DESIGN STORM FOR OSIJEK'S URBAN DRAINAGE

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Abstract: Reconstruction of the sewage system and urban drainage planning resulted in establishing rainfall monitoring and runoff monitoring for Osijek's urban area. Registered perennial rainfall data from different locations of Osijek's area are suitable for analysis because they include a distinctly thirsty and a distinctly showery year.
The paper presents analysis of intensive rainfalls that are isolated from rainfall data (1998-2002) registered at five ombrographs. For each isolated storm – hydrograph increase time, decrease time, overall duration, maximal intensity, complexity of shape and space character are defined. The statistical characteristics of those storm events are outlined. Based on there data and simultaneosly registered overload of the sewage system, as well as on usual definitions, the paper attempts to determine the designed storm for local urban drainage problems.
Keywords: rainfalls, rainfall event, design storm, urban drainage

BESTIMMUNG DES PROJEKTREGENSCHAUERS FÜR DIE ENTWÄSSERUNG DER STADT OSIJEK

Zusammenfassung: Die Rekonstruktion des Kanalisationsnetzes und die Entwicklungsplanung haben zur Errichtung eines Niederschlag- und Abflussmonitorings auf dem Gebiet der Stadt Osijek geführt. Die durch mehrere Jahre an verschiedenen Stadtlokalitäten angesammelten Daten waren für die Analysen sehr günstig, weil sie ein ausgesprochen trockenes und ein ausgesprochen feuchtes Jahr umfassen.
Die vorliegende Arbeit präsentiert die Analyse der Starkregen, die aus den Regendaten (1998-2002) abgesondert und an fünf Ombrograhen aufgezeichnet sind. Für jeden abgesonderten Regen-Hydrogramm wird ausgeschieden: Aufstiegszeit, Verminderungszeit, Gesamtdauer, Maximalintensität, die Formkomplexität und der Raumcharakter. Durch die Verarbeitung wurden statistische Bestimmungen dieser Regenschauer festgelegt. Aufgrund dieser Bestimmungen sowie der festgestellten Kanalisationsverstopfungen, wird, gemäß den allgemeinen Definitionen, ein Versuch (Vorschlag) der Projektregenbestimmung gegeben, der zur Problemlösung örtlicher Stadtentwasserung führen soll.
Schlüsselworte: Niederschläge, Regenereignisse, Projektregenschauer, Stadtentwässerung

1. Introduction

Rainfall has received the lion's share of study in urban areas. Certainly rainstorms are associated with flooding and combined system overflows in temperate environments and rain is considered the most important variable that drives runoff and flow processes. (Schilling, 1991).

For the hydrology, and especially for the engineering hydrology main interest does not represent the percipitation itself, but mainly the discharge that is caused (Bonacci, 1994). Special interest represents the determing of maximal flow and volume of the hydrograph, one tries to solve that with the analysis of strong precipitation of short duration. For needs of such analyses in the middle of the twentieth century in the engineering hydrological practice, on the occasion of dimensioning firstly the urban drainage, and then other sewage systems, a term has been introduced - design storm. The aim of introducing this term was to determine the entrance in the hydrological process that will describe real but general hydrographs of the precipitation. On top of that the wish was to achieve that the return period of percipitation as the input approximately responds to the return period of the discharge characteristics as the output. (Bonacci, 1994)

The specification of a rainfall event, called a «designed storm», as a design criteria is widely used in engineering practice. Despite this widespread use, however, the subject of design storms is controversial. Much od the controversy stem from the lack of realistic and accurate definitions of design storms, and confused thinking about their application. The main criticisms of design storms arise from the practice of assigning a particular frequency to a design storm, neglect of antecedent catchment conditions, and design on the basis of the return frequency of rainfall rather than runoff.

2. Design storm and current practice for calculating the design storm

Arnell (1982) has given the following definition of design storm: »This is the precipitation which has been developed for the design of specific types of objects for example waste-pipes or retention the pools. The design storm concept assumes a precipitation event of a particular frequency will produce a runoff event of the same frequency.«.

The design storms are the most frequently used form of precipitation data for rainfall-runoff simulation. Design storms are developed from statistical analysis of local precipitation records. Design storms are widely used because they:

- Require minimal resources in terms of time and money;
- Can give conservative results;
- Are generally accepted in practice;
- Have the advantage of consistency of methodology.

A design storm statistically represents the variability of precipitation depth, and temporal and area distribution occurring in nature. The design storm is a distribution of rainfall depths over a time increment for a given storm duration and frequency. Design storm means a hypothetical discrete rainstorm characterised by a specific duration, temporal distribution, rainfall intensity, return frequency and total rainfall depth.

The principle elements of design storms are:

Depth: the depth of precipitation occurring during specified storm duration. Statistical analyses of historical precipitation data are used to find the maximum rainfall depth for given duration and frequencies.

Duration: the period of time over which precipitation occurs. The duration of a design storm is dependent on the objective of the hydrologic analysis. Design storms are classified as short-duration storms (less than or equal to 24 hours) and long-duration storms (greater than 24 hours).

Frequency: the frequency in which a specified precipitation depth is equalled or exceeded within a specified time. The frequency is often expressed in terms of the return period. The statistical concept of return period or recurrence interval aids in assigning a probabilistic meaning to a precipitation event.

Temporal distribution: the time-related distribution of the precipitation depth within the duration of the design storm. Temporal distribution patterns of design storms are based on the storm duration. The temporal distribution pattern for short-duration storms represents a single cloudburst and is based on rainfall statistics. The temporal distribution for long-duration storms resembles multiple events and is patterned after historic events.

Spatial distribution: the aerial distribution of the precipitation depth over the watershed. This is typically disregarded for small watersheds but is included for larger watersheds or for major structure design by using storm-centring techniques.

Design strom may be different, it depends on the part of the draining system, which is designed. If it is the question of sewer system dimension, then it is crucial to define the exact peak of the hydrograph; if it is about retention pools dimension, then it is important to define the exact volume of the hydrograph. Majority of today known and developed design storms have been developed for the estimation of the upper flow of hydrograph but they are used to design the retention pools dimensions, that may be more or less correct.

Design strom should have the important characteristics of historical measured rain showers, so it should be real and libareted from all so called random errors or inflows, which every separate storm carries inevitably with it. (Bonacci, 1994). Besides this characteristic the design storm is requested to cause most inconveniently but realistically possible discharge in the determined watershed, consequently the maximal upper flow or the maximal volume of hydrograph. Also there is a wish the that design storm has at least similar characteristics that would make possible that the return period od precipitation becomes similar if not identical to the return period of maximal flows hydrograph.

Although the design storm must reflect required levels of protection, the local climate, and catchment's conditions, it need not be scientifically rigorous. It is more important to define the storm and the range of applicability fairly precisely to ensure safe, economical and standardized design.

The two types of design storm are recognized: synthetic and actual (historic) storms. Synthesis and generalization of a large number of actual storm is used to derive the former. The latter are event which have occurred in the past, and which may have well documented impact on the drainage system. However, it is the usual practice in urban storm water drainage to use synthetic design storms.

Synthetic design storms are normally defined by their duration, total rainfall depth, temporal pattern, spatial characteristic and some measure of antecedent rainfall. The total rainfall depth is normally selected so that the depth-duration combination has some specified return period. It should be noted that any frequency associated with the "storm" is likely to be different from the frequency associated with the peak runoff flow, runoff volume, or pollutant loading which results from the rainfall.

Design storm duration is an important parameter that defines the rainfall depth or intensity for a given frequency, and therefore affects the resulting runoff peak and volume. Current practice is to select the design storm duration as equal to or longer than the time concentration for the catchments (or some minimum value when the time of concentration is short). Intense rainfalls of short duration usually occur within longer-duration storms rather than as isolated events. It is common practice (Packman and Kidd, 1980) to compute discharge for several design storms with different duration, and then base the design on the "critical" storm that produces the maximum discharge. However the "critical" storm duration determined in this way may not be the most critical for storage design.

The return period is defined as the average interval in years between the occurrences of a specified discharge or large. This has been expressed as a probability of exceedance in exceeding a discharge of certain magnitude (The institution of Engineers, 1987). The decision as to the return period to be adopted in design is essentially a problem of balancing average annual benefits against average annual cost, with regard to the standard of protection from flooding with the community demands. Ideally, the design storm return period should be selected on the basis of economic efficiency. In practice, however, economic efficiency is typically replaced by the concept of level of protection. The selection of this level of protection (or return period), which actually refers to the exceedance probability of the design storm, rather than the probability of failure of the drainage system, is largely based on local experience. Typical return periods used in the United States and Canada, are given in Table 1, although longer return periods are sometimes used. The recommended return periods by deferent authorities and experts for design and analysis of different components of urban drainage system in Australia are summarized in Table 2.

Table 1: Typical design Storm Frequencies in USA and Canada (Design and construction of stormwater management, 1992)

Land Use	*Design Storm Return Period (Frequency)*

Minor Drainage System • Residential • High value general commercial area • Airports (terminals, roads, aprons) • High value downtown business areas	 2- 5 years 2-10 years 2-10 years 5-10 years
Major Drainage System Elements	Up the 100 years

Table 2.: The recommended return periods by deferent authorities for design and analysis of different components of urban drainage system in Australia (Dayaratne, 2000)

Kind of drainage area	*Return period (years)*		*References*
	Design	*Analisis*	
Road surface (hydroplanning)	0.5-2		NAASRA, 1986
Major roads-Gutters Inlets; Table drains; Catch drain Major roads	5-10 10-20	10-25 25-50 100	NAASRA, 1986 NAASRA, 1987
Minor roads-Gutters; Inlets Table drains; Catch drain	5-10 10-20	10-25 25-50	NAASRA, 1986
Intensely developed business, commercial and industrial areas	20 20-50		ARR, 1958 ARR, 1987
Business, comercial and inustrial areas, closely but nost intensely developed	10 25-100 5-40		ARR, 1958, 1987 ARR, 1977 O'Loughlin and Avery, '80
Intensely developed residential areas	10 10-25 5-20		ARR, 1958, 1987 ARR, 1977 O'Loughlin and Avery, '80
Sparsely developed residential areas	5 1-10		ARR, 1958, 1987 ARR, 1977
Sparsely built-up areas	3 1-10		ARR, 1958 ARR, 1977

The different methods for developing a synthetic design storm exist in practice around the world. Commonly used methods are:

1. The NRCS method (formerly the SCS)
2. The Constant Intensity Method
3. The IDF
4. Huff's
5. Chicago
6. French design storm (Desbordes)

Some of these design methods have been based on particular rainfall data of the area od interest (e.g., Chicago storm), and therefore cannot be directly applied to other regions. To this category we can include the well-known Huff's curves for Illinois (Huff, 1967) although they have been used in several studies for other regions, as well. The design storms that are based on the well-known intensity-duration-frequency (IDF) curves of the particular area of interest overcome this drawback. The main feature of the IDF-based procedures is that they lead to a unique hyetograph with no other inherent assumptions and they use data from area of interest.

Current UK practice for calculating the design rate of flow from an impermeable area assumes a constant rainfall intensity of, for example, 50 mm/hr and 100 % run-off from the surface. The flow rate in then used to determine the size of the site drainage system needed to collect and convey the surface runoff to the point of discharge. This design procedure may be adequate for small paved areas around buildings. It is however not satisfactory for large surfaces since it takes no account of the geographical location of the site, the duration and design period of the storm, or the time taken by the run-off to flow across the paved surface and enter the drainage system.

In the UK national Annexes ND and NE of BS EN 752 Part 4 (1998) (Hydraulic design of paved areas, Design Guidance, 2003) various methods are suggested for determining the design rainfall intensity and flow rates. These methods range from constant-rate rainfall to time-varying profiles and the choice of method is related to the size of catchment under consideration. However, the more sophisticated methods require the use of urban drainage software packages and procedures, which are not always available to the drainage engineer, and do not provide any information on water depths occurring on the catchment during the design storm.

The new proposed guidance differs from current UK practice in that it is based on more detailed factors such as: the critical storm intensity and duration for the particular geographical location of the catchment; the frequency of occurrence (or return period) of the event and the characteristics of the catchment. These are concepts that have been used in the determination of run-off from pervious cathments and in the more complex urban drainage design methods, and are equally applicable to impervious surfaces. (Hydraulic design of paved areas, Design Guidance, 2003)

In Germany the standard design event for urban runoff management is one inch of rainfall falling in 15 minutes. This would be a 10-year return frequency event in southeastern Pennsylvania. The runoff requirements for urban areas that are undergoing redevelopment should be based on the type of the storm that is linked to chronic runoff-related problems (e.g. nuisance flooding, combined sewer overflow, TMDL exceedances). By-and-large these are summer downpours. Therefore, runoff abatement programs should focus on these storms. (Use of Vegetated Roof Covers in Runoff Management, Roofscapes inc., Green Technology for the Urban Envirenment, Philadelphia, 2002)

A constant rainfall intensity and the IDF curves are used in Croatian practice for determing design storms. The recommended return periods in literature are (Margeta, 1998):

1. Minor Drainage System 1 year
2. Major Drainage System Elements 2 years
3. Major Sewer 5 years
4. High value city areas (museums, history monuments, high technology, archive, etc.) 5-50 years

3. Design strom based on research of the Osijek's rainfall characteristics

In context of project "Drainage model with the idea project for the sewage system of the city of Osijek" one of the planned activities is Monitoring of rainfalls and drainage (*, 2000). Faculty of Civil Engineering, Osijek was chosen for that activity as a subperformer. What was going to be measured, where and how was agreed with all for the project relevant clients.

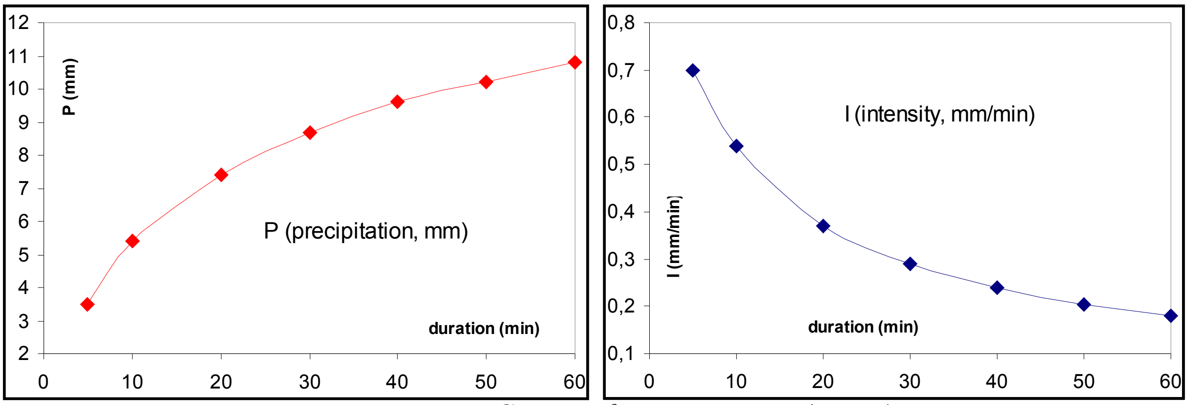
By that occasion, the ombrographs network inside the city was establishedat first. It consists of five automatic ombrographs. Two ombrographs was established in 1998., and another three at the beginning of the 1999. They are distributed along the city zone according to the placing possibilities, undisturbed work insurance and the existing state of water gathering by the sewage system. Electronic rain gauges – ombrographs are characterized by automatic work and continuous measuring. This rain gauges network enable the data collecting about rainfall quantity in space and time. The used ombrographs record digitally time and growth of the total rainfall event in form of rainfall impulses accuracy from 0,1 mm (volume of the measuring container on seesaw). (Patrčević at all, 2002):

The measurings, in the context of the mentioned project,were at first planned in duration of four months (only to connect rainfall and drainage), but afterwards it was agreed to continue the measurings.

Table 3. Strong rain (storm) according the practice in Croatia

Rain duration T (min)	*The lower threshold rain*		
	P (mm)	*I (mm/min)*	*I (L/s/ha)*
10	5,4	0,54	90

20	7,2	0,36	60
30	9,0	0,30	50
40	9,6	0,24	40
50	10,0	0,20	33
60	10,8	0,18	30



Picture 1a, b: Criteria for strong rain (storm)

Collected data till the end of 2002 were used to study short-duration storms.This observed period includes particularly wet periodes (1999) and particularly dry (2000) and several average periods, therefore it can be evaluated,in the sense of precipitation, as a good example of the events in the observed area. The performed monitoring established undoubtfully that the rainfalls show the difference along the elongated urban area of the city of Osijek due to time and space asymmetry. For the longer period of observation the total rainfalls in the city are of equal amount, but for the shorter period the differences on the locations are evident (Maričić at all, 2002, 2003).

5-minutes rains from all locations were observed. Those were followed by the separation of single storms according to the criteria given in the Table 3 and Picture 1a, b, which agrees with the practice of Metereological and Hydrological Service. 116 single events were observed within 47 different rain episodes (Table 4).The quantities were determined for each rain event: maximum intensity, total volume, total duration, hydrograph increasing time and hydrograph decreasing time and it was estimated if the hydrograph has complex or simple shape and if the rain is local or aerial. In view of this data basis determined statistic parameters were used to define synthetic design storm.

Table 4. Data base of storm research for Osijek

RESEARCH OF THE RAINFALLS FOR OSIJEK'S URBAN AREA	PERIOD OF MEASURING			1998 - 2002	
	NAMBER OF RAINGAUGE			5	
YEAR	1998	1999	2000	2001	2002	Σ
RAINFALL EVENT	0	57	1	27	31	116

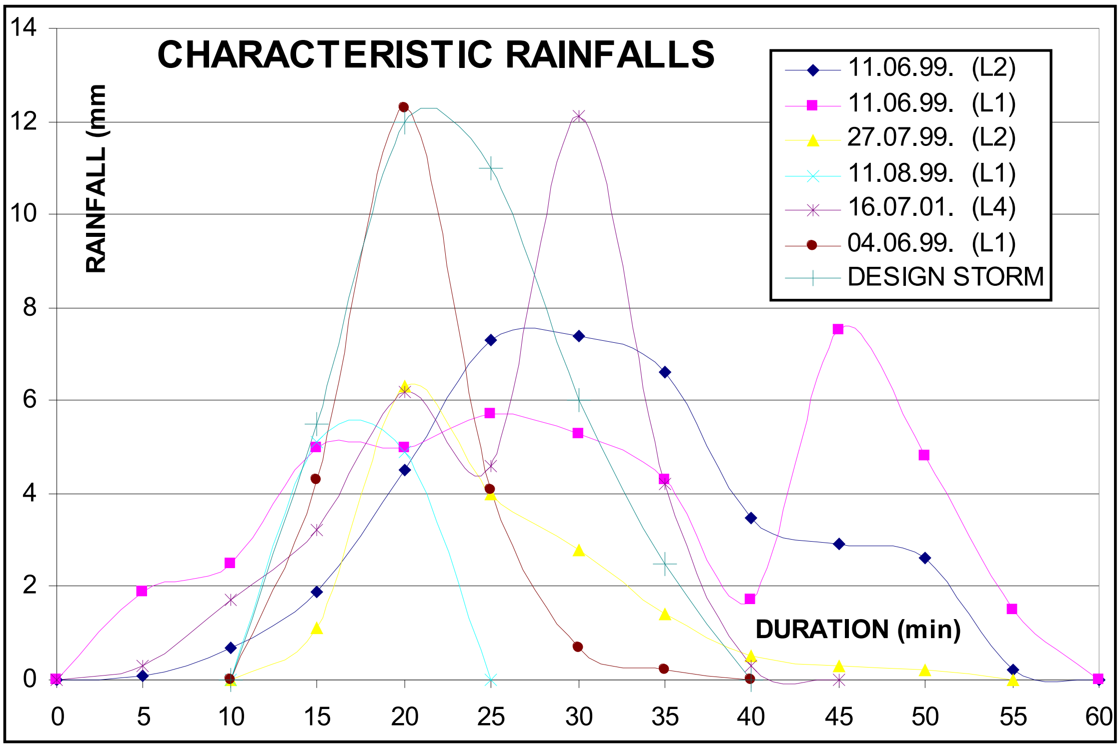
RAINFALL EPISODE	0	20	1	11	15	47

STATISTICAL DATA	VOLUME (mm = l)	MAX. 5-MIN. PRECIPITATION (mm)	DURATION (min)	INCREASE (%)	DECREASE (%)
MAX.	45,2	12,3	60	75,0	85,5
MIN.	5,0	2,4	10	15,6	25,0
AVG.	14,5	4,9	28	44,5	55,5

For the design storm duration the average duration of all duration was adopted. The top of the hydrograph shows maximum of the measured intensity (5-minutes rainfall); volume comes up to the maximal registrated values; inreasing and decreasing of the hydrograph are defined according to the average registrated values in percentage. The Picture 2 shows design storm, where it can be compared to some of the registrated events.

When using this kind of synthetic storm, namely his area distribution, it should be taken into consideration that both local and aerial manifestation of heavy rains was recorded.

The received design storm should be understood as only one of the posibilities, which is based on the measuring data. The following comparison to the other variations and practical experiences on the drainage objects will point to the quality of this storm.



Picture 2.Design storm and characteristic rainfalls for Osijek's drainage area

4. Conclusion

There are many ways to define the term and determining of the design strom.

A design storm is not an actual measured storm event. In fact, a real storm identical to the design storm has probably never occurred and it is unlikely that it will ever occur. However, most design storms have characteristic that are average of the characteristics of storms that occurred in the past and therefore represent the average characteristics of storm events that are expected to occur in the future.

The same stands for the particular design storm for Osijek town, given in this work.

Has been determined the form of design storm on the basis of the measurement of precipitation with five rain gauged on the urban area of the city of Osijek. Have been analyzed hyetographs of short rain showers of strong intensity to 60-minute duration. His characteristic are that they have rapid increase and decrease, in relation to the maximum intensity. The acceptance of the particular statistically determined characteristics of the analysed rainfalls was followed by the suggestion of design storm for the observed area. Different spatial distribution of the suggested design storm enables the observing of the critical places within the existing drainage system of the town Osijek and its planning for the future.

The very next thing to do is the result comparison of this design storm application to the applications of the other methods and possible correction of its shape based on the proceeding analyses of the enriched rainfall data base.

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