Regional techniques for extreme rainfall and runoff prediction

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ABSTRACT
A regional technique for extreme rainfall and runoff prediction is presented. The method uses five nomographs in which flood and storm characteristics are associated and by which design flood peak and volume can be derived, once the return period and storm duration and depth have been determined. Problems of basin non-linearity do not affect the method which proved to be accurate, fast and simple. These qualities render the method useful for engineering and research applications, especially in ungauged basins.

KEY WORDS: Extreme storm — Runoff prediction — Design flood — Ungauged basin — Greece.

INTRODUCTION
The study of extreme and flood characteristics and the subsequent prediction of design floods when designing hydraulic works constitute basic problems in engineering hydrology. The usual method of combining a statistical analysis of rainfall with the unit hydrograph, based on the assumption of basin linearity, is the best known methodology developed for such problems. However, problems are encountered with this method in ungauged drainage basins, and besides, unit hydrograph concepts may prove misleading in non-linear basins (Rogers and Zia, 1982, Mimikou, 1983). In this paper a regional method for extreme rainfall and runoff prediction is presented. The method can be easily applied in ungauged catchments and it is also helpful in avoiding problems arising from basin non-linearity.

DATA USED
The precipitation and runoff data used in the study were obtained from four drainage basins covering a considerable portion of western and north-western Greece. This region is of major hydrological importance since it

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contains four major rivers of Greece and several hydraulic works, such as dams and reservoirs, spillways, flood protection works, etc. The study basins are associated with the Acheloos, Aracthos and Aoos Rivers and vary in magnitude from 200 to 1,350 km². The criterion for the selection of these basins was their relatively good record of past flood events. A general map of the study area is shown in Fig. 1.

From the available stage recordings at the outlet of each drainage basin, several extreme flood events were identified in terms of flood peak and volume. The selected flood recordings, 65 in total, were then transformed to flood hydrographs by using appropriate stage-discharge relationships. From these, both total and net discharge peaks Q and volumes V were calculated. Base flow separation was carried out using a typical procedure commonly suggested (Wilson, 1974; Linsley et al., 1975). Moreover, for each flood event the respective hydrograph and the causal storm were studied and a matrix with the following characteristics was compiled: total flood duration $q_{ot}$, time of rise to the peak $t_r$, storm duration $t$, total areal rainfall depth $h$ and mean areal rainfall intensity $i$, baseflow at the peak $Q_{bf}$, baseflow volume $V_{bf}$, and mean rate of precipitation losses $f$. The areal rainfall characteristics were calculated by using the Thiessen polygon method.

**FIG. 1.** General map of the region.

*Carte générale de la région.*

**ANALYSIS OF MAXIMUM ANNUAL FLOOD PEAKS AND VOLUMES**

Samples of annual extremes of net flood peak, $Q_n$, and volume, $V_n$, were selected from each station, with the exception of the Vovousa basin at the Aoos River because of its limited record. Vovousa basin was used instead for verification purposes. The samples were then fitted with the appropriate extreme value distribution functions. Specifically, the EV1 distribution function (Gumbel) was chosen for maximum flood peaks, while the Log Pearson III distribution was chosen for maximum flood volumes. The fitting was carried out according to established methodologies (Yevjevich, 1972), using the Weibull plotting position. For the estimation of parameters of the EV1 distribution the Gumbel method was followed (Gumbel, 1958), while the parameters of the Log-pearson III distribution were derived by the method of frequency coefficients. The goodness of fit was tested for both distributions. The pairs $(Q_n(T), V_n(T))$ were used in nomograph 1, shown in Fig. 2, which was constructed with the reduced variables $V_n/A$ and $Q_n/A$, $A$ being the drainage basins area, as coordinates. Curves of equal return period are plotted for $T =$
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(2,5,10,20,50,100). From this nomograph one can obtain for any given pair of variables (e.g. $V_n$, $T$), the third (e.g. $Q_n$).

For a design flood to be described, the base flow discharge at the time of the peak, $Q_{bf}$, and the total baseflow volume $V_{bf}$, are also required. Therefore a relation was sought between $Q_n$ and $Q_{bf}$ and correspondingly between $V_n$ and $V_{bf}$. For the relations sought, the dimensionless ratios $Q_{bf}/Q_n$ and $V_{bf}/V_n$ were defined as dependent variables and, to remove the effect of basin area $A$, the specific values $Q_n/A$ and $V_n/A$ were used as independent variables. A semi-logarithmic regression for the discharge resulted in the relation:

$$g = 0.1146 \exp (-0.8837 \frac{Q_n}{A}) \quad (r = -0.865)$$

(1)

while a semi-logarithmic regression for the volumes resulted in the relation:

$$E = 0.4807 \exp (-6.0817 \frac{V_n}{A}) \quad (r = -0.887)$$

(2)

Eq. (1) has been plotted as nomograph 2 in Fig. 3 and Eq. (2) has been plotted as nomograph 3 in Fig. 4. For given net values and the basin area, the respective base flow estimate can be instantly deduced from these graphs.

ANALYSIS OF EXTREMES STORM EVENTS

For each maximum flood event examined, information on the respective storm was collected as previously described. This information specifically included: Areal rainfall depth, $h$ (mm); Total rainfall volumes, $V_{R,\text{tot}} = h A$, $(10^6 \text{m}^3)$; Storm duration, $t$ (hr); Mean rainfall intensity, $i = h/t$, (mm/hr); Rainfall losses, $V_{R,f} = V_{R,\text{tot}} - V_n$, $(10^6 \text{m}^3)$, and Mean rate of rainfall losses, $f = V_{R,f}/A t$, (mm/hr$^{-1}$).

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Using these data, a relationship between the mean rainfall intensity, the mean loss rate and rainfall duration was sought across the study region. For this purpose, the events were classified by duration in classes of 12, 24, 36, 48 and 60 hours. For each class a linear relation was found between mean rainfall intensity \( i \) and mean loss rate \( f \), in the form:

\[
f = A_i \]

(3)
where $A_t$ is a proportionality coefficient depending on duration. The values of $A_t$ in Eq. (3) obtained for each class were further correlated with duration $t$ and a linear relationship gave the best fit in the form:

$$A_t = a + bt$$

Substituting in Eq. (3) for $A_t$, the required relationship was derived:

$$f = (a + bt) i$$

The estimated values of the coefficients $A_t$, $a$ and $b$ in Eqs (3) and (5), with the corresponding determination coefficients, are shown in Table I. Obviously, this relation is empirical and no physical justification is attempted, and its validity has not been checked outside the range of storm durations in the sample. Based on Eq. (5) the nomograph 4 in Fig. 5 was constructed with $f$ and $i$ as coordinates, and various storm durations represented by straight lines. For a given mean intensity of rainfall, one can obtain the corresponding mean loss rate for various storm durations. Apparently, this nomograph is valid within the study region and most importantly for given rainfall intensity and duration it produces a mean loss rate which may be interpreted as an average over the range of return per-

<table>
<thead>
<tr>
<th>Storm duration $t$ (hr)</th>
<th>$\lambda t$</th>
<th>Coeff. of determination $r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>0.7165</td>
<td>0.976</td>
</tr>
<tr>
<td>24</td>
<td>0.5760</td>
<td>0.865</td>
</tr>
<tr>
<td>36</td>
<td>0.5070</td>
<td>0.850</td>
</tr>
<tr>
<td>48</td>
<td>0.4436</td>
<td>0.700</td>
</tr>
<tr>
<td>60</td>
<td>0.2380</td>
<td>0.658</td>
</tr>
</tbody>
</table>

$\lambda T - t$ regression: $\lambda t = a + bt$

$a = 0.8230$, $b = -0.0091$, $r^2 = 0.954$

**Fig. 5.** — Mean loss rate — rainfall intensity — duration relationships - Nomograph 4 - Taux moyen des relations perte-intensités de précipitation-durée.
iods implicitly existing in the sample, since the extreme storm events considered for the derivation of Eq. (5) were used regardless of their return periods. One would expect the mean loss rate to decrease as the return period increases. Therefore, for the nomograph to be applicable beyond the return period limit of the sample size, a reduction coefficient should be defined in terms of the return period. Thus, a subset of events was selected, representative of the complete range of return periods of the samples, regardless of storm duration. For each of these events the actual mean loss rate (computed directly from rainfall and flow data) was compared with the value (from now on denoted as f) estimated by means of Eq. (5) for the given rainfall intensity and duration, and a correction coefficient was derived. A logarithmic regression \( r = -0.473 \) between these correction coefficients and the respective return periods revealed a weak tendency described by the following equation:

\[
a = 113.33 T^{-0.0919}
\]

where \( a = \frac{f(i, t, T)}{f(i, t)} \) in % and \( f(i, t) \) is an average within the sample size with respect to T. Eq. (6) is plotted in Fig. 6 as nomograph 5. It can be seen that for small return periods the correction coefficient is a magnification coefficient whereas for larger return periods it becomes a reduction coefficient, decreasing with increasing T. The limiting value of T (a = 100%) is within the interval determined by the sample size as expected, since \( f(T) \) is monotonic and \( f \) is an average with respect to T within the sample. For practical reasons the assumption was made that this pattern of decrease of the rate of losses is valid for larger return periods and the plot in Fig. 6 was drawn by extrapolation up to T = 100.

By combined use of the two nomographs 4 and 5, the rate of rainfall losses of any event in the region with given intensity, duration and return period (within the specified limits) can be estimated. In doing so, for return periods within the sample limits the correction for T might be omitted, but for larger return periods it should be accounted for according to Eq. (6) or nomograph 5.

ESTIMATION OF DESIGN FLOOD CHARACTERISTICS

For the estimation of design flood characteristics, the return period T and the storm duration t have to be decided and with these as inputs, mean rainfall intensity \( i \) and rainfall depth h can be derived by using the available

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**Fig. 6.** Loss rate correction coefficient in terms of return period - Nomograph 5 - 
Taux du coefficient de correction de pertes en fonction de la période de retour.
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depth-duration-frequency relation for the region. The procedure proposed for the calculation of the respective flood characteristics is as follows:

- step 1 — With i and t known, the average loss rate $f$ is calculated from the nomograph 4. This value is then corrected for the return period by applying the correction coefficient from nomograph 5 and a rate of losses $f$ is estimated;

- step 2 — From the losses rate $f$, the given duration $t$ and the drainage basin area $A$, the losses are computed as

$$ V_{R,I} = A ft $$

The total rainfall volume is given by

$$ V_{R,\text{tot}} = A h $$

From Eqs (7) and (8), the net flood volume $V_n$ is calculated

$$ V_n = V_{R,\text{tot}} - V_{R,I} $$

- step 3 — With given return period, area and net volume, the net peak discharge $Q_n$ is calculated using nomograph 1;

- step 4 — with net values $Q_n$ and $V_n$ already estimated, the respective base flow values $Q_{bf}$ and $V_{bf}$ are deduced from the nomographs 2 and 3;

- step 5 — The required flood peak and volume for the given storm duration, area and return period are estimated as:

$$ V_{\text{tot}} = V_{bf} + V_n \quad \text{and} \quad Q_{\text{tot}} = Q_{bf} + Q_n $$

APPLICATION-VERIFICATION

For verification purposes two flood events, not previously included, in the Vovousa basin of Aoos River were selected. This basin, according to the criterion of non linearity suggested by Rogers and Zia (1982) was found to be strongly non-linear (slope of the logarithmic peak discharge distribution $m = 0.646$ as compared to $m = 1$ for linear basins).

The verification data and results are shown in Table II. The prediction error (percentage deviation of the estimated from the observed value) was sufficiently small to render the proposed method promising.

<table>
<thead>
<tr>
<th>Event</th>
<th>Input data</th>
<th>Observed</th>
<th>Predicted</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>h (mm)</td>
<td>t (hr)</td>
<td>T (yr)</td>
<td>$Q$ (m$^3$/s)</td>
</tr>
<tr>
<td>10-12/1/84</td>
<td>90.4</td>
<td>34</td>
<td>2</td>
<td>183</td>
</tr>
<tr>
<td>30/10-3/11/74</td>
<td>123.3</td>
<td>59</td>
<td>5</td>
<td>270</td>
</tr>
</tbody>
</table>

CONCLUSIONS

There is a need for developing regional methods for the estimation of design flood characteristics in ungaged basins, regardless of their non-linearity. The proposed methodology is relatively precise, fast and easy to use and therefore it appears to be promising for design or research applications in the region, within the limits imposed by the historical record regarding flood rarity.
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