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DESIGN STORMS FOR URBAN DRAINAGE
UWRCC DESIGN STORM TASK COMMITTEE

by

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On passe en revue les caractéristiques des averses de projet applicables aux égouts urbains. On signale qu'en présence de certaines conditions ces averses de projet donnent des résultats de la simulation des eaux de ruissellement semblables à ceux que l'on a simulé pour les précipitations déjà enregistrées.

Design Storms for Urban Drainage

UWRRC Design Storm Task Committee*

The characteristics of design storms for urban drainage are reviewed. There are indications that, under certain conditions, design storms produce runoff simulation results which are equivalent to those simulated for actual recorded precipitation.

Introduction

The subject of synthetic design storms for urban drainage has received much attention from both researchers and practitioners during the last decade. Recognizing the importance of this issue to the engineering profession and the often controversial nature of reported findings on design storms, the Urban Water Resources Research Council of ASCE set up an ad hoc committee to study this issue. This committee produced an annotated bibliography on the subject and is preparing a state-of-the-art report. The paper that follows is another result of the committee's efforts.

Historical Perspective

The approach to urban drainage has evolved from the practice of fast removal of surface runoff to complex drainage schemes that attempt to solve local drainage problems, protect receiving waters against flooding and prevent deterioration of water quality. Such changes in design philosophy spurred the development of a variety of design tools ranging from simple empirical formulas for estimating peak discharge to complex distributed urban runoff models. Block rainfall adequate for empirical formulas was of no use as input for distributed routing models and, consequently, design storms were developed. Finally, the use of historical rainfall records was introduced to satisfy the needs of continuous simulation. Table 1 presents a summary of current design practices with reference to drainage problems, design tools and rainfall inputs.

It is apparent from Table 1 that urban drainage practice comprises a whole spectrum of design problems and appropriate design tools. Considering uncertainties in all computational methods and their inputs,

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advantages of more complex approaches over simple yet adequate ones are questionable. Thus, the simplest method capable of meeting the design requirements within some practical range of accuracies should be acceptable.

Table 1. Drainage Design Problems, Tools and Rainfall Inputs

Design Problem	Design Tool	Typical Design Rainfall
Sewer pipe sizing in small urban developments (minor drainage)	Rational method	Block rainfall (Intensity-Duration-Frequency curves)
Minor drainage design in small to intermediate areas	Discrete event urban runoff models	Design storms, synthetic or historical
Minor and major drainage in large areas, systems with storage, water quality design	Continuous simulation models	Long-term rainfall records

Examination of studies critical of design storms in late seventies reveals that these studies addressed misuse of design storms or weaknesses of specific types of design storms. Recent work indicates, however, that properly structured design storms can produce results comparable to those obtained using continuous simulation with recorded precipitation data(Voorhees and Wenzel, 1984). Instead of endorsing or condemning the use of design storms, this paper attempts to objectively evaluate their applicability.

Acceptance of Design Storms in Practice

Design storms are used widely in urban drainage practice partly because of the lack of proven alternatives and partly because they are easy and inexpensive to use. Frequency analysis of synthetic runoff records obtained by continuous simulation is sometimes offered as an alternative to the use of design storms. However, the costs and complexity of this approach are hard to justify because the reliability of simulated runoff is questionable due to the lack of calibration data. On the other hand, perception of an uniform level of protection as a design objective is widely accepted which leads to the specification of a design event. Thus, for the design of a large portion of urban drainage structures, the design storm concept has been and will continue to be used.

Ideally, the reliability of design storms should be assessed against actual precipitation and runoff records. In the absence of such records, reliability analysis is reduced to the question whether design storms can produce results comparable to those obtained by the best alternative methods, such as continuous simulation. Although conventional design storms are not particularly suitable for design of runoff detention or quality control facilities, many designers use them because of the lack of other alternatives. In principle, the discussion in this paper is limited to the use of design storms in sewer sizing in catchments without runoff detention facilities.

Design Storm Characteristics

A design storm is generally defined as a synthesized rainfall event characterized by a certain return period, total rainfall depth , temporal rainfall distribution and other characteristics which may include spatial distribution, storm movement and development and decay. The relative importance of each of these factors varies with the type of application and catchment characteristics.

Ideally, the design return period, T, should be selected on the basis of economic efficiency, i.e. to minimize total costs defined as the investment plus damages, in order to optimize design. However, the concept of optimal design in urban drainage is conventionally replaced by a concept of a prescribed level of protection. This often is interpreted to apply to the exceedance probability of some rainfall event and not to the probability of exceedance of the peak flow.

The assignment of a return period is considered by some researchers among the weakest points of the design storm concept. Such criticism usually follows from the analysis of actual recorded storms which show widely varying characteristics and from the investigations of joint probabilities of factors affecting storm runoff peaks. In defence of design storms, it can be argued that the catchment acts as a filter which attenuates the effect of the variability in rainfall events. Pilgrim and Cordery(1975) noted that the actual relationship between the frequencies of rainfall events and produced floods is obscure, as each part of the overall design model introduces some joint probability. They argued that by adopting median or average values of all parameters other than rainfall, the effects of joint probabilities are minimized and the frequencies of design storms and generated runoff peaks will be similar.

The total rainfall depth, D, for a particular storm is a function of T and storm duration t_d. The total rainfall is then described by Intensity-Duration-Frequency(IDF) curves which are available from weather bureau offices, provided that both T and t_d were specified.

Storm duration is an important factor which defines D for a given T and affects the storm intensity and hence the resulting peak flow. The value of t_d selected in design depends on the catchment time constant t_k which has been traditionally defined as the time of concentration.

Variation of rainfall intensity over t_d is an important factor for determining the magnitude and timing of simulated peak flows. An estimate of this distribution is obtained by analysis of precipitation data from a recording rain gage network. Since the maximum intesities are reported for durations of 5 minutes or longer, it is practical to use the 5-minute interval as the minimum discretization interval.

Storm spatial characteristics arise from the geometry, movement and development of storm cells. The present knowledge of these phenomena indicates their profound importance for large catchments, particularly when dealing with operation or control of large drainage systems.

Design storms can be characterized by some antecedent precipitation occurring within a certain time period before the storm. Such precipitation then controls catchment antecedent conditions which in turn may affect the generation of runoff. In urban catchments, runoff is generated primarily on impervious surfaces and this reduces the sensitivity of runoff peaks to antecedent precipitation.

Considering all the above storm characteristics, it would be almost impossible to find an actual storm which would meet all the above conditions and had the stipulated return period. From the practical point of view, this difficulty does not pose a serious problem because a synthetic design storm represents a certain convention developed for the purpose of uniformity in drainage design. The attributes of the synthetic storm are then selected such as to produce calculated flows which would have an approximately correct return period.

Design Storms Reported in the Literature

The earlier published annotated bibliography(UWRRC, 1983) lists details of 12 urban design storms. The basic characteristics of eight of these storms, pertinent to Canadian and U.S. drainage studies, are listed in Table 2.

Table 2. Basic Characteristics of Eight Urban Design Storms

Design Storm	Recommended Storm Duration	Temporal Distribution	Primary Application
AES(Canada)	1 and 12h	tabulated	urban drainage design
Chicago	3h or t_c	from IDF curves	sewer sizing
Hydrotek (Canada)	1h	linear/exponential functions	sewer sizing
ISWS	1h	tabulated	urban drainage design
SCS	1h - 48h	tabulated	design of small hydraulic structures
Uniform	user specified	uniform	sewer sizing
Voorhees and Wenzel	three times the entry time	Beta function	urban drainage design
Yen and Chow	user specified	triangular	design of small drainage structures

Recommended Approach to Developing Design Storms

Conventional design storms are best applicable to design of minor drainage systems, without storage facilities, in relatively small areas (up to 100 ha). Applications to other cases increase the requirements on design storm characteristics. For storage design, frequencies of rainfall/runoff volumes need to be considered and, for larger areas, adjustments of catchment rainfall need to be done to account for spatial distribution. Both these aspects will require further study.

The return period of the design storm is usually given by design criteria produced by the client. For minor drainage design, such a period is typically selected in the range from two to ten years and applies strictly to the total rainfall depth. The total rainfall depth is determined from local IDF curves for a selected storm duration and return period.

The recommended storm durations vary substantially. Two approaches seem to be common - a fixed time duration which is convenient for data processing and relevant to the catchment response time(e.g. one hour) and durations related only to the catchment response. In the latter case, Voorhees and Wenzel(1984) recommended to select the storm duration as three times the entry(inlet) time. Difficulties with determining storm duration can be avoided by using several durations and adopting the value producing the maximum discharge for sewer sizing(Packman and Kidd, 1980). The above durations may not be suitable for storage design.

The literature survey suggests that the temporal intensity distributions are best determined by fitting a selected distribution model to rainfall data(UWRRC, 1983). For this purpose, local rainfall records are discretized into individual events and only severe storms are retained for distribution analysis. The selection criteria can be based on the total rainfall depth which would correspond to a particular return period(e.g. two years). The reduced set of events is then discretized using a certain interval and a selected distribution is fitted to these data. In the absence of comprehensive evaluations and comparisons of various distributions, it is recommended to use the simpler ones, such as the triangular or combined triangular/exponential distributions. The fitting of these distributions is done by the method of moments. The selected distribution is then applied to total rainfall and the storm hyetograph is produced.

In considerations of antecedent conditions, potential runoff contributions from pervious areas and their timing are analyzed. Such contributions decrease with an increasing soil infiltration capacity and decreasing storm return period(lower intensities). There are indications that in urban catchments the runoff from pervious parts is overshadowed by runoff from impervious surfaces and the catchment runoff peak is insensitive to antecedent conditions(Urbonas, 1979). In any case, design storms are best applicable to catchments with low sensitivity to antecedent moisture conditions.

Evaluation of Design Storms

Evaluation of properly developed design storms used within their applicability domain can be broken into two parts, depending on the catchment runoff peak generation sensitivity to antecedent conditions:

(A) Catchments with low sensitivity - can design storms produce runoff peak frequency curves comparable to those obtained from computations for recorded storms, and

(B) Catchments sensitive to antecedent conditions - can design storms produce runoff peak frequency curves comparable to those obtained from continuous simulation.

The first case is relatively simple and there is sufficient evidence that design storms derived from local historical storms produce results fully comparable to those obtained for historical storms(Hydrotek, 1985; Marsalek, 1978; Urbonas, 1979). Examples of such results for various design storms are shown in Fig.1.

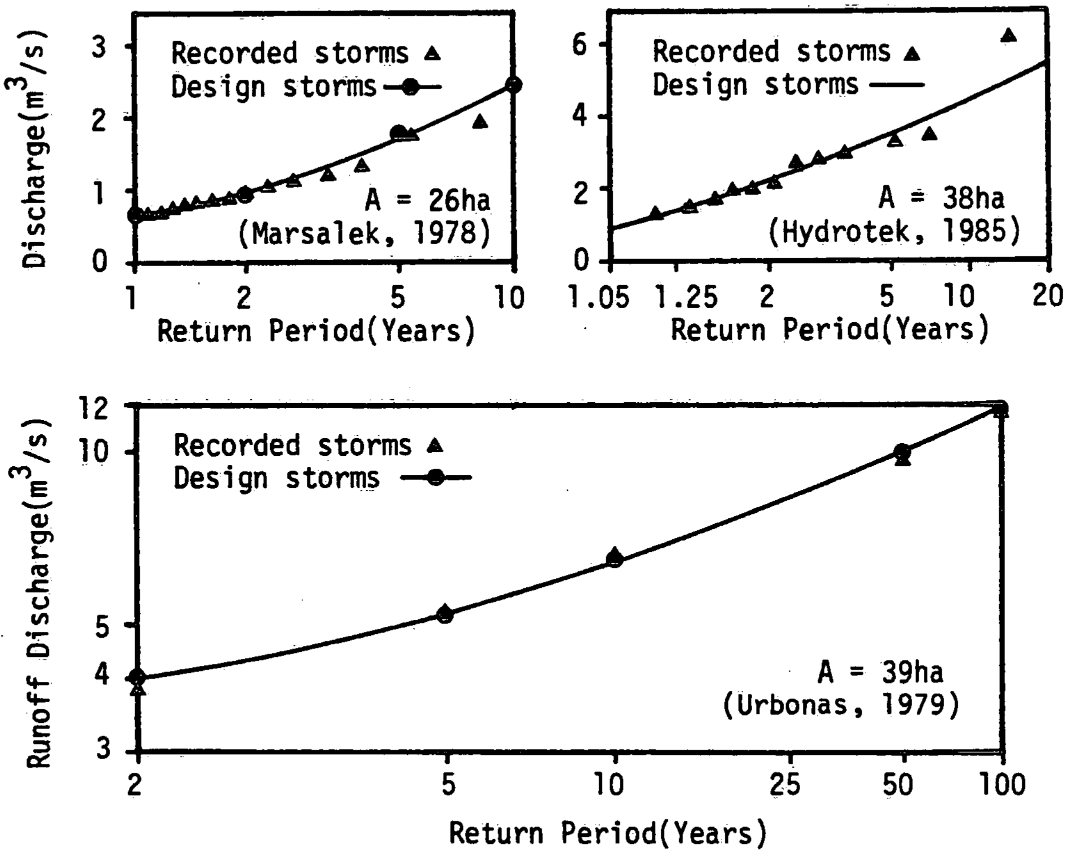

Fig.1. Comparisons of Runoff Peaks Simulated for Recorded and Design Storms(after Hydrotek, 1985; Marsalek, 1978; Urbonas, 1979)

The second case is much more difficult because it has been rarely addressed in research studies. An approach based on the use of the expected value of antecedent moisture index was suggested by Voorhees and Wenzel(1984) and produced a good agreement between design storm and continuous simulation results,as shown in Fig.2. Another feasible approach is to select antecedent moisture conditions on the basis of sensitivity

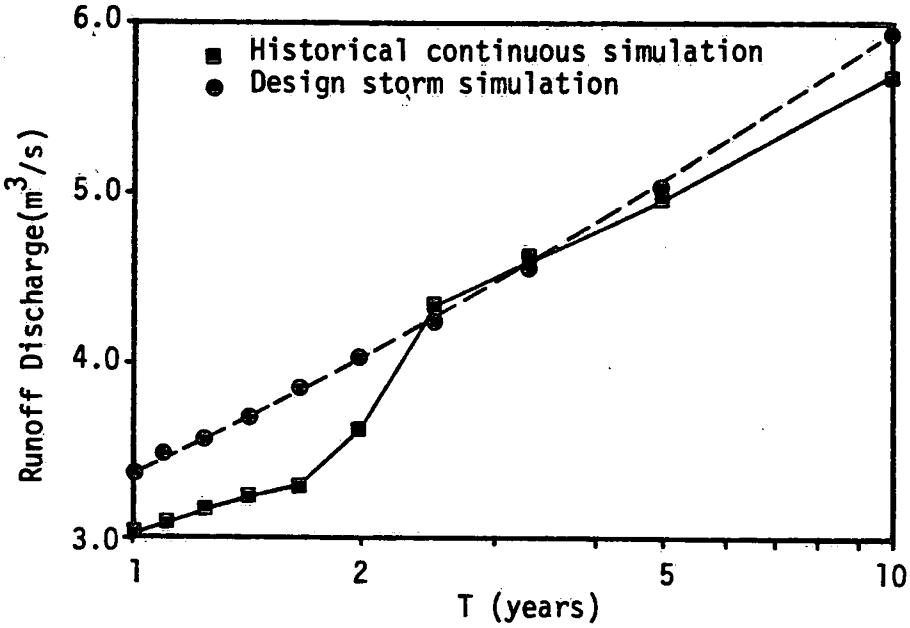

Fig.2. Hypothetical Catchment Response Using Reliability Analysis(after Voorhees and Wenzel, 1984)

analyses(Packman and Kidd, 1980). Further research on these aspects is needed.

Conclusions

A retrospective look at urban design storms indicates that their concept which was developed in early days of runoff modeling for sewer sizing may have been transposed to more recent design problems where it may not be applicable. In particular, attempts to apply simple conventional design storms to catchments with high contributions of runoff from pervious areas, large catchments with spatially nonuniform rainfall distribution, or even water quality considerations led to justified criticism of design storms. The other source of problems was the lack of knowledge of rainfall patterns in urban areas.

It appears from the critical literature survey reported on here that urban design storms are useful for and best applicable to a certain class of urban drainage design problems. Such problems comprise the design of minor drainage, without storage, for sewer pipe sizing in catchments with small areas and low sensitivity of runoff peaks to antecedent moisture conditions. The design storms should be derived from recorded local severe storms and defined by storm duration(from one to three hours, for catchments under consideration), total rainfall obtained from IDF curves for the selected duration, and temporal distribution derived from local recorded storms. As one departs from the above conditions, the validity of the design storm concept may become questionable and should be tested.

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