Prediction of design storms and floods

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Abstract In this work a method to estimate design floods based on rainfall information has been proposed and verified. A design hyetograph has been developed on the basis of 30-years of pluviographic records from 36 meteorological stations. The general formula describing rainfall intensity–duration–frequency relationship has been derived from recorded series. The spatial distribution of the derived parameters made it possible to estimate rainfall intensity quantiles at each site within the territory of Poland. The typical temporal pattern of storms have been obtained for the genetic type of rainfall and for the selected pluviographic regions. The determined synthetic storms were then transformed into outflows for the same return periods. The method has been verified by fitting probability distributions to maximum annual flows calculated from direct observations from the analysed catchments. This method, apart from giving maximum flows, gives more comprehensive information in the form of the hydrograph of stated probability (design hydrograph), as the hydrological basis for hydrotechnical design.

ESTIMATION OF THE DESIGN STORM

Frequency analysis of extreme rainfall has been based on an annual exceedance series. Frechet’s model (Sevruk & Geiger, 1981) selected from the family of generalized extreme value distributions the one that proved to fit best to the empirical series and made possible the estimation of quantile values beyond the range of the observed data sets. The probability density function of Frechet’s distribution is expressed as follows:

\[ f(x) = \begin{cases} \frac{\beta}{\alpha} \left( \frac{x - \varepsilon}{\alpha} \right)^{-\beta-1} \exp \left[ -\left( \frac{x - \varepsilon}{\alpha} \right)^{-\beta} \right] & x > \varepsilon \\ 0 & x \leq \varepsilon \end{cases} \] (1)

The Maximum Likelihood Method was used to estimate the two parameters (\(\alpha, \beta\)). The third (\(\varepsilon\))—displacement parameter—was derived from the rainfall data properties. The graphic form of rainfall intensity–duration–frequency relationship is illustrated in Fig. 1. The general formula developed to describe the intensity–duration–probability relationships is of the following form:

\[ I_p = e^A \cdot t_r^B \] (2)

where \(I_p\) is rainfall intensity (at given probability level), \(t_r\) is the rainfall duration, \(A\) and \(B\) are parameters for each range of return intervals.
Figures 2 and 3 illustrate spatial variations of parameters $A$ and $B$ respectively, for Polish areas for the return period of 100 years. The design hyetograph was developed on the basis of the detailed data covering the years 1961–1990. The maximum rainfall storms grouped into 13 classes according to their duration were extracted from independent rainfall events ranging from 10 minutes to 24 h. Rainfall series were then subdivided according to the type of events on the basis of statistical analysis of rainfall characteristics and also the main features of genetic type. The key rainfall characteristic was found to be the function of the total depth of a rainfall event to its duration. Rainfall episodes were subdivided into three sections corresponding to time of duration intervals. The variation of depth–duration relationship expressed the modification of storm characteristic and also proved the occurrence of changes within the precipitation producing mechanism. The distinction between groups of storms is due to the physical background and may be related to the original type of precipitation (Sumner, 1988). The episodes belonging to section I are linked with convection type processes; those in section 2 result from frontal activity, while those in section 3 result from rainfall generated by a moving depression or convergence zone on a synoptic scale. The length and slope of the selected sections obtained from the depth–duration curve at each site proved to be useful and provided objective criteria for regional analysis of rainfall. The stations were classified into the following four regions by applying the hierarchical cluster analysis method (Johnson & Wichern, 1982):

(a) sites with continental features and pre-mountainous sites,
(b) maritime sites,
(c) mountainous area sites,
(d) the group of sites strongly influenced by local circulation.

For evaluation of homogeneity of the regions, discordancy measures based on the L-moments method (Hosking & Wallis, 1993) have been estimated.

The typical temporal pattern of storms has been obtained for each type of rainfall and for selected pluviographic regions. These storm profiles can be accepted as the pattern of the design hyetograph.
SELECTION AND TESTING OF MODELS

Six different conceptual models were applied for rainfall–runoff transformation. As the main objective of the study was to work out the method to estimate design storms for ungauged basins, the following criteria were applied when choosing models for the analysis:
(a) model should have small number of parameters,
(b) parameters should be easily estimated from existing topographic maps. Applied
models included:
(i) Wackermann model in original version I (Thiele & Euler, 1981) and modified one II (Ignar, 1993),
(ii) three versions of the GIUH (Rodriges-Iturbe & Valdes, 1979; Soczyńska & Nowicka, 1989; Ostrowski, 1994),

All the above-mentioned are the lumped type of models. The models were adopted for 11 basins. Most of them are located in mountainous regions. A total of 95 different recorded flood events were used in the analysis. The SCS and runoff coefficient methods were adopted for effective rainfall determination. Thirteen different parameters were evaluated for testing of chosen models. They comprised physiographic and river bed parameters and effective rainfall characteristics. Physiographic parameters of basins were calculated from the topographical maps using the ILWIS GIS package. The type of parameters and characteristics used are summarized in Fig. 4.

A computer program in Turbo Pascal was used to simulate flood hydrographs and testing of the models. Examples of flood hydrographs simulated for Sleza River basin using different models are shown in Fig. 5.
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On the basis of the results obtained (analysis of the correlation coefficient $R$, special correlation coefficient $RS$, total square error $CBK$—Delleur et al., 1973) four models have been selected for further research: Wackermann I and II, GIUH III and the Lutz model.

DESIGN FLOOD ESTIMATION

Design storms were transformed into the design flood hydrographs assuming the flood discharge has the same probability as the design storm. The following steps were necessary to follow in order to verify the proposed method:

Fig. 5 Results of flood hydrograph simulation in Sleza River basin at Bialobrzezie (7 March 1980).
(a) estimation of the maximum probable rainfall as an input to hydrological models,
(b) estimation of the maximum probable flows by statistical analysis using data series longer than 30 years,
(c) estimation of probable hydrographs using hydrological models,
(d) comparison of simulated maximum probable flows with the values of flood probability curves described by Pearson III type distribution.

Rainfall–runoff transformation was conducted with the following assumptions:
(a) CN parameter of the SCS method was equal to 100 and respectively runoff coefficient $\alpha = 1$,
(b) considered design storms were of a duration longer than 8.5 h in all rainfall–runoff transformations.

Examples of results are shown for the Skawa basin at the Osielec cross-section. Figure 6 shows a comparison of flood probabilities curves determined on the basis of applied models and the statistical distribution. Figure 7 presents example of design flood hydrographs estimated by the Lutz model for Skawa basin at the Osielec cross-section.

CONCLUSIONS

(a) Elaborated method of the design flood hydrograph estimation can be applied for the ungauged natural basins.
(b) In mountainous basins with relatively large slopes and good conditions for direct runoff creation, design storm can constitute an input to rainfall–runoff models without reduction for losses.
(c) In most cases the simulated probable flows were less than observed ones, especially for low probabilities ($p < 20\%)$.
(d) Results of simulations obtained from different models were close to each other and therefore all of chosen models could be applied in practice.
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![Design flood hydrographs for the Skawa River basin at Osielec for probabilities \( p = 1\%, 50\%, 90\% \).](image)

(e) Application of the method for lowland basins requires additional studies especially with regard to effective rainfall and concentration time determination.

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