Cambridge University Press
978-1-107-01875-4 - Floods in a Changing Climate: Inundation Modelling
Giuliano Di Baldassarre
Excerpt
More information

1 Introduction

1.1 FLOODS: NATURAL PROCESSES AND (UN)NATURAL DISASTERS

Since the earliest recorded civilizations, such as those in Mesopotamia and Egypt that developed in the fertile floodplains of the Tigris and Euphrates and Nile rivers, humans have tended to settle in flood-prone areas as they offer favourable conditions for economic development (Di Baldassarre *et al*., 2010a). However, floodplains are also exposed to flood disasters that might cause severe damage in terms of society, economy, environment and loss of human lives (Figure 1.1).

A flood disaster is said to occur when an extreme event coincides with a vulnerable physical and socio-economic environment, surpassing society's ability to control or survive the consequences. Currently, flood disasters account for half of all deaths caused by natural catastrophes (Ohl and Tapsell, 2000). In 2010, floods were responsible for the loss of more than 8,000 human lives and affected about 180 million people (Figure 1.2; EM-DAT, 2010).

Yet the catastrophic floods that occurred in 2010 (e.g. Pakistan and China) are only the most recent examples of worldwide increasing flood damage. Figure 1.3 shows, for instance, that the number of people affected by floods in the African continent has dramatically increased over the last decades (EM-DAT, 2010). Sadly, similar diagrams can be derived by analysing flood damage and fatalities in other continents.

To mitigate the continuously increasing flood risk the currently proposed approach is integrated flood management (aimed more towards 'living with floods'), which has replaced the more traditional flood defence approach ('fighting floods'). This approach aims to minimize the human, economic and ecological losses from floods while, at the same time, maximizing the social, economic and ecological benefits (UNESCO-IFI, International Flood Initiative). Thus, flood managers should be concerned not only about the reduction of the potential damage of extreme flood events, but also about the protection of floodplains, which are among the most valuable ecosystems for providing goods and services to society and supporting biodiversity (Costanza *et al*., 1997; Nardi *et al*., 2006; Opperman *et al*., 2009).

However, how to implement integrated flood management schemes including the needed capacity development activities in an ever changing world is often unknown and requires research and rethinking of our current approaches (Uhlenbrook *et al*., 2011). This seems to be true in particular in the developing world, where better flood management is very much needed to limit the societal impacts of floods (Di Baldassarre and Uhlenbrook, 2011).

1.2 DEFINITIONS

Flood is a natural process that can be defined as a body of water which rises to overflow land that is not normally submerged (Ward, 1978). It can be generated by many causes (and combinations thereof) that include: heavy rain, rapid snow/ice melt, glacial lake breaches, ice breakup, debris entrapment, dam breaks, levee breaches, landslide blockages and groundwater rises. The most common types of flood are storm surges, river floods and flash floods. Flood risk is typically defined as the result of the integration of two components, i.e. probability and consequences (Sayers *et al*., 2002; Simonovic, 2012):

$$Risk = Probability \times Consequences \tag{1.1}$$

This concept of risk is strictly related to the probability that a flood event of a given magnitude occurs, while consequences are the expected environmental, economic and social losses caused by that flood event. This definition of risk is also used in the recent European Flood Directive 2007/60/EC (European Parliament, 2007) where flood risk is a combination of the probability of a flood event and the potential adverse consequences for human health, the environment, cultural heritage and economic activity.

Another widely used definition of flood risk specifies the two contributions to the consequences caused by a hazardous event,

Figure 1.1 River Aniene (Italy) during the March 2011 flooding (photo by Max Pagano).

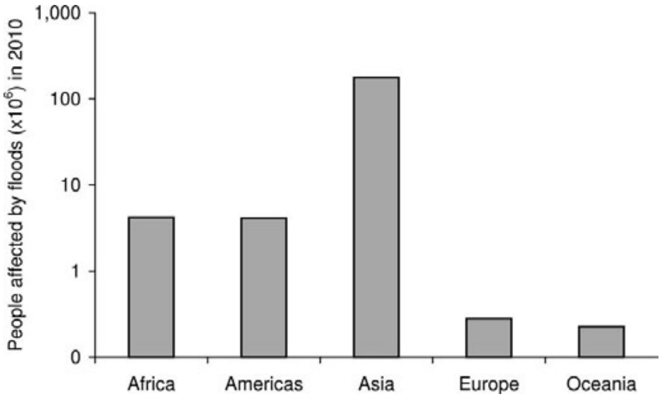

Figure 1.2 Number of people affected by floods in 2010 by continents. Note the use of the logarithmic scale. In order for a disaster to be entered into the OFDA/CRED International Disaster Database at least one of the following criteria has to be fulfilled: (i) 10 or more people reported killed, (ii) 100 people reported affected, (iii) a call for international assistance, (iv) declaration of a state of emergency (EM-DAT, 2010).

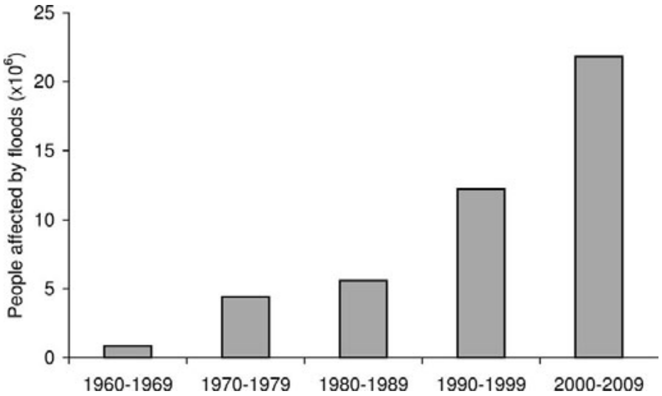

Figure 1.3 Number of people affected by floods in Africa (EM-DAT, 2010).

i.e. vulnerability and exposure (Sagris *et al*., 2005; Landis, 2005; UN-ISDR, 2004):

$$Risk = Hazard \times Exposure \times Vulnerability \quad (1.2)$$

This definition requires that a vulnerable area (from a social, economic or environmental point of view) is actually exposed to the hazard. If an event occurs where there is no vulnerability or no exposure, then there is also no risk.

The two definitions of flood risk, (1.1) and (1.2), are clearly interrelated and interchangeable and each of these two definitions has certain advantages in different applications (e.g. Sayers *et al*., 2002; Landis, 2005; Merz *et al*., 2007). More details on flood risk management can be found in Simonovic (2012).

As mentioned, facts and hard data clearly indicate that flood risks have increased over the last decades. This dramatic increase may have been caused by a combination of climate and

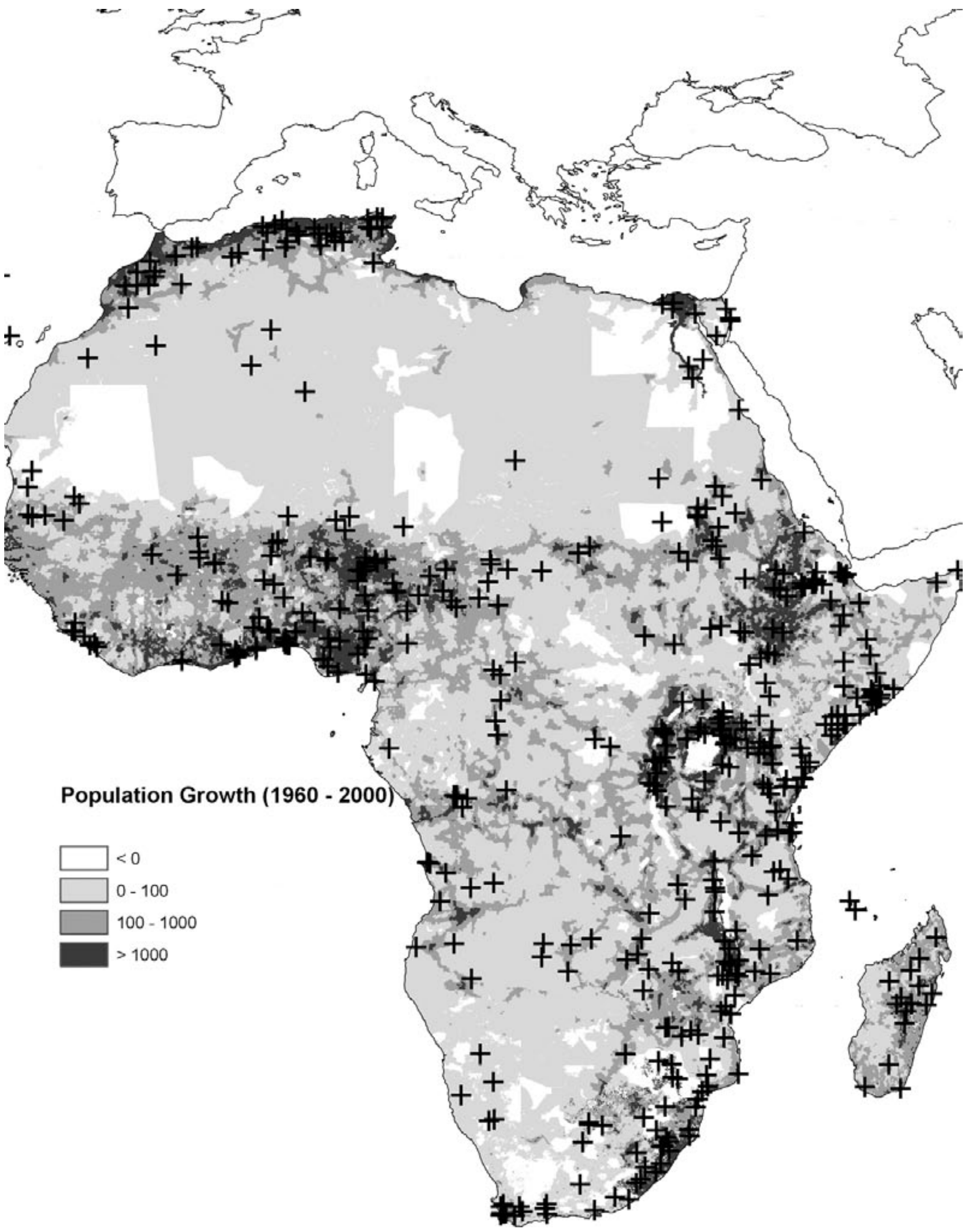

Figure 1.4 Spatial distribution of population growth (as number of inhabitants per cell of 2.5′) and location of the most recent floods (crosses); see also Di Baldassarre *et al*. (2010a).

land-use changes, which may have increased flood probability, and economic and demographic changes, which may have led to increased human vulnerability to extreme hydro-meteorological conditions. For instance, the aforementioned increase of flood losses in Africa was found to be caused by intensive and unplanned urbanization of flood-prone areas, which has played a major role in increasing the potential adverse consequences of floods (Figure 1.4).

In particular, Figure 1.4 shows, at the continental scale, the dynamics of human settlements (i.e. population growth between 1960 and 2000) and the location of the latest floods in Africa (Dartmouth Flood Observatory, 2010) and highlights that most of the recent floods (i.e. period 1985–2009) have occurred where the population has increased more. This is not only the case for the African continent. A dramatic example is the May 2004 flooding of the transboundary River Soliette (Haiti and the Dominican

Republic) where formal and informal human settlements in the floodplain led to dramatically high flood casualties, i.e. more than 1,000 people were killed in addition to many hundreds of people left homeless (Brandimarte *et al*., 2009).

Lastly, although risk awareness and population dynamics are rather different, intensive urbanization of flood-prone areas is also widely present in more developed countries. For instance, over 12% of the population of the United Kingdom (UK) live on fluvial and coastal floodplains, about half of the population of the Netherlands live below (or close to) mean sea level, and in Hungary about 25% of the population live on the floodplain of the River Danube and its tributaries (BRISK, 2011).

These dramatic figures indicate the need for urgent mitigation actions to tackle the increasing flood risk, such as floodplain mapping, which can help in discouraging new human settlements in flood-prone areas and raising risk awareness among the population living in floodplains (Padi *et al*., 2011).

1.3 FLOOD INUNDATION MODELLING

Flood inundation models are numerical tools able to simulate river hydraulics and floodplain inundation processes (Horritt *et al*., 2007). In recent years, the increased socio-economic relevance of river flood studies and a shift of these studies towards integrated flood risk management concepts have triggered the development of various methodologies for the simulation of the hydraulic behaviour of river systems (see Chapter 5). In particular, flood inundation models have been proved to be useful tools in floodplain management, understanding sediment dynamics and flood risk mitigation. For instance, their ability to predict inundation extents can be used to reduce the potential flood damage by: (i) supporting a more appropriate land use and urban planning (when present); (ii) raising the awareness of people living in flood-prone areas; and (iii) discouraging new human settlements in floodplains.

Flood modellers are well aware that a significant approximation affects the output of their models. Uncertainty is caused by many sources of error that propagate through the model and therefore affect its output. Three main sources of uncertainty have been identified (Götzinger and Bardossy, 2008): (i) observation uncertainty, which is the approximation in the observed hydrologic variables used as input or calibration data (e.g. rainfall, temperature and river discharge); (ii) parameter uncertainty, which is induced by imperfect model calibration; (iii) model structural uncertainty, which originates in the inability of models to perfectly schematize the physical processes involved. In recent years, there has been an increasing interest in assessing uncertainty in flood inundation modelling, analysing its possible effects on floodplain mapping, and making a more efficient use of data to constrain uncertainty (Di Baldassarre *et al*., 2009a).

Nowadays, a great opportunity to reduce the uncertainty of models is offered by the increasing availability of distributed remote sensing data, which has led to a sudden shift from a data-sparse to a data-rich environment for flood inundation modelling (Bates, 2004a). For instance, flood extent maps derived from remote sensing are essential calibration data to evaluate inundation models (Horritt *et al*., 2007). From space, satellites carrying synthetic aperture radar (SAR) sensors are particularly useful for monitoring large flood events (Aplin *et al*., 1999). In fact, radar wavelengths, which can penetrate clouds and acquire data during day and night, are reflected back to the antenna by smooth open water bodies, and hence mapping of flood extent areas has become relatively straightforward (Di Baldassarre *et al*., 2011a). Also, an accurate description of the geometry of rivers and floodplains is crucial for an appropriate simulation of flood propagation and inundation processes. This is currently allowed by modern techniques for topographical survey, such as airborne laser altimetry (LiDAR; e.g. Cobby *et al*., 2001), that enable numerical descriptions of the morphology of riverbanks and floodplain areas with planimetric resolution of 1 m and finer. The elevation accuracy of these LiDAR data is between 5 and 15 cm, which makes this type of topographic data suitable to support flood inundation modelling. Lastly, it is worth mentioning that, in the last decade, there has been dissemination of topographic data that are freely and globally available, such as the space-borne digital elevation model (DEM) derived from the Shuttle Radar Topography Mission (SRTM), which has a geometric resolution of 3 arc seconds (LeFavour and Alsdorf, 2005) and covers most of the land surfaces that lie between 60° N and 54° S latitude (Figure 1.5).

Confirmation of the utility of globally and freely available data therefore indicates the potential to remove an important obstacle currently preventing the routine application of models to predict flood hazards globally, and potentially allows such technology to be extended to developing countries that have not previously been able to benefit from flood predictions. However, clear guidelines to fully and properly utilize the current 'flood of data' (Lincoln, 2007) are still to be developed (Di Baldassarre and Uhlenbrook, 2011).

1.4 CLIMATE AND FLOODS

There is global concern that flood losses might grow further in the near future because of many factors, such as changing demographics, technological and socio-economic conditions, industrial development, urban expansion and infrastructure construction, unplanned human settlement in flood-prone areas, climate variability and change (full report of the Scientific and Technical Committee, UN-ISDR, 2009).

Figure 1.5 This world map shows the SRTM-derived flow accumulation area (greyscale; from black to white), i.e. the amount of basin area draining into each cell. Larger rivers are recognizable as white areas.

In recent years, a large part of the scientific community has made efforts in analysing the impact of climate change on water resources and proposing adaptation strategies (Wilby *et al*., 2008). The usual framework of this type of studies can be summarized as follows (Di Baldassarre *et al*., 2011b): (i) choice of one or more scenarios of the IPCC (Intergovernmental Panel on Climate Change) special report on emission scenarios (Bates *et al*., 2008), which depend on the future economy and energy use policies; (ii) choice of one or more global climate models (GCM); (iii) downscaling of the GCM output to the specific river basin scale; (iv) use of the downscaled GCM outputs as inputs for a hydrologic model; and (v) analysis of hydrologic model results by comparing them to the corresponding results related to the current climate or different possible future climates (see also Mujumdar and Kumar, 2012; Teegavarapu, 2012). This approach has become very popular as it potentially allows the quantification of changes in floods, flow duration curves, and the appropriate part of the hydrologic cycle. However, it should be noted that different techniques may lead to opposing trends and contradicting recommendations for policy-makers (Blöschl and Montanari, 2010).

It has been customary for water communities to use climate model outputs as quantitative information for assessing climate impacts on water resources and, in particular, flood risk management (Simonovic, 2012). However, caution is always needed in considering certain modelling aspects, such as: (i) the choice of the particular model or set of global models to use; (ii) domain configurations for regional models; (iii) choosing appropriate model physics especially for those handling moist convective processes related to reproducing observational climatology and inter-annual features of regional and local precipitation. Di Baldassarre *et al*. (2011b) indicated the need for good practice in climate impact studies. This practice should include the following requirements: (i) results should not be presented in a simplified way assuming a one-way cause–effect relationship; (ii) ensembles of several climate model projections should be used to reflect their large variability; (iii) the performance of the models applied to historical data should be provided; (iv) appropriate downscaling techniques should be used and the underlying assumptions should be reported; and (v) appropriate uncertainty analysis techniques should be applied to the entire modelling chain. Blöschl and Montanari (2010) recommended that impact studies should not only present the assumptions, results and interpretation, but also provide a clear explanation of 'why' certain changes are projected by the applied models. The idea is that we should not trust that the results are valid unless we understand why an impact study projects changes in a given hydrologic variable.

More details of climate impact on floods are reported in the other volumes of the book series on Floods in a Changing Climate (Mujumdar and Kumar, 2012; Simonovic, 2012; Teegavarapu, 2012). As far as this book is concerned, the two main changes that flood inundation modellers should consider are the changes in the frequency (and magnitude) of floods and sea level rise, which impact the boundary condition of flood inundation models (see Chapters 4–7).

For what concerns changes in the frequency of floods, Wilby *et al*. (2008) recently recommended precautionary allowances for the design flood (i.e. peak river flow corresponding to a given return period; Chapter 7) of +10% in 2025, and +20% in 2085 (Wilby *et al*., 2008). It should be noted that, given the aforementioned uncertainty related to climate impact on floods, these

Cambridge University Press
978-1-107-01875-4 - Floods in a Changing Climate: Inundation Modelling
Giuliano Di Baldassarre
Excerpt
More information

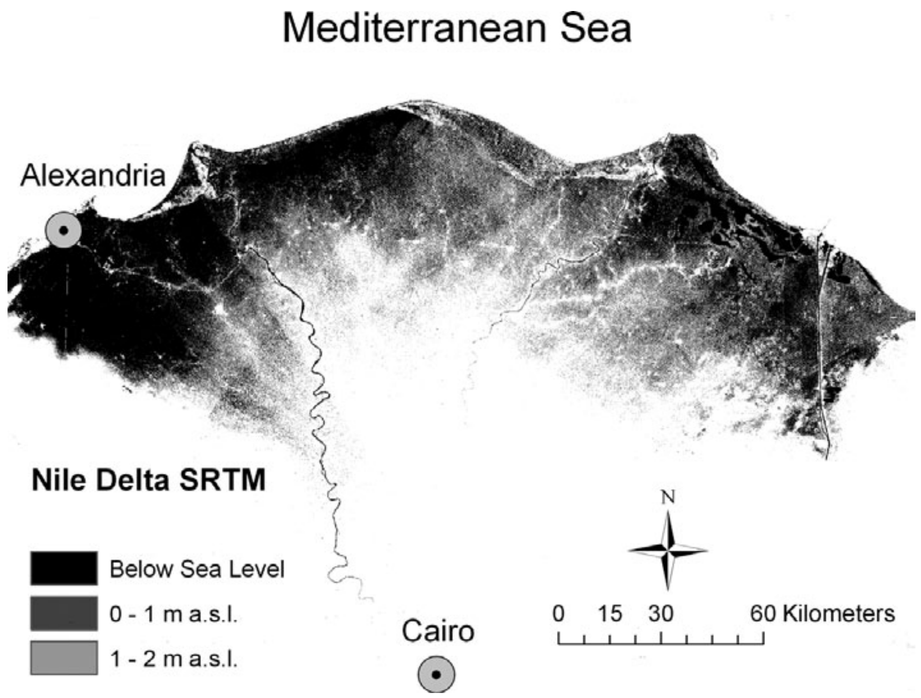

Figure 1.6 Potential impact of sea level rise on the Nile Delta, Egypt. The SRTM topography is classified to show the regions that are currently below sea level (black areas), and the territories that might be potentially flooded by sea level rise (greyscale; see legend).

adjustment factors might be updated in the near future as a result of currently ongoing research.

For sea level rise, Bates *et al*. (2008) indicated, 'The average rate of sea-level rise during the 21st century is very likely to exceed the 1961–2003 average rate (around 1.8 mm/yr)' and is expected to be characterized by 'substantial geographical variability'. More recently, Church and White (2011) pointed out, 'Since the start of the altimeter record in 1993, global average sea level rose at a rate near the upper end of the sea level projections of the Intergovernmental Panel on Climate Change's Third and Fourth Assessment Reports.'

To illustrate the potential impact of sea level rise, Figure 1.6 shows, as an example, the Nile Delta (Egypt, Mediterranean Sea). The Nile Delta covers only 2% of Egypt's territory, but is home to 41% of the Egyptian population and includes 63% of its agricultural land (Hereher, 2010). Figure 1.6 was derived by following a simplified approach, based on the use of SRTM topography (see Chapter 4) with the only objective being to illustrate the potential increase of exposure to coastal flooding related to sea level rise.

UNEP/GRID (2000) and Hereher (2010), which investigated the vulnerability of the Nile Delta with more elaborate techniques, pointed out that sea level rise might seriously affect the Nile Delta as it would lead to shoreline erosion, contamination of lagoons, deterioration of water quality, and inundation of much valuable and productive agricultural land (Figure 1.6). Sadly, similar issues are being experienced in many coastal regions and deltas of the world (UNEP/GRID, 2000).

1.5 PROBLEMS ADDRESSED BY THIS BOOK

This book deals with numerical models able to simulate flood propagation and inundation processes. It provides a dissertation about the state-of-the-art in hydraulic modelling of floods as part of the flood risk management exercise (Simonovic, 2012).

More specifically, the first part of the book (Chapters 2 and 3) provides a concise description of the basic hydraulic principles, steady and unsteady flow equations, and their numerical and analytical solutions. Chapter 4 discusses different data sources to support flood inundation modelling by describing traditional ground-surveyed data (e.g. cross sections, hydrometric data) as well as remotely sensed data (e.g. satellite and airborne images). Chapter 5 deals with model implementation in both theoretical and practical terms. In particular, the chapter introduces the principle of parsimony and the main criteria behind the selection of the most appropriate hydraulic model for simulating flood inundation. Then, numerical tools for flood inundation modelling are classified and briefly described. The chapter also deals with the most common issues related to model building, such as the schematization of model geometry and the parameterization of flow resistance. Chapter 6 discusses the evaluation of flood inundation models. After the introduction of basic concepts, the chapter presents performance measures that are commonly used to compare model results and observations. The calibration and validation of hydraulic models is also discussed.

Lastly, the chapter introduces methodologies recently proposed in the scientific literature that can be used to cope with uncertainty in hydraulic modelling. Chapter 7 deals with the use of model results in GIS environments and describes the necessary steps to build flood hazard maps. It also includes a comparison of deterministic and probabilistic approaches to mapping floodplain areas.

The last part of the book (Chapters 8–11) reports four different example applications. In these examples, flood inundation models are used to: simulate urban flooding, evaluate changes on flood propagation caused by human activities, estimate changes of the stage–discharge rating curve, and compare different floodplain management strategies.

The overall aim of this book is to support an efficient and appropriate implementation of flood inundation models, which have been proved to be useful and essential tools for flood management under climate change. However, it should be noted that modelling flood propagation and inundation processes is only a small part of the risk management exercise. In this context, Szöllösi-Nagy (2009) stated, 'Models play the same role as the heart in human body. Small, but one just cannot exist without it.' It is also worth quoting here the message of Kofi Annan to the World Water Day (2004):

> Modern society has distinct advantages over those civilizations of the past that suffered or even collapsed for reasons linked to water. We have great knowledge, and the capacity to disperse that knowledge to the remotest places on earth. We are also beneficiaries of scientific leaps that have improved weather forecasting, agricultural practices, natural resources management, disaster prevention, preparedness and management . . . But only a rational and informed political, social and cultural response – and public participation in all stages of the disaster management cycle – can reduce disaster vulnerability, and ensure that hazards do not turn into unmanageable disasters.

Cambridge University Press
978-1-107-01875-4 - Floods in a Changing Climate: Inundation Modelling
Giuliano Di Baldassarre
Excerpt
More information

Part I
Theory