried out from the top side/clean water side of the screen with the guide rods, combs drive unit being easily removed for inspection or replacement. The main framework and screening bars should not be required to be removed, however should this be necessary, each module may be split from its partners and removed separately.

Copa Cyclone

Another system for clear the CSO is a cylinder non-powered and self-cleaning storm screen that start the operating until the water level reaches the shaft level.

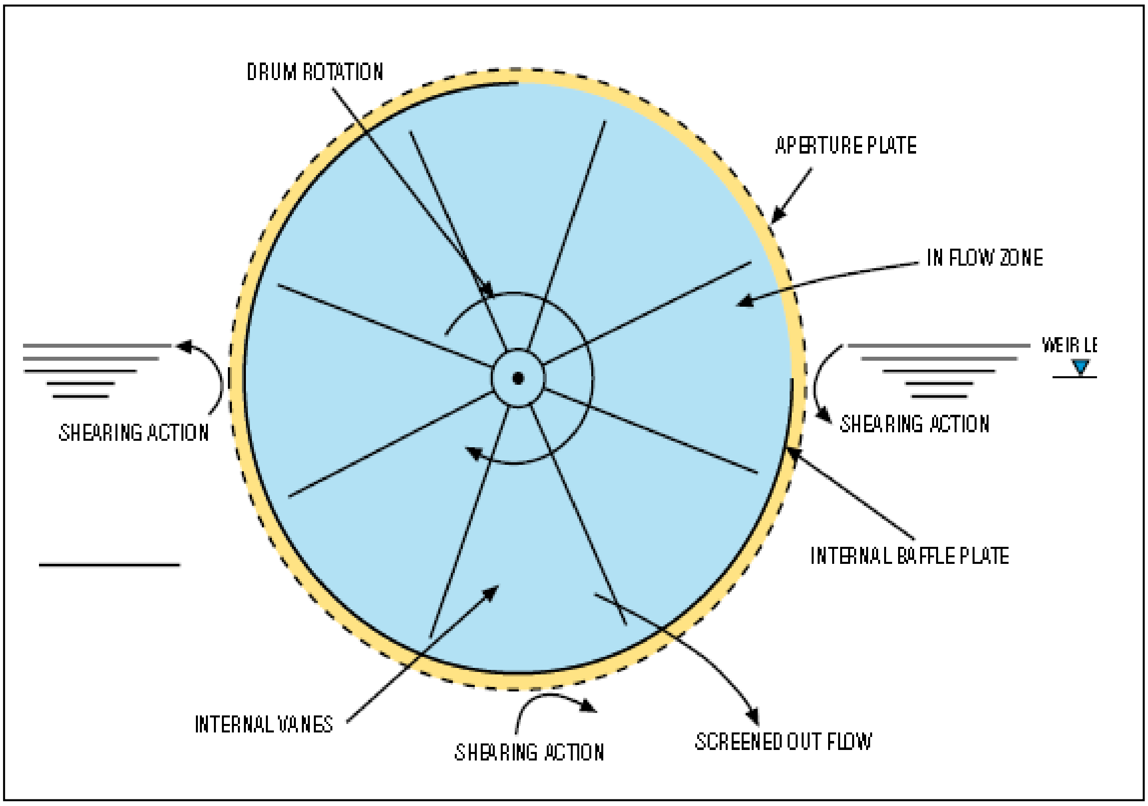


Figure 5. To show how Copa Cyclone works

With even the smallest inflow the drum will start to rotate. Since there is a high shear action between the drum face and the surrounding water, any screenings attached to the outside of the drum, will be stripped from the aperture face. The maintenance is to inspect the drum annually to ensure that is clean and rotating freely.

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The role of rainfall events for combined sewer system mathematical modelling – example of SWMM model of Maribor sewer system

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ABSTRACT: In this paper is discussed the role of rainfall data and analysis for sewer system simulation and, consequently, design and operation. It has been shown that design rainfall events in sewer system modelling are not sufficient and should be complemented with simulations based on observed rainfalls. Analysis of the sewer system in Maribor under historical rainfall events (especially extreme ones) provided detection of sewers and overflows of insufficient capacity and further prioritisation of measures for the sewer system rehabilitation. Simulation of observed rainfall events in the Maribor city using SWMM model facilitated rehabilitation of the sewer system implying decrease of probability of both, manhole flooding and combined sewer overflows (CSOs). Decrease of overflows at numerous CSOs is major conclusion because the Drava river is major receiving water, which is within the Danube - Drava National Park.

Key words: City of Maribor, combined sewer system, CSO, design storms, historical rainfalls, SWMM, sewer outlets, WWTP.

INTRODUCTION

In this paper is considered the importance of simulation of the waste water system using observed rainfall events. The analysis of Maribor sewer system performance based on design storms and observed extreme rainfalls was performed. It is shown that poor system performance under extreme rainfall causes pollution of Drava River, which is part of the Danube - Drava National Park. A series of improvements of pipes and structures of the sewer systems are recommended and their positive impact on water quality should be proven by using SWMM model.

The paper consists of the following: a discussion of the usual criteria for design rainfall events and brief explanation of the EPA SWMM model is given. In next chapter the EPA SWMM

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model of the Maribor sewer system is described. In the third chapter are described results of analysis of EPA SWMM model and recommendations for Maribor system improvement.
The concept of so called “return period” which is based on criteria rainfall and consequently criteria flow rates, is widely accepted as simple and clearly defined out of other models. But, this doesn’t define frequency or probability of overflows nor flooding in combined sewer systems. Thus, nor the pollution could be based on those. Moreover, modelling of quality and pollution at overflows, as well as flow toward WWTP is not modelled while the both having stochastic nature [1].

In general, into deterministic models of rainfall runoff and sanitation rainfall runoff imply a stochastic nature, or uncertainty, and also into the WWTP operation, particularly with observed storms. Such uncertainty can be decreased significantly, but not eliminated at all [1].

There are three phases in waste water management in cities, such as: waste water system modelling, including CSOs, WWTP operation and receiving water(s) analysis.
Analysis of the combined system reliability should also include flooding from the system trough covers and inlet grates, impacts toward WWTP operation and pollution of the receiving water [2]. This paper is based on the reports [3], [4] and paper [5].

Rainfall events for sewer system simulation

Combined sewer systems traditionally were designed due to 5-year return period rainfall, but the storm drainage systems use to be designed upon 2-year return period rainfall, whereas large combined sewers should accept runoff due to rainfall of 10 year or higher return periods [6]. The combined sewer overflows used to be designed to be in function 10 to 20 times a year [6, 7, 8].

Design rainfall events are usually of uniform intensity. However, real rainfall events rarely meet this assumption, which is confirmed by e.g. tipping bucket rainfall observations. If there were two rainfall events and elapsed time between events is not sufficiently long to provide sewer system to drain most of the runoff due to previous rainfall (e.g. over 90%) prior to a second rainfall event, then these events should be treated as a single rainfall event. Otherwise, these events should be treated as independent. Average intensity of the “composite” rainfall would be somewhat smaller than the average intensities of the two rainfalls (due to inclusion of dry period in-between events), but the runoff volume would not because of prolonged duration.

Additional complexity is introduced by rainfall high spatial variability, especially in urban areas where convectional rain dominates. Direction of storm and spatial initial soil wetness distribution significantly influence runoff. On top of that, higher flow rates could be reached while storm is moving along the runoff direction / downstream.

Facts listed above impose the need for detailed and comprehensive rainfall analysis instead commonly used IDF curves [9]. It is proposed that beside those also historical rainfall data should be used for modelling of the combined system [10].

SWMM model

The EPA Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used for event or continuous simulation of runoff quantity and quality from urban areas. It has been commonly used for sewer system simulations. SWMM enables estimation of the quantity and quality of runoff generated within each subcatchment, and the flow rate, water depth and water quality in each conduit during a simulation period [11].

Runoff modelling implies catchment delineation, calculation of effective rainfall for every subcatchment and surface runoff routing through a conveyance system of pipes, channels, storage/treatment devices, pumps, and regulators. Effective rainfall can be calculated using Horton, Green-Ampt or SCS-CN methods. SWMM enables simulation of steady flow routing, whereas unsteady flow can be simulated using Kinematic or Dynamic Wave model. Sewer roughness can be described using Darcy-Weisbach or Hazen-Williams equations. Water quality model implies specification of pollutants' build-up and washoff models (e.g. exponential). For every model certain parameters should be specified (e.g. maximal and minimal infiltration rate and decay constant for Horton loss model), along with the characteristics of system and watersheds (e.g. conduit's geometry). Details about this software can be found on website [11].

DATA AND STUDY REGION

Sewer system of Maribor

Combined sewer system is employed in Maribor city. Waste water and stormwater are conducted through sewer system toward WWTP (PPOV) situated at Dogoša, in the South part of the city (Fig. 1). Receiving water for sewer system are the following, the Drava River (Fig. 2), Stražunski canal and a hydropower system canal. A numerous combined sewer overflows – CSOs, out of which some are in function even during rainfall of low and mild intensity along the Maribor sewer system. The combined sewer system overflows are rather frequent, causing flooding with polluted water, but also surcharged by high stage of the Drava river (Fig. 3).

Prior to construction of the WWTP, at numerous outlets sewage discharging into Drava River had caused its eutrophication, but also frequent flooding of the streets in the lower parts of the city. However, frequent CSOs lead to polluted water reaching Drava River regardless WWTP. This constitutes rather significant issue, because Drava River is part of the Danube - Drava National Park. Therefore it is rather important to detect sewers and overflows of insufficient capacity and recommend their rehabilitation.

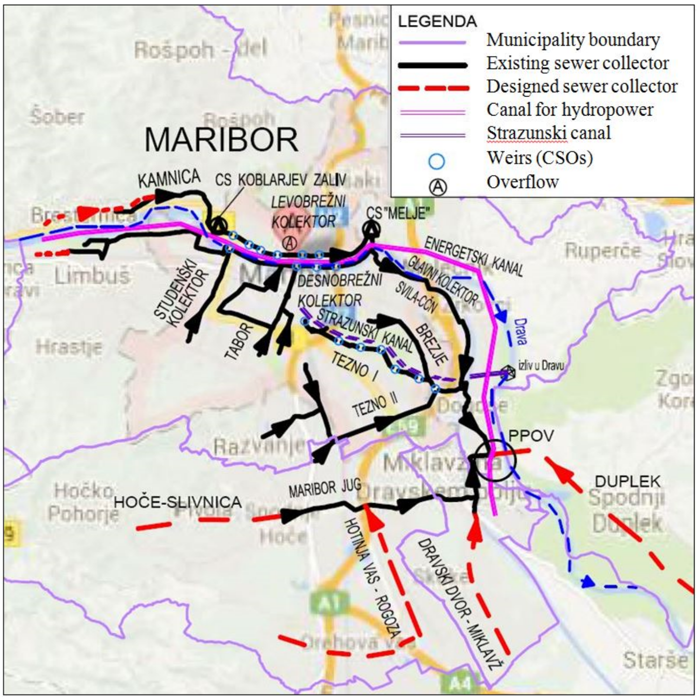

Figure 8. Sewer system of the Maribor city (PPOV – Waste Water Treatment Plant, CS – pump stations)

Figure 2. An overflow at the Maribor sewer system in June 2009 due to high rainfall

Figure 3. Combined sewer system outlet at the Drava River, partially surcharged what often occurs even for medium and low intensity rainfall events

Rainfall data

Rainfall data available for this study include rainfall observations at Tabor rain gauge, which is situated at the Maribor airport approximately 15 km south of city centre, and rain gauge situated in the immediate vicinity of WWTP (WWTP rain gauge).
The depth – duration - frequency (DDF) curves were derived by ARSO based on observations at the Tabor rain gauge from 1948 to 2006, and according to goodness-of-fit tests the Gumbel distribution was selected [9]. Derived DDF curves along with the rainfall events observed at WWTP rain gauge that resulted in flooding during 2008 and 2009 are given in the Fig. 4. Those were described in details in the reports [3, 4].

Table 5. The DDF curves for Maribor-Tabor based on Gumbel distribution [9]

Rain duration (min)	RETURN PERIOD [years]					
	2	5	10	25	50	100
5	8	11	12	15	17	18
10	11	15	18	22	24	27
15	14	19	23	27	30	33
20	16	22	26	30	34	38
30	18	25	29	35	39	43
45	21	29	34	40	44	49
60	23	31	36	43	48	53
90	26	35	41	49	55	60
120	28	37	44	52	58	64
180	32	41	47	55	61	67
240	35	45	51	59	65	71
300	38	48	54	62	68	74

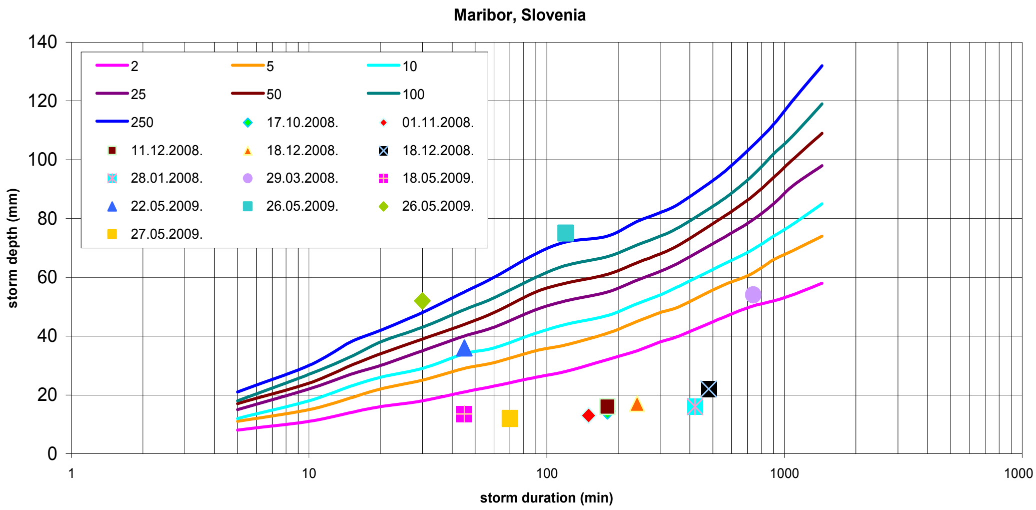

Figure 4. The DDF criteria curves for the city of Maribor after ARSO, and observed rainfalls during the years 2008 and 2009 at the WWTP rain gauge [4]

SWMM model of Maribor sewer system

The SWMM model applied to Maribor combined sewer system is developed to meet following goals:

- Assessment of existing system performance,
- Detection of the pipes, nodes and CSOs of insufficient flow capacity,
- Assessment of flood volumes due to sewer system overflows,
- Assessment of the CSOs' performance and pollution during overflows into the Drava river and the hydro – electro channel (ENERGETSKI channel), see Fig. 1,
- Estimation of water quality at WWTP and at sewer system outlets into receiving waters.

The SWMM model of Maribor sewer system includes 1069 sub-catchments, 1450 computational nodes, 49 outlets, 32 ponds, 1539 pipes/trunks, 13 pump stations and WWTP. Details on the sewer system can be found in [5].

The details concerning Maribor sewer system SWMM model are listed below:

- Horton model: infiltration rats, initial 300 mm/h, final 10 mm/h,
- Impervious surfaces comprise up to 70 % of city centre area,
- Roofs' slopes amount 1 %, streets' slopes up to 20 %,
- Impervious surfaces' retention capacity amounts 5 mm, pervious surfaces' retention capacity is up to 15 mm. Retention capacity of roofs, that constitute approximately 25 % of impervious surfaces, is considered to be negligible,
- Direct runoff was modelled using SCS TR 55 method,
- Flow routing was modelled using dynamic wave equation along with the mass conservation equation.

Some of the SWMM model's results include:

- Flow in sewers at outlets, volume of overflows due to design (Fig. 5) and observed rainfall events (Figures. 6 and 7).
- Water quality parameters at the system outlets are presented in Table 2, which are amongst the most often used for analysis and calculation of CSOs.

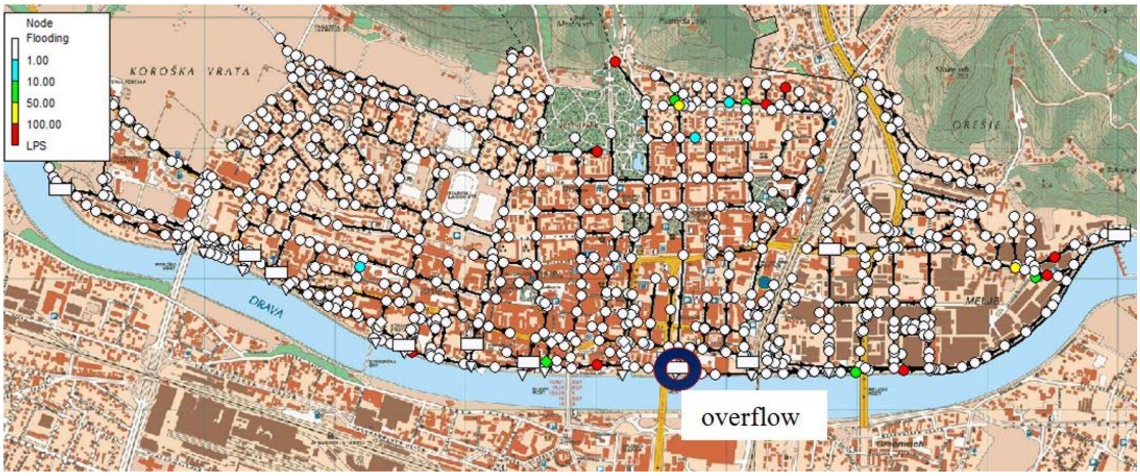

Figure 5. Simulated flooding at nodes (in lps) at the Drava river left bank based on SWMM due to 20 min. and 20 % probability design rainfall and surcharged CSO

In Fig. 7 is presented flooding in nodes JSTE-7 and JZG_RADO, simulated upon the recorded rainfall on August, 2009.

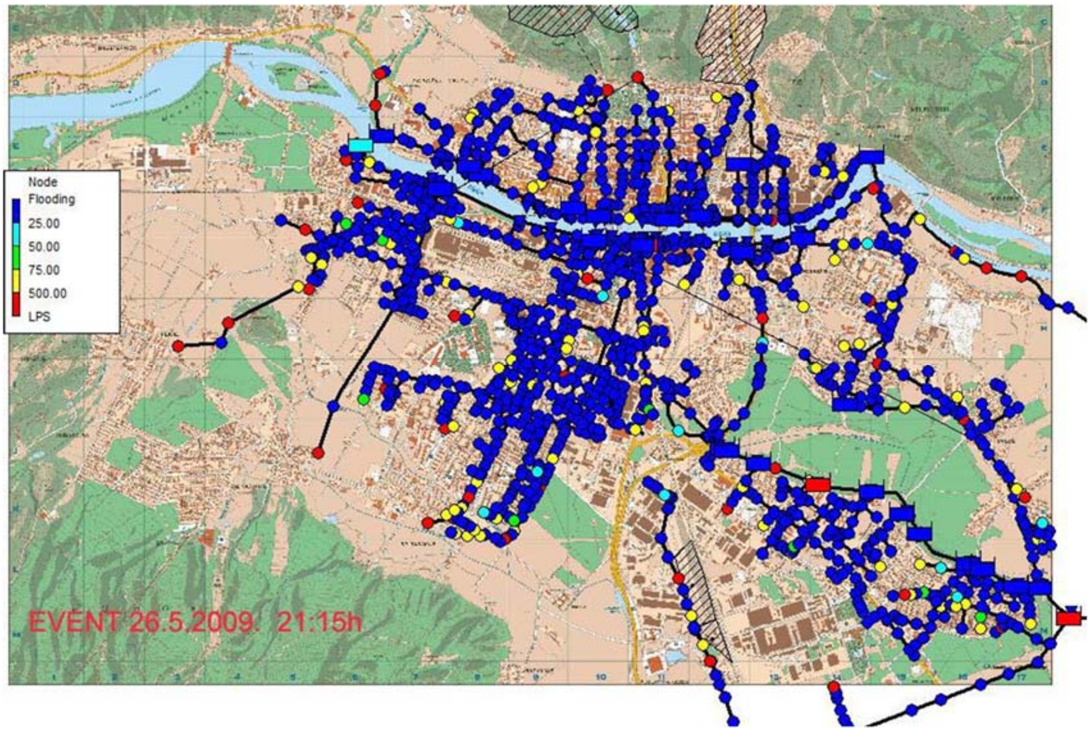

Figure 6. Flooding at a series of nodes (in lps) at the Drava river left bank based on SWMM due to rainfall recorded on the 26th of May 2009

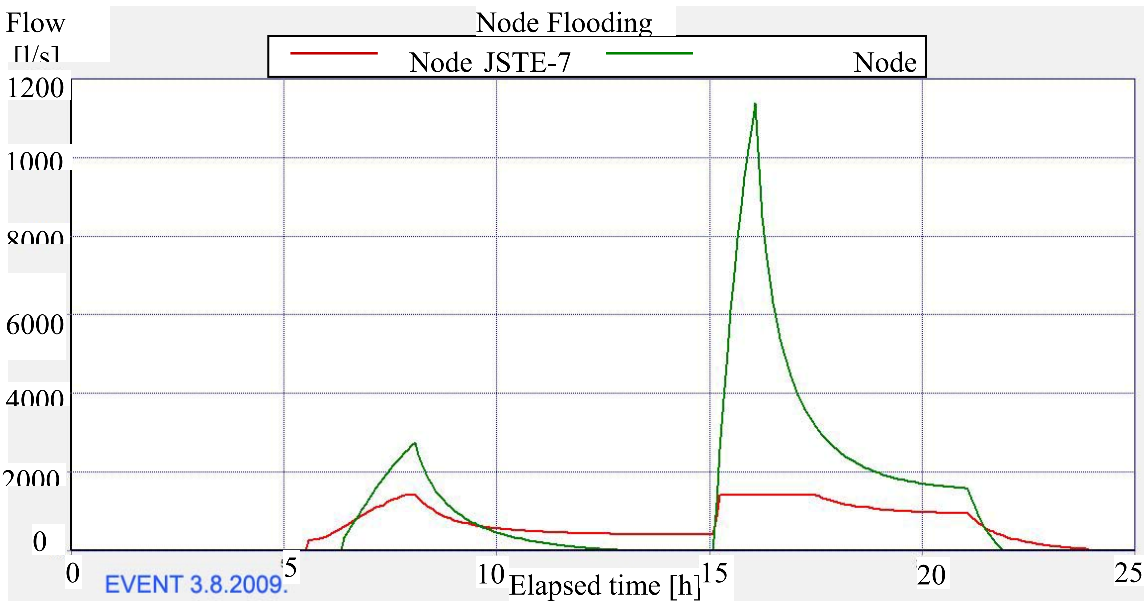

Figure 7. The overflow at the given nodes due to rain recorded on August 3, 2009

OUTLETS	A1	A2
R1	<10	<10
R2	yes	no
R3	no	no
R4	no	no
R5	no	no
R6	no	no
R7	no	no
R8	<10	no
IZ533	no	no
IZ1014	yes	yes
IZ61	<10	no
IZ6927	no	no
IZ512	yes	yes
IZ20002	no	no
IZ36	<10	no
KOBLER	yes	<10

Table 6. Simulation of pollution of at the series of outlets at the left bank of the Drava river according to criteria A1 (15 l/s/ha) and A2 (1 mm/h) provided assessment of those CSOs [3, 4].

RESULTS AND RECOMMENDATIONS FOR THE REHABILITATION OF THE SYSTEM

According to SWMM model results recommendations for Maribor sewer system rehabilitation can be summarized as follows:

- Design and construction of new structures of the overflows with increased crests, in order to decrease frequency of CSOs,
- Set up check valves on sewer lines and on retention-sewer connection, in order to manage overflows,
- Replacement of existing sewers with the new ones, as given in documentation [3, 4]
- New capacities aimed at the retentions construction, e.g. Jurančić, Gorki [4],
- Adjustment of capacity of pump stations (e.g. pumping station "Studenci"),
- Construction of micro - retentions for households or blocks,
- A continuous monitoring of the most frequent CSOs,
- Pilot project of pre-treatment at the overflows.

Figure 8. Along Tomšičeva street is proposed new pipe between the junctions 298 and 381- DIA 500 and length 78 m, pipe between junctions 290 and 334 - DIA 400 and length 45 m, also new pipe between junctions 302 and 385 of DIA 350

For example, a series of measures aiming at improvement are recommended, as follows:

- At Tomšićeva street: from sewer junction 298 to node 381 (DIA 500, length 78 m), and from junction 290 to 334 (DIA 400, length of 45 m) and new pipe between junctions 302 and 385, of DIA 350 mm; see Figs. 10, 9.
- For Svetozarevska street: construction of pipe from the overflow to the fish pond in the local park (conveying overflow to the pond), and redirection of part of flow to neighbouring retentions, in order to reduce peak flows, and construction of new retention in Svetozarevska street; Fig. 10 [3,4].

An improvement of the proposed measures has been proved by SWMM model simulations. Proposed reconstructions along Tomšičeva Street would lead to decrease in pressure and so decrease in flooding of streets would occur (Fig. 9), whereas new pipes along Svetozarevska street lead to decrease in peak flows (Fig. 11).

At the given series of examples of analysis and modelling and also the measures that should be undertaken, in a rather controlled development and housing of that part of the city of Maribor, it can easily be concluded that urbanisation is not the only aspect of relevancy for a combined sewer system modelling. It also could be of significance the models and methods that have been used and applied trough times.

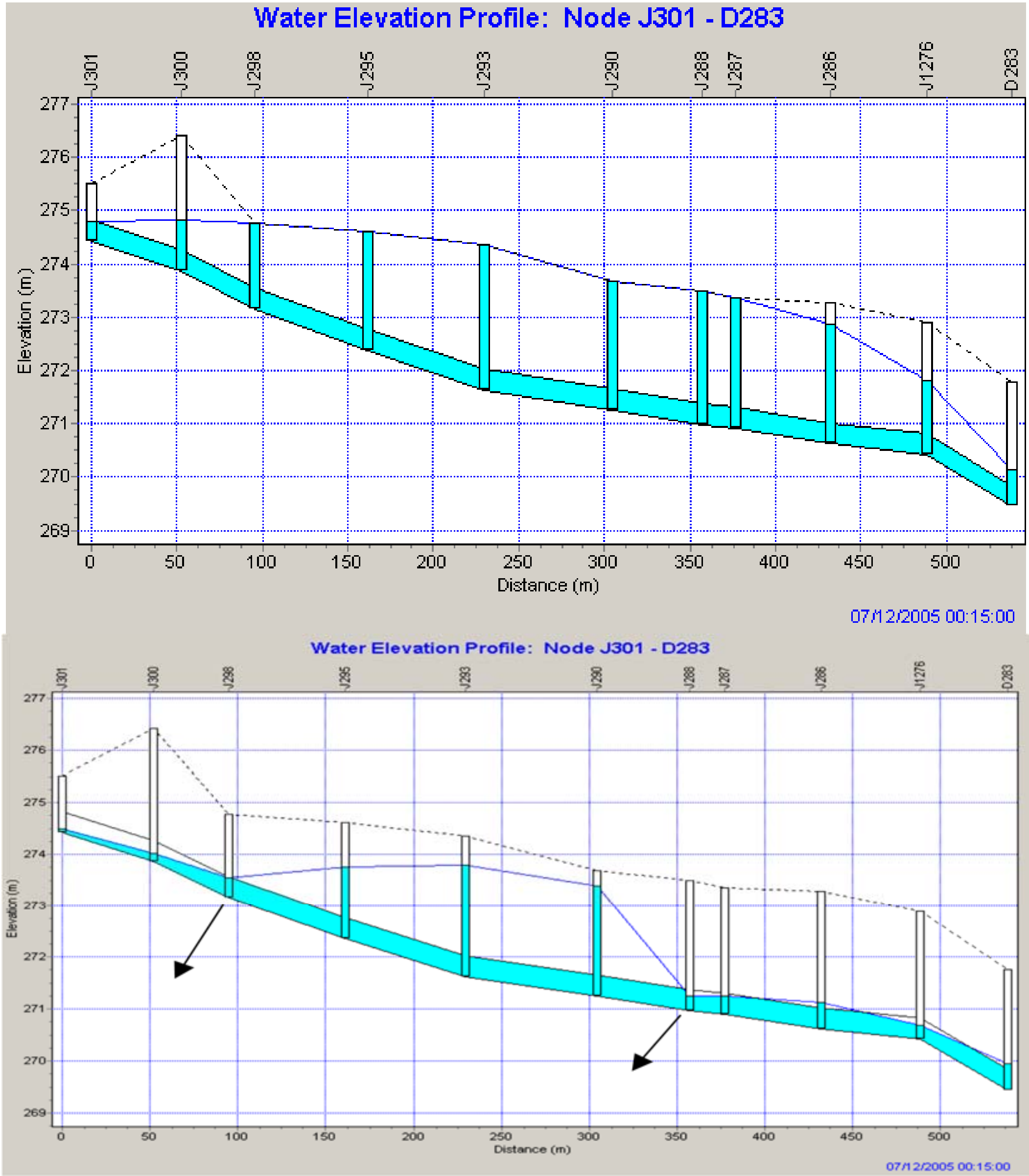

Figure 9. Decrease of pressure head in sewer along Tomšičeva Street for rainfall event measured December 7, 2005: existing (above) and improved sewer system (below)

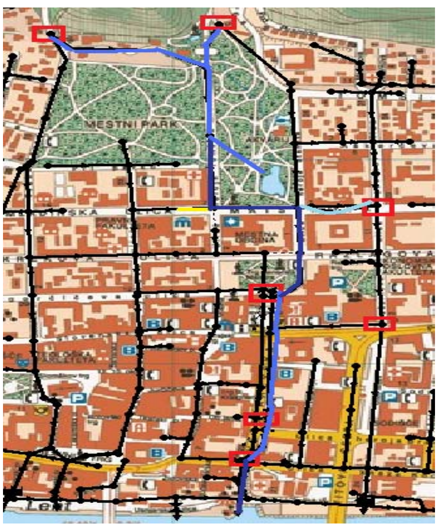

Figure 10. Recommendations for sewers along Svetozarevska street: new sewer from existing overflow to the pond in the city park, redirect flow to neighbouring retentions and construction of new retention

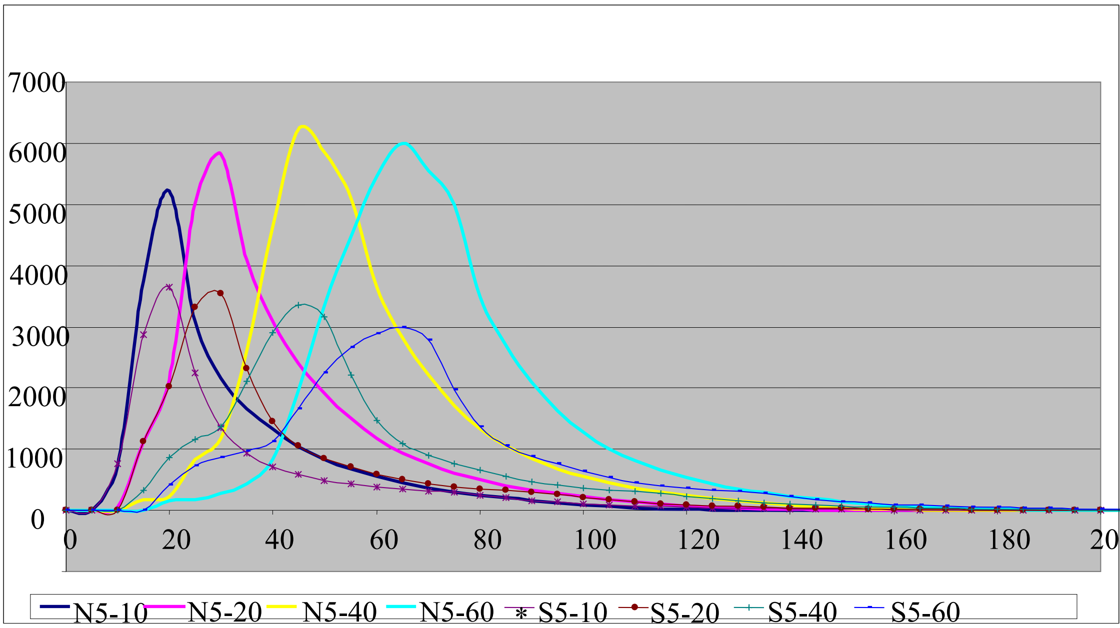

Figure 11. Comparison of simulated hydrographs due to design rainfall of 5 years return period for existing (S) and proposed (N) sewers along Svetozarevska street

CONCLUSIONS

In this paper are presented results of simulation of flow based on design and historical rainfall events using SWMM model. Using of the observed rainfall events provided reveal of inadequate designed pipes and CSOs, incident floods upon which recommendations and measures for improvement of the Maribor sewer system.

The analysis presented in this paper also highlighted the needs for:

- Cadastre of all the pipes, CSOs, structures, outlets and dividing structures,
- Installation of additional rain gauges in Maribor, which would enable capturing rain spatial variability in further studies,
- Simultaneous measurements and monitoring of rain, flow rates, water quality and WWTP performance, including overflows into the Drava river and energy power channel.

It is argued that traditional but inadequate combined sewer overflows' design lead to incomplete separation between polluted and less polluted water, causing both, polluted water being discharged directly into a receiving water and flow with pollutants' concentrations smaller than design ones reaching WWTP and causing its malfunction. For the sake of preserving efficiency of CSOs and WWTP poor operation under extreme rainfall events the common belief that establishing WWTP mitigates impact on the environment is questioned. The first step in overcoming these issues is comprehensive analysis of design rainfall events which probably should be repeated including new data of recorded rainfall during last years, and even a revision of the design storm concept itself [7].

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Proposed general measures for sustainable development of Belgrade existing sewerage system

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Dejan Ilic[2]

Introduction

The City of Belgrade with population of approximately 1.6 million is located at the confluence of the Danube and the Sava rivers at about 100m above sea level.
Water and wastewater services in the City are provided by the Belgrade Waterworks and Sewerage Company (BWS co.), which is a public utility company founded and owned by the City of Belgrade.

The first sewerage construction dates from 1905 in the area on the right bank of the Sava and the Danube. The most intensive period of construction was between 1970 and 1985 when 60% of the sewerage network was built.

The whole sewerage system covers approximately 120 sq km of the urbanized city area. Rainfall runoff from the whole area, which is topographically diverse and unevenly urbanized, drains towards the Sava and Danube Rivers and these rivers are the recipients of the wastewater and storm water.

According to the Sewerage Master Plan, the Sewerage system is divided into five independent zones as shown in Figure 1 - Sewerage Zones below.

Figure 1 - Sewerage Zones

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The Central system is the oldest and most complete, the Batajnica and Banat systems have been partially implemented but the Ostruznica and Bolec systems practically don't exist. Presently, the population of Ostruznica and Bolec relay on septic tanks.The present service areas are indicated in Figure 2.

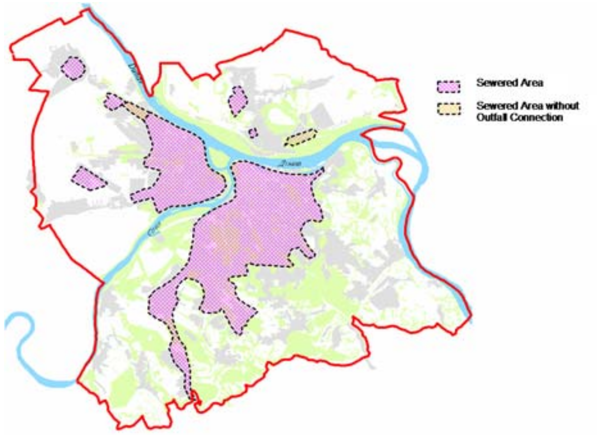

Figure 2 - Sewered areas within the Master Plan Area of Belgrade

Approximately 40% of the existing sewerage system is on the combined system with the remaining 60% being on separate system.

Storm water network

The concept of collection and discharge of storm water is, in general and mostly, defined by the topography. Northern and Western city area are relatively flat whilst Southern and Northern parts display considerable relief.

There are a great number of streams which are recipients of storm waters, as well. Some streams have been captured upstream at the outskirts of Belgrade and then flow through large trunks while arterial roads and boulevards are constructed above them. That means that streets and buildings have interrupted numerous natural drainage ways.

Around 35% of the territory does not have a stormwater network. The main problems with regard to inadequate sewerage coverage occur in settlements on the periphery of the urban areas but flooding mainly occur downstream of the catchment. The main reasons are inadequate pipe dimensions due to changes in the Urban Master Plan, illegal settlements or because of the deficit of collectors which has been already planed and designed.
The last Master plan has never been fully implemented because of financial problems during the last 15 years. Population and urban development progressed much faster than the sewerage system.

Progressive buildings occur mainly on the periphery of the urban areas causing some green and agricultural land to become resident or industrial area and further Master plan changes. This change naturally creates challenges for the sewer system especially on downstream part of the catchments.

Also climate change is causing noticeably influence on the sewerage scheme, since Belgrade experienced increasingly frequent flood events during recent 10 years. The most serious flooding occurs during intense rainstorms while the storm water drainage system became overloaded more frequently, including surcharging and overflows from the pipes and trunks.

It is essential to prevent furthermore overloading of the existing sewerage system and to undertake flood control measures. The aim is to reduce the threat of stream and street flooding by building and maintaining flood protection facilities in the sewerage system.

We have to be aware that flood control projects are very expensive and take years to complete. That is why we have to define:

- phases in construction of main storm water facilities outlined in Master Plan,
- new storm water facilities as a response for intensive lend use changes,
- possible temporary and short term solutions for the most flooded areas,
- use of sustainable urban drainage structures (SUDS) wherever possible.

Latest activities of BWS's within the Department of Development regarding issue of sewerage:
Improvement of sewerage systems through phases (Design terms and conditions for the construction project of residential and business complex on the site in Kumodraz catchment area). Incorporating new dry and/or wet storm water ponds and SUDS in urban plans (Conceptual Design of Sewerage System for the Airport Industrial Area)
Urgent reconstruction works as temporary solutions (Hydraulic analysis and design of Valjevska street catchment)

Design terms and conditions for the construction project of residential and business complex on the site in Kumodraz catchment area The Building Directorate of Serbia has been appointed to manage, on behalf of the Government of the Republic of Serbia, a construction project of residential and business complex on the site of predominantly green area in Belgrade. In March 2010 BWS issued design terms and conditions (in relation to sewerage system) required by the Directorate.

The site is part of the Kumodraz catchment area. The main recipient of the area for storm and waste water is combined collector built in Kumodraz stream valley. The collector was designed and built in accordance with the old master plan to transport waste and storm water from the Kumodraz catchment and Kumodraz stream water as well.

Intensive urbanization causes downstream flooding and environmental problems due to overloaded combined sewer which cannot handle the volume of runoff even for one in two year rainfall event. Construction of the new residential and business complex will increase storm water runoff and deteriorate already dramatic situation of the whole catchment area. Design terms and conditions for the project underlines the necessity to undertake planned flood protection measures before new urbanizations.

New collector and dammed stream reservoirs in the Kumodraz catchment area has been designed (*Conceptual Design of Kumodraz Catchment* -University of Belgrade, 2004; *General Design of Mokroluski Catchment* - Jaroslav Cerni Institute, 2010) and outlined in Master plan. New collector will receive stream water, storm water and overflow from the existing collector. The reservoirs have been planned as flood control facilities.

Because of the restricted city budget, BWS suggested phased construction of the new facilities. First phase consists of construction of downstream pipe section (with diameter of 250 cm and length of approximately 600 m) and so-called "Kumodraz 1" reservoir. Construction of the first phase will only decrease the problem. It was also underlined that only complete implementation of proposed measures can give adequate flood protection of the Kumodraz catchment area. The second phase consists of construction of the remaining collector sections (with diameter of 200 cm and length of approximately 2200 m) and one more reservoir on the Kumodraz stream.

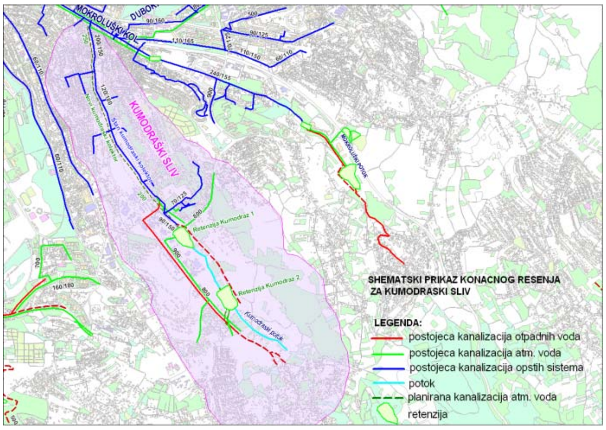

Figure 4: Kumodraz catchment improvement project

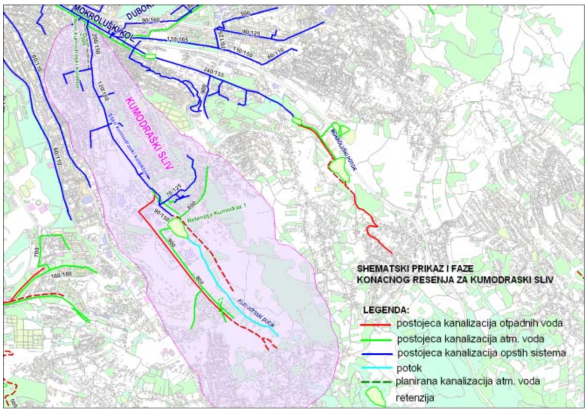

Figure 5: First phase of the Kumodraz catchment improvement project

Conceptual Design of Sewerage System for the Airport Industrial Area

Changes to the urban master plan in the western part of the city means some 140 ha of green and agricultural land near the Belgrade-Zagreb highway will become an industrial area, bordered by Nikola Tesla airport to the South, a rail line to the West and Danube on the North. It has been essential to provide infrastructure for what is likely to be a very attractive area for companies to relocate.

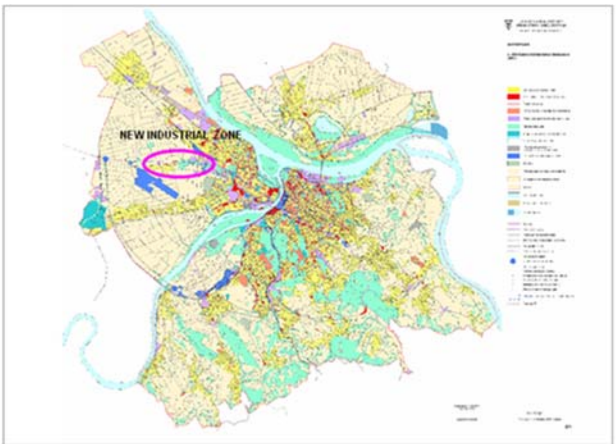

Figure 6: New industrial area location

The most complex challenge is dealing with stormwater. In order to present to the City government the possible results from building an unplanned industrial zone, computer model of the sewerage network has been made for the area. Several possible sewer network options were presented, with the Danube as the main receiving water body.
Ground levels are high near the Danube and in the industrial area, but very low in the middle section. When this most sensitive element of the network had been indentified, a rainfall scenario with a maximum peak flow of 25 minutes was chosen. Flooding occurs in the low section, meaning that increasing the amount of runoff in the industrial zone would create new areas of flooding, even with a one in two year rainfall event.

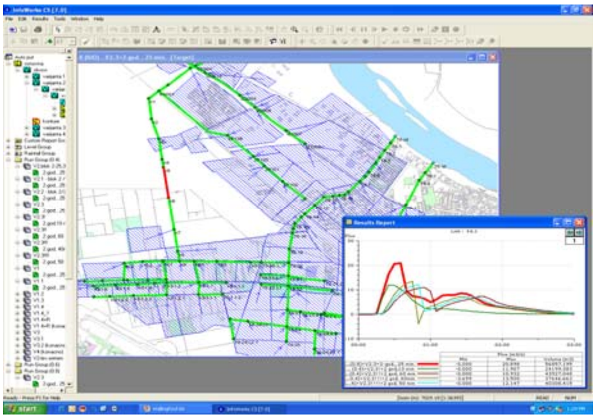

Figure 7: Computer model of the network

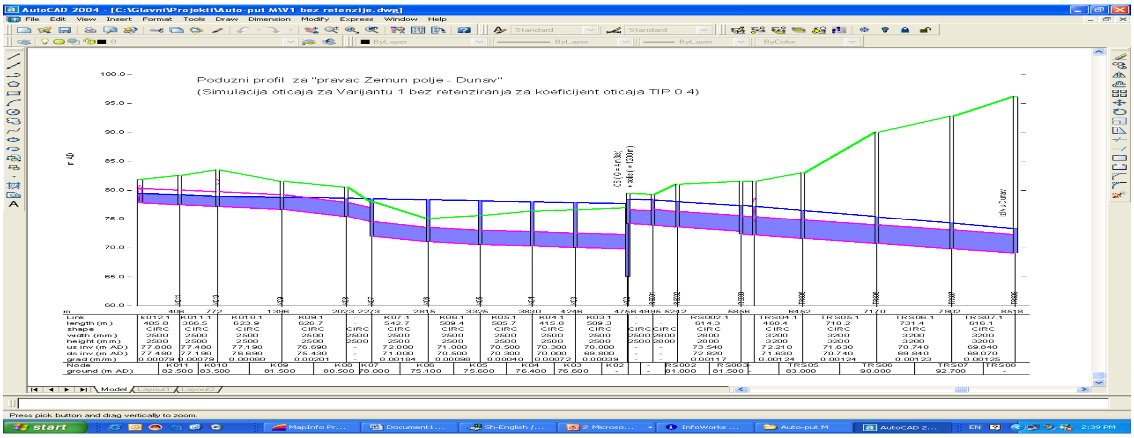

Figure 8: Longitudinal section of the collector Zemun polje – Dunav

By analyzing the catchment with different percentages of pervious area it was possible to show the consequences of building the new industrial zone. The results of hydraulic analyzes showed that it is necessary to incorporate storage tanks into the sewer network. Three possible locations for stormwater storage tanks were indentified. The effects of network variations were also analyzed.

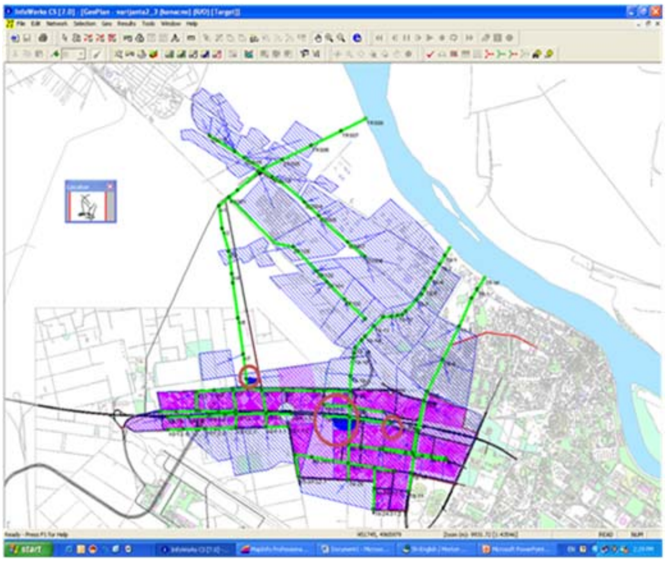

Figure 9: Storm water tanks location

General conclusions derived from the project are:

- Maintenance and construction costs cannot be the only decisive factors when considering possible variants of sewerage networks. System stability and flood protection also have to be taken into consideration. The model showed that storage tanks increased stability.
- City authorities need to encourage future site owners to take adequate measures to decrease the runoff coefficient of their properties. Use of sustainable urban drainage structures (SUDS) must be considered.
- Hydraulic analysis and design of Valjevska street catchment
- The study identifies existing problems, issues and weaknesses in the drainage system of the catchment including flooding and inadequate pipe capacity. Also it is proposed some temporary solutions as urgent works to improve the performance of the existing drainage system on the catchment.
- Valjevska street catchment is a part of the Central Sewerage Zone with separate drainage system. It is relatively small (aprox.150ha) but steep catchment with average slope of 5.5% up to 9.5%.

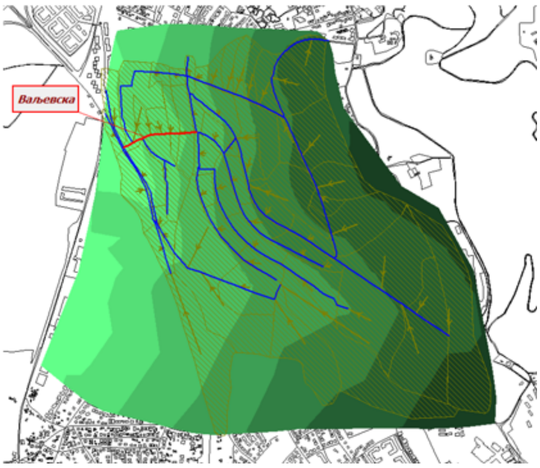

Figure 10: Catchment topography

Existing storm water network has inadequate capacity and drainage. Rainwater in this area runs off the steep catchment quickly causing surcharging and overflows from the pipes. Flood occurs predominantly in Valjevska Street as the most downstream part of the catchment. Computer model of the catchment shows flow volumes and velocities along pipe network and marks all surcharge points during rain events.

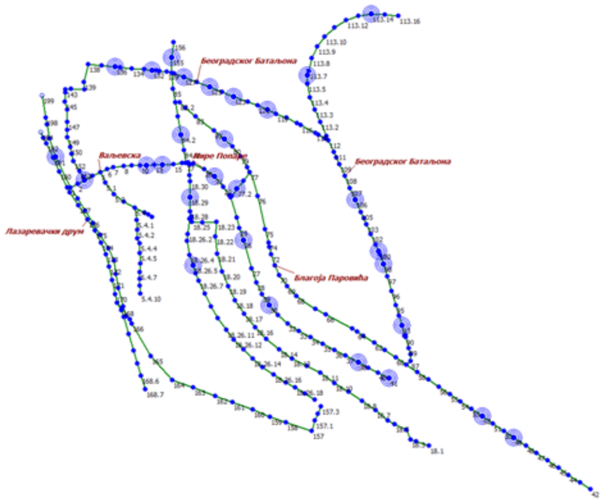

Figure 11: Surcharge points

Solution for the above mentioned problems is construction of earlier designed collector (Detailed design of storm collector Valjevska – Topcider river, “Hidroprojekt” 1992) which would collect all storm water from the catchment and convey it to the Topcider River. Unfortunately, because of problems with illegal constructions, land acquisition and wayleaves, construction of the collector has had to be postponed. It was necessary to find some urgent temporary solution for decreasing the flood problem in the area especially after very severe flood events in April and then again in June 2010. It has been assessed that thay were more than one in 5 year rain events.

Several possible design alternatives have been analyzed with investigation of potential downstream impacts of the proposed works. The one that has been chosen has the most positive impact on the area flooding. It is construction of additional pipes in Valjevska Street and in Zarkovacka Street and redirection of the runoff from some subcatchments.
As additional measure to take the water away from the road surface and to increase storm water harvesting is adding more storm water gullies with adequate intercepting capacity and position.

Figure 12: Chosen alternative plan

Conclusion

It is believed that a consequence of climate change will be more extreme weather events. Bearing that in mind we have to consider possible changes in planning and designing public sewerage systems. This mean allowing system flexibility so that sewerage network can easily be upgraded, implementing sustainable drainage that keeps surface water out of sewers where appropriate and possible and reducing flows into sewerage systems with new dry and/or wet storm water ponds. Over the long term this should become the dominant elements to reduce risks from flooding in urban areas.
Rainfall and sewerage flow monitoring and development of computer modeling are the tools to model the impact of the future changes on the Belgrade's sewerage system, and assess options to provide sewage management services in the future.

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CLIMATE CHANGE

About the trend detection in Portuguese long hydrologic time series and the climate change

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ABSTRACT: During the history of the Earth several climate changes have occurred, some of them with a well defined pattern. The majority of such changes happened in periods of hundreds, thousands or even millions of years and as results of natural causes. However, in recent decades, it has been progressively accepted by the scientific community that the emissions of greenhouses effect gases to the atmosphere have been responsible for the climate changes that seems to be occurring during the last century and mainly during the last 50 years. If there were changes in such a recent and small period them they should be presented – by means of trends or non-homogeneities – in the time series of those variable more directly related with the climate, as the rainfall or the temperature. In the previous scope several studies have been accomplished in the last decade aiming at identifying trends in long hydrological time series and at trying to understand those trends from a climate change perspective. Some of the models applied in Portugal for that purpose, as well as some of the results achieved are briefly summarized. In general, the studies showed that for the time being most of the hydrologic time series do not exhibit the behavior that is generally pointed out as denoting the effects of the climate change.
Key words: climate change, hydrologic time series, trend detection, moving average, statistical model.

CONTEXT

Nowadays there is a consensus that the increase of the atmosphere temperature will intensify the hydrological cycle, thus amplifying the magnitude of some of the extreme hydrologic events, as well as changing the temporal and the spatial patterns of most of the hydrologic variables. It is more and more often mentioned that some regions, especially those located in the higher latitudes, will become more humid while other regions will get drier, as those around the Mediterranean Sea (IPCC, 2007). Also the extreme hydrologic events – like droughts and floods – will become more frequent and intensive in some areas that will become more prone to hydrologic disasters. These results are mainly provided by general circulation models (GCM) based on scenarios of the greenhouse gas concentration.

For Mainland Portugal, though a decrease in the rainfall is generally pointed out, the results from different climate scenarios denote substantial differences meaning that there is a considerable uncertainty regarding the future projections of the rainfall (Santos; Miranda, 2008).

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Heavier or more intense precipitation events (in the North) as well as more drought occurrences (in the South) are also mentioned. In terms of the annual surface runoff the models were unable to identify any pronounced trend though they suggested some changes in the temporal pattern along the year, more often with less water during spring, summer and fall (Veiga *et al.,* 2006). An increase of the spatial asymmetry of the water distribution may also occur as the reduction of the water availability is expected to become more pronounced towards the South of Portugal (Santos; Miranda, 2008). However, it seems that there is some misunderstanding regarding the water shortness effectively due to the climate changes and the one resulting from the increased water request of the modern society.

While some authors choose to apply GCM to analyze the effects of the climate change in Mainland Portugal, other authors apply different approaches based on the analysis of long time series. This is the cases of all the research that support this article which have been focused in the detection of trends in long hydrologic time series and at relating those trends to the climate change. It should be mentioned that the Portuguese hydrologic database comprehends a large number of measuring points some of them with very long time series, especially rainfall series, thus enabling the trend detection, for instance, based on statistical approaches.

The first studies carried out utilized monthly, quarterly and annual rainfall records at a few rain gages. Statistical tools, as well as moving average techniques and specific procedures to detect non-homogeneities were applied (Portela; Quintela, 2001). Afterwards not only the rainfall series at a much larger number of rain gages were studied (Santos; Portela, 2008), but also the performance of irrigation reservoirs under changing hydrologic constraints was analyzed (Portela *et al*., 2006, and Santos, 2008). These constraints involved changes in the temporal patterns both of the inflows to the reservoirs and of the outflows, in the latter due to changes in the crop evapotranspiration. More recently, trend detection in extreme rainfall series (Vaz, 2008) and in the within-the-year rainfall pattern were also accomplished (Martins, 2010).

Some of the more relevant results thus achieved as well as the models applied are briefly mentioned in this paper. In general terms the studies showed that for the time being most of the hydrologic time series do not exhibit the trends that are generally pointed out as resulting from the climate change.

APPROACHES

The results from the trend analysis applied to long hydrologic time series herein summarized were the outcome from different recent studies which utilized several models generally well set in the literature and identified bellow. Specific relevant aspects related with the conception or with the application of those models are also briefly mentioned.

The studies were mainly focused in rainfall series – annual, seasonal and monthly rainfalls and also short duration intense rainfalls – and most of the models had statistical nature. To ascertain the effect of the climate change in the reliability of the water supplies based on artificial reservoirs, stream flow series as well as evapotranspiration series were also included in the trend analysis though only as components of the simulation algorithm applied to detect changes in the storage capacity of artificial reservoirs.

One of the models more often applied in the analysis of rainfall series was the **moving average technique** (Kenney; Keeping, 1962), which is a very common tool to smoothen out short-term fluctuations or to highlight longer term trends or cycles. For an annual series with length N, the moving average with length n is formed by the averages over the N-n+1 subsets of n consecutive years each in which the original series can be split (with $N > n$) – Figure 1.

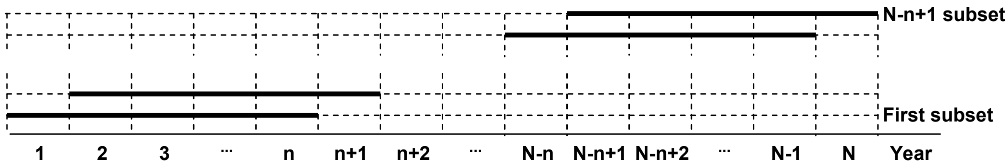


Figure 1. Application of the moving average technique to a series with length N. N-n+1 subsets with constant length n.

The length *n* should be large enough to ensure that the consecutive averages mirror the statistical behavior of the different subsets (as a thumb rule, *n* should be larger than 15 years). A larger *n* results in a decrease of the number of subsets with averages compared and smoothes the trends. In the applications carried out, *n* was fixed based on a sensitive analysis considering subsets with different lengths.

Another technique applied to the rainfall series aimed at detecting non-homogeneities based on the statistical comparison of the averages of consecutive pairs of **cumulative moving averages**. For this purpose each time series with length *N* was split into two series, temporally contiguous, one built upon the first *n* elements – **anterior subset** – and the other built upon the last *N-n* elements – **posterior subset**. The averages of these two subsets are compared in statistical terms. The division of the original series into paired subsets is successively repeated by increasing by one the length of the anterior subset and consequently by decreasing by one the length of the posterior subset – Figure 2 – until the minimum length of *n* is reached for the posterior subset. For a series with length *N*, the total number of averages compared is twice the total number of contiguous pairs of subsets, that is to say, is equal to *2 x (N-2n+1)*. The statistical comparison of the two averages of each pair of one anterior subset and one posterior subset utilized the **Student parametric test** and the **Mann-Whitney nonparametric test** (Yevjevich, 1972, Siegel, 1975).

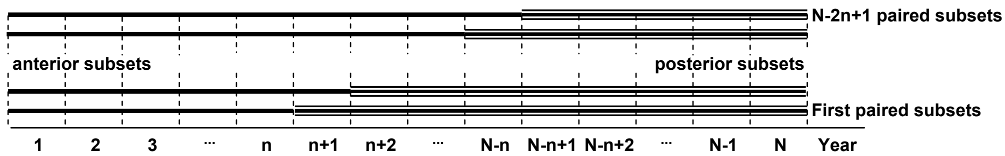


Figure 2. *N-2n+1* paired subsets considered in the detection of non-homogeneities.

A non-homogeneity was considered to occur whenever at least one of the previous tests indicated that the two averages under comparison were statistically different. The analysis carried out showed two kinds of non-homogeneities: the sporadic ones due to a period of time (a few years, seasons or months) with extremely high or extremely low rainfall and those persisting along the time and indicating successive posterior subsets with averages consistently different from the averages of the corresponding anterior subsets, thus, denoting a trend. In other words, a **trend was considered to occur whenever persistent non-homogeneities were detected**.

The well known **Mann-Kendall nonparametric test** (Mann, 1945, Kendall, 1975) was also applied to detect trends in monthly and annual rainfall series. By applying the **Sen slope estimator** (Sen, 1968, Hirsch *et al.,* 1982, *in* Lettenmaier *et al.*, 1993), the trends thus detected were additionally characterized in terms of dimensionless magnitudes.

In the three tests previously mentioned (Student, Mann-Whitney and Mann-Kendall tests) a significance level of *α=5%* was adopted (non-exceedance probability of $1-\alpha/2=0.975$ for bilateral or two-sided tests).

The analysis of extreme rainfall events utilized annual maximum daily rainfall series – *Pamd* series – which were treated also by means of the moving average technique based on subsets with length *n* (Vaz, 2008). The annual maximum daily rainfall series are built upon one value per hydrologic year, the maximum rainfall amount in 24 h.

The study also included the comparison of the *N-n+1* probability distribution functions of the Gumbel law (Raynali; Salas, 1986, Reiss; Thomas, 2001), obtained by considering separately each one of the *N-n+1* consecutive subsets with length *n* into which the *Pamd* series with length *N* was split. For each subset the probability distribution function was obtained by applying the method of moments based on the Weibull plotting position formula (Cunnane, 1978).
The last study focused on rainfall that will be mentioned in this paper tried to ascertain changes in the within-the-year pattern of the rainfall as we

ll as in the distribution of the maximums rainfalls. The study utilized the moving average technique complemented by the application of the Student and Mann-Whitney tests (Martins, 2010).

Along with the previous studies focused on the rainfall analysis, the performance of artificial regulating reservoirs aiming at providing water for irrigation was also analyzed (Portela *et al.* 2006, Santos, 2008). The models used for that purpose were more extensive and complex then the ones applied to rainfall data as they needed to account for the trends both in the inputs to the reservoirs (river flows) and in the outputs from the same (irrigation supplies). A monthly time step was adopted.

As the stream flow series are generally not as long as the rainfall series, rainfall-runoff models were employed to extend the flow data, namely the soil sequential water budget (Thornthwaite, 1948, Brooks, 2003, Lencastre; Franco, 1984, Varenne, 1972-1973) and the Temez model (Temez, 1977, Monreal, 1993). To ascertain the trends in the crop water requirements long evapotranspiration series were established based on the Thornthwaite (Lencastre; Franco, 1973, Quintela, 1967) and on the Penman-Montheith (Pereira *et al.*, 2000, Pereira, 2004) models. Different supplies – in terms of volumes and guaranties/reliabilities – were considered. The analysis utilized computational simulation algorithms based on the mass equation.

MAIN RESULTS

The moving average technique and the trend detection based on the identification of persistent non-homogeneities between consecutive pairs of anterior and posterior subsets were firstly applied to the rainfall series in the rain gages 1 to 11 schematically located in Figure 3 (Portela; Quintela, 2001). For that purpose, annual rainfall series as well as rainfall series in different seasons and months of the year were analyzed. All the series were referred to the hydrologic or water year which, in Portugal, starts October 1st. The minimum length of each moving average was fixed at *n=15* years which was also the minimum length of any anterior and posterior subset.

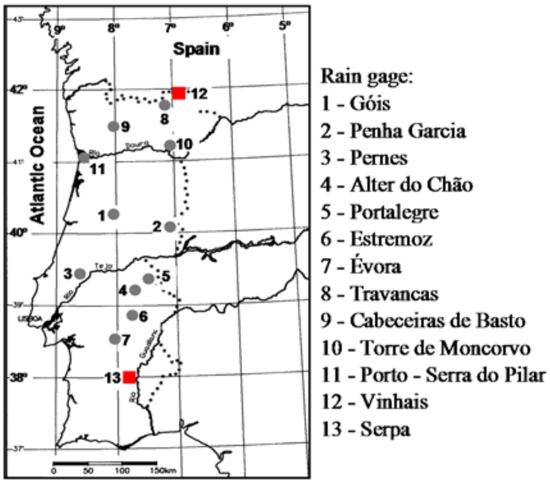


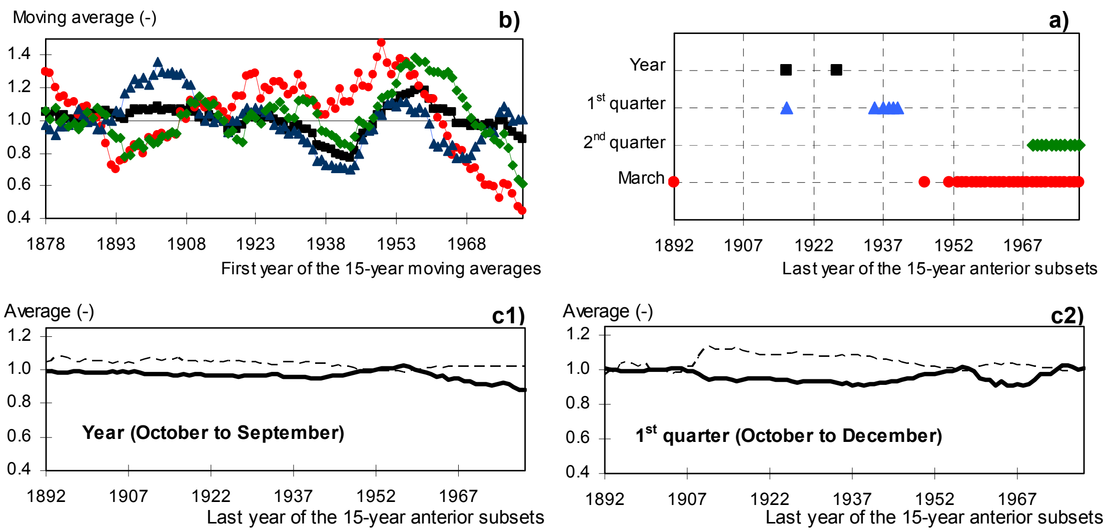
Figure 3: Location of some of the rain gages considered in the trend analysis

The results achieved are exemplified in Figure 4, based on the 117-year rainfall series at Torre de Moncorvo gage (rain gage number 10).

In Figure 4, for each given period of time (year, season or month), the moving averages as well as the averages of the consecutive pairs of anterior and posterior subsets were made dimensionless by division by the average of the respective rainfall series in the total period of $N=117$ years. Each moving average was identified by the first year of the corresponding $n=15$-years' period. The averages of each pair of anterior and posterior subsets were identified by the last year of the corresponding anterior subset.

Figure 4 clearly shows that the rainfall series in March at Torre de Moncorvo exhibits a downwards trend which is also visible in the 2nd quarter of the hydrologic year, also as result from the decrease of the rainfall in March.

For each one of the first 11 rain gages of Figure 3, Table 1 allows comparing the averages of the rainfall series in the recording periods and in the last 15 years analyzed by Portela; Quintela, 2001.



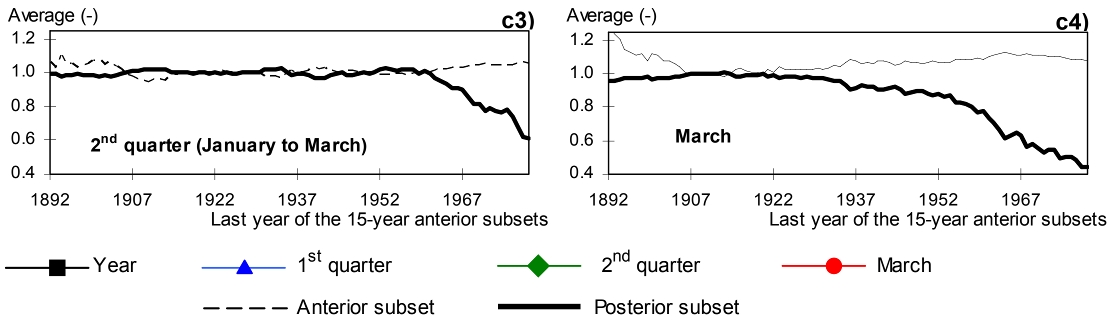


Figure 4. Torre de Moncorvo rain gage. October 1878 until September 1995 (*N=117* hydrologic years): a) dimensionless moving averages in 15 year-periods; b) non-homogeneity occurrences; and c1) to c4) averages of the successive pairs of anterior and posterior subsets.

Table 1. First 11 rain gages of Figure 3. Average rainfalls in the recording periods and in the last 15-year periods.

Rain gage	Recording period					Last 15 years				
	Period (from October to September)	Average rainfall				Period (from October to September)	Dimensionless average rainfall			
		Year (mm)	1st quarter (mm)	2nd quarter (mm)	March (mm)		Year (-)	1st quarter (-)	2nd quarter (-)	March (-)
Góis	1917- 1999	1162	404	441	132	1985 - 1999	0.927	1.040	0.755	0.439
Penha Garcia	1910 1999	803	306	289	89	1985 1999	0.976	1.123	0.800	0.368
Pernes	1915 1995	834	310	323	100	1981 1995	0.784	0.922	0.589	0.376
Alter do Chão	1911 1999	625	224	236	72	1985 1999	1.028	1.212	0.820	0.436
Portalegre	1910 1997	854	312	325	101	1983 1997	0.975	1.105	0.762	0.436
Estremoz	1911 1995	658	243	248	82	1981 1995	0.878	1.022	0.651	0.434
Évora	1900 1996	640	239	240	76	1982 1996	0.924	1.049	0.724	0.418
Travancas	1913 1999	993	345	336	101	1985 1999	0.935	1.061	0.727	0.451
Cabeceiras Basto	1913 1999	1505	527	562	166	1985 1999	0.982	1.173	0.775	0.394
Torre Moncorvo	1878 1995	563	204	173	54	1981 1995	0.882	1.012	0.614	0.442
Porto-Serra Pilar	1900 1994	1187	440	415	127	1980 1994	0.985	1.075	0.796	0.651

The previous table shows that all the rain gages exhibit notorious decreases in the rainfall in March. In annual terms, the last periods of 15 years were drier than the total recording periods. However, the tests applied showed that the decreases of the annual rainfall are within the natural variability of the phenomenon and, therefore, that they do not represent non-homogeneities.

To apply the Mann-Kendall test along with the Sen slope estimator 94 years of monthly and annual rainfall (from October 1910 to September 2004) in 144 Portuguese rain gages were selected (Santos; Portela, 2008). Some of the series had sporadic gaps that were filled up based on linear regression analysis (Yevjevich, 1972). The Mann-Kendall test showed that most of the trends denoted by the 144 monthly and annual rainfall series were statistically meaningless, being explained by the natural temporal variability of the rainfall. Whenever the Mann Kendall test pointed out a significant trend in a monthly or annual rainfall series the Sen estimator was applied to quantify the magnitude of such trend.

By means of a GIS, maps with the spatial distribution (based on the kriging interpolation method) of the Sen estimator were produced, as shown in Figure 5 in which the dots represent the 144 rain gages considered in the study. Any value from one of the maps in Figure 5 represents a change (increase or decrease) in the annual amount of rainfall expressed in percentage of the mean annual rainfall in the period to which the map under consideration refers.

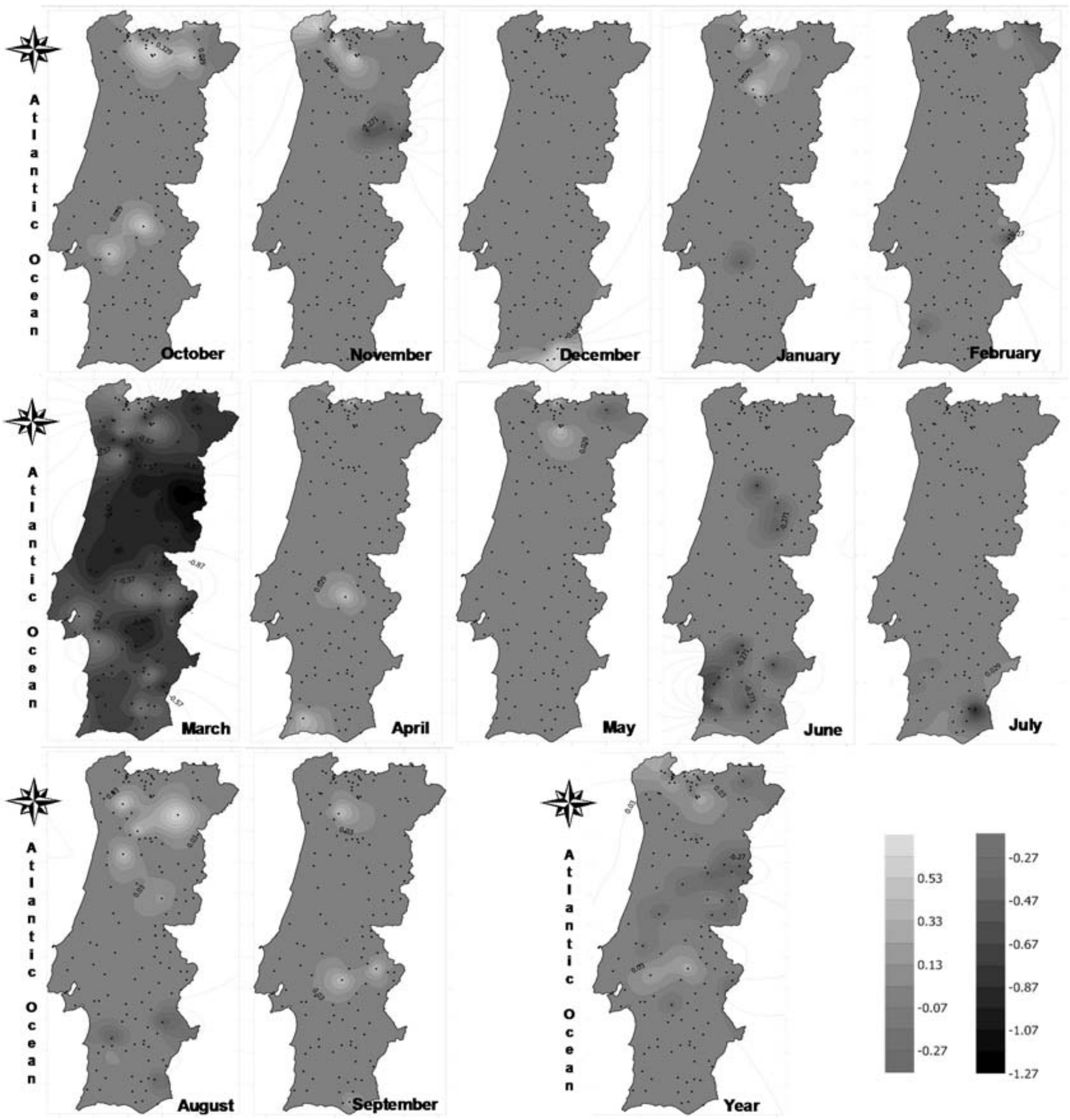
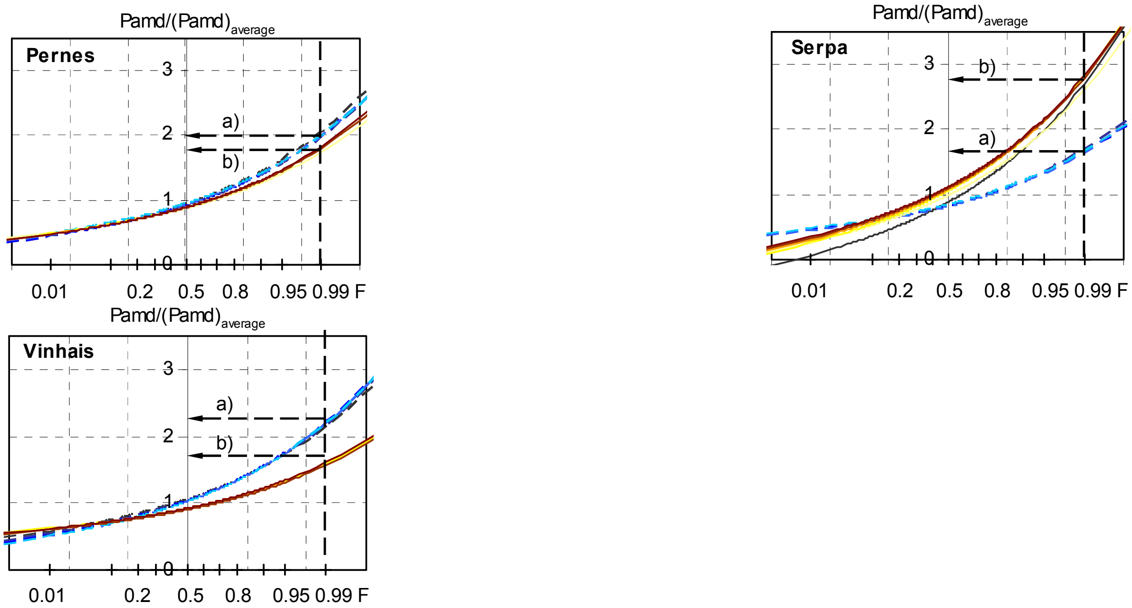


Figure 5: Trends in the monthly and annual rainfall series at 144 Portuguese rain gages. For each interval (month or hydrologic year) the scale represents the yearly variation (light grey for the increase and dark grey for the decrease) of the rainfall, expressed in percentage of the mean annual rainfall in that time interval. The dots represent the 144 rain gages utilized in the study.

Figure 5 clearly shows that most of the rainfall changes are spatially quite circumscript and almost neglectable. Only the rainfall in March exhibits a very pronounced and widespread downwards trend. However, it should be said that except for a small region in the North of Portugal, the rainfall in March is always smaller than 150 mm which means that a maximum annual decrease according to the Sen estimator of about 1.3% will, in fact, represent a decrease of the annual amount of rainfall in March of only 2 mm.

To analyze the effect of considering different periods in the estimates of the annual maximum daily rainfall given by the Gumbel law, the Pamd series at 24 rain gages were analyzed (Vaz, 2008). The results achieved for the recording period of 70 years (from October 1931 to September 2001) in three of those rain gages are exemplified in Figure 6 (rain gages numbers 3, 12 and 13 in Figure 3).



Series order:
a) Dark blue to light blue: first five 25-year series (----1 ----2 ----3 ----4 ----5)
b) Yellow to brown: last five 25-year series (42 43 44 45 46)

Figure 6: Application of the Gumbel law based in different recording periods.

In each rain gage the Gumbel cumulative distribution was computed based on each one of the successive subsets of 25 consecutive years each (total number of subsets of 70-25+1=46). For each of the three rain gages, Figure 6 contains the representation of the Gumbel cumulative distribution based on the first five and on the last five subsets of 25-years each (each subset is identified by the rank of its initial year). The vertical axes were made dimensionless by dividing the estimates of the maximum annual daily rainfall by the average of the Pamd sample in the 70-years' period and the horizontal axes represent non-exceedance probability, F. The estimates of Pamd for the non-exceedance probability of 0.99 (100-year return period) are highlighted.

Figure 6 shows that for Vinhais gage (North of Portugal) the estimates based on the latest records are not as high as those supported by the oldest records. The opposite situation occurs in Serpa gage (South of Portugal) while in Pernes (Center of Portugal) both estimates are very close. One of the conclusions that can be drawn out based on the results exemplified in Figure 6 is that different periods need to be analyzed in order to ensure safe/conservative design criteria. Another conclusion is that the behavior of the extreme rainfall time series may refuse (like in Vinhais or even in Pernes) or confirm (like in Serpa) the upwards trend that, for Portugal, is generally pointed out as denoting the climate change effect.

In the latest study focused on long rainfall series (Martins, 2010), four different procedures were applied, by means of moving average techniques complemented by the Student and the Mann-Whitney statistical tests. Two of those techniques aimed at identifying possible changes in the contribution to the total annual rainfall of the three months with highest rainfall and in the most frequent period of the year of occurrence of the maximum monthly rainfall. The remaining procedures focused on the intra-annual rainfall distribution by analyzing the months in which 20, 40, 60 and 80% of the annual rainfall is achieved, and also the contribution of each one of the four trimesters of the hydrologic year relatively to a 25-years average trimester. The study was based on the monthly rainfalls, from 1910/11 to 2003/04, in 31 rain gages stations located in Portugal mainland.

The analysis carried out showed that there is only a single hint of change in the intra-annual rainfall pattern with statistical significance among the majority of the 31 rain gages that were analyzed. Such change expresses a progressive and effective replacement of the 2nd trimester of the hydrologic year (from January to March) by the 1st trimester (from October to December) which became the most frequent period of occurrence of the maximum monthly rainfall, and the period with the highest contribution to the total annual rainfall. This shift, which is also due to the reduction of the rainfall in March, reflects a notorious change in the within-the-year temporal pattern of the rainfall in Portugal.

Along with the analysis of long rainfall series a study focused on trend detection in stream flows series and on the behavior of artificial reservoirs was also carried out. In fact, due to the temporal irregularity that characterizes the Portuguese hydrologic regime, most of the water supplies are ensured by artificial reservoirs created by dams, a significant part of these infrastructures having been built in the early fifties and sixties. So, a question arises: due to the climate change, are the reservoirs still able to ensure the amount of water adopted as design criteria with the reliability/guaranty required by each type of water utilization? This question is especially pertinent when reservoirs for irrigation purposes are under consideration as both the crop demand and the water availability may be influenced by the trends exhibit by the hydrologic series. To answer this question, the performance of ten hypothetical irrigation reservoirs was analyzed, by means of computational simulation techniques. The water budget technique was applied to rainfall and evapotranspiration data to obtain long monthly inflow series (94 years' length). The crops requirements (outflows from the reservoirs) were modeled by means of the monthly evapotranspiration.

Some of the trends detected are schematized in the Figure 7. The dark grey arrows denote worse constraints – decrease (-) of the inflows to the reservoir or greater (+) storage capacities to ensure the same water demand with the same guaranty – and the light grey arrows better constraints – increase (+) of the inflows to the reservoir or smaller (-) storage capacities to ensure a given water demand with a given guaranty. The water demands were expressed in percentage of the mean annual inflows and guaranties of 80 and 90% were considered. On a monthly basis, the guaranty can be understood as the percentage of months with total fulfillment of the water requirements. The guaranty applied to the irrigation supply is generally around 80%.

	Case study	**Trend in the mean annuall inflow**	**Trend in the storage capacity as a function of the water demand and of the guaranty of the water supply**					
			Water demand (% of mean annual inflow)					
			30	50	70	30	50	70
			Guaranty of water supply					
			80%			90%		
North Portugal	Vinhais-Qta da Ranca	+	-	-	-	+	-	-
	Castro Daire	-	+	+	+	+	+	+
	Cabriz	-	-	-	-	+	-	-
	Vale Giestoso	+	-	-	-	-	-	-
	Cunhas	-	+	+	+	+	+	+
Centre Portugal	Couto de Andreiros	-	+	+	+	+	+	+
South Portugal	Torrão do Alentejo	-	+	+	+	+	+	+
	Albernoa	+	+	+	+	+	+	+
	Monte da Ponte	+	+	+	+	+	+	+
	Vascão	+	-	-	+	-	-	+

Figure 7. Irrigation artificial reservoirs. Trend detection and guaranty of the water supplies.

Figure 7 shows that most of the case studies – with special emphasis on those located in the centre and in the southern regions of Portugal – denote loss of reliability as more storage capacity would presently be required to ensure the same water demand with a given guaranty. In some of the case studies this even happens when increases of the water inflows occurred. However, it should be pointed out that all the increases/decreases under consideration were very small and often almost negligible.

COMMENTS

Though some anomalies were already detected – such as the reduction of the rainfall in March or the shift in the period of the year with more precipitation – in general terms the studies developed until now showed that the hydrologic series can be much more resilient than the human perception and that it is difficult, for the time being, to clearly identify signs of the climate changes in such series. This circumstance suggests that further studies and scientific judgments are required as, somehow, there is a gap between what is already considered as resulting from the climate change and the effective behaviour denoted by some of the hydrologic time series.

But does this mean that the stationarity assumption of most of the hydrologic models is no longer valid? Will the future be statistically different from the past and if so how can we introduce this dissimilarity in the hydrologic models and in the design criteria? Though for the time being this is still an unsolved question it undoubtedly points towards the need to account for hydrologic uncertainty, for instance, by means of risk analysis tools based on scenarios.

A final comment regarding freshwater availability: it is very pertinent to distinguish the water shortness (in terms of both quantity and quality) that results from the increase in the water demands in the modern society from the water shortness effectively expected from the climate change. While the international scientific community is focused in the climate issue, regardless its relevance, water became progressively insufficient (once more, in quantity and quality) without apparently representing a world-wide problem as, in fact, it should be.

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Trend and variability in heavy precipitation in Croatia

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Ksenija Cindrić[2]

ABSTRACT: This analysis deals with three types of precipitation time-series. Initiatory annual and seasonal amounts are discussed, followed by trend analysis in six indices of precipitation extremes indicating intensity and frequency of extreme rainfall events. Indices has been proposed by World Meteorological Organization and calculated after daily precipitation amounts. The data sets cover the period 1901-2008 at five meteorological stations in Croatia covering different climate regions: continental, mountainous and maritime.

Trends are estimated by a simple least squares fit of the linear model, and tested for statistical significance by a non-parametric Mann-Kendall test. Sneyers progressive analysis of the time series characterized by the significant trend is performed in order to determine the beginning of the trend. Short-term fluctuations are taken out of the data series by the weighted 11-year binomial moving average filter. Variability is performed by time series analysis of coefficients of variation in consecutive 20-year periods. The extreme quantiles for annual one-day and five–day precipitation maxima series have been estimated by Generalized Extreme Value (GEV) distribution and discussed in relation to the original time-series.

Since the beginning of the 20th century annual precipitation amounts show a downward trend in all parts of Croatia, thus joining the trend of drying across the Mediterranean. Precipitation amounts have large interannual variability, both on annual and seasonal scales. It shows a decrease in NW Croatia, mountainous region, northern littoral and in the eastern lowland by the end of the 20th century. Dalmatian islands experienced an increase of variability in a period from the middle of the 20th century.

In the area of drying such as Croatia there is no signal of major secular changes in extremes related to the high amounts of precipitation and frequency of heavy rainfall days over the larger part of Croatia.

Key words: trend analysis, precipitation variability, indices of precipitation extremes, seasonal precipitation, annual precipitation, GEV distribution, Croatia

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1. INTRODUCTION

Many of the impacts of climate change will be felt through extreme events. These increase a demand for determining from the observational record whether there have been significant changes in the magnitude and frequency of extreme events. Furthermore it is necessary to appraise the causes of extreme weather events, and possible attribution of any such change to natural or anthropogenic drivers. This paper deals with statistical techniques in the framework of time-series analysis of historical precipitation data in Croatia. They include long-term evolution of trends and variability in the precipitation parameters which point at the intensity and frequency of precipitation extremes. The results should be initial input data in climate change risk information for adaptation and prevention planning in the area of water resources management including sewerage systems, dams, reservoirs and bridges. An investigation of observed changes is one of the important steps towards understanding possible future trends.

2. DATA AND METHOD

This analysis deals with two types of precipitation time-series: annual and seasonal amounts and six indices of precipitation extremes over the 1901-2008 period for five meteorological stations in Croatia covering different climate regions: continental, mountainous and maritime. The annual and seasonal data series give a general overview of the precipitation temporal change. Precipitation indices enable a consistent approach to the monitoring, analysis and detection of changes in extremes of precipitation by countries and regions across the globe. They are calculated using daily precipitation amounts after recommendation of the joint expert team on Climate Change Detection and Indices (ETCCDI). It is founded by World Meteorological Organization, Commission for Climatology (WMO-CCl) and the Research Programme on Climate Variability and Predictability (CLIVAR). In order to evaluate the intensity and frequency of more rare events, the use of extreme value theory is introduced and applied to the time-series of the annual 1-day and 5-day maximum amounts. Estimates of extreme quantiles or return values that are exceeded with a particular probability are calculated by Generalized Extreme Value (GEV) distribution ((Jenkinson, 1969; Faragó&Katz, 1990). Position of original data points in relation to the estimated 20-year return values for the observed secular series is discussed.

Long-term trends are estimated by a simple least squares fit of the linear model, and tested for statistical significance at the 95% confidence level using a non-parametric Mann-Kendall rank statistics *t*. For the series showing the significant trend identified by the Mann-Kendall coefficient *t*, a Sneyers progressive analysis of the time series is performed by the statistic *u(t)* in order to determine the beginning of the trend (Mitchell et al., 1966; Sneyers, 1990). In order to eliminate short-term fluctuations and to show longer time scale changes more clearly, the noise is taken out of the data series by the weighted 11-year binomial moving average filter, which is often used for the analysis of climate variability (Böhm et al., 2001). A search for change in variability is performed by time series analysis of coefficients of variation (c_v) in consecutive 20-year periods.
RESULTS

3.1. Trends in annual and seasonal precipitation and variability

During the 20th and at the beginning of the 21st century annual amounts of precipitation showed a downward trend in all parts of Croatia, thus joining the trend of drying across the Mediterranean (Table 1 and Figure 1). Precipitation amounts have large interannual variability, both on annual and seasonal scales. Therefore, in order to find out position of 10 driest years, it could be seen that they did not occur grouped in some period (Table 2). Variability of annual precipitation amounts indicates a decrease in NW Croatia, mountainous region and northern littoral (Figure 2). Such a decrease was present in the eastern lowland by the end of the 20^{th} century as well, but the changes since the beginning of the 21^{st} century contribute to an increase of variability. Dalmatian islands experienced an increase of variability in a period from the middle of the 20^{th} century.

Table 1 Decadal trends in precipitation amounts. Trends significant at 5% level are bolded.

	Osijek	Zagreb-Grič	Gospić #	Crikvenica	Hvar
Precipitation amount trend 1901-2008 (% / 10 years)					
Winter	-0.0	-0.4	-2.9	-1.6	-2.9
Spring	-3.2	-0.9	-1.8	-1.9	-1.3
Summer	+1.3	+1.1	+0.1	-2.9	+2.9
Autumn	-2.0	-1.3	-0.2	-1.1	-0.5
Annual	-0.8	-0.3	-1.0	-1.7	-1.0

since 1924

Table 2 Ten driest years. Years from the period 1991-2008 are bolded.

Osijek		Zagreb-Grič		Gospić #		Crikvenica		Hvar	
year	mm	year	mm	year	mm	year	mm	year	mm
2000	316	1949	581	1983	910	1949	704	1983	384
1921	422	1973	607	1953	973	1945	726	2003	431
1983	467	1971	616	1949	1085	2003	752	1989	444
1947	494	1927	624	1971	1091	1953	786	1913	461
1953	500	2003	624	2003	1099	1971	835	1903	479
1949	505	1921	651	2007	1109	1973	842	1977	496
2003	517	1946	665	1989	1119	1956	850	1938	505
1971	519	1942	671	1994	1121	1921	861	1946	542
1928	522	1938	688	1975	1135	1983	877	1950	557
1924	523	1911	691	1946	1136	1920	882	1992	563

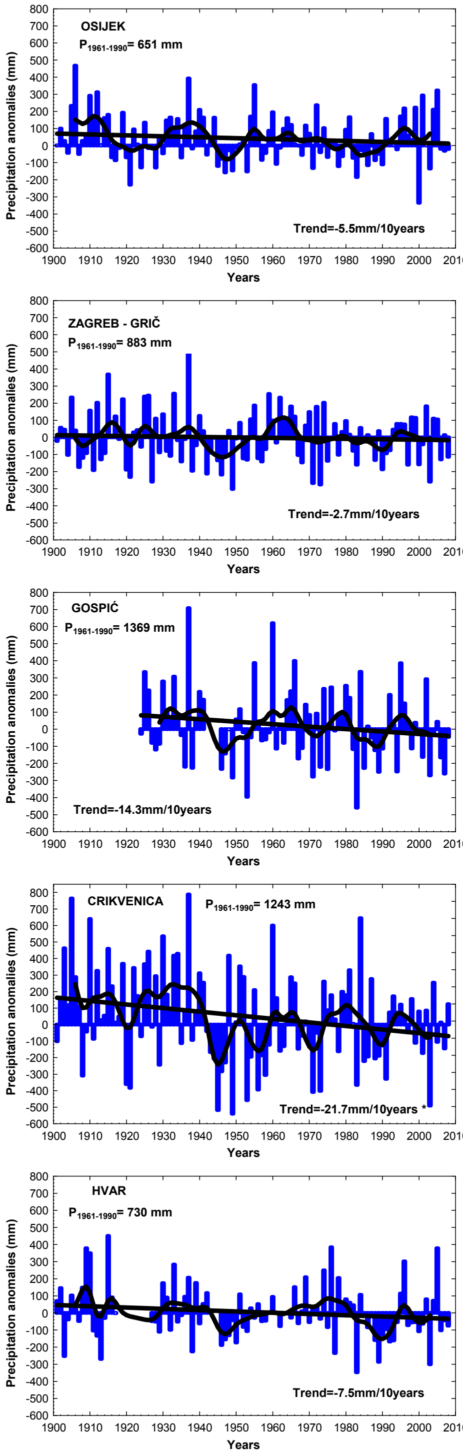

Figure 1 Time series for the annual precipitation amounts, related 11-year binomial moving averages and trends. Unit is anomalies (mm) with respect to 1961-1990 average.

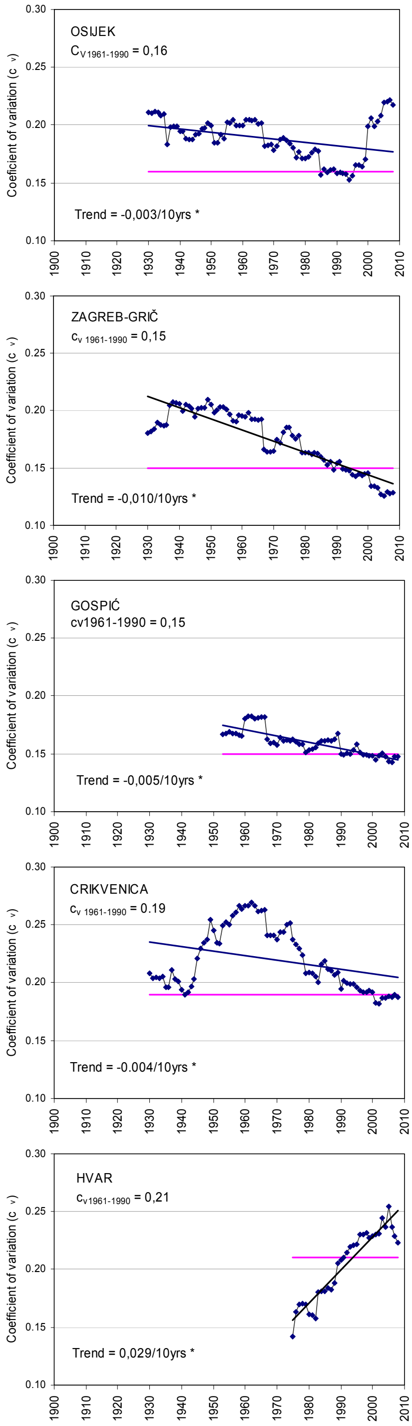

Figure 2 Time series for the coefficients of variation for 30-year periods with one year shift and trends. (Asteriks denotes trend significant at the 5% level).

3.2. Trends in indices of precipitation extremes

Change in precipitation regime patterns, which can result in precipitation decrease in Croatia, can be also indicated by tendency in frequency and intensity of precipitation extremes (dry and wet) defined by number of days in which the precipitation amount R_d exceeds defined thresholds (dry days, wet days and very wet days), i.e. part of annual precipitation amount occurring during very wet days, annual maximum 1-day and 5-day precipitation amounts. Dry days are defined as days in which R_d<1.0 mm, wet days have $R_d \geq 75^{th}$ percentile and very wet days $R_d \geq 95^{th}$ percentile of daily amounts, determined by the sample of all precipitation days (R_d≥1.0 mm) within standard reference period 1961-1990.

In the period 1901-2008 there was statistically significant increase of annual number of dry days (R_d<1.0 mm) in the whole area of Croatia. Negative trend in wet days (Rd≥R75%) prevailed, and it is statistically significant in Osijek and Crikvenica. However, there was no change in the number of very wet days (Rd≥R95%) (Table 3). Fraction of annual total precipitation due to very wet days (R95%T) is almost unaltered. Absolute annual 1-day and 5-day maxima indicate large interannual variability. Estimated long-term linear trend shows weak positive tendency only on Dalmatian islands, while in the inland and littoral there is a decrease of precipitation amounts during heavy precipitation events, statistically significant for 5-day maxima in Osijek (-1.0mm/10years) and 1-day maxima in Gospić (-1.4mm/10years). It should be stressed that further research has to be oriented to shorter periods in order to identify changes in last decades. During these periods a monotonous increase in 5-day maxima at Osijek is present. In Gospić and at the coast the appearance of some outliers can be observed. Such changes are difficult to be identified by long-term linear trends. The illustrations (Figure 3-6) concern cases with abundant rainfall, while the analysis of changes in dry spells is beyond the scope of this paper.

Table 3 Trends in indices of precipitation extremes (DD – dry days, R75% - wet days, R95% - very wet days, R95%T – annual precipitation fraction due to very wet days, Rx1d – annual 1-day precipitation maxima, Rx5d – annual 5-day precipitation maxima). Trends significant at the 5% level are bolded.

	Osijek	Zagreb-Grič	Gospić #	Crikvenica	Hvar
Trend 1901-2008 (in 10 years)					
DD (days)	+1.0	+1.4	+1.4	+2.3	+1.1
R75% (days)	-0.2	+0.1	-0.2	-0.5	-0.2
R95% (days)	-0.1	+0.1	+0.0	-0.1	-0.0
R95%T (%)	-0.2	+0.3	+0.1	-0.0	+0.3
Rx1d (mm)	+0.2	-0.2	-1.4	+0.8	+0.9
Rx5d (mm)	-1.0	-0.6	+0.3	-2.4	+0.6

since 1924

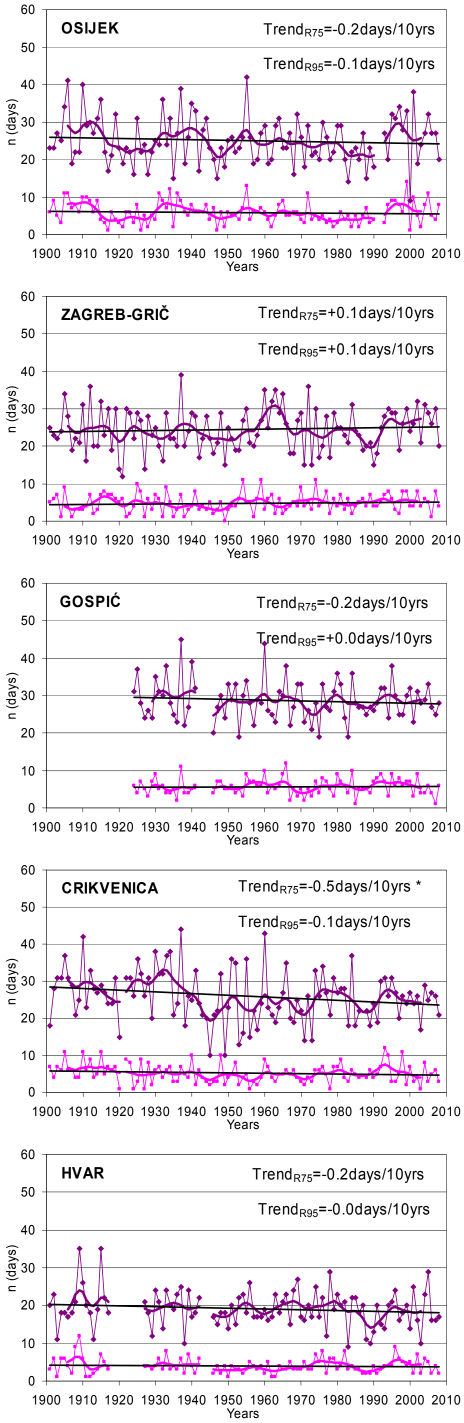

Figure 3 Time series for the number of wet and very wet days, unit is anomalies (days) with respect to 1961-1990 average, related 11-year binomial moving averages and trends. Asteriks denotes trend significant at the 5% level.

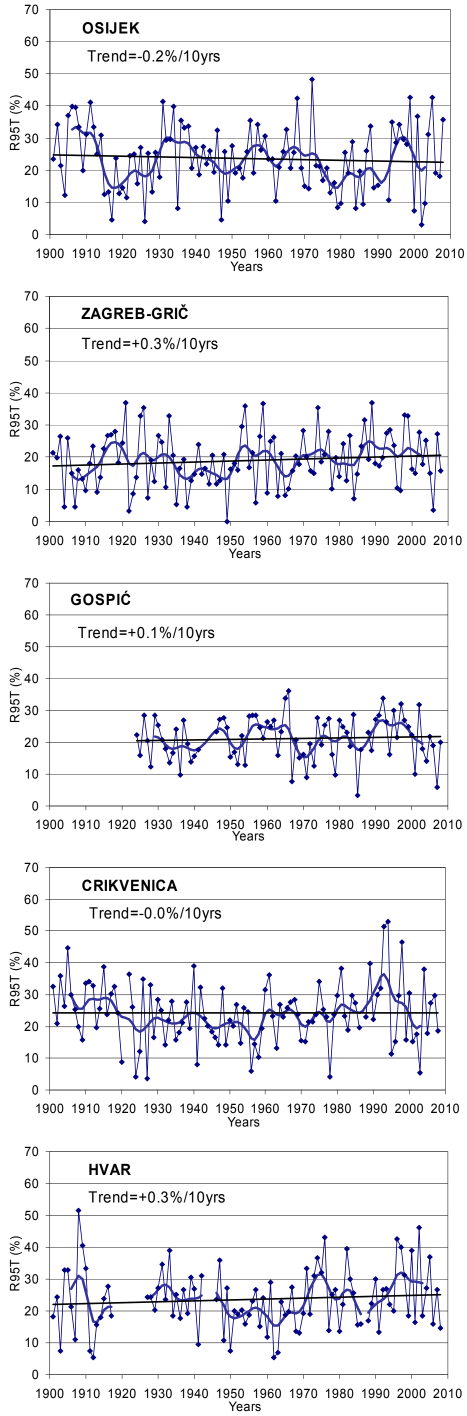

Figure 4 Time series for the percentage of annual total due to very wet days, unit is anomalies (%) with respect to 1961-1990 average, related 11-year binomial moving averages and trends. Asteriks denotes trend significant at the 5% level.

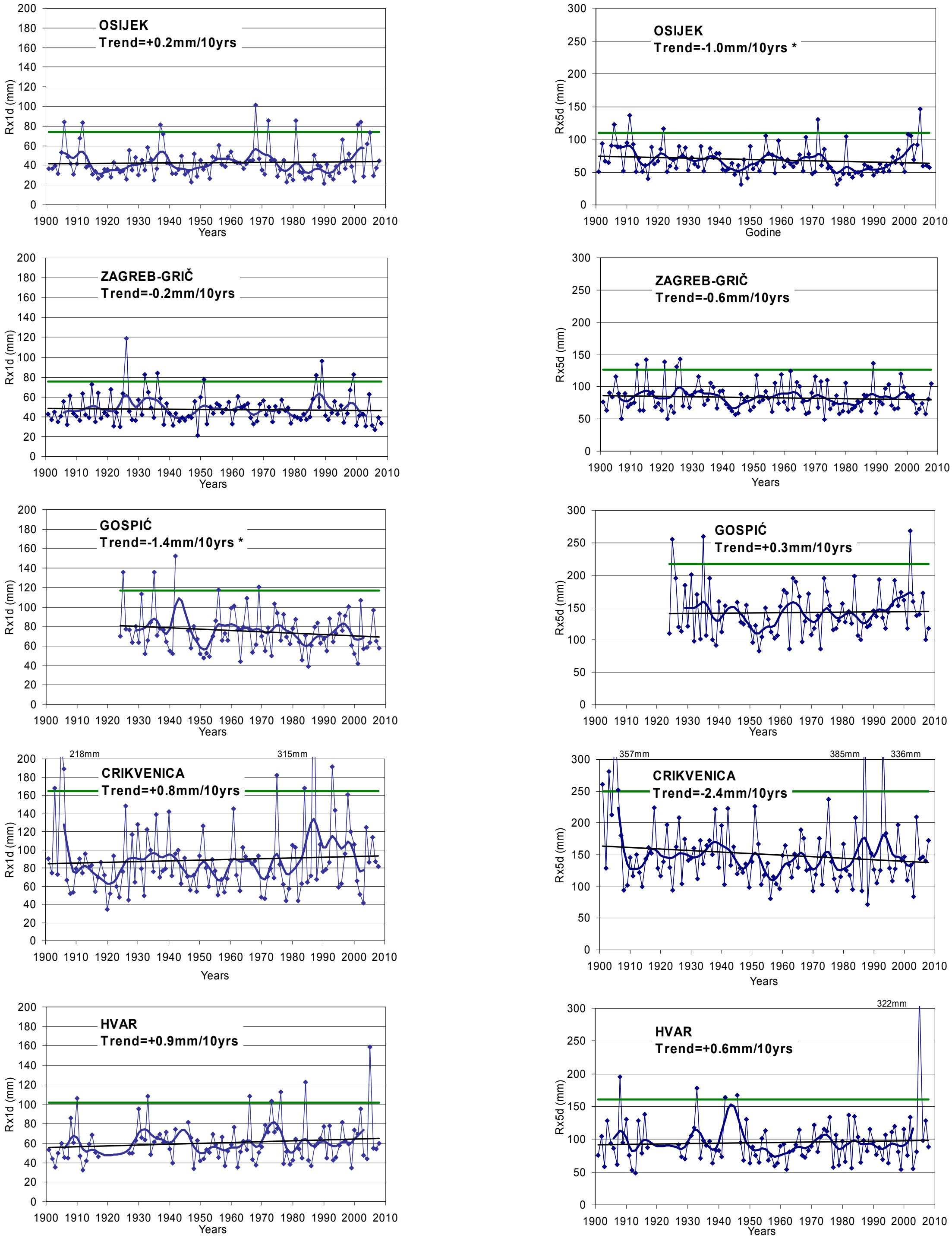

Figure 5 Time series of annual 1-day maxima (left) and 5-day maxima (right). 11-year binomial moving averages denote decadal variations. The black line indicates trend and green line indicates the 20-year return value estimated from the fitted GEV distribution. Asteriks denotes trend significant at the 5% level.

Values of absolute extremes, such as the highest five-day precipitation amount in a year (Rx5d), can often be related to extreme events that affect human society and the natural environment. Indices of the count of days crossing certain fixed thresholds can also be related to observed impacts, in particular if the thresholds refer to values of hydrological significance. Indices based on the count of days crossing percentile thresholds are less suitable for direct impact comparisons but may provide useful indirect information relevant to impact studies and adaptation. For instance, trends in R95% index (the number of days with rainfall above 95th percentile of daily amounts) are relevant for comparing the changes in demands on drainage and sewerage systems at different locations.

Climate change in extreme value analysis

The descriptive indices developed by ETCCDI refer to moderate extremes that typically occur several times every year. Extreme value theory complements the descriptive indices in order to evaluate the intensity and frequency of rare events that lie far in the tails of the probability distribution of precipitation variables, say events that occur once in 20 years.
The fitting of several theoretical distributions (Gumbel, Gulton, Frechet, Pearson III, log Pearson III, and the Generalised Extreme Value or GEV distribution) to the annual daily precipitation maximum series in Croatia pointed at the GEV distribution as the best adjustment according to the Kolmogorov-Smirnov test and quantile-quantile (Q-Q) graph. (Gajić-Čapka&Čapka, 1997). The application of this extreme value theory assumes that time series are stationary.

The main sources of the uncertainty in the estimates may be related to the statistical techniques but dependent particularly on the sample, especially the series length, which needs not to be the same for all regions. Investigation on the normal series length for daily precipitation maxima at Croatian meteorological stations, indicated stabilisation during 50 years in the eastern Croatia (Osijek, Pannonian lowland) and in the north-western Croatia (Zagreb-Grič) and along the Adriatic coast (Crikvenica) during 80 years (Gajić-Čapka, 2000).

According to the previous results the GEV distribution was fitted to the 1901-2008 time series of Rx1d and Rx5d for five observed locations in order to evaluate rare precipitation events of one-day and five-day amounts. The maximum likelihood estimates for the three GEV parameters are in the Table 4. They indicate negative values of shape parameter k meaning that for longer return periods the return values will be overestimated. Due to the series length it is reasonably to use the estimated return values for the return periods not longer than about two times the length of the original data set. The 20-year return values for the observed locations for both precipitation parameters are indicated by the green horizontal line in Figure 5. In the observed 108-year period it is expected that five to six data points exceed the 20-year return value. Figure 5 shows that for one-day maximum this happened somewhat more often at all locations: seven times at Crikvenica, Hvar and Zagreb-Grič, eight times at Osijek, and five times at Gospić where the analysed period is shorter (82 years). These points are evenly distributed across the entire period at inland stations (Osijek and Zagreb-Grič) and on the Dalmatian island (Hvar). At Gospić they appeared in the first half of the observed period from 1924 to 1969 and at Crikvenica (Kvarner bay) at the very beginning of the 20th century and in the twenty-year period from 1975 to 1993. Five-day maxima higher than estimated 20-year return values were rarer than expected at Crikvenica and Gospić (three cases). At all stations they mostly appeared in the first half of the 20th century.

Table 4 GEV distribution parameters for five locations. Period: 1901-2008 (# 1924-2008)

Parameter	Osijek	Zagreb-Grič	Gospić #	Crikvenica	Hvar
Rx1d					
Location (Rx1d $_0$)	34,8	40,5	64,5	69,7	50,6
Shape (k)	-0,20	-0,10	-0,05	-0,20	-0,16
Scale (α)	9,68	10,13	16,25	23,4	13,58
Rx5d					
Location (Rx5d $_0$)	58,3	72,4	124,0	125,8	79,1
Shape (k)	-0,05	-0,09	-0,05	-0,14	-0,15
Scale (α)	16,10	15,86	28,99	33,53	22,04

4. Conclusions

As seen from the long-term time-series analysis, in the area of drying such as Croatia there is no signal of major secular changes in extremes related to the frequency of wet and very wet days and high amounts of precipitation over the larger part of Croatia. The reduction in the annual amounts of precipitation can be attributed to changes in the frequency of low-intensity rainy days and significant increase in incidence of dry days all over Croatia.

For more rare precipitation extremes, the highest 1-day and 5-day precipitation amount in a year, GEV distribution was applied. Location parameters show rather differences between the locations. Shape parameters have the same sign. They are all negative, indicating a strong influence of outliers and temporal variability. This is less expressed in Gospić (mountainous plateau) for the 1-day maxima and in inland (Zagreb-Grič, Osijek and Gospić) for the 5-day maxima.

The highest annual 1-day precipitation amounts exceeding 20-year return values are evenly distributed across the entire observed period for inland stations. Five-day maxima occurred mostly in the first half of the 20th century. They don't indicate grouping during the last decades that can eventually point at the possible recent decadal trend that are often reported.

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Rainfall based flood hazard indicators for Novi Sad

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ABSTRACT: Spatial and temporal flood hazard early warning indicators have been defined for Novi Sad. Firstly a six-month Standardized Precipitation Indicator (SPI-6) was taken into consideration. Because its input data is rainfall only, it was necessary to introduce additional parameters. For the effective flood early warning for Novi Sad it is necessary to continuously monitor upstream hydrological and meteorological parameters using spatial and temporal information system.
This paper presents first step of the combination of chosen parameters, putting attention on their complementarity for the development of the most optimal indicators.
Key words: flood, rainfall, hazard, early warning, indicators, hydrological and meteorological
INTRODUCTION

Intergovernmental Panel on Climate Change (IPCC), in its fourth report, describes progress in understanding of climate change's natural and anthropogenic driving mechanisms, and projected climate change scenarios in the near future. The report stressed the need for detailed and accurate data sets, better understanding of processes and their simulation models, and for better understanding of uncertainty and confidence intervals. Unambiguous climate changes were the trigger for consideration of secondary changes.

Climate change and natural hazards

Considering the Earth a closed system, climate change causes a domino effect. It also indicates the connection between parameters of various phases of the hydrological cycle. It's mutual correlation has enabled the development of indicators used for speculation, anticipation and identification of trends and changes in different segments of the hydrological cycle. As a consequence of climate change, occurrence of catastrophic events of large scale, which have started to threaten individuals, businesses and society as a whole, are more frequent. Flood is declared as a natural disaster, and is defined as an extreme event. Like most other natural hazards, excluding drought, floods occur quickly, with great intensity, randomly, regardless of the time, place and degree of vulnerability of the affected area. Such extreme events require remediation of losses, damages, and considerable financial investments. For this reason, prevention is considered to be better than rehabilitation. Hazard monitoring systems and hazard early announcement are most frequent means of prevention. After that other elements of prevention (implementation of legislation, determining the zone of vulnerability, defining the methods of management and control of vulnerable zones, etc.) can be applied.

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Hazard assessment refers to the probability of occurrence of events. Its computation is possible only if we have adequate relative historical data. From data collected, one can calculate probabilities of flood waves. Taking climate change into consideration, those calculations are no longer simple; prognosis of occurrence of a particular hazard requires the consideration of introducing a trend of change. As a result, and all in order to facilitate the usage of long time series, indicators, whose analysis indicates the possible development of catastrophic events, are developed.

RAINFALL BASED INDICATOR FOR FLOOD MONITORING

Six-Month Standardized Precipitation Index (SPI-6)

Standardized Precipitation Index (SPI) was developed by T. McKee and others in 1993. for better representation of dry and wet periods. Unlike the Palmer index, which is based on monthly water balance, which included precipitation, evapotranspiration, runoff and soil moisture, SPI was developed to quantify the surplus (deficit) of rainfall for different time periods. Nature of the SPI index allows determination of the frequency of occurrence, the time of occurrence or anomaly in the occurrence of rain (wet) period for a specified time period.
SPI was developed as a drought index but it can also be used as an indicator of the progress of soil saturation conditions conducting to floods. According to McKee at all 1993, SPI may be computed over an extensive variety of time scales. The use of different timescales allows assessing the effects of precipitation on different water resources components like groundwater, reservoir storage, soil moisture, stream flow (Morid at all, 2006). Six-month SPI (SPI-6) refers to the medium-term trends in precipitation, and points out the effect of rainfall on groundwater resources, and surface waters. Positive SPI values indicate that the precipitation is above the average, in this case for positive values of SPI-6 is expected to raise groundwater levels and increase the amount of water in the streams due to reduced infiltration capacity of the ground. In Vojvodina (six stations considered) the SPI-6 values did not exceed 0.8. One could not conclude that there are periods of extremely wet events, based on the amount of rain. But the peaks, which are in the interval 0.5 to 0.7 for Novi Sad, coincide with periods of flood occurred. This coincidence has led to the conclusion that when the SPI-6 is in interval between 0.5 and 0.7 in the area of Novi Sad high water levels, a possible flood wave or the appearance of urban flooding can be expected, due to already saturated ground and raised level of ground water. In order to confirm this it was necessary to analyse the temporal distribution of rainfall, water level, and flow of Danube in Novi Sad.

Overview of determination of indicators for flood monitoring in Novi Sad

Temporal rainfall variation is expressed by the mean total annual precipitation, to facilitate the analysis. In order to make comparisons and to express the complementarity of hydrological and meteorological parameters, their linear trends are determined.

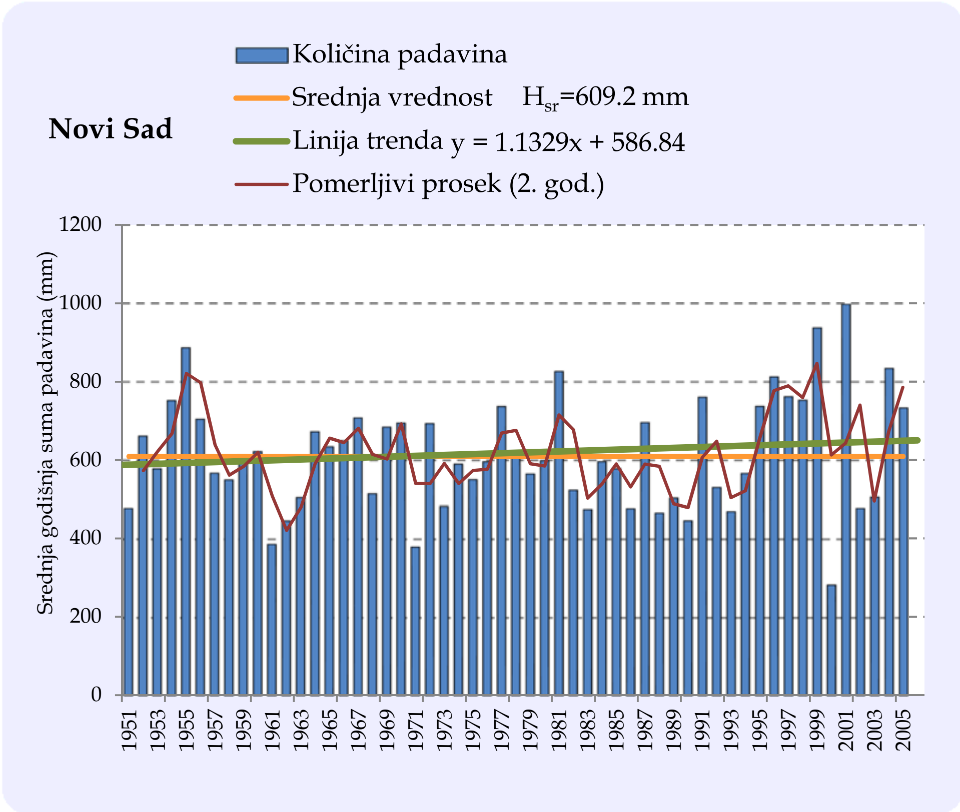

Figure 1. Mean annual precipitation trend line (mm) at the meteorological station Novi Sad (Rimski Šančevi), for the period 1951 - 2005.

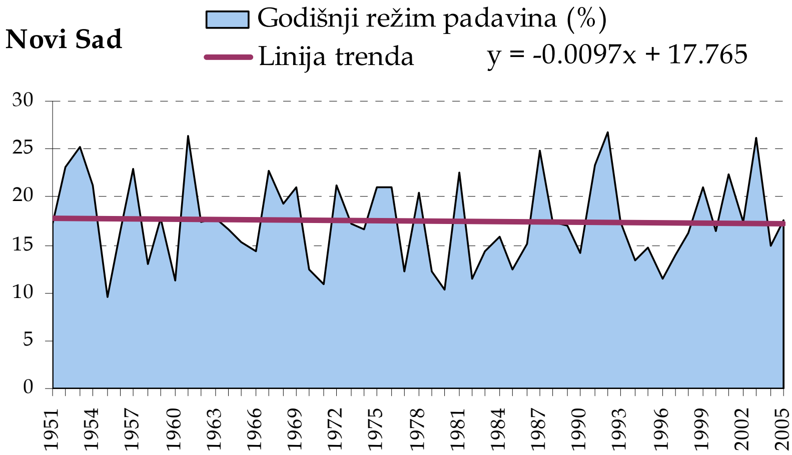

Figure 2. Annual rainfall regime change trend line (%) for the territory of the meteorological station Novi Sad (Rimski Šančevi) for the period 1951 - 2005.

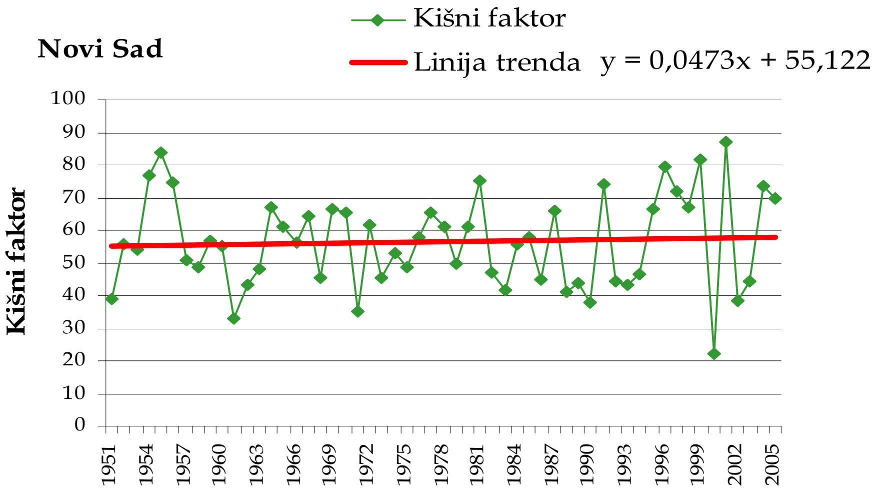

Figure 3. Rain factor trend line change for the meteorological station Novi Sad (Rimski Šančevi) for the period 1951 - 2005.

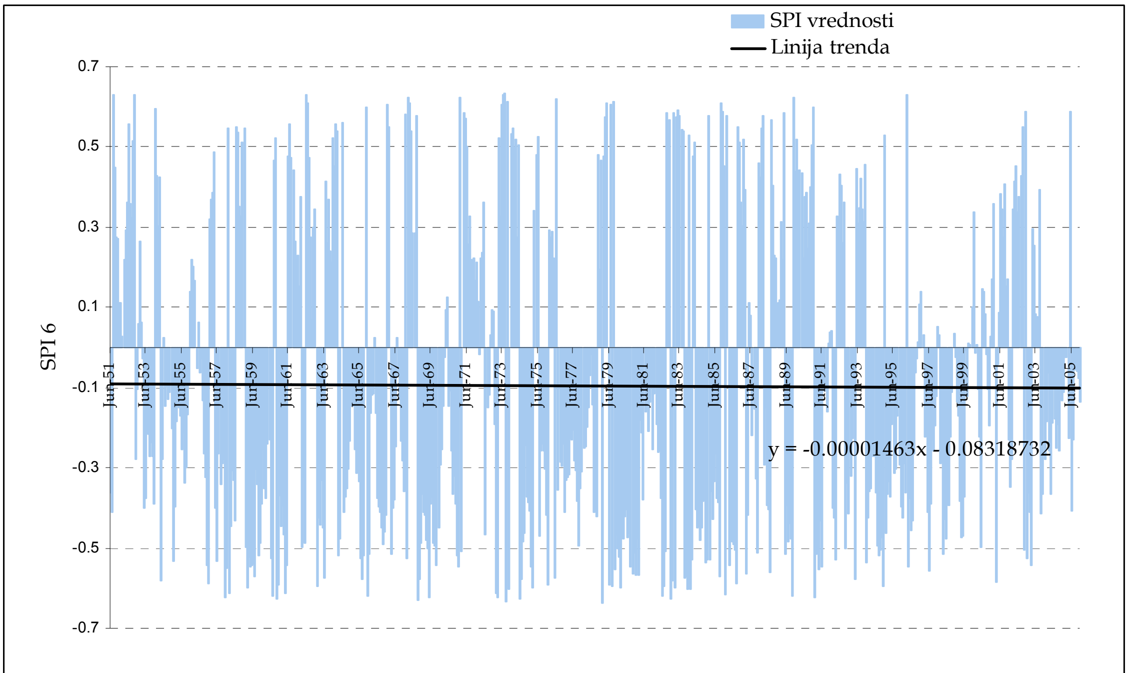

Figure 4. SPI-6 values and it's trend line for the territory of the meteorological station Novi Sad, for the period 1951-2005.

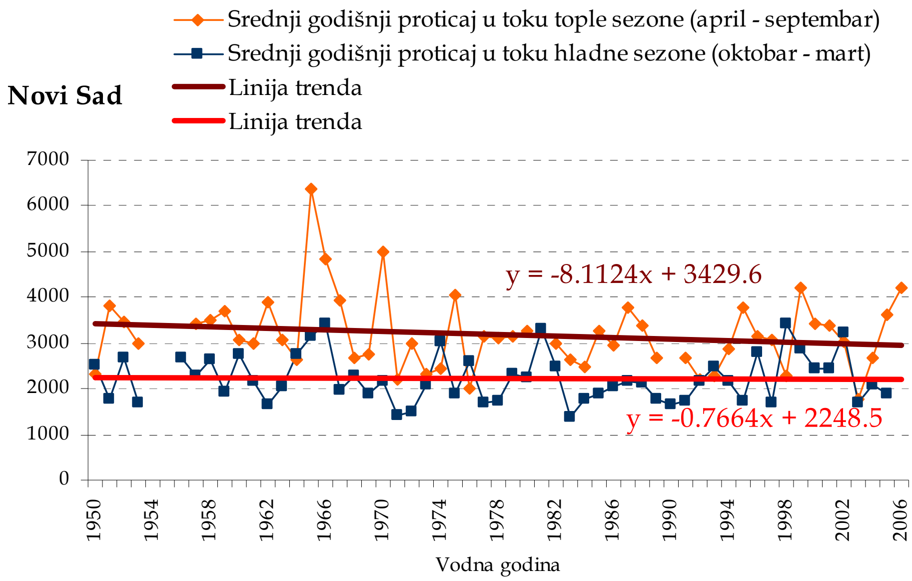

Figure 5. Mean annual discharge trend lines (m3/s) of Danube River at Novi Sad hydrological profile during hot and cold season for the period 1950 to 2006

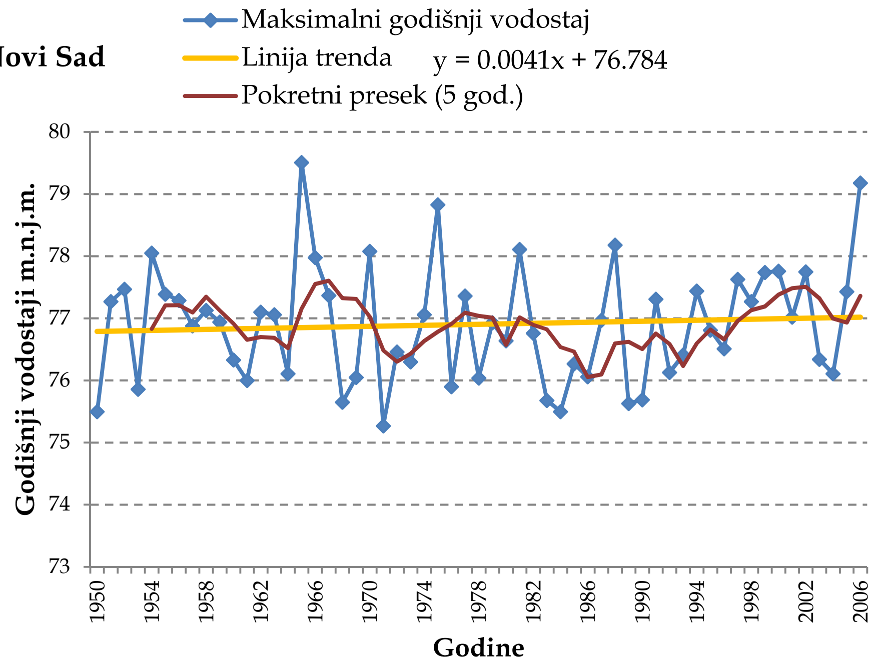

Figure 6. Maximum annual water levels trend for the period 1950-2006, at the hydrological profile of Novi Sad on Danube River

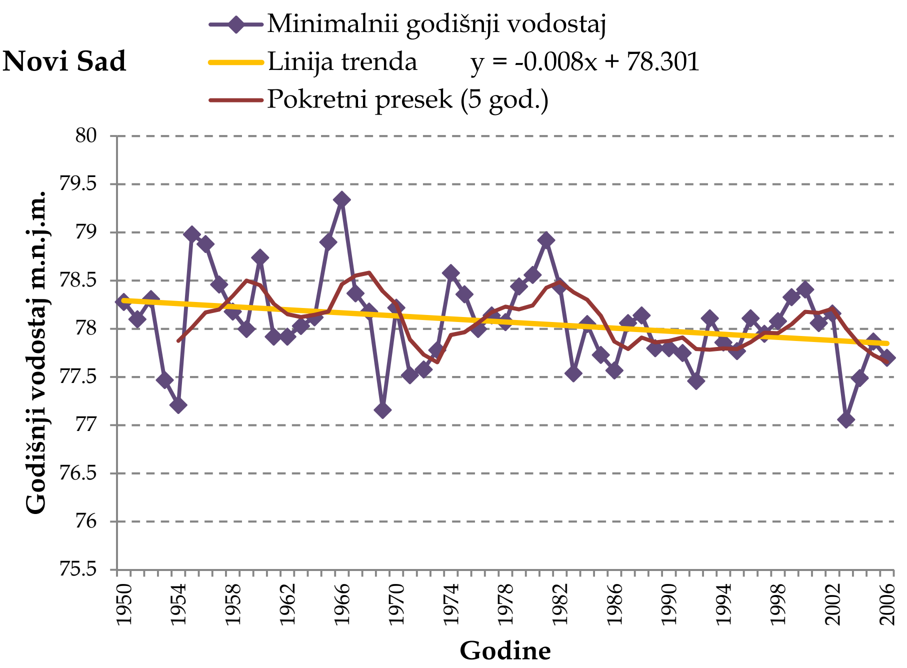

Figure 7. Absolute minimum annual flow trend for the period 1950-2006, at the hydrological profile of Novi Sad on Danube river

Performed trend analysis of climatological and meteorological parameters in Vojvodina (Pavlović, 2009) led to the conclusion that flow and rainfall trends in Vojvodina are consistent and moderate. Single outliner was observed in increased rainfall during the summer, accompanied by a strong upward trend, in contrast to the decreasing trend of runoff during the same period. River basin of Vojvodina is specific due to presents of several major transit rivers suffering different impacts. If the geographical position of Vojvodina has taken into consideration, one might conclude, without exaggeration, that this territory is under hydrological and meteorological influences from western, northern and Eastern Europe. So it is necessary, for further analysis and monitoring, to take a wider area than Vojvodina. Consideration of climate change in the Province have led to the conclusion that Vojvodina is an integral part of the European continent, so it is subject of numerous influences, and the observed changes result from a series of cumulative impacts, which originate outside of the province. Considered linear trends of mean annual precipitation, maximum and minimum water levels, and average annual discharge at station Novi Sad showed that those parameters are heterogeneous and it is necessary to group them for the purpose of monitoring and indicators establishment.

Possibilities of application of indicators for early warning and control of flood risk

In terms of social and economic development of Vojvodina (Serbia) one can expect a permanent increase in the need for land use in flood zones, followed by a progressive increase in the value of goods and increasing concentration of population. Although the risk of flooding could not be eliminated, even with a large economic investments the goal of sustainable development is seeking for an integrated concept for flood protection, which includes compliance of requirements of a "human" component (protection of property and human life) and "environmental" component (the preservation or restoration of natural functions and resources floodplain) (Institute Jaroslav Černi, 2001).

The aim of the climate change analysis is an early warning, and the possibility of preventing future environmental disasters, if the predictions would be seriously included in the infrastructural, agricultural, socio-economic, political, and other relevant studies. Of the great importance is the adaptation of human activities to the available renewable natural resources, not endangering them.
In line with the integrated water resources management and flood risk reduction, the development of an integrated early warning model and flood risk zone management is undergoing.

One of the segments of the model includes the following elements:

- Flood occurrence's indicators
- Risk related indicators
- Development of the spatial and temporal monitoring system
- Indicators calculation
- Optimization of the weight factors
- Flood hazard distribution

A case study presents a model for assessing risk in the urban area of Petrovaradin, which on the basis of selected indicators shows the degree of exposure to certain areas at risk from flooding and therefore allows damage assessment.
After obtaining information that flood will actually occur in the flood zone of interest, and based on the assessment of indicators, model in the next step analyzes the exposure of different types of buildings, land, roads and forests. It also gives the information about what buildings, roads, forests, and arable land are flooded. Furthermore, those most important indicators are included in the vulnerability assessment.

Integrated model-based early warning indicators and assessment of flood risk for Novi Sad

For the selected area, analysis and comparison of occurrence of maximum water levels and precipitation series during that period were performed. The aim was to develop an indicator which uses measured precipitation as an input parameter, and put in line with reliable scenarios of appearance of alarming water level. So far, the measured water levels are compared with the existing base of indicated extremes, and progression of an SPI-6, which indicates the saturation of ground due to earlier rain during the observed period reducing infiltration capacity in case of new rainfall and indicates possible flood occurrence in the urban catchment area of Novi Sad. Ground saturation, and indicated high water level, with the possible announcement of a flood wave, for which is necessary to examine both trends of selected indicators on the upstream profiles, are indicators of the risk of flooding for Novi Sad. Next step of the model is visualization of flooded area due to predicted flood wave, raising the ground water in the flood zone or increasing surface runoff due to reduced or ineffective infiltration.

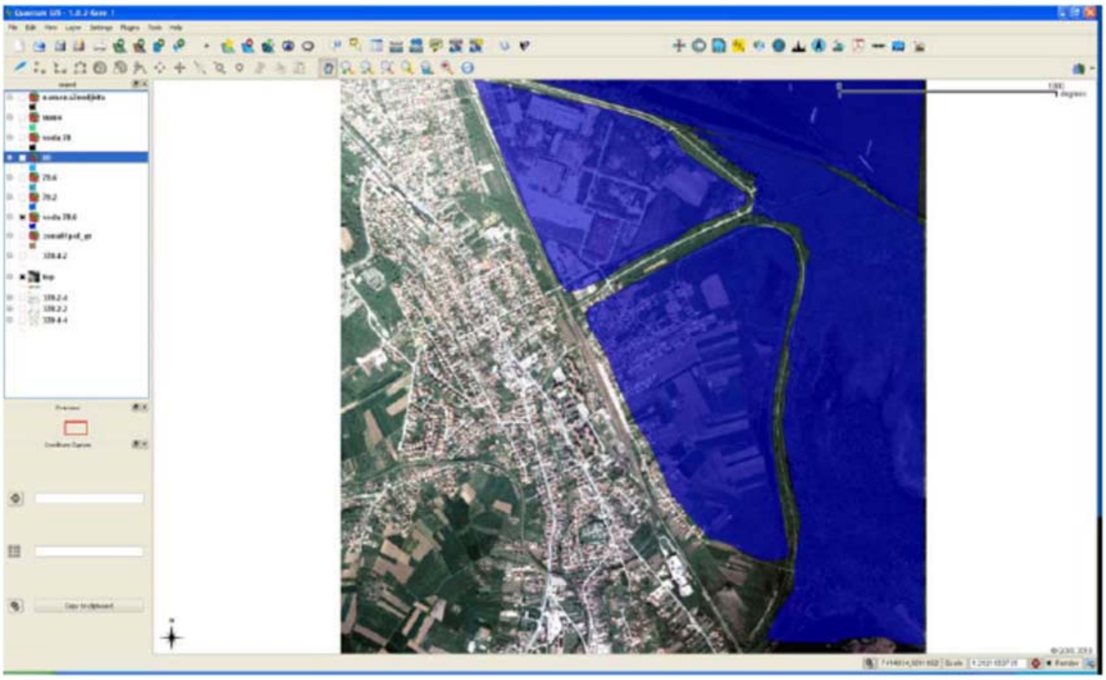

Figure 8. Example of a simulation of early warning for Danube River water level of 78.6m near Novi Sad and the spatial distribution of flood wave in the flood zone Petrovaradin

CONCLUSION

An integrated model of the flood early warning and risk management, presented in this paper, is based on particular indicators. It would allow monitoring of the distribution of potential extreme events in time and space. This monitoring system would be optimized for real-time monitoring of one up to three hydro meteorological parameters. For this purpose it is necessary to consider the monitoring of selected meteorological parameters for hydrological stations.

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We would like honorable to mention our colleagues, from Disaster Risk Reduction Research Center, PhD Đorđe Ćosić and MSc Srđan Popov who are involved in development of described model. Without help of particular that mentioned above we would face many difficulties while doing on the model development.

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