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Simulation of rainfall events for design purposes with inadequate data

D. Koutsoyiannis and D. Zarris
Department of Water Resources,
National Technical University of Athens, Greece

Presentation contents

- Existing methods
    - Design storms
    - Continuous simulation
    - Event - based simulation
- Basic elements of the proposed method
    - Rainfall process
    - Disaggregation model
- Application and Results
- Summary and Conclusions

Design Storm Approach

- Arbitrary temporal distribution based on empirical observations or simple (e.g. geometrical) shapes
- One-to-one correspondence between the return periods of storm and peak discharge
- **Hyetographs synthesised by the IDF curves:**
  - Inherent arbitrary assumption about equality of probability of rainfall for various durations
  - Correlation structure between short term rainfall intensities is not considered

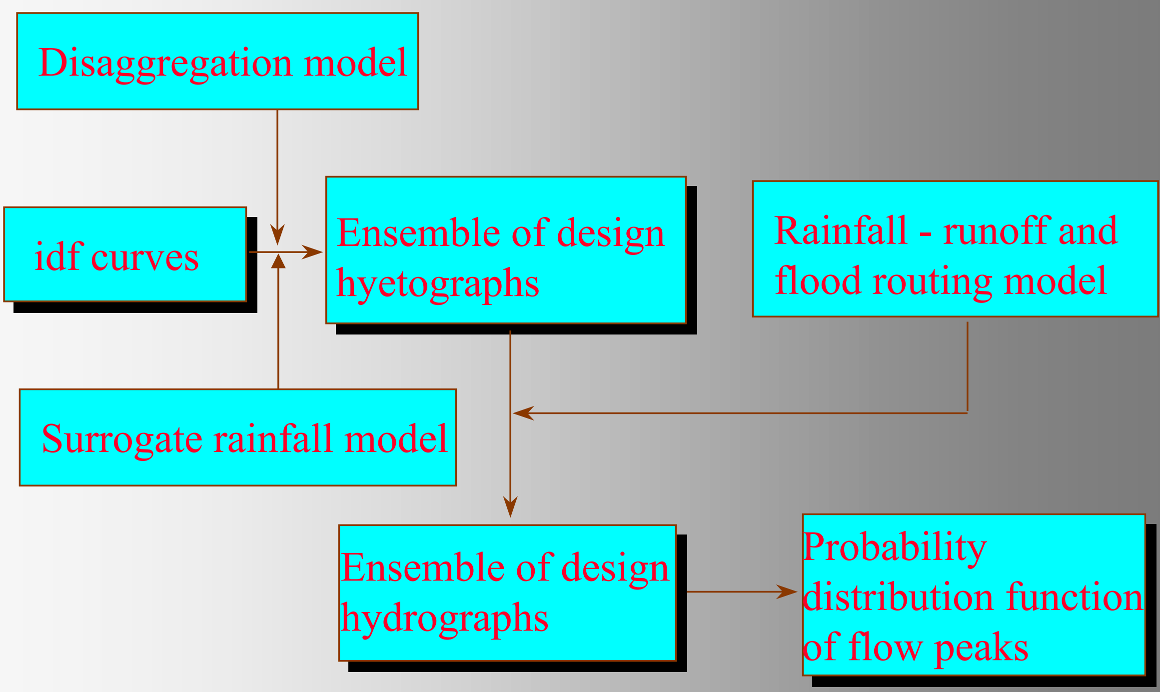
Continuous Simulation

- ✔ Capable of adequate representation of the rainfall process through a range of temporal scales of aggregation
- ✔ Reliable estimation of peak discharges and flood volumes for a given exceedance probability (?)
- ✔ Antecedent conditions are taken into full account (?)
- Problems on parameter estimation when large levels of aggregation are involved (e.g. 12 and 24 hours)
- Inadequate representation of rainfall extremes for small durations
- Long lasting, short time step, reliable and continuous data sets are not generally available

Event - based simulation

- Considerable simplification of continuous simulation since only intense rainfall events are analysed
- Ability of performing simulation with the input variables from their probability distributions
- Conditions prior to storms are arbitrarily considered (sensitivity analyses, etc.)
- An objective risk measure is difficult to be assigned

Schematic outline of the proposed method



General outline of the proposed method

- Total rainfall depth is estimated based on the IDF curves of the particular region and a preselection of event duration
- Parameter estimation (*β, φ,* and γ_{x}) of the covariance structure of the surrogate rainfall process
  - ➔The stochastic disaggregation model is set up.
  - ➔A number of rainstorms are produced and the IDF curves for each set of parameters are computed.
  - ➔The resulting IDF curves are compared with the given ones.

General outline of the proposed method (cont.)

- A series of random and probable time profiles (hyetographs) for the final set of parameters are introduced into a a rainfall-runoff and flood routing model.
- An equal number of output hydrographs are produced.
- The empirical distribution function of the flood peaks is determined.
- A probability level is selected and the corresponding outflow peak is determined.

Rainfall process

The covariance structure of a simple scaling model of storm hyetograph is adopted.

$Cov[\Xi(t, D), \Xi(t+\tau, D)] = \psi(\tau/D) - \{E[\Xi(t, D)]\}^2$,

where $\psi(\tau/D) = \alpha\,[(\tau/D)^{-\beta} - \zeta]$

and α, β, ζ parameters ($c_1 > 0, \alpha > 0, 0 < \beta < 1, \zeta < 1$)

Rainfall process (cont.)

Incremental depth, X_i, for a time interval $\Delta = D / k$

$$X_i = \int_{(i-1)\Delta}^{i\Delta} \Xi_t dt, i = 1, 2, \ldots, k$$

$$Var[X_i] = \left(\frac{\mu_H}{k}\right)^2 \frac{1}{1-\phi}\left[\left(1+a_H{}^2\right)\left(k^\beta - \phi\right) + \phi - 1\right]$$

$$Cov[X_i, X_{i+m}] = \left(\frac{\mu_H}{k}\right)^2 \frac{1}{1-\phi}\left\{\left(1+a_H{}^2\right)\left[k^\beta f(m,\beta) - \phi\right] + \phi - 1\right\}$$

where $\varphi = \zeta\,(1-\beta)\,(1-\beta/2)$, α_H:coefficient of variation of H

$$f(m,\beta) = \begin{Bmatrix} \frac{1}{2}\left[(m-1)^{2-\beta} + (m+1)^{2-\beta}\right] - m^{2-\beta}, m > 0 \\ 0, m = 0 \end{Bmatrix}$$

Main differences from the design storm approach

- A stochastic disaggregation model is used to derive the temporal distribution of the design storm(s)
- An ensemble of random, probable and realistic hyetographs are produced instead of an arbitrary one
- A conditional probability distribution function of the outflow peak is obtained instead of a single "design hydrograph"

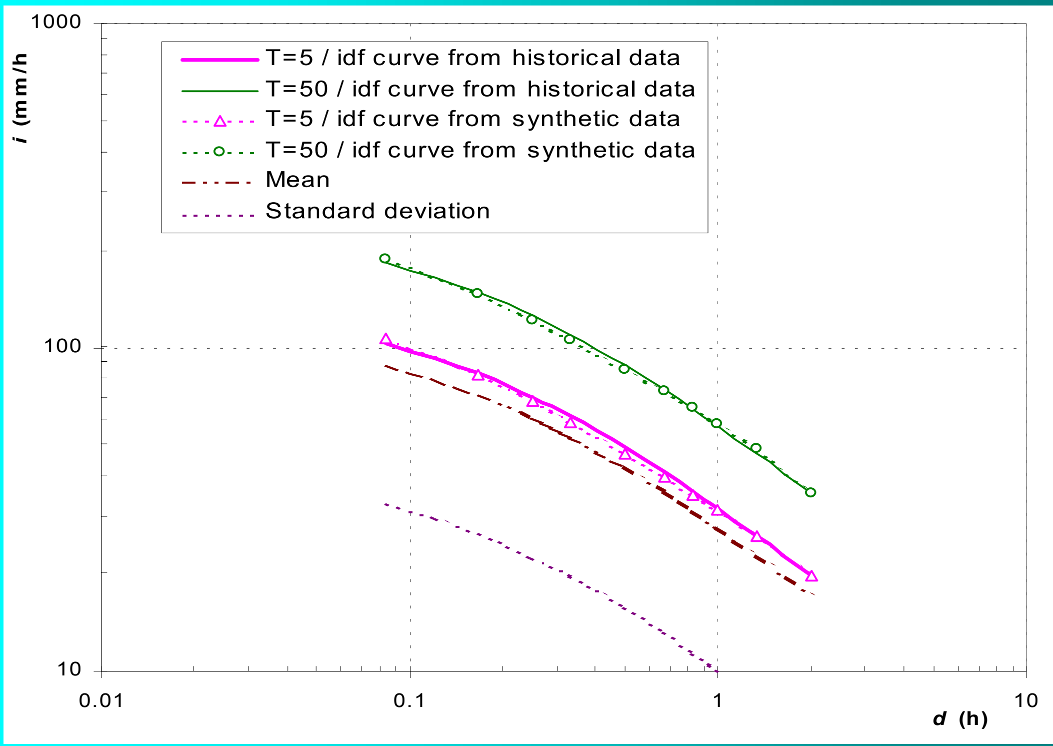
Application 1: Design of sewer network

- IDF curves for Greater Athens Region

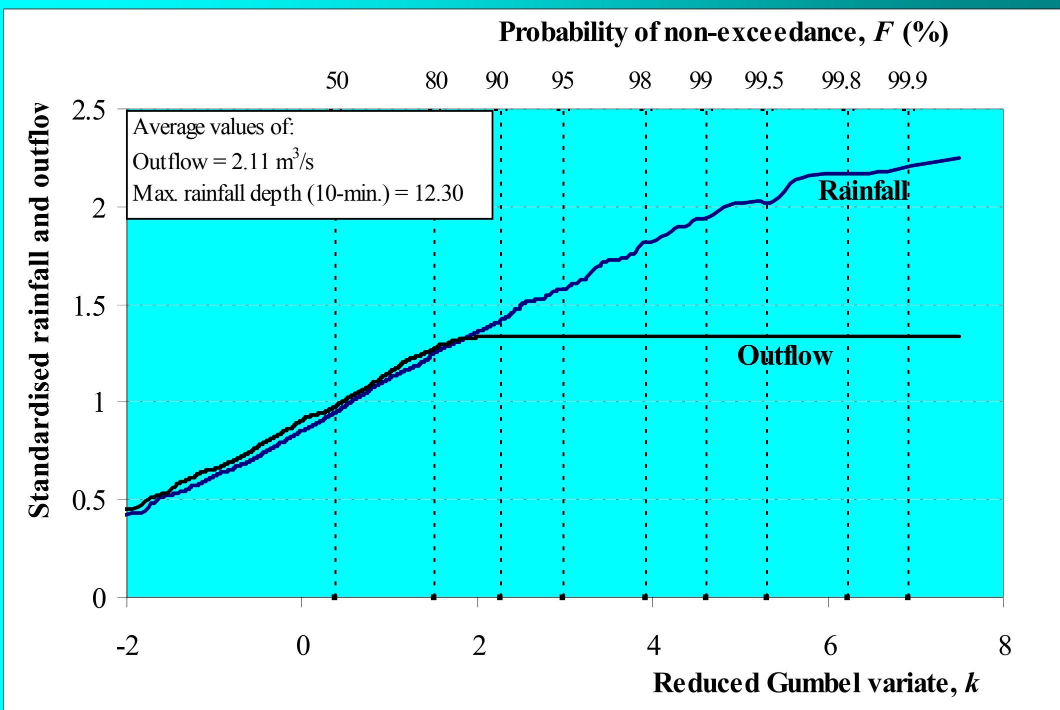
$$i(d, T) = 40.6\,(T^{0.185} - 0.45)/(d + 0.189)^{0.796}$$

- Assumptions
  - D = 2 hours
  - T = 5 years
  - H = 39.06 mm
  - Mean imperviousness 72.3%
- Catchment configuration
  - Area 14 ha
  - Sewer length 2 km
  - Average slope 4.3%

Comparison of synthetic IDF curves with historical data for the adopted parameter set



Conditional probability distribution functions of the maximum 10-min rainfall depths and flood peaks



Peak flows vs. maximum 10-min rainfall depths

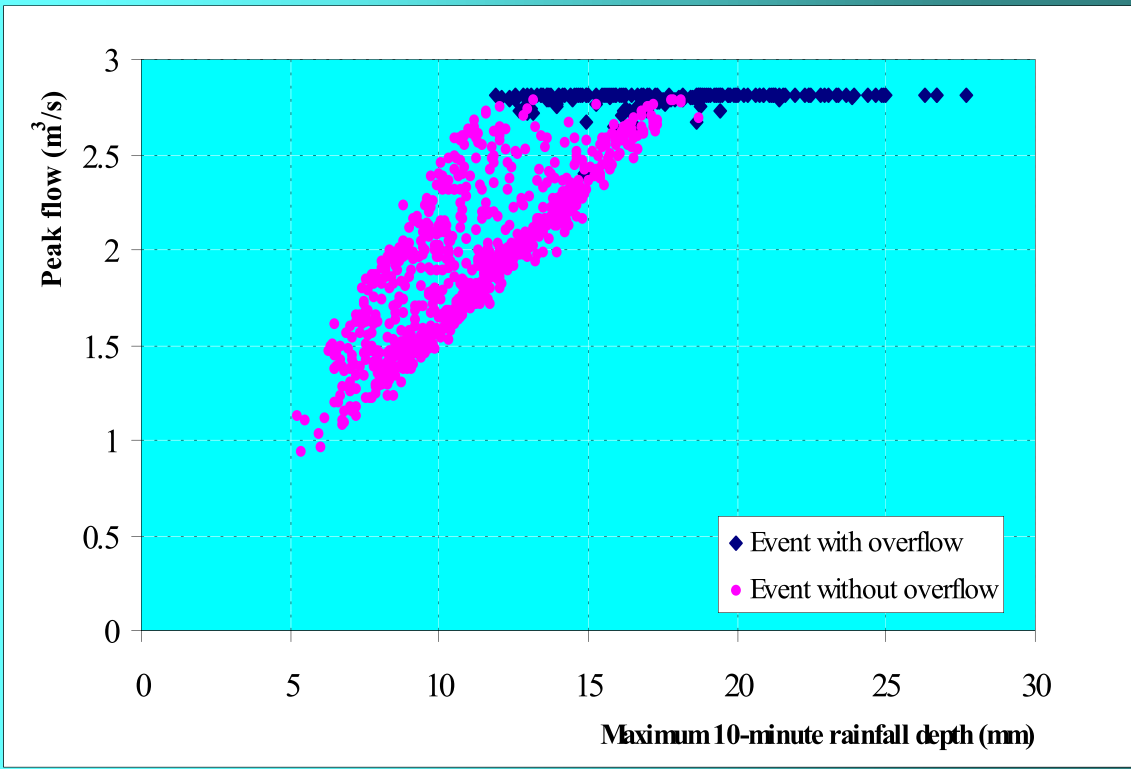


Table of results

Method	Case	Rainfall Peak (5-minute increment) (mm)	Rainfall Peak (10-minute increment) (mm)	Outflow Peak (m^3/s)
Proposed method	Mean	8.86	12.30	2.11
D = 2 h, H = 39.06 mm, T = 5	50% probability level	8.36	11.61	2.04
years,	80% probability level	10.81	15.34	2.67
Imperviousness 72.3%	90% probability level	12.67	17.34	2.80
	95% probability level	14.07	19.43	2.81
Huff curve, 50% first quartile storm, D = 2 h, H = 39.06 mm, Imperviousness 72.3%	-	6.64	12.89	2.03
Alternating block method D = 2 h, H = 39.06 mm, Imperviousness 72.3%	-	8.55	13.83	2.40
Rational method D = 10 min, H = 13.83 mm, Imperviousness 72.3%	-	6.915	13.83	2.21

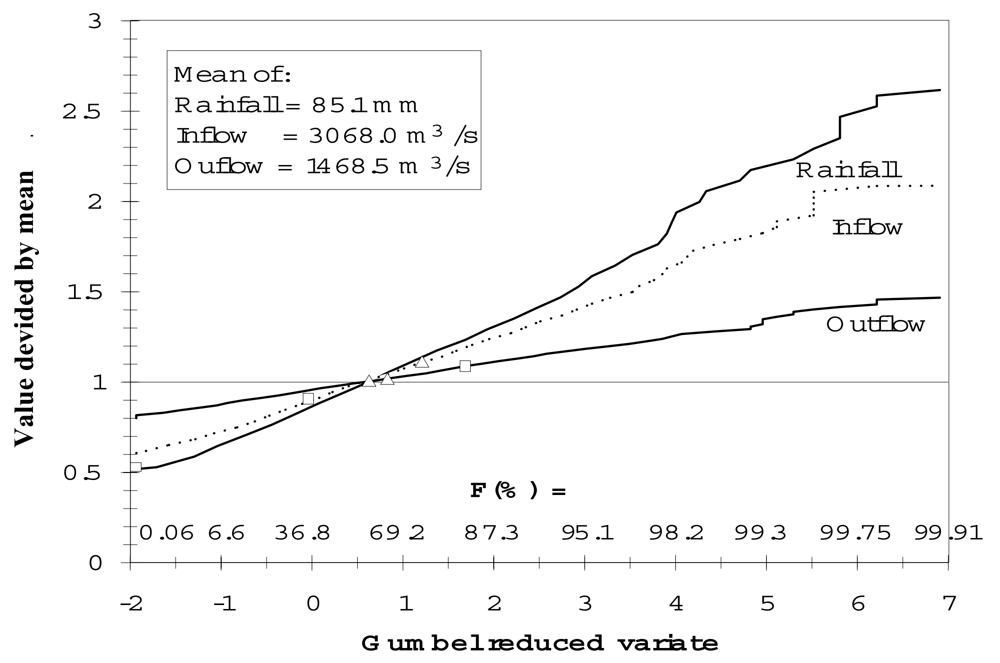
Application 2:
Design of dam spillway

- IDF curves for the upstream catchment for Steno dam in Aracthos river

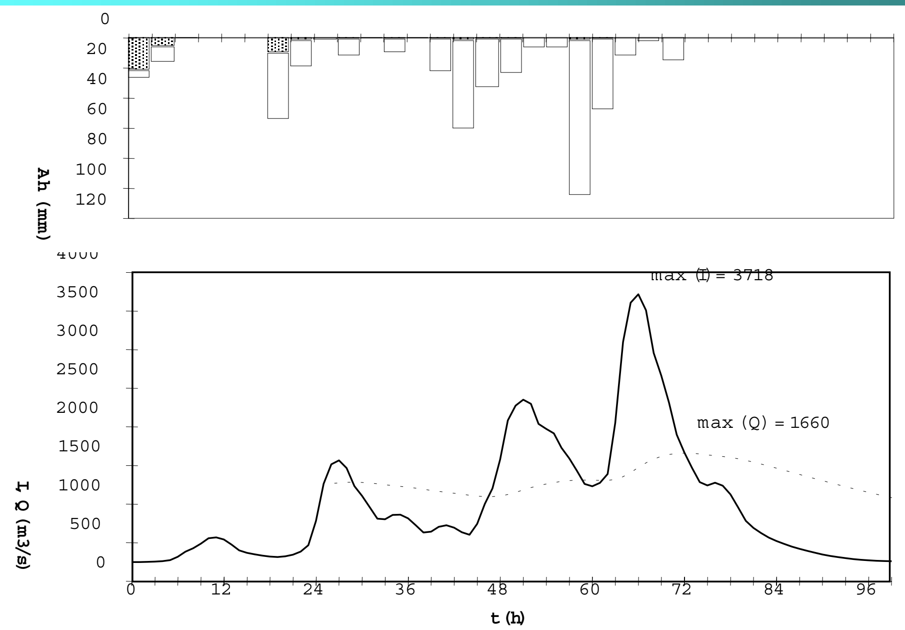
$$i = 17.96 T^{0.105} / d^{0.457}$$

- Assumptions
  - D = 72 hours
  - T = 10000 years
  - H = 481.7 mm
- Catchment configuration
  - Area 618 km^2
  - Flood storage about 100 hm^3

Probability distribution functions of the peaks of hyetographs and inflow and outflow hydrograph at Steno dam, Aracthos river



Example of design storms and associated hydrographs Event corresponding to the 90% non-exceedance probability for peak flows



Summary and Conclusions

- ✔ Utilises only the IDF curves as input data
- ✔ Represents the extreme values of rainfall for small durations and different levels of aggregation
- ✔ Generates an ensemble of design hyetographs all having the same storm duration and total depth instead of a single and arbitrary one
- ✔ Preserves the stochastic nature of real storm events (random shapes with more than one peaks)
- ✔ Introduces the stochastically generated hyetographs in rainfall - runoff and flood routing models

Summary and Conclusions (cont.)

- ✔ Computes the conditional probability distribution of outflow peaks (allowance for probabilistic design)
- Difficulty to combine the probability of non-exceedance of the total rainfall depth with the selected conditional probability level
- Antecedent conditions are not taken into full account (sensitivity analyses, mean values or random sampling of catchment characteristics)