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Editorial

Issues and Challenges in Flood Risk Management—Editorial for the Special Issue on Flood Risk Management

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Abstract: Recent flood-related disasters (Japan, Thailand, US, Australia) emphasize the need for an effective management of flood risks. As an introduction to this special issue, this editorial summarizes some of the key challenges in the field. Flood risk management needs to recognize the interconnections between infrastructures, economic systems and the role of human factors in assessing and managing the risk. The challenge for flood management in the future is to develop robust and resilient solutions that perform well in uncertain future conditions.

Keywords: flood management; flood risk; challenges

1. Background

The year 2011 was characterized by a number of flood-related disasters with severe human and economic impacts. Floods that occurred in early 2011 led to substantial damages in the Brisbane region in Australia, and highlighted the challenge engineers have to both balance water resource supply and flood management [1]. The Tohoku earthquake and tsunami that occurred in March of that year affected large parts of the coast of Japan and resulted in more than 15,000 fatalities. In spring, record levels of rainfall combined with spring snowmelt led to severe flooding in the Mississippi river Basin (US). Although this enormous flood event led to several billions of dollars of damage it has been estimated the extensive flood management infrastructure saved 10 million acres of land and nearly one million structures from inundation while preventing more than $110 billion in damages [2]. During summer and autumn, Thailand was severely disrupted by prolonged flooding that occurred in the Chao Praya River Basin. The damage is estimated to be more than US $45 billion [3], making it one of the most costly disasters in history. On a global scale the losses due to floods and other natural disasters are increasing [4]. One of the most important drivers of this trend is the increase of population and economic values in flood-prone areas in coastal, riverine and delta regions [5].

These events emphasize the need for an effective management of flood risks. This special issue aims to contribute to the field by discussing state-of-the-art approaches that cover various aspects of flood risk management. We highlight a number of challenges for flood risk management in the twenty-first century that have emerged from recent events and literature, and how the papers in this special issue provide new insights and approaches to addressing aspects of these challenges.

2. Challenges in Flood Risk Management

In this rapidly changing world, it is necessary to expand the definition of flood risk management to recognize the important challenges faced by modern policy makers, practitioners and scientists. Flood risk management must recognize the increasing interconnectivity between physical infrastructure and economic systems and the important role of human factors in determining flood risk. Innovative technologies are emerging to help manage flood risk, but these are not always straightforward to implement and technology alone will not address all our challenges.

2.1. Management and Maintenance of Flood Management Systems

All over the world we see problems in achieving effective management and maintenance of flood management systems. After the catastrophic flooding of New Orleans due to hurricane Katrina in the year 2005, it became apparent that many of the levees were subsided and not properly designed and maintained to withstand geotechnical failures [6]. The Netherlands is often seen as an example of "the best protected delta in the world", with high safety standards and an advanced organizational and funding structure for flood management. It is therefore striking that in the most recent safety assessment it became apparent that about one third of the primary defense mechanisms in the Netherlands are not up to standards [7]. In all these regions the investments to improve the flood management infrastructure to an acceptable level are very high, yet many countries are cutting budgets.

One of the issues in rapidly developing countries, such as Thailand, China and Vietnam is that the economy is growing very rapidly (5% to 10% per year) and societies have transformed in only a few decades from mainly agricultural to having large industrial sectors. In many instances, the flood and water management systems have not kept pace with this growth and can lag the land use and economic development by years or decades. More extreme flood events highlight the vulnerability of the rapidly developed society to flooding. Whilst such events might have caused limited damage decades ago, economic losses to industrial and commercial sectors can be enormous in the current situation.

In Thailand, a number of industrial estates near Bangkok have been developed over the last couple of decades on lands that used to be part of the floodplains of the Chao Phraya River. Although some form of flood protection was present around most of these industrial areas, seven were flooded during the 2011 event. The industries in these estates demand to be protected before the next flood season and the improvement of flood management at a wider systems scale is a challenging task that will take years to decades. In the months after the flood, stronger concrete floodwalls were erected around the estates.

These examples highlight some of the issues in the development and implementation of effective flood management systems. Several papers in this special issue present successful case studies and perspectives from different regions. Lund [8] (this issue) explores flood management issues in California and considers how governmental and funding arrangements are needed to achieve sustainable management of flood risk in the future. Dongya Sun *et al.* [9] (this issue) illustrate how non-structural measures for flash flood risk reduction have been successfully implemented in China.

2.2. Cascading Failures and Interconnected Infrastructures

Modern infrastructures are increasingly interdependent—forming a 'system of systems'. These interdependencies are inevitable: water is needed to cool power stations but power stations are vulnerable to the effects of flooding. Thus, flood events can disrupt individual infrastructures, but also result in cascading failure across different infrastructure systems, impacting over much wider spatial extents than the flood footprint. For instance, floods in the UK in 2007 resulted in 350,000 people losing water supply for up to 17 days, 42,000 people losing electricity supply for over 24 hours and over 10,000 people being stuck on a Motorway or stranded on trains [10]. Recent studies [11] show that infrastructures in the Sacramento–San Joaquin river delta in California are highly interconnected. For example, the reliability of water supply from the delta to Southern California will highly depend on the functioning of the flood protection system in the delta.

Neglecting or underestimating these interdependencies can cause planners and decision makers to underestimate overall risks. It is therefore vital that methods are developed to understand these interconnected systems risks are fully understood. The recent national scale infrastructure analysis undertaken by Hall *et al.* [12] is one such example of an emerging analytical capability. However, interdependencies also provide opportunities to increase redundancy and resilience and thereby improve efficiency and reduce costs if considered carefully [13]. In the context of flood risk management, Dawson *et al.* [14] showed that sand eroding from cliffs could benefit nearby low-lying areas in East Anglia—as it travels along the beach it provides sediment and protection to flood defenses, thereby reducing the probability of their failure. However, in that case, reductions in flood risk need to be considered against the loss of land and properties along the cliff.

2.3. Multifunctional (Flood Management) Infrastructures

Many existing flood management infrastructures, such as dikes and levees, are already multifunctional as they often have a transportation or ecological function. Some systems also have multiple flood risk management purposes. The coastal dikes in Japan have the function to protect the hinterland against both tsunamis and the storm surges generated by typhoons. In Thailand, the irrigation system in the Lower Chao Phraya river basin that consists of canals, dikes and structures, also serves as a flood management system during extreme events [15]. In such situations these systems need to be designed to perform well under multiple hazards and loading situations to achieve their objectives.

In many areas there is a need to adapt the flood management infrastructure to account for climatic and socio-economic drivers (e.g., due to economic or population growth). This can lead to a conflict with existing or planned land use. In such cases multifunctional flood defenses that combine the function of flood defense with a housing, commercial or amenity function, provide opportunities to balance economic and flood risk management objectives. A proposed 'Thames Hub' provides a grander vision for combining transport, flood protection and energy generation in the estuary of the River Thames in the UK [16].

In the Netherlands, specific attention is given to so-called deltadikes (superlevees in Japan) that are wide flood defenses on which waterfront housing can be developed. For these systems several research questions remain, such as the safety of houses on a superlevee during extreme conditions, the damages due to 'controlled' overflow, the implementation of multifunctional defenses in an existing urban area and the role of local superlevees in a larger flood management system. Moreover, new concepts need to be developed for the management and maintenance of these multifunctional structures, since most management organizations are currently focused on a single task (*i.e.*, agencies responsible for flood management are not the main decision-makers in urban planning).

Perhaps the most compelling case for multi-functional flood risk management technologies is in urban areas, where space is often limited and design and aesthetics are particularly important. At smaller scales to the major infrastructure described above, water plazas and green roofs improve local air quality, provide urban cooling and reduce surface water runoff as well as offering potential water management benefits. However, the most cost-effective locations to deploy these technologies and the spatial extent over which they need to be implemented to achieve useful results needs to be much better understood.

2.4. Impacts of Floods on the Regional and Global Economy

Impacts can not only propagate through physical systems but also social and economic systems. As the events in Japan and Thailand showed, these can lead to national or even global effects. Apart from the direct impact on the Thai society and economy, the floods had global effects on the production and supply of a wide range of goods, including cars and hard drives. About 25% of all hard drives in the world are manufactured in Thailand, as a result the prices of hard drives in other parts of the world rose [4]. The economic effects of such large events will be felt after water has receded; the recovery process of the affected industries can take time and may ultimately lead to long term changes in the local economic structure.

Another indirect impact, also observed around the world, emerged after the tsunami in Japan. The nuclear accident that occurred with the Fukushima–Daishi power plant led to global discussions on the safety of nuclear power plants during extreme events. Several countries have decided to change their nuclear energy policies, postponing or cancelling investments in new nuclear power plans (Germany), or to close down most of the existing nuclear plants (Japan). The reduction in energy generation capacity in Japan led to additional economic impacts for Japanese industry that were unable to operate at full capacity [17].

Most approaches for damage estimation focus on direct damages due to physical impacts of floodwaters on structures, facilities and objects (see e.g., [18,19]). More limited research has been undertaken to characterize the effects of flood disasters to the regional or national economy [20].

Although these broader scale economic effects are complex to predict, these analyses suggest that limiting economic analysis to just direct damage components can substantially underestimate overall impacts on the economy.

2.5. Predicting and Modeling Floods: Taking into Account Human Actions

Human operations and emergency actions before, during and after a flood incident have the potential to reduce the probability of flooding as well as change the spatial properties of a flood through altering flood pathways. These actions can also significantly reduce flood damages by influencing the behavior of individuals and organizations. Flood incident management actions can include operation of dams, erecting temporary flood defenses and evacuating communities - or as in Thailand in 2011 use of the military to protect embankment structures from sabotage.

Over much longer timescales, changes in flood risk are altered by climate which alters the probability of flooding. Two papers in this special issue by Dangendorf *et al.* [21] and Mather *et al.* [22] explore some of the uncertainties associated with changes in the coastal flood management system associated with sea level rise; even more importantly, development and land management choices which can increase vulnerability and exposure to flooding. For example, analysis by Huong and Pathirana [23] in Vietnam showed that flood depths in Can Tho could increase by 20% from urbanization alone.

Accounting for this human activity in flood risk analysis is challenging because people respond and adapt their behavior to the conditions to which they are exposed (*i.e.*, they are reflexive systems). However, advances in so-called social simulation techniques are enabling flood event responses to be explored. Rijcken *et al.* [24] show how serious gaming can be used as an interactive tool, also to record stakeholder preferences. Elsewhere Dawson *et al.* [25] applied agent based modelling techniques to simulate the evacuation of a town subjected to flooding. Whilst Dawson *et al.* [26] quantified the long term change in flood risk associated with different urbanization patterns in London—highlighting that whilst sea level rise was an important driver of risk, socio-economic influences could be far greater. The role of social science and public participation to understand the role of human agency (Heintz *et al.* in this issue [27]) remains crucial. These emerging models should be used with care and where possible incorporate social science input and evidently uncertainties in modeling human agency remain. However, early results show great potential for substantially advancing our understanding of the role of people and communities in flood risk management.

3. Flood Management in an Uncertain Future

The value of a resilient flooding system is its capacity to cope with unforeseen events and longer term drivers such as global environmental change.

Recent events have exposed the vulnerability of engineered and economic systems to flooding, and also the complexity of understanding and anticipating the impact of floods. An integrated analysis of loads, defenses and inundation (see Wadey *et al.* in this issue [28]) in combination with accurate flood mapping (Gilles *et al.* in this issue [29]) and consequent impact analysis is required to better understand and quantify flood risks. Decision analyses techniques, (e.g., Mazzorana *et al.* in this issue [30]) can help policy makers grapple with the complexities of decision making.

Whilst important advances in some key challenges for flood risk management have been considered above, and reported in this issue and elsewhere, it is important to acknowledge the limits to our data, models and long term forecasts and manage flood risk accordingly. For example, van de Sande *et al.* [31] (this issue) show how the choice of a digital elevation model could greatly affect the outcomes of a flood risk assessment. Thus, it is often more desirable to seek interventions that perform acceptably well under a wider range of possible future conditions, rather than those that seem to be 'optimal' under a design event. Handling uncertainty is therefore central to sustainable and successful flood risk management. This has been at the heart of recent long-term planning for major flood infrastructure works in the Netherlands [32] and UK [33] where flexible flood risk management pathways were identified that could be implemented subject to actual sea level rise.

More generally, the robustness and resilience of flood management interventions under conditions of uncertainty can be managed through building capacity by:

(1) Continuous monitoring and analysis of the natural system, flood defenses and protected assets to understand current flood risks and how they might change in the future;
(2) Managing vulnerability and exposure of the population and built environment—for example, through awareness raising and training [34];
(3) Reducing the cost of repair, recovery and the time to respond in the event of a flood—not just through improved emergency preparation and response but by exploring alternative models such as greater local access to financial resources and more flexible governance systems [35];
(4) Keeping options open by adopting flexible, multiple use solutions and enhancing variety [36], which may involve development of adaptable engineering techniques in construction and refurbishment.

It is crucial to recognize that the flooding system must be considered broadly to include physical processes such as rainfall; man-made systems intended to convey flood discharges and resist or control inundation; economic, social, and environmental assets within a floodplain; organizations with responsibilities for flood risk management and stakeholders with an interest in flooding impacts. Therefore, the above processes must be implemented across ecological, economic, social and technological systems—essentially taking a portfolio approach to minimizing risks across society in the broadest sense.

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