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978-1-108-44705-8 — Floods in a Changing Climate
Slobodan P. Simonović
Excerpt
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1 Flood risk management

A flood is a very simple natural phenomenon that occurs when a body of water rises to overflow land that is not normally submerged (Ward, 1978). At the same time, a flood is a very complex phenomenon that connects the natural environment, people, and the social systems of their organization. Flooding causes loss of human life. It damages infrastructure such as roads, bridges, and buildings, and hurts agricultural productivity because of lost crops and soil erosion. Flood disaster relief often requires enormous funding. Connectivity increases risks. As more links are present among the elements of natural, social, and technological systems, these systems develop unexpected patterns of connections that make breakdown more likely.

We are witnessing many catastrophic flood disasters. European floods in 2002 caused more than €7 billion damage. Hurricane Katrina caused flooding in 2005 that was the costliest natural disaster, as well as one of the five deadliest, in the history of the USA. At least 1,836 people lost their lives in the actual hurricane and in the subsequent floods; total property damage was estimated at US$81 billion. In June of 2006, northeastern Bangladesh disappeared under monsoon floods as rains drenched the region. The floods stretched across hundreds of kilometers of what had been dry land a month earlier and inundated two thirds of the territory of the country. Typhoon Morakot of 2009 was the deadliest typhoon to impact Taiwan in recorded history. It created catastrophic damage in Taiwan, leaving 461 people dead and 192 others missing, and roughly US$3.3 billion in damage. The storm produced huge amounts of rainfall, peaking at 2,777 mm (109.3 in). The extreme amount of rain triggered enormous mudslides and severe flooding throughout southern Taiwan. One mudslide buried the entire town of Xiaolin, killing an estimated 500 people. In the wake of the flood, Taiwan's President Ma Ying-jeou faced extreme criticism for the slow response to the disaster, having initially deployed only roughly 2,100 soldiers to the affected regions. Later additions of troops increased the number of soldiers to 46,000. Days later, the president publicly resigned due to the government's slow response to the disaster. The 2010 China floods began in early May. The total death toll as of August 5 was 2,507. More than 305 million people in 28 provinces, municipalities, and regions were affected, while at least 12 million people had been evacuated because of the risk of flooding and landslides by early August. As I am writing these words, Pakistan's deadliest floods in decades have killed more than 1,500 people and overwhelmed government efforts to provide aid. The flood's death toll may rise to 3,000. Approximately 20 million people had been affected by floods by early August. Regions downstream in the Indus River valley, where most of Pakistan's 162 million people live, are bracing for floods that may damage crops.

1.1 THE GLOBAL FLOOD PROBLEM

Assessing the global flood problem is not an easy task due to gaps and numerous deficiencies in statistics, the highly variable quality of the available data, and the problems of comparing flood impacts across the wide socio-economic development spectrum. Most of the information to be presented here is from the Dartmouth Flood Data Observatory (2010) in Germany, the Emergency Events Database EM-DAT of the Centre for Research on the Epidemiology of Disasters (CRED, 2009) in Belgium and the Munich Re NatCatSERVICE online database (Munich Re, 2011).

The longer time period records (traced back to 1900, although more reliable after 1950) show a relentless upward movement in the number of natural disasters (Figure 1.1) and their human and economic impact (Figure 1.2). Black indicates the number and impacts of flood disasters. It is troubling that disaster risk and impacts have been increasing during a period of global economic growth. On the good side, a greater proportion of economic surplus could be better distributed to alleviate the growing risk of disaster. On the bad side, it is possible that development paths are themselves creating the problem: increasing hazards (for example through global climate change and environmental degradation), human vulnerability (through income poverty and political marginalization), or both.

The information on flood disasters presented in Figures 1.3 to 1.6 is taken from EM-DAT: The CRED International Disaster Database for the period 1950–2010. In order for a disaster to be entered into the database at least one of the following criteria has to be fulfilled: 10 or more people reported killed; 100 people reported

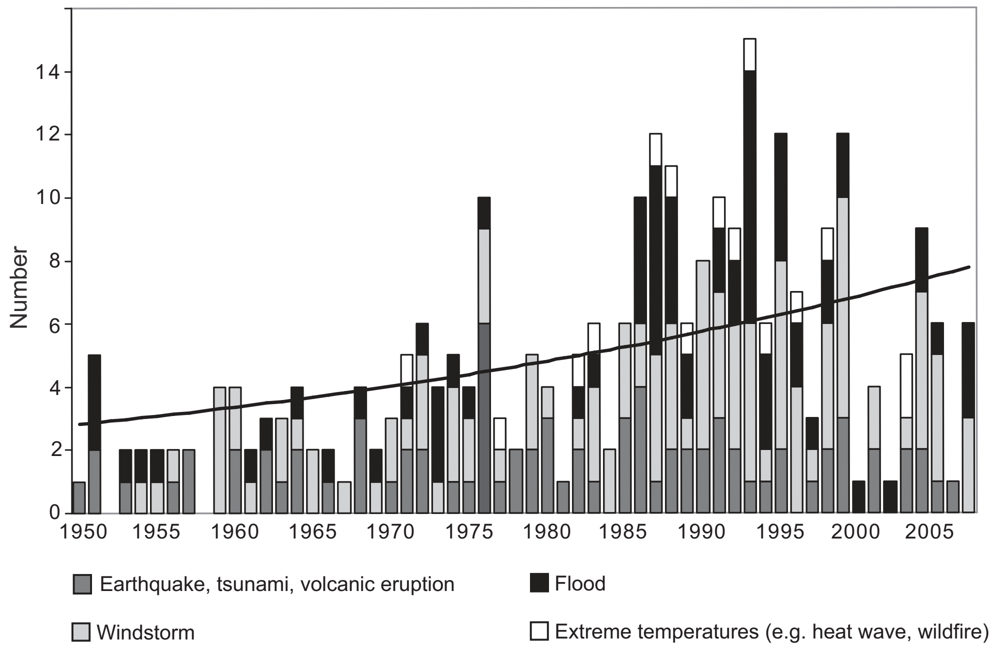

Figure 1.1 Great natural disasters 1950–2007: number of events (source: Munich Re, NatCatSERVICE).

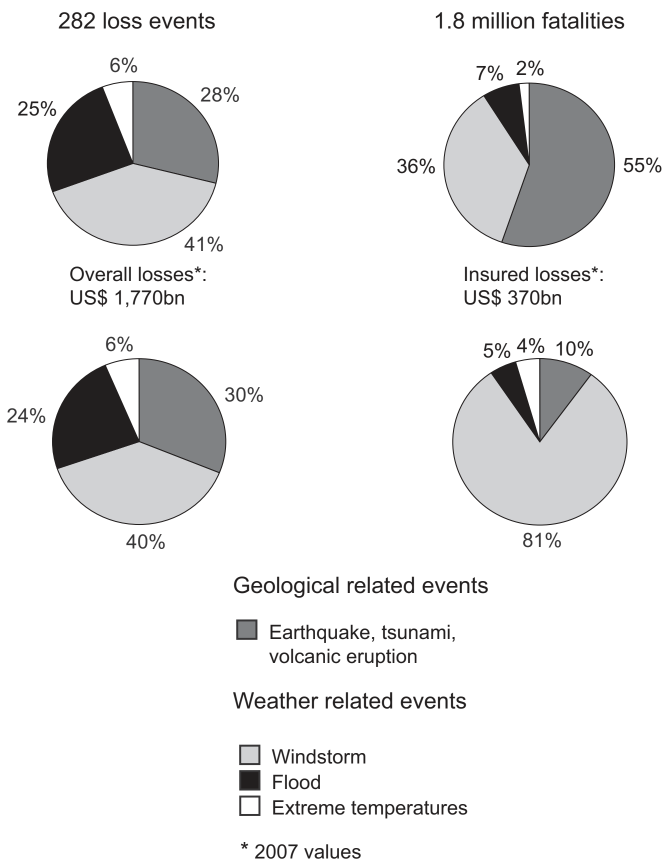

Figure 1.2 Great natural disasters 1950–2007: percentage distribution worldwide (source: Munich Re, NatCatSERVICE).

affected; a call for international assistance; and declaration of a state of emergency.

The damage related to floods is direct and indirect. Deaths of people and animals, damage to houses, properties, and standing crops, damage to physical infrastructure, etc. may be the direct consequence of floods. Other effects, such as a change in ecosystem or spread of diseases, may be indirect damage due to floods.

Throughout the world, floods are inflicting substantial damage year after year. According to the information presented in Figures 1.4 to 1.6 and the statistics of the International Red Cross organization, the average number of people who suffered from flood damage during the period from 1973 through to 1997 amounted to more than 66 million a year. This makes flooding the worst of all natural disasters (including earthquakes and drought). The average number of people affected by flooding for the five-year period from 1973 through to 1977 was 19 million and escalated sharply to 111 million for the period 1988 through 1992 and still further to 131 million for the 1993 to 1997 five-year period. The average death toll per year has been recorded as approximately 7,000 people for the last 25 years. In 1998 alone, this figure reportedly came close to 30,000.

A typology for floods is provided in Table 1.1 with estimates of the frequency of occurrence for the period between 1985 and 2009. More than 90% of floods are attributed to meteorological processes, with hydrologic types only contributing about 5% of the events.

Floods are the most common and widespread of all natural disasters, besides fire. They are also the number one killer. Flood disasters account for about a third of all natural disasters (by

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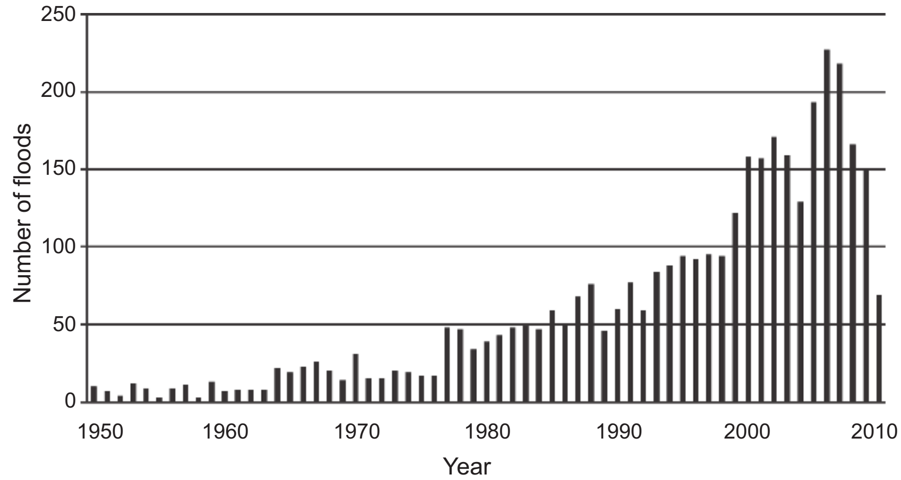

Figure 1.3 The number of flood disasters (source: EM-DAT CRED).

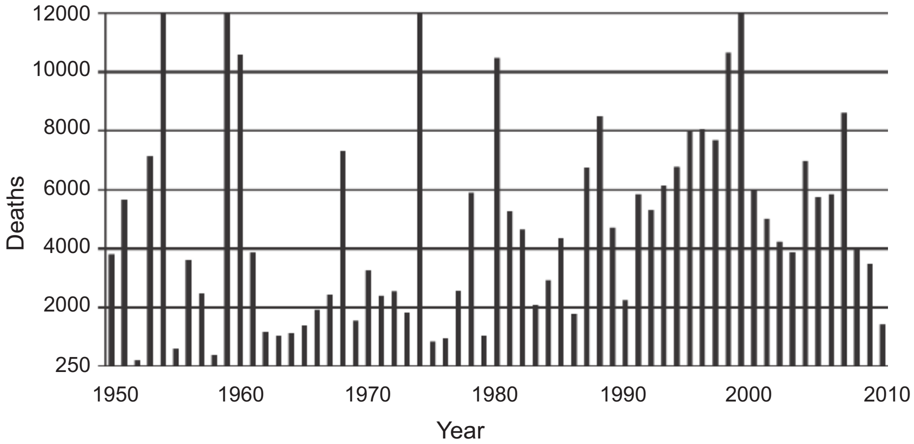

Figure 1.4 The total number of deaths caused by flood disasters (source: EM-DAT CRED).

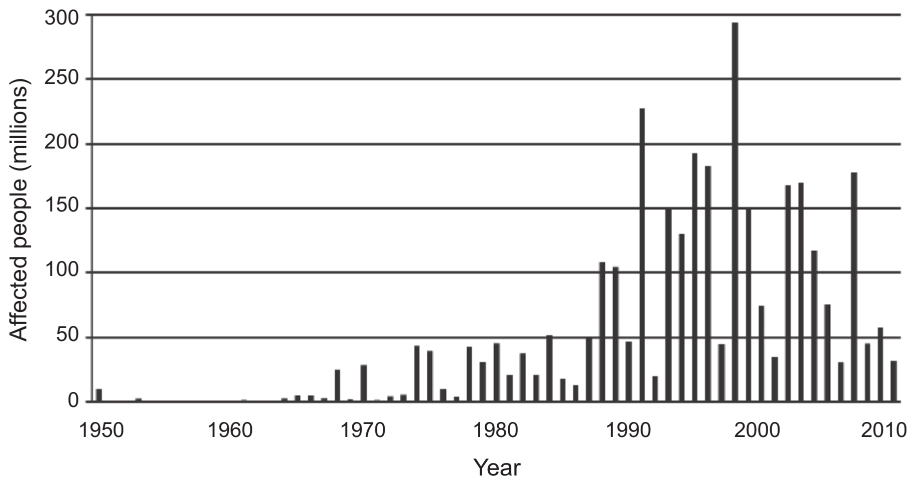

Figure 1.5 The total number of people affected by flood disasters (source: EM-DAT CRED).

Table 1.1 *Types of floods and their frequency of occurrence 1885–2009*

		Number	Frequency (%)	Total for class (%)
Human induced	Dam/levee break	47	1.34	1.34
Natural event	Avalanche-related	2	0.06	0.14
	Landslide	1	0.03	
	Outburst flood	2	0.06	
Hydrologic	Rain on snow	84	2.40	4.97
	Snowmelt	60	1.72	
	Ice jam/breakup	30	0.86	
Meteorological	Brief torrential rain	297	8.49	92.40
	Extra-tropical storm	19	0.54	
	Heavy rain	2235	63.89	
	Monsoon rain	280	8.00	
	Torrential rain	27	0.77	
	Tropical cyclone	348	9.95	
	Tropical storm	26	0.74	
Other	Tidal surge	4	0.11	1.14
	Not determined	36	1.03	
Total		**3498**		**100**

Source: the Dartmouth Flood Data Observatory

number and economic losses). They are responsible for over half of the deaths associated with all such disasters.

The estimates of damage by floods given here are estimates in the pure sense of the word. It is very difficult to calculate the damage from floods in terms of numerical values due to their wide regional coverage and also due to the fact that much of the damage (e.g., ecological damage, human pain, suffering, deaths, distress) cannot be directly expressed in terms of monetary values.

Floods form one of the most important parts of the world's natural disasters today, and there is an increasing trend in the resulting damage and deaths due to them. The flood disasters that were strongly evident throughout the second millennium have always been a part of the human experience. They are going to continue to be so in the third millennium. They continue to be destructive and they are more widespread and harmful now than in the past.

1.2 PROBLEM CONTEXT

The beginning of the third millennium is characterized by the major and widespread change known as the ***global change***. It encompasses the full range of global issues and interactions concerning natural and human-induced changes in the Earth's environment. In more detail, it is defined by the US Global Change Research Act of 1990 as "changes in the global environment – including alterations in climate, land productivity, oceans or other water resources, atmospheric chemistry, and ecological systems – that may alter the capacity of the Earth to sustain life." Global change issues include understanding and predicting the causes and impacts of, and potential responses to: long-term climate change and greenhouse warming; changes in atmospheric ozone and ultraviolet (UV) radiation; and natural climate fluctuations over seasonal to inter-annual time periods. Other related global issues include desertification, deforestation, land use management, and preservation of ecosystems and biodiversity. They are all directly related to flooding. Flood hazards and disasters have always been part of human history. They will continue to be so into the future. In the context of global change they are as much a

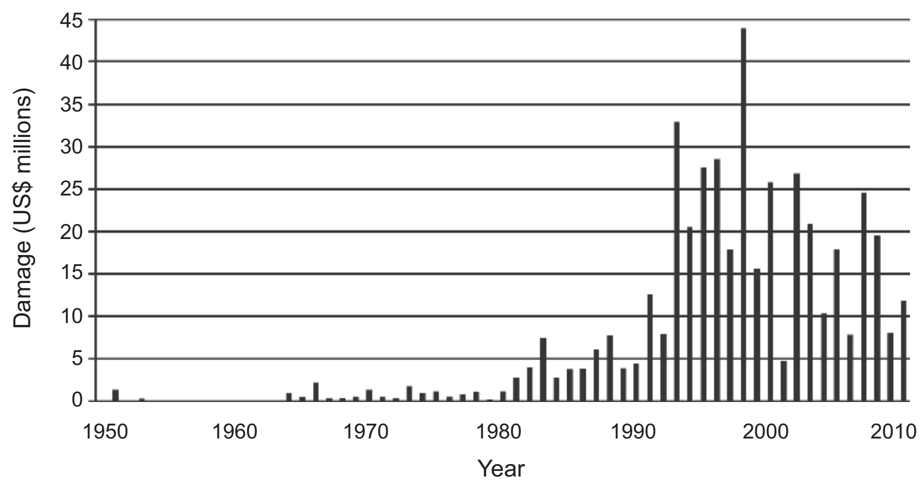

Figure 1.6 The total estimated damage (US$) caused by flood disasters (source: EM-DAT CRED).

part of the history of humankind as population growth, settlement, industrialization, computerization, and repeated cycles of recession and expansion. Flood hazards and disasters are an intrinsic component of accumulated cultural experience which manifests itself in complex social structures and practices. Flood hazard and risk are inherent in these structures and practices. The key issue for the global community today is the extent to which flood hazards and disasters can be contained and reduced.

Floods as physical features are most affected by ***climate change*** (a very detailed discussion of climate change and risk of flooding follows in Chapter 2). Many of the impacts of climate variations and climate change on society, the environment, and ecosystems are caused by (i) changes in the frequency or intensity of extreme weather and climate events, and (ii) sea level rise. The IPCC Fourth Assessment Report (IPCC, 2007) concluded that many changes in extremes had been observed since the 1970s as part of the warming of the climate system. These included: more frequent hot days, hot nights, and heat waves; fewer cold days, cold nights, and frosts; more frequent heavy precipitation events; more intense and longer droughts over wider areas; an increase in intense tropical cyclone activity in the North Atlantic; and sea level rise.

Recent climate research has found that rain is more intense in already-rainy areas as atmospheric water vapor content increases (The Copenhagen Diagnosis, 2009). Recent changes have occurred faster than predicted by some climate models, emphasizing that future changes could be more severe than predicted. In addition to the increases in heavy precipitation, there have also been observed increases in drought since the 1970s. This is consistent with the decrease in mean precipitation over land in some latitude bands. The intensification of the global hydrologic cycle with climate change is expected to lead to further increases in precipitation extremes, both increases in very heavy precipitation in wet areas and increases in drought in dry areas. While precise predictions cannot yet be given, current studies suggest that heavy precipitation rates may increase by 5–10% per °C of warming, similar to the rate of increase of atmospheric water vapor.

Population density in coastal regions and islands is about three times higher than the global average. Currently 160 million people live less than 1 meter above sea level. This allows even a small sea level rise to have disastrous consequences. Effects may be caused by coastal erosion, increased susceptibility to storm surges and resulting flooding, groundwater contamination by salt intrusion, loss of coastal wetlands, and other issues. Sea level rise is an inevitable consequence of global warming for two main reasons: ocean water expands as it heats up, and additional water flows into the oceans from the ice that melts on land. Since 1870, global sea level has risen by about 20 centimeters (IPCC, 2007). The average rate of rise for 1993–2008 as measured by satellite is 3.4 millimeters per year, while the IPCC projected a best estimate of 1.9 millimeters per year for the same period. Actual rise has thus been 80% faster than projected by models (Rahmstorf *et al.*, 2007). Future sea level rise is highly uncertain. The main reason for the uncertainty is in the response of the big ice sheets of Greenland and Antarctica. Sea level will continue to rise for many centuries after global temperature is stabilized, since it takes that much time for the oceans and ice sheets to fully respond to a warmer climate. The future estimates highlight the fact that unchecked global warming is likely to raise sea level by several meters in the coming centuries, leading to the loss of many major coastal cities and entire island states.

The Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (2009) reports that the world population, at 6.8 billion in 2009, is projected to reach 7 billion in late 2011 and 9 billion in 2050. Most of the additional 2.3 billion people expected by 2050 will be concentrated in developing countries, whose population is projected to rise from 5.6 billion in 2009 to 7.9 billion in 2050. The world is undergoing the largest wave of ***population and urban growth*** in history. In 2008, for the first time in history, more than half of the world's population was living in towns and cities. By 2030 this number will swell to almost 5 billion, with urban growth concentrated in Africa and Asia. While mega-cities have captured much public attention, most of the new growth will occur in smaller towns and cities, which have fewer resources to respond to the magnitude of the change. In principle, cities offer a more favorable setting for the resolution of social and environmental problems than rural areas. Cities generate jobs and income. With good governance, they can deliver education, health care, and other services more efficiently than less densely settled areas simply because of their advantages of scale and proximity. Cities also present opportunities for social mobilization and women's empowerment. Most of the world cities are along rivers, lakes, and ocean shores. The first attractions of such locations were as sources of food and drinking water. Later, the attractions also included water for irrigation and transportation. In the present, the closeness to water also provides power generation, commerce, and recreation. Riverbanks and flood plains are also attractive for agriculture, aesthetics, and as a way of disposing of wastes. Over several thousand years cities, settlements, and other infrastructure have increasingly encroached into the floodplains. Negative impacts of flood disasters are directly related to population trends and changes. A larger number of people translates directly into larger exposure and potentially higher risk from flooding.

Population and climate change are connected. Most climate change is attributed to anthropogenic impacts. Flood disasters, climate change, and population interactions will have one more dimension of complexity in the future – climate migrations. One of the observations of the IPCC (2007) is that the greatest single impact of climate change could be on human migration – with millions of people displaced by shoreline erosion, coastal flooding, agricultural disruption, etc. Since 2007 various analysts have tried to put numbers on future flows of climate migrants (sometimes called "climate refugees"). The most widely repeated prediction is 200 million by 2050 (IOM, 2008). But repetition does not make the number any more accurate. The scientific argument for climate change is increasingly confident. The consequences of climate change for human population distribution are unclear and unpredictable. The available science translates into a simple fact – the population of the world today is at higher level of risk. The disasters that will move people have two distinct drivers: (i) climate processes such as sea level rise, salinization of agricultural land, desertification, and growing water scarcity, and (ii) climate hazard events such as flooding, storms, and glacial-lake outburst floods. It is necessary to note that non-climate drivers, such as government policy, general population growth, and community-level resilience to natural disaster, are also important. All contribute to the degree of vulnerability people experience. The problem is one of time (the speed of change) and scale (the number of people it will affect).

Issues of ***sustainable development*** were drawn closer to water resources systems management after the publication of the Brundtland Commission's report "Our Common Future" (WCED, 1987), which introduced the concept of sustainable development as "The ability to meet the needs of the present, without compromising the needs of future generations." This vision of sustainable development may never be realized, but it is clearly a goal worthy of serious consideration. There is an increasing realization that exposure and vulnerability of population and environment to flooding are important dimensions of sustainable communities.

Applying principles of sustainability to management of flood risks requires major changes in the objectives on which decisions are based and an understanding of the complicated interrelationships between existing ecological, economic, and social factors. The broadest objectives for achieving sustainability are environmental integrity, economic efficiency, and equity (Simonovic, 2009). Another important aspect of sustainable flood risk management is the challenge of time (i.e., identifying and accounting for long-term consequences). We are failing to provide basic flood protection for a large portion of the world population, and therefore are not at the starting point in terms of dealing with the needs of future generations. For some developments, the prediction of long-term consequences is difficult. The third aspect of the sustainable flood risk management context is the change in procedural policies (implementation). Pursuing sustainable flood risk management through the implementation of structural projects and use of non-structural solutions will require major changes in both substantive and procedural policies. The diverse policy questions raised include: How should the flood risk management decision methods and processes be used? What should be the reliance on market as opposed to regulatory mechanisms? And what should be the role of public and interest groups in flood risk management decision-making?

Flood risk management involves complex interactions within and between the natural environment, human population (actions, reactions, and perceptions), and built environment (type and location). A different thinking is required to address the complexity of flood risk management. Mileti (1999, page 26) and Simonovic (2011, page 48) strongly suggest adaptation of a global ***systems perspective***. Systems theory is based on the definition of a system – in the most general sense – as a collection of various structural and non-structural elements that are connected and organized in such a way as to achieve some specific objective through the control and distribution of material resources, energy, and information. The basic idea is that all complex entities (biological, social, ecological, or other) are composed of different elements linked by strong interactions, but a system is greater than the sum of its parts. This is a different view from the traditional analytical scientific models based on the law of additivity of elementary properties that view the whole as equal to the sum of its parts. Because complex systems do not follow the law of additivity, they must be studied differently. A systemic approach to problems focuses on interactions among the elements of a system and on the effects of these interactions. Systems theory recognizes multiple and interrelated causal factors, emphasizes the dynamic character of processes involved, and is particularly interested in how a system changes with time – be it a flood, floodplain, or disaster-affected community. The traditional view is typically linear and assumes only one, linear, cause-and-effect relationship at a particular time. A systems approach allows a wider variety of factors and interactions to be taken into account. Using a systems view, Mileti (1999) and Simonovic (2011) state that flood disaster losses are the result of interactions among three systems and their many subsystems: (i) the Earth's physical systems (the atmosphere, biosphere, cryosphere, hydrosphere, and lithosphere); (ii) the human systems (e.g., population, culture, technology, social class, economics, and politics); and (iii) the constructed systems (e.g., buildings, roads, bridges, public infrastructure, and housing).

All of the systems and subsystems are dynamic and involve constant interactions between and among subsystems and systems. All human and constructed systems and some physical ones affected by humans are becoming more complex with time. This ***complexity*** is what makes flood disaster problems difficult to solve. The increase in the size and complexity of the various systems is what causes increasing susceptibility to disaster losses. Changes in size and characteristics of the population and changes in the constructed environment interact with changing physical systems to generate future exposure and define future disaster losses. The world is becoming increasingly complex and interconnected, helping to make disaster losses greater (Homer-Dixon, 2006).

The first component of the complexity paradigm is that flood risk management problems in the future will be more complex. Domain complexity is increasing. Further population growth, climate change, and regulatory requirements are some of the factors that increase the complexity of flood risk management problems. Flood risk management strategies are often conceived as too short-sighted (design life of dams, levees, etc.). Short-term thinking must be rejected and replaced with flood risk management schemes that are planned over longer temporal scales in order to take into consideration the needs of future generations. Planning over longer time horizons extends the spatial scale. If resources for flood risk management are not sufficient within an affected region, transfer from neighboring regions should be considered. The extension of temporal and spatial scales leads to an increase in the complexity of the decision-making process. Large-scale flood risk management processes affect numerous stakeholders. The environmental and social impacts of complex flood risk management solutions must be given serious consideration.

The second component of the complexity paradigm is the rapid increase in the processing power of computers. Since the 1950s, the use of computers in water resources management has grown steadily. Computers have moved from data processing, through the user's office and into information and knowledge processing. Whether the resource takes the form of a laptop PC or a desktop multiprocessing workstation is not important any more. What is important is that the computer is used as a partner in more effective flood risk management (National Research Council, 1996; Global Disaster Information Network, 1997; Stallings, 2002). The main factor responsible for involving computers in flood risk decision-making processes is the treatment of information as the sixth economic resource (besides people, machines, money, materials, and management).

The third component of the complexity paradigm is the reduction in the complexity of contemporary systems tools. The most important advance made in the field of management in the last century was the introduction of systems analysis. Systems analysis is defined here as an approach for representing complex management problems using a set of mathematical planning and design techniques. Theoretical solutions to the problems can then be found using a computer. In the context of this book, systems analysis techniques, often called "operations research," "management science," and "cybernetics," include simulation and optimization techniques that can be used in the four-phase flood risk management cycle (discussed in detail in Section 1.3). Systems analysis is particularly promising when scarce resources must be used effectively. Resource allocation problems are very common in the field of flood risk management, and affect both developed and developing countries, which today face increasing pressure to make efficient use of their resources.

1.3 FLOOD RISK

The terms "floods," "flooding," "flood hazard," and "flood risk" cover a very broad range of phenomena. Among many definitions of floods that do not incorporate only notions of *inundation* and *flood damage*, for the purpose of this text I will stay with the definition provided by Ward (1978) that a flood is a body of water which rises to overflow land which is not normally submerged. This definition explicitly includes all types of surface inundation, but flood damage is addressed only implicitly in its final three words. Both inundation and damage occur on a great range of scales.

According to Smith and Ward (1998) the impact of floodwaters through deposition and erosion, or through social and economic loss, depends largely on the combination of water quality, depth, and velocity. Flood hazards result from the potential for extreme flooding to create an unexpected threat to human life and property. When severe floods occur in areas occupied by humans, they create natural disasters, which may involve the loss of human life and property together with disruption to existing activities of urban or rural communities. Flooding of a remote, unpopulated region is an extreme physical event – usually only of interest to hydrologists.

Terms such as "flood risk" and "flood losses" are essentially our interpretations of the negative economic and social consequences of natural events. Human judgment is subject to value systems that different groups of people may have and therefore these terms may be subject to different definitions. The flood risk, at various locations, may be increased by human activity – such as inappropriate land use practices. Also, the flood risk may be reduced by flood management structures and/or effective emergency planning. The real flood risk therefore, stems from the likelihood that a major hazardous event will occur unexpectedly and that it will impact negatively on people and their welfare (Smith and Ward, 1998). Flood hazards result from a combination of physical exposure and human vulnerability to flooding. Physical exposure reflects the type of flood event that can occur, and its statistical pattern, at a particular location. Human vulnerability reflects key socio-economic factors, such as the number of people at risk on the floodplain, the extent of flood defense works, and the ability of the population to anticipate and cope with flooding.

The philosophical discussion of risk definition is well documented in Kelman (2003). It ends with the statement that to understand risk, we must understand ourselves. For the purpose of this text the formal definition of ***flood risk*** is a combination of the chance of a particular event with the impact that the event would cause if it occurred. Flood risk therefore has two components – the chance (or probability) of an event occurring and the impact (or consequence) associated with that event. The consequence of an event may be either desirable or undesirable. In some, but not all, cases (Sayers *et al.*, 2002), therefore, a convenient single measure of the importance of a flood risk is given by:

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

If either of the two elements in (1.1) increases or decreases, then risk increases or decreases respectively.

It is important to avoid the trap that risks with the same numerical value have equal significance, since this is often not the case. In some cases, the significance of a risk can be assessed by multiplying the probability by the consequences. In other cases it is important to understand the nature of the risk, distinguishing between rare, catastrophic events and more frequent, less severe events. For example, risk methods adopted to support the targeting and management of flood warning represent risk in terms of probability and consequence, but low probability/high consequence events are treated very differently than high probability/low consequence events. An additional factor to include is how society or individuals perceive a risk (a perception that is influenced by many factors including, for example, the availability of insurance, government assistance, or similar) and uncertainty in the assessment.

1.4 HOW DO WE MANAGE FLOOD RISK?

In many countries flood risk management is evolving from traditional approaches based on design standards to the development of risk-based decision-making, which involves taking account of a range of loads, defense system responses and impacts of flooding (Sayers *et al*., 2002). The difference between a risk-based approach and other approaches to design or decision-making is that it deals with outcomes. Thus, in the context of flooding it enables intervention options to be compared on the basis of the impact that they are expected to have on the frequency and severity of flooding in a specified area. A risk-based approach therefore enables informed choices to be made based on comparison of the expected outcomes and costs of alternative courses of action. This is distinct from, for example, a standards-based approach that focuses on the severity of the load that a particular flood defense is expected to withstand.

The World Meteorological Organization (WMO, 2009) is promoting the principle of integrated flood management – IFM – that has been practiced at many places for decades. Integrated flood management integrates land and water resources development in a river basin and aims at maximizing the net benefits from the use of floodplains and minimizing loss of life from flooding. Globally, both land – particularly arable land – and water resources are scarce. Most productive arable land is located on floodplains. When implementing policies to maximize the efficient use of the resources of the river basin as a whole, efforts should be made to maintain or augment the productivity of floodplains. On the other hand, economic losses and the loss of human life due to flooding cannot be ignored. Integrated flood management recognizes the river basin as a dynamic system in which there are many interactions and flux between land and water bodies. In IFM the starting point is a vision of what the river basin should be, followed by the identification of opportunities to enhance the performance of the system as a whole. Integrated flood management takes a participatory, cross-sectoral and transparent approach to decision-making. The defining characteristic of IFM is integration, expressed simultaneously in different forms: an appropriate mix of strategies, carefully selected points of intervention, and appropriate types of intervention (structural or non-structural, short or long term). An IFM plan should address the following six key elements: (i) Manage the water cycle as a whole; (ii) integrate land and water management; (iii) manage risk and uncertainty; (iv) adopt a best mix of strategies; (v) ensure a participatory approach; and (vi) adopt integrated hazard management approaches.

Flood risk management, according to Equation (1.1), aims to reduce the likelihood and/or the impact of floods. Experience has shown that the most effective approach is through the development of flood risk management programs (Simonovic, 2011) incorporating the following elements:

- *Prevention*: preventing damage caused by floods by avoiding construction of houses and industries in present and future flood-prone areas; by adapting future developments to the risk of flooding; and by promoting appropriate land use, agricultural, and forestry practices.
- *Protection*: taking measures, both structural and non-structural, to reduce the likelihood of floods and/or the impact of floods in a specific location.
- *Preparedness*: informing the population about flood risks and what to do in the event of a flood.
- *Emergency response*: developing emergency response plans in the case of a flood.
- *Recovery*: returning to normal conditions as soon as possible and mitigating both the social and economic impacts on the affected population.

A change to proactive flood risk management requires identification of the risk, the development of strategies to reduce that risk, and the creation of policies and programs to put these strategies into effect.

1.5 SYSTEMS VIEW OF FLOOD RISK MANAGEMENT

Flood risk management is a part of all social and environmental processes aimed at minimizing loss of life, injury, and/or material damage. Mileti (1999) and Simonovic (2011) advocate a systems view of flood risk management processes in order to address their complexities, dynamic character, and interdisciplinary needs of management options. A primary emphasis of systems analysis in flood risk management is on providing an improved basis for effective decision-making. A large number of systems tools, from simulation and optimization to multi-objective analysis, are available for formulating, analyzing, and solving flood risk management problems.

The question I would like to answer in this section is: What are we trying to manage? We keep trying to manage environments (water, land, air, etc.). We keep trying to manage people within environments. It seems that every time we push at one point, it causes unexpected change elsewhere – the first fundamental systems rule. Perhaps it is time to sit back and rethink what we are trying to manage.

A model**:** In order to apply a continuous improvement approach to flood risk management it is essential to have a way of thinking – a model – of what is being managed. Without this it is not possible to see where energy or resources are being wasted, or might significantly alter outcomes. Up to now, no such general model has been proposed, let alone accepted, as a basis for predicting outcomes from different flood risk management interventions, and their combinations.

The system in our focus is a social system. It describes the way floods affect people. The purpose of describing the system is to help clarify the understanding and determine the best points of systems intervention.

Management systems principles**:** The flood risk management system comprises four linked subsystems: individuals, organizations, and society, nested within the environment. Individuals are the actors that drive organizations and society to behave in the way they do. They are decision-makers in their own right, with a direct role in mitigation, preparedness, response, and recovery from flooding. Organizations are the mechanism people use to produce outcomes that individuals cannot produce. Organizations are structured to achieve goals. Structure defines information and/or resource flows and determines the behavior of the organization. The concept of society is different from those of individuals and organizations, being more difficult to put boundaries around. In general, society itself is a system of which individuals and organizations are subsets and contains the relationships people have with one another, the norms of behavior, and the mechanisms that are used to regulate behavior. The environment includes concrete elements such as water and air, raw materials, natural systems, etc. It also encompasses the universe of ideas, including the concept of "future." This concept is important in considering flood risk management – it is the expectation of future damage and future impacts that drives concern for sustainable management of flood disasters.

Management principle 1: To achieve sustainable management of flood risk, interactions between the four subsystems: individual, organization, society and environment, must be appropriately integrated.

A second principle we can use in developing our framework is that we can order systems inputs and outputs into three categories: resources, information, and values. These connect individuals, organizations, society, and environment, linking the four subsystems. Only information and resources flow link people and organizations. Value systems are influenced by these two flows, but operate in a different way. Value systems are generated within the individual or organization but feed off information and resource flows.

Management principle 2: Two flows – resource flows and information flows – link the individual, organization, society, and environment subsystems. Value systems are the means through which different values are attached to information and resource flows.

All open systems require input of energy – resources – to produce output. The need to constantly access resources is a major mechanism for the operation of subsystems. Each subsystem relies on other subsystems and on the environment for its resources. In an ideal state, the goals of each subsystem, and performance relative to those goals, must represent a gain for other subsystems for all to continue to receive resources. The physical environment exerts passive pressure on the subsystems to ensure fit. In addition, the environment can limit the action by running out of a resource or by changing circumstances to make the resource more precious – for example changing climate.

Management principle 3: The ongoing need of subsystems for resources from one another sets the limits of their exploitation of one another and of the environment, and is a determinant of behavior within the system.

Information is used by each of the subsystems to make decisions required to ensure fit with other subsystems and the environment. Without flows of information from outside the system – or subsystem – the system must rely on its own internal information (knowledge) to make decisions. Such a circumstance increases the risk that the subsystem will drift out of fit with its context. Regardless, it constantly receives signals from the outside world, and is itself sending signals to other systems. Well-functioning systems have structures built into them to capture relevant information and use that information to maximize their chances of utilizing resources to achieve their systems goals.

Management principle 4: Information is used by subsystems to make decisions intended to ensure fit with the needs of other subsystems and the environment.

Data do not in themselves have meaning. A process of interpretation occurs between information and meaning, and this process is driven by existing values. Value systems determine what individuals, organizations, and societies find important: (i) the sorts of resources they will pursue; and (ii) the interpretation of information received and used. Value systems are embedded in the culture of society and organizations, and in the values held by individuals, and they determine how subsystems behave. Use of value systems may be triggered by information, and shaped by flow of resources.

Management principle 5: Values provide meaning to information flows that are then used to determine resource use by subsystems.

The reality of linking mechanisms indicates that it is the availability of resources that largely conditions choice. It is information about availability that signals to the decision-maker (individuals, organizations, or society) whether it is implementing appropriate management strategies. It is through the process of optimizing resource access that learning takes place and significant changes in culture and values are achieved. So, the most powerful management strategies will go directly to resource access, and will initiate signals that show which social or environmental performance will allow for access to resources on improved terms.

Management principle 6: The most effective management strategies for sustainable management of flood risk are those that condition access to resources.

Each subsystem utilizes different mechanisms for minimizing negative impacts of flood disasters. Within each subsystem there are many different interactions and many different options to optimize resource use.

***No "right" management strategy*:** Flood risk management is a process of managing behavior. There is no one strategy that will be optimal for any situation. Neither regulation, nor economic incentives, nor education, nor shifts in property rights, is the "right" management strategy. What will work will vary with the social system being managed, in response to three variables: the information and resource flows, and the value systems that are in place. The challenge for the flood risk manager is to manage these three elements, across individuals, organizations, and the society and within the environment, to achieve the most effective outcome that is possible.

Management principle 7: More intensive focus on the systems view of flood risk management will accelerate understanding of what management strategies work, and particularly why they might work.

For example, when one program deals with economic incentives, another deals with improving information flows, and a third is focused on regulatory enforcement, it is very easy to believe that they are focused on different aspects with fragile links. What is necessary is a systems model to make sense of the interactions and dynamics that are being managed. This will allow us to learn from what we are so "clumsily" doing, so that eventually we can do it better.

1.6 CONCLUSIONS

Flood risk management involves complex interactions within and between the natural environment, human population (actions, reactions, and perceptions) and built environment (type and location). A different thinking is required to address the complexity of flood risk management. Adaptation of a global systems perspective is strongly recommended. For the purpose of this text the formal definition of flood risk is a combination of the chance of a particular event with the impact that the event would cause if it occurred. Flood risk management aims to reduce the likelihood and/or the impact of floods. Experience has shown that the most effective approach is through the development of flood risk management programs incorporating prevention, preparedness, emergency response, and recovery to normal conditions.

A change to proactive flood risk management requires identification of the risk, the development of strategies to reduce that risk, and the creation of policies and programs to put these strategies into effect. Flood risk management is a part of all social and environmental processes aimed at minimizing loss of life, injury, and/or material damage.

A systems view of flood risk management is recommended in order to address the complexity, dynamic character, and interdisciplinary needs of management options. A primary emphasis of systems analysis in flood risk management is on providing an improved basis for effective decision-making. A large number of systems tools, from simulation and optimization to multiobjective analysis, are available for formulating, analyzing, and solving flood risk management problems. The main objective of this book is to present a variety of systems tools for flood risk management.

1.7 EXERCISES

1.1. Describe the largest flood disaster experienced in your region.

   a. What were its physical characteristics?
   b. Who was involved in the management of the disaster?
   c. What is, in your opinion, the most important flood management problem in your region?
   d. What lessons can be learned from the past management of flood disasters in your region?
   e. What are the most important principles you would apply in future flood disaster management in your region?

1.2. Review the literature and find a definition of integrated flood management. Discuss the example from Exercise 1.1 in the context of this definition.

1.3. Discuss characteristics of the flood disaster from Exercise 1.1.

   a. What are the complexities of the problem in Exercise 1.1?
   b. Identify some uncertainties in the problem.
   c. Can you find some data to illustrate the natural variability of regional conditions?
   d. How difficult is it to find the data? Why?