Extremeness of extreme floods

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Abstract Any treatise on the extremeness of floods should begin by defining the criteria in terms of which particular floods can be classified as being extreme. These criteria are very likely to differ in the UK, Brazil, Iceland and Hungary. Drawing on the conclusions of former studies and on the data collected from different countries, a proposal is submitted for analysing rare natural flood events. This consists of using the hydrological characteristics of flood waves and the socio-economic losses caused thereby to compile parameters that are easy to handle, are insensitive to the inaccuracies inherent in the basic data and are suited to quantifying the extremeness of a flood event. The three parameters proposed can be used separately or in combination, and they allow previous floods to be classified into nine extremeness categories. Some practical applications of this theoretical approach are presented.

Key words drainage basin; extremeness; flood hydrology; peak flood discharge; probability of flood; risk of flooding

INTRODUCTION

The attribute “extreme” has frequently been encountered in analyses of floods without quantifying or defining it accurately. This causes widely differing interpretations. A professional thinking in global terms would be interested in relating the extremeness of a particular flood to the size of the drainage basin. From knowledge of the local conditions it is possible to assess the uniqueness of the parameters of a particular flood wave relative to earlier floods on the same stream.

On the other hand, a socio-economic assessment of its consequences will denote a flood as extreme if it has caused extremely high losses, regardless of the meteorological or hydrological conditions which have triggered it.

In quantifying extremeness of floods caused by natural hydrological situations, it is believed advisable to take each of the three aforementioned considerations into account in a manner which makes the derived parameters useful separately and also in combination. Moreover, the parameters adopted should be simple to calculate and be insensitive to the inaccuracies inherent to the basic data used in deriving them.

Floods unrelated to hydrology (due to volcanic eruptions, landslides, dam failures, etc.) are impossible to generalize and have to be analysed individually, and must be distinguished by another term, e.g. extraordinary floods.

HYDROLOGICAL CHARACTERISTICS

Floods on rivers are characterized traditionally in terms of the peak discharge and stage. However, these parameters alone are unsuitable for comparing floods occurring
at different locations, and thus in assessing their extremeness. Under the approach outlined above, characteristics had to be found which meet the criteria of global and local comparison. Of the parameters used in hydrology, the following two are proposed for this purpose:

**The basin size–discharge relationship** Under similar climatic and topographic conditions, rivers draining a larger drainage basin are known to carry normally larger flows. Therefore, disregarding local conditions, this relationship appears suited to assess flood extremeness. Once a database is compiled, it will be possible to decide how abnormal the peak flow arriving from a drainage basin of a given size is relative to other catchments of comparable size around the globe.

Very useful data applicable to the analysis proposed have been published by the International Commission on Irrigation and Drainage (Framji & Garg, 1977) and IAHS (Rodier & Roche, 1984), and a simple solution was proposed by Francou & Rodier (1967) for describing the relationship considered, which experience has shown to be valid for catchments larger than 100 km² in size. According thereto the total catchment ($A$, in km²) upstream from a given station is related to the peak flood discharge ($Q$, in m³ s⁻¹), to find the first parameter:

$$e_1 = 10 \left( 1 - \frac{\log Q - 6}{\log A - 8} \right) \quad (1)$$

Values of $e_1$ between 6 and 7 indicate floods which are classified extreme on a global scale. Such floods have occurred mainly in tropical monsoon and equatorial catchments. Under continental climates the highest floods had $e_1$ values between 2 and 4.

**Probability of water levels and their duration** The most familiar characteristic of flood waves is the flood hydrograph that indicates besides the peak stage, also the period of time for which the water level persists above a given datum. These data are relevant in assessing the extremeness of a particular flood wave where a sufficiently long continuous record is available for a given gauging station on the stream and the conventional statistical analyses have been performed. The result is normally a stage probability, or the inverse thereof, showing the frequency (the average recurrence interval if annual data are processed) at which a peak stage of similar height is likely to occur. In some cases, the stage duration is also assessed and repeated attempts recently have been made at taking both factors into account simultaneously by introducing the term, flood load.

The extremeness of a flood at a particular gauge on a given stream preferably is expressed by one of the aforementioned annual occurrence probabilities. To comply again with the requirements mentioned in the introduction, the following parameter is proposed:

$$e_2 = \log n \quad (2)$$

where $n$ is the inverse of the familiar annual probability of occurrence ($p$), that is the average recurrence interval in years. A flood is customarily considered extreme, if the period of recurrence is greater than a generation. It rarely occurs that a flood has characteristics beyond the range of values of the available (maximum 100–150 years
RISK PARAMETERS

There is a growing demand for the quantification of flood risk, i.e. the estimation of the socio-economic consequences, although this is rarely used in current practice. An exact treatment of the problem has failed to produce a widely accepted interpretation in the case of floods, though the basic mathematical equation of risk analysis is well known:

\[ r = p \cdot k \]  

where \( r \) is the magnitude of risk, \( p \) is the probability of a loss event and \( k \) is the severity of the consequences of the event.

The first results of practical interest in flood risk estimation date from the 1953 storm flood disaster in The Netherlands (Pasman, 1993), whilst the West European practice of managing flood losses has been reviewed recently under a large-scale project (EUROFLOOD-I, 1994; EUROFLOOD-II, 1996) launched by the European Union. With due regard to the conclusions thereof, two parameters are proposed for assessing the risk of flood losses:

**Economic risk** Most extreme floods entail severe economic consequences. The majority of the losses are caused in the inundated areas, though the costs of emergency measures may also be appreciable. Surveys after floods can produce a fairly accurate estimates of the total losses, the economic significance of which may be expressed in terms of the annual product of the economic unit (e.g. country) affected. According to the basic equation (3):

\[ r_e = p_f \frac{L + M}{\text{GDP}} \]  

where \( r_e \) is the magnitude of economic risk, \( p_f \) is the annual probability of the inundation causing the loss, \( L \) is the magnitude of loss, \( M \) is the cost of emergency measures, and GDP is the annual gross domestic product of the economic unit (country). It should be noted that the probability of inundation \( p_f \) equals the probability of occurrence \( p \) used in connection with the hydrological parameters only in the case of natural (unprotected) flood plains.

**Risk to human life** The risk of casualties caused by flooding is expressed with the available data as follows:

\[ r_h = p_f \frac{D}{P} \]  

where \( r_h \) is the magnitude of risk to human life, \( p_f \) is the probability of occurrence of floods claiming human life, \( D \) is the number of lives lost, and \( P \) is the number of people in the exposed area (flood plains). The foregoing remark applies here again to the probability of inundation, and the number of people exposed should be related to the entire economic unit (e.g. country).
Combined socio-economic risk

As in the case of the hydrological characteristics, an inundation risk parameter by which the extremeness of a particular flood could be expressed in a simple manner and with an approximately identical order of magnitude, was considered desirable. The approach is founded on the proposal formulated at The Second World Congress on Safety Science at Budapest (Marx, 1993): the very low dimensionless numbers obtained with the basic expression are multiplied accordingly by $10^6$ and termed microrisk/year ($\mu r \text{ year}^{-1}$). Allowance further had to be made for the European practice of attaching greater weight to human life than to economic loss so that a multiplier of 10 was introduced to the former.

In the light of the foregoing, the following combined parameter describing the socio-economic risk of inundation by an extreme flood is proposed:

$$e_3 = \log(1 + R_e + 10^6 R_h)$$

where $R_e$ is the magnitude of economic risk in $\mu r \text{ year}^{-1}$ units, and $R_h$ is the magnitude of risk to human life in $\mu r \text{ year}^{-1}$ units.

With the actual loss data processed so far for floods considered to be extreme, the magnitude of the proposed parameter ranged from 1 to 3.5. The loss data for some of the widely known large floods and the risk parameters calculated therefrom are shown in Table 1, however some $e_3$ values also are presented in Table 2.

**ASSESSMENT**

The three proposed parameters are individually suitable for quantifying the extremeness of a particular flood, viz.:
- $e_1$ in terms of the peak flood flow related to the size of the drainage basin.
- $e_2$ in terms of the probability of flood wave characteristics (peak stage, duration)

### Table 1 Loss data and risk parameters for some countries and floods.

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
<th>Lives lost</th>
<th>Economic loss ($10^6$ US$)</th>
<th>Risk ($\mu r \text{ year}^{-1}$): human</th>
<th>economic</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>1927</td>
<td>423</td>
<td>400</td>
<td>7</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td>1993</td>
<td>50</td>
<td>15 000</td>
<td>1</td>
<td>47</td>
</tr>
<tr>
<td>China</td>
<td>1954</td>
<td>33 000</td>
<td>300</td>
<td>10</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>1998</td>
<td>1320</td>
<td>12 200</td>
<td>1</td>
<td>1220</td>
</tr>
<tr>
<td></td>
<td>1999</td>
<td>725</td>
<td>8000</td>
<td>1</td>
<td>1510</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>1997</td>
<td>48</td>
<td>2400</td>
<td>5</td>
<td>462</td>
</tr>
<tr>
<td>Poland</td>
<td>1970</td>
<td>-</td>
<td>200</td>
<td>-</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>1997</td>
<td>60</td>
<td>2500</td>
<td>3</td>
<td>358</td>
</tr>
<tr>
<td>Germany</td>
<td>1997</td>
<td>-</td>
<td>800</td>
<td>-</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>1999</td>
<td>-</td>
<td>1100</td>
<td>-</td>
<td>56</td>
</tr>
<tr>
<td>Hungary</td>
<td>1838</td>
<td>153</td>
<td>5</td>
<td>17</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>1879</td>
<td>151</td>
<td>2</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>1965</td>
<td>-</td>
<td>10</td>
<td>-</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>1970</td>
<td>-</td>
<td>50</td>
<td>-</td>
<td>61</td>
</tr>
</tbody>
</table>
calculated from the annual maxima on record.

- $e_3$ in terms of the magnitude of the socio-economic losses.

To adopt several assessment criteria simultaneously, the sum of selected parameters can be used in the following manner:

**Assessment in terms of a single criterion:**

- $e_1 \geq 6$ extreme flood on a worldwide scale from the viewpoint of hydrology
- $e_2 \geq 2.5$ extreme flood on a particular stream from the viewpoint of hydrology
- $e_3 \geq 2$ extreme flood relative to the socio-economic situation of the given economic unit (country)

**Assessment in terms of two criteria:**

- $2.5 \leq (e_2 + e_3) \leq 3.5$ locally extreme flood
- $3.5 \leq (e_2 + e_3) \leq 4.5$ extreme flood on an international scale
- $4.5 \leq (e_2 + e_3)$ extreme flood on a global scale

**Assessment in terms of three criteria:**

- $(e_1 + e_2 + e_3) \geq 3$ extreme flood for a dry climate
- $(e_1 + e_2 + e_3) \geq 4.5$ extreme flood for a continental climate
- $(e_1 + e_2 + e_3) \geq 8$ extreme flood for a tropical climate

A few parameters of extreme floods on international scale are summarized in Table 2.

It should be noted that a comparison of parameters $e_2$ and $e_3$ will yield interesting conclusions with regards to the level and socio-economic justification of flood control development and emergency measures. The analyses so far have revealed that for:

- $e_2 < e_3$ flood control is poor and should be introduced or improved
- $e_2 = e_3$ the level of safety is optimal, any improvement should follow development in the protected area
- $e_2 > e_3$ the defences are oversized, no development is warranted

<table>
<thead>
<tr>
<th>River</th>
<th>Year</th>
<th>Parameters of extremeness:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$e_1$</td>
</tr>
<tr>
<td>Mississippi</td>
<td>1927</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>1993</td>
<td>1.59</td>
</tr>
<tr>
<td>Yangtze</td>
<td>1954</td>
<td>4.15</td>
</tr>
<tr>
<td></td>
<td>1998</td>
<td>3.86</td>
</tr>
<tr>
<td>Odra</td>
<td>1970</td>
<td>1.56</td>
</tr>
<tr>
<td>(in Poland)</td>
<td>1997</td>
<td>1.80</td>
</tr>
<tr>
<td>Danube</td>
<td>1838</td>
<td>1.84</td>
</tr>
<tr>
<td>(in Hungary)</td>
<td></td>
<td>1965</td>
</tr>
<tr>
<td>Tisza</td>
<td>1879</td>
<td>1.18</td>
</tr>
<tr>
<td>(in Hungary)</td>
<td></td>
<td>1970</td>
</tr>
</tbody>
</table>
The method presented has been developed for assessment of previous floods. By carrying out the same principle, an evaluation system for design floods can be executed as well.

REFERENCES