The world’s maximum observed floods

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Abstract Knowledge of exceptionally large floods is essential in solving many problems in water resources management and to assess the susceptibility to flooding of structures in or in the vicinity of rivers. The study, initiated by IAHS, UNESCO and WMO, addresses the collection and analyses of flood data from questionnaires sent to 166 countries. For each country, details are requested for the maximum flood, method of measurement, rainfall if available, hydrological information and a selection of long-term series of annual maximum floods. Envelope curves of maximum floods are presented. The objective is to update the World Catalogue of Maximum Observed Floods (Rodier & Roche, 1984).

Key words maximum floods; catalogues; rainfall-runoff; jökulhlaup; landslide floods; coastal floods

INTRODUCTION

Floods may be classified into categories corresponding to their return frequency, such as semi-annual, annual, 100-year, 1000-year, and for very rare “mega-floods”, a multi-million-year geological time scale. Floods are commonly judged in terms of the human or material damage inflicted, and the amplitude of such damage may be measured as inversely proportional to their anticipation, or readiness or preparedness for dealing with the event (Fairbridge, 1999). For example, the recent Mozambique catastrophic flood, which is estimated to have a return period of up to 100 years, affected 2 million people and the readiness or preparedness was under question.

Not all flooding, however, has a negative connotation. In this category are the classical floods of the Nile River and the Tigris–Euphrates River which have made possible and nourished the dawn of human civilization as early as 10 000 years ago. The same would apply to the Indo-Gangetic Plain, and in China the lower Yangtze River and the lower Yellow River. On a smaller scale it is the rich alluvial flats of the Thames River that made possible the agricultural economics of the early Britons.

Flood categories

- Riverine overbank flooding: the banks of a mature river are adjusted to the average annual discharge. Infrequent discharges at decadal to century frequency cause overbank floods with inundation of flood plains except in regions of engineered controls.
- Riverine gorge and canyon flooding: the upper courses of rivers are liable to snowmelt and exceptionally heavy precipitation on a local basis.
- **Landslide or glacier-blocked rivers**: temporary blocks and manmade dams in river valleys lead to lake impoundment. Seepage and collapse of landslide debris, poorly constructed dams, or glacier melting beyond a certain threshold, can lead to a catastrophic flood downstream.

- **Estuarine and deltaic flooding**: wide-mouth estuaries and ocean-facing estuaries are confronted from time to time by a double hazard, involving fluvial flooding due to excess rainfall inland and rises at sea level, the effects of which may back up the river by as much as 100 km inland. The river discharge may be at an extremely high level. The Brahmaputra, for example, with an annual average discharge of \(317,000 \text{ m}^3 \text{s}^{-1}\), may rise in one year to over 1 million \(\text{m}^3 \text{s}^{-1}\). This was the case of the Bangladesh floods of 1998 due to heavy snowfall and seasonal melt in the Himalaya Mountains, combined with normally high monsoonal rainfall in Assam, the world's highest at Cherrapunji, and the usual monsoon rains over the delta.

- **Coastal flooding**: as distinct from estuarine and deltaic situations, open coasts are subject to both long-term (century trends) and short-term events (hourly–7 days). In the first category there are sea-level rises in the order of 1–10 mm year\(^{-1}\). It is said that no one is drowned by a 1-mm-year\(^{-1}\) rise of sea level. However, a threshold effect may be catastrophic. The history of western European low coastal areas (Leatherman, 1981) shows clearly the impact of the threshold effect on regions marked by a secular (1 mm year\(^{-1}\)) water level rise. The Roman period was noted for a falling eustatic sea level that caused widespread exposure of coastal mudflats and saltmarshes that became farming land due to the population explosion. Today there are 1600 km of dikes on the German coast alone. At the beginning of the twenty-first century the mean rate of sea-level rise is globally about 1 mm year\(^{-1}\). However, the local rise may be much greater, e.g. 10–20 mm year\(^{-1}\) in parts of the Mississippi delta, 3–5 mm year\(^{-1}\) at Atlantic City. Much has been written about global warming in the twentieth century and the greenhouse effect. However, since the Little Ice Age (max. 1680) there has been a global rise of sea-level of 400 mm. Coastal flooding disasters are thus in no way a result of the net secular rise in sea-level, but are related to meteorological events, sometimes in combination with extreme luni-solar tides.

- **Volcanic related flooding**: two types of volcanic activity lead to catastrophic floods: (a) the boiling mudflow or lahar, and (b) the sub-glacier eruption and meltwater flood or jökulhlaup. The first type is best known in Indonesia and so frequent (approximately decadal) that the name lahar (in Malay) is familiar to the population. Jökulhlaup floods are common only in Iceland, where the region likely to be inundated in uninhabited parts of the country is abundantly monitored seismically so that adequate warnings can be issued. The preliminary signs (seismicity, melting ice) may precede the flood outbreak by several weeks.

**BACKGROUND**

In 1976, in the framework of the International Hydrological Programme, UNESCO published the world catalogue of very large floods (UNESCO, 1976). Upon the publication of this report, IAHS, one of the participating organizations in the
Catalogue, decided to launch an inquiry for the publication of a world catalogue of maximum floods, these floods to be as far as possible measured or observed. The project became a joint IAHS/UNESCO venture, resulting in the *World Catalogue of Maximum Observed Floods* (Rodier & Roche, 1984).

In 1999, IAHS, UNESCO and WMO agreed that the time was right to bring the Catalogue up to date, it being noted that Rodier & Roche considered an interval of 20 years to be appropriate for a future edition. In their concluding remarks to the introduction to the 1984 Catalogue they made the comment: "For the future, few rivers will remain without anthropogenic modification and the task of our successors in framing the next such catalogue will be made more difficult. We wish them success".

**THE UNESCO WORLD CATALOGUE OF VERY LARGE FLOODS**

The UNESCO Catalogue was the result of work commencing in 1970 under the framework of the IHP Working Group on Floods and their Computation. Thirty-five countries responded to the questionnaire and although the publication was found extremely useful to hydrologists and engineers it was not specifically intended for the collection of maximum floods and it is believed that only those floods of acceptable accuracy were included. Nevertheless it was the first such attempt on a worldwide basis to catalogue floods and 34 of the 35 countries responding were included in the IAHS Catalogue.

**THE IAHS WORLD CATALOGUE OF MAXIMUM OBSERVED FLOODS**

The UNESCO Division of Water Sciences contributed to this project by facilitating contacts with hydrologists of several countries and the inquiry also benefited from cooperation with hydrologists and consultants. In all, 110 countries were invited to supply maximum flood information and 95 countries responded by supplying information on the maximum observed flood discharge for 1400 stations or observation sites. In their review of the Catalogue, Rodier & Roche suggested a flood index in order to compare one flood with another (Francou & Rodier, 1967). In this they used a coefficient $k$ where $k$ is given by:

$$k = 10\{1 - [(\log Q - 6)/(\log A - 8)]\}$$  \hspace{1cm} (1)

where $Q$ is the largest flood in m$^3$ s$^{-1}$ and $A$ is the drainage basin area in km$^2$.

Rodier & Roche selected the 41 highest floods and found that for drainage basins larger than 100 km$^2$, the value of $k$ exceeded 5.75. They produced a plot of log $Q$ against log $A$ for 38 of the 41 values (Fig. 1) which is a straight line regression ($k = 6$) having the equation:

$$Q = 500A^{0.43}$$  \hspace{1cm} (2)

Figure 2 presents an envelope curve of the maximum rainfall–runoff floods in the USA compared with the maximum rainfall–runoff floods from China and the IAHS Catalogue's 41 maximum floods (Costa, 1987). In Fig. 3 the same observations are plotted and regression equations deduced (Herschy & Fairbridge, 1998) as follows:
Fig. 1 Maximum observed flood discharges in the world (after Rodier & Roche, 1984).

Fig. 2 Envelope curve of the maximum rainfall-runoff floods measured in the USA compared with the maximum rainfall-runoff floods from China and from the IAHS Catalogue of Maximum Observed Floods (after Costa, 1987).

\[
Q = 90A \quad (3)
\]

\[
Q = 850A^{0.357} \quad (4)
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With regard to return periods, Rodier & Roche suggest that for the 1400 values of the maximum floods, the return periods were probably of the order of less than 100 years and many probably as low as 10 years.
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Fig. 3 Regression curves fitted through the observations in Fig. 1 (Herschy & Fairbridge, 1998).

It was clear from the Catalogue that much more information was required on small drainage basins as very little was known on their performance in the region of high k values. It is also noted that no European country managed to get into the list of the 41 maximum observed floods (k values do not exceed 5.65 even in Mediterranean countries) and plotting the highest European floods on log-log paper gives a regression with large scatter significantly less than the world curve of Rodier & Roche having the equation:

\[ Q = 164A^{0.36} \]  

(5)

THE UPDATE OF THE 1984 CATALOGUE

In order to update the IAHS 1984 Catalogue, questionnaires were sent to 166 countries worldwide using the same format as the 1984 edition. This consists of tables, giving the hydrology of the station, the maximum flood, method of measurement, uncertainty, rainfall and long-term series of maximum floods. The new catalogue is still at an early stage but will be based on the 1984 Catalogue. Although it would at this stage seem unlikely that the Rodier & Roche maximum regression (Fig. 2) would be exceeded, many more floods are expected to be included.

ACCURACY (UNCERTAINTY)

Measuring a flood to high accuracy by any of the standard methods of streamflow measurement is onerous. The methods employed in the 1984 edition were, apparently, velocity-area (uncertainty in stage, velocity or extrapolation); slope-area (uncertainty
in slope, Manning’s n or Chezy’s c values); measuring structures (uncertainty in coefficient and hydraulic limitations); floats (uncertainty in velocity, depth, area and velocity reduction factor). Rodier & Roche (1984) put the estimate of the uncertainty of the 41 largest floods at about 15% and mention velocities of 7 m s\(^{-1}\) measured by current meter and derived velocities in excess of 8 m s\(^{-1}\).

Rainfall from one or more raingauges can only be classed as an indicator and no uncertainty can be ascribed to it. Although it is expected that many more additional maximum floods will be included in the new edition, it is unfortunately evident that neither the global streamflow nor the raingauge networks are as yet satisfactory for acceptable water resources assessment and in fact have not experienced the improved coverage expected since the first edition of the Catalogue (Rodda, 1999).

REFERENCES


