Spatial Flood Risk Management

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Implementing Catchment-based Retention and Resilience on Private Land

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Mark E. Wilkinson is a senior research scientist in catchment hydrology. His research focuses on the use of Nature-Based Solutions (NBS) for mitigating and adapting to hydrological impacts of extreme events. This particularly focuses on floods, in which context NBS is also commonly referred to as Natural Flood Management (NFM), but more recently also includes droughts. He also explores the wider multi-purpose benefits associated with NBS, such as for ecosystem health (e.g., water quality, temperature). Mark has over 10 years' direct experience in NBS research, managing NFM related projects and has authored a number of peer-reviewed publications on the topic.

Vesna Zupanc is an agricultural scientist and environmental planner with over 20 years' experience in soil–water interactions, water balance, and soil and groundwater pollution. Her research on establishing flood management on agricultural lands concentrates on drainage system management, agrohydrology, changes in soil physics, transfer of pollutants with floodwaters and soil, and strategies to protect agricultural soil potential. Her current research focus is soil degradation and soil quality of reclaimed and remediated soils.

Foreword

Sally Priest

The past decade or so has witnessed a substantial increase in research on Nature-Based Solutions (NBS). Research efforts have principally concentrated on technical aspects of their efficacy and effectiveness for managing flood risk and establishing key technical solutions for having most impact. The use of the NBS concept has also evolved and broadened to not only consider rewilding and flood storage, but to incorporate inter-urban solutions and led to the adoption of terms such as blue-green and sponge cities. Work such as the development of criteria for NBS and the production of guides (e.g. USACE's *Engineering with Nature Atlas*, now in its second edition) have helped to bring NBS more into the mainstream. Their position has also risen on the political agenda with the multi-benefits of aligning the reduction of flood risks with realizing the broader goals of sustainable development and greening the environment. However, despite their potential critical importance there is a problem concerning the availability and accessibility of space on which to develop nature-based solutions. Significantly, this often involves the need to access privately owned land, and for wider community benefits, this is a key challenge for the successful application of nature-based flood risk management. It is this implementation gap that is the focus of this book and associated initiatives.

This volume is the final culmination of the Land4Flood European Union COST Action (CA16209). I have had the pleasure of witnessing how this initiative has brought together researchers, practitioners and other stakeholders to discuss key barriers, share best practices and seek transferrable solutions to NBS implementation challenges. Integrating scientific understanding from an extensive range of disciplines (e.g. hydrology, geomorphology, engineering spatial planning, geography, sociology, political science, economics, etc.), policymaking and practice-based experience of the development of NBS together with landowners and local expert knowledge of those affected has been particularly powerful in understanding the complexity of these issues. Land4Flood has utilized an array of engagement and knowledge transfer approaches to capture the attention of a range of interests, but also looked to train the next generation of scientists working in NBS to ensure that they understand the significance of private land and appreciate the value of including so called ‘lay’ knowledge and stakeholder perspectives in the debate.

The book is structured according to three key approaches to nature-based solutions and this comprehensive perspective is to be applauded. Not only is there a section considering typical measures such as flood retention, but one is also dedicated to water retention in the hinterland and efforts to improve land management and soil infiltration. Finally, the consideration of resilient cities challenges the more traditional conceptualization of NBS as being located in rural catchments on mainly agricultural land. Coupled with this comprehensive outlook is the inclusive perspective of land embracing both the biophysical and socio-political context and centralizing the role and perspectives of key stakeholders. The cross-disciplinary and international co-authorship, with physical and social scientists of many countries coming together, provides wide-ranging evidence-based examples of best practices. Adopting this collaborative approach to authorship prevents the silos often seen in academic contributions and the presentation of broader theoretical, policy and practice-oriented lessons.

Among the important conclusions of the book the following stands out. There is much we can learn from integrating disciplinary knowledge and integrating expert and lay understandings of NBS, that independently receive less recognition. Although many of the examples stress the importance of context, and it is necessary to consider the natural, socio-political, economic, legal and of course technical feasibility of any NBS options, there is much best practice available from which we can learn. So the solution or inspiration for solutions are potentially out there to solve implementation challenges if we care to look for them, and this volume is a great place to start. Finally, the Editors’ development of the concept of spatial flood risk management is a novel addition to the theoretical consideration of NBS and their place in achieving solutions. Its inclusion emphasizes the importance to consider private land and access to it for flood risk management, an aspect which has been somewhat underplayed until now.

Acknowledgement

Academics and professionals from more than 35 countries and various disciplines – covering hydraulic engineering, economics, spatial planning, governance, law, and many more – collaborate in the LAND4FLOOD network that made this book possible. LAND4FLOOD is a European COST Action project that explores the implementation of spatial flood risk management on private land.

With this book, we want to reach out to academics and high-level policy makers in water management, spatial planning, law, and other relevant disciplines that are involved in spatial flood risk management. To allow a broad dissemination, the COST Action No. CA16209 Natural flood retention on private land, LAND4FLOOD (www.land4flood.eu), supported by COST (European Cooperation in Science and Technology, www.cost.eu), funded the open access of this book.

This book results from the passion of individuals who want to find solutions to the rising flood risk in a collaborative manner across disciplines and boundaries. We, the editors, are incredibly grateful for each contribution and the discussions and exchanges within LAND4FLOOD that led to this book. In addition, we are proud that each chapter has been prepared by multiple authors from different countries. We aim with this book to not only establish the concept of spatial flood risk management, but we also hope to continue the necessary debate on the relation between land and flood risk management and encourage other academics to pick up the challenges of LAND4FLOOD.

This publication is based upon work from COST Action LAND4FLOOD, supported by COST (European Cooperation in Science and Technology).

COST (European Cooperation in Science and Technology) is a funding agency for research and innovation networks. Our actions help connect research initiatives across Europe and enable scientists to grow their ideas by sharing them with their peers. This boosts their research, career and innovation.

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1. Introduction to *Spatial Flood Risk Management: Implementing Catchment-based Retention and Resilience on Private Land*

Thomas Hartmann, Lenka Slavíková and Mark E. Wilkinson

Land is needed for flood risk management – land to store the water masses and retain it without major damage. This land is often in private ownership, i.e. it is owned by a large variety of different actors (individual owners, municipalities, etc.) rather than those responsible for flood risk reduction. This book explores the different options of where and how to store water within catchments – in the hinterland before it reaches large watercourses, along the rivers and in resilient cities. The notion of land is threefold: (a) land as a biophysical system (including hydrological aspects), (b) land as a socio-economic resource, and (c) land as a solution to flood risk management (asking for policy interventions to activate the land for measures). These three areas and the three analytical lenses allow opportunities for drawing comprehensive lessons for how to use the retention function of land strategically to reduce the impact of flooding. The focus of the book is on inland pluvial and fluvial flooding. The Global North (mainly European focused) context is considered when discussing governance strategies.

In Europe, inland flooding represents the most expensive natural disaster. The IPCC states – with "high confidence" – that damages caused by river floods will substantially increase in Europe in the next decades (IPCC, 2018). The sheer amount of damage and the vulnerability of European urban areas urge researchers and practitioners to find ways to cope with increasing flood risk. Since the 1990s, many countries in Europe have experienced multiple large inland floods within and across the borders of national states (such as the floods in 1993 and 1995 on the Rhine, in 1997 on the Oder and the Danube, and in 2002, 2006 and 2013 on the Elbe and the Danube). These floods were always caused by heavy rainfalls that usually started at the 'hydrological' roof of Europe and continued downstream.

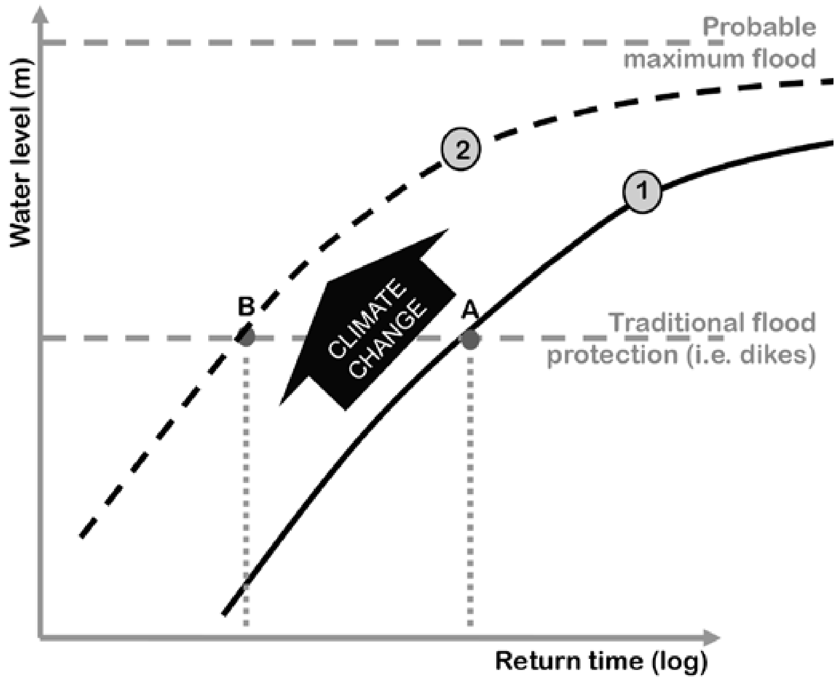

Figure 1.1 *Dynamics of flood risk*

Floods of certain water levels return statistically within certain periods (line 1 in Figure 1.1) (Bornschein and Pohl, 2018); however, return periods and their discharges are not static (Pohl, 2020). As a possible consequence of climate change, but also owing to increasing urban development in riparian areas or other changes in upstream land uses, which demands heightened and strengthened dikes (upstream), discharge flows at a given point of the river increase and the return periods shorten (line 2 in Figure 1.1).

The most prominent and prevailing approach to floods is building so-called grey infrastructure, such as dikes (Patt and Jüpner, 2013). Dikes protect and provide fertile and profitable riverside properties by keeping the water out (Petrow et al., 2006). As a result, they make many socio-economic activities along rivers possible. But (1) grey infrastructure is always designed for a specific threshold and has an inherent likelihood of failure; (2) grey infrastructure provides a sense of security which often leads to an increase in the area of land use at risk for flooding. Both of these factors ultimately increase flood vulnerability and flood hazard. The return period of the event for which a dike is designed decreases from [A] to [B] (see Figure 1.1). Consequently, dikes will be overtopped more often, and the flood protection level will decrease.

1.1 A CATCHMENT PERSPECTIVE: THREE OPTIONS TO STORE WATER

A society that keeps intensifying the use of land needs to rethink traditional flood risk management. Specifically, it needs to decide where to put the abundant water from floods in a river catchment.

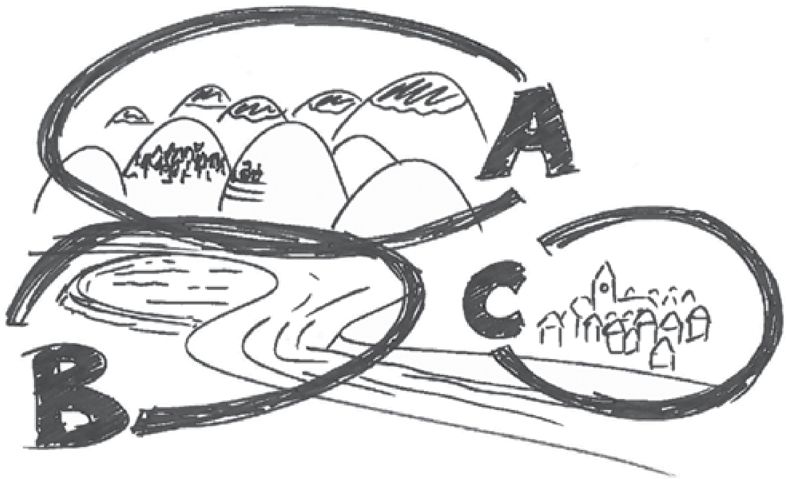

Figure 1.2 Options for water storage

From a catchment perspective, there are generally three options (Figure 1.2): [A] *decentralized water retention in the hinterland* before the water reaches larger streams and rivers;[1] [B] flood polders and washland to temporarily store the peak of a flood wave upstream of cities (*flood retention*); [C] adapted urban areas (*resilient cities*) that can be inundated without major damage. These three options have different characteristics and effects on the flood risk. Although different types of retention measures cannot entirely substitute for traditional flood protection, their value for reducing flood risk has been discussed and acknowledged in academic debate (Bruijn, 2005; Patt and Jüpner, 2013; Dadson et al., 2017; Fekete et al., 2020) and politics (Directive 2007/60/EC). The cry has been heard to make more space for rivers (Hartmann, 2012). Why is it so difficult in practice?

Nature-based solutions (NBS) such as natural water retention measures or green and blue infrastructure have been identified as promising options to ensure additional retention. It has been widely discussed that these types of measures help to reduce flood risks, and they also provide additional environmental services including increased biodiversity, microclimate regulation and recreation opportunities (Nesshöver et al., 2017; Somarakis et al., 2019). However, a common characteristic of NBS is that they often claim more land than traditional flood risk management (i.e. a retention area requires more land surface than a dike). This land, which is already being used for other purposes, is also often privately owned. Mobilizing private land for temporary flood storage means coordinating different actors and institutions in water management, essentially including landowners in management plans (Hartmann, 2012).

The important assumption of this book is that land use issues and ownership are not independent of flood risk management plans but critical for them. This perspective has largely been neglected in research and in the practice of flood risk management. Land users are often regarded as mere recipients of flood protection and not as key stakeholders (Hartmann et al., 2018). Putting them in a central position in finding flood retention solutions may help to propose and co-create new forms of temporal and spatial land uses. Synergies with other land use (ecological, agricultural) need to be identified with respect to the three retention options mentioned.

Different measures can be used for decentralized water retention in the hinterland [A], such as afforestation, improved soil infiltration, temporary storage ponds and wetlands, and agricultural and upland drain/ditch management. The possible effects on the flow discharge would not significantly affect the more extreme floods but make a greater difference during minor and average flood events (Burgess-Gamble et al., 2017; Wilkinson et al., 2019). Such flood mitigation cannot prevent floods entirely, but it can reduce negative consequences of some floods and also usually has ancillary benefits (e.g., for ecology, water quality improvements, managing soil erosion or tourism). Using such ancillary benefits can be an essential step in getting land users to collaborate on NBS implementation in the hinterland. This implies adopting a wide range of multifunctional retention measures located appropriately throughout river catchments.

A typical example of flood retention [B] along rivers is a polder or washland. The idea is to cut off the peak of a flood wave by orchestrating a controlled flooding into a designated retention area upstream of vulnerable areas (Löschner et al., 2019). Usually, such measures have been constructed as highly specialized and rather mono-functional technical measures. For larger-scale flood retention, however, this implies retention basins that not only provide temporary water storage but that also include a range of additional services including recreational opportunities and water pollution control.

Dikes are traditionally regarded as 'lines of defence'. These lines are boundaries that separate wet and dry areas. Resilient cities [C] challenge these boundaries. A flood-resilient city is able to absorb negative consequences of flooding (Begum et al., 2007; Tempels and Hartmann, 2014) – i.e. flooding cities with minimal damage (Disse et al., 2020). This requires adaptation of vulnerable land uses with direct participation of users and owners of land and buildings in flood-prone areas. Multifunctional measures (such as sustainable urban drainage systems) are needed, which enable temporary storage of excess floodwater at the local scale, but also adapting to inundations in these areas to reduce vulnerabilities and allow quicker recovery (Disse et al., 2020; Fekete et al., 2020).

1.2 DIFFERENT NOTIONS OF LAND

The first step in developing a holistic approach to flood risk management is to actively adopt and operationalize a catchment-based approach in which hydrological connectivity between distinct land use mosaics is clearly articulated. Using a catchment-based approach as mandated by both the EU Water Framework Directive (WFD) and the Flood Directive (FD) would allow NBS to be fully integrated into flood risk governance.

Unfortunately, although there is a natural science evidence base regarding the impact of NBS on flood risk reduction on the local scale, the knowledge is splintered (Dadson et al., 2017; Burgess-Gamble et al., 2017; Wilkinson et al., 2019). So, to foster the implementation of NBS options on private land, there is a need to find and implement ways to better connect academic interdisciplinary knowledge with real-world policy formulation and decision-making. Achieving this aim requires not only access to information on the physical impact of these types of soft engineering measures but also a focus on the motivations, interests, knowledge and capacity of different types of private and public actors at the local, regional and catchment levels.

Systematic transdisciplinary efforts to address the availability of ‘land for floods’ in its complexity are scarce. Usually, flood risk managers assume that property rights and land management issues are robust (unchangeable). From this perspective, the critical areas to focus on are technical issues, such as better forecasting, modelling, or disaster management. From 2017 to 2022, the LAND4FLOOD COST Action called “Natural flood retention on private land” (funded by the European Cooperation in Science and Technology programme, www.cost.eu) has aimed at building this transdisciplinary understanding consisting of experts from 35 countries. Applying the multidisciplinary views of our members, we found that land can concurrently be considered from different perspectives:

1. land as a biophysical resource;
2. land as (private) property rights;

3. land as an institutionalization of interests.

These different perspectives form separate analytical dimensions, and from each of the perspectives different challenges and opportunities to realize the three retention options emerge. At the same time, these perspectives on land are interrelated and also influence each other. Therefore, a holistic perspective on land is necessary that embraces all the mentioned aspects:

Environmental conditions (the effects of land on catchment hydrology): A comprehensive understanding of the effects of land use and land management on local and catchment-scale hydrology is needed to support programmes of measures which make use of private land to reduce downstream flood risk. The hydrologic and hydraulic expertise underlying grey infrastructure solutions for local-scale flood risk reduction is thoroughly documented and well understood. However, this expertise is incompletely integrated with the knowledge base on NBS for water retention and flood risk reduction. Furthermore, a unified framework supporting local-scale decision-making about green and grey infrastructure potential for flood risk reduction is lacking (Collentine and Futter, 2018). More critically, our understanding of the aggregate impact of local-scale land use decisions on catchment-scale flood risk is fragmented and in large part lacking. The perspective of understanding the biophysical aspects of land for water retention helps to identify hydrologic and hydraulic consequences of local-scale land management on catchment-scale flood risk reduction and develop a more comprehensive understanding of the role of land use in flood risk and the potential for enhancing retention capacity for different spatial scales ranging from individual property parcels to large catchments.

Socio-political contexts (property rights, opportunities and limitations for negotiating land for flood risk management): Increasing the flood risk management capacities of river catchments demands a better understanding of the socio-political contexts that determine the opportunities and limitations to provide land for flooding. Despite the strong public interest to increase the capacities of land for managing flooding, i.e. in order to better protect settlements and economic assets (Marshall et al., 2019), surprisingly little is known about how institutional and legal structures influence the potential to use private land for flood risk management. In particular, scientific knowledge is fragmented concerning the ownership of land at risk from flooding, the organization of property and land use rights in catchments as well as the regulation of retention services in different legal contexts. This perspective on land reveals the institutional and legal structures, which constitute the flood-related rights of property and land use. This perspective also helps to understand tensions between the collective interest to increase the flood management capacities of private land and private interests to limit the infringement on individual property rights.

Stakeholders and interests (negotiating and mobilizing processes to secure land for flood risk management): Successful implementations of measures that enhance flood-retention capacities and reduce downstream flood risks are not only hampered by the limited availability and accessibility of private land suitable for flood retention but also by the strategic use of policy instruments – both formal and informal – in order to mobilize private land more effectively for flood retention. The perspective of land as an institutionalization of interests allows using policy instruments more targeted to specific situations.

1.3 OBJECT, CONTEXT, AND PROCESS OF THREE RETENTION OPTIONS IN A CATCHMENT

In its briefest form, the three land perspectives can be understood as looking at the object of land, the context of land, and the processes for governing land. Object, context, and process thus form three analytical lenses on land that each raises specific questions for realizing the three options to store water in a catchment. This "vertical" and "horizontal" division of the problem constitutes the framework for this book.

The structure and content of chapters is based on a 3×3 matrix which uses an analytical division in hinterland retention, flood storage along the rivers, and resilient cities on the one hand, and the aspects of environmental conditions, socio-political context, and stakeholders and interests on the other. Each field in the matrix represents a chapter of the book (nine chapters together). The key issues and guiding questions (specified in Table 1.1) serve as an indication of particular chapter focus. The goal is to interconnect previously isolated knowledge domains through various disciplinary contributions in catchment-wide land governance with multi-level perspectives that consider academic and practical aspects.

1.4 CHAPTER OVERVIEW

In Chapter 2, Bourke, Wilkinson, and Srdjevic open the debate on the use and effects of NBS in the hinterland presenting measures that can be implemented in the wider catchment landscape (e.g. headwater areas) upstream of vulnerable communities highlighting the connectivity of catchments. The authors discuss the challenges in scaling up NBS but provide insights into the wider benefits these measures provide. Albrecht and Nikolić Popadić (Chapter 3) follow with a discussion on types and proportionality of legal and financial instruments to be used to ensure flood retention. The focus of the chapter is also on obstacles of implementing water retention measures in the hinterland and possible solutions from a legal perspective. The hinterland retention chapters are concluded with the contribution by Ungvári and Collentine (Chapter 4) analysing the

Table 1.1 Key issues and guiding questions of spatial flood risk management

	Environmental conditions (land as an object)	Socio-political context (land as a context)	Stakeholders and interests (land as a process)
Hinterland retention	**CHAPTER 2**	**CHAPTER 3**	**CHAPTER 4**
	Small scale measures, accumulative effects, cause and effect difficult to prove • *What measures can be used?* • *Where should measures be targeted?* • *What are the accumulative impacts of these measures at larger scales?*	Legal challenges of restricting land • *What are legal issues when designating flood emergence zones?* • *How, and to which extent can ownership rights be limited in order to apply restrictions and obligations for flood retention?*	Causality makes hard instruments difficult to apply • *Do we need quantified proof for implementing multiple multi-functional small-scale NWRM?* • *Or shall we just proceed with "likely" impacts?* • *What is the role of transaction costs in reaching flood retention up-stream?*
Flood retention	**CHAPTER 5**	**CHAPTER 6**	**CHAPTER 7**
	Controlled polders vs. room for the rivers, hydrological effects and thresholds of polders, dams, and dikes • *What scale and type of measure is needed to manage floods at the catchment scale?* • *How can these measures be modified to allow other land uses to utilize the measure at other times (e.g. farming, recreation)?*	Financial compensation & legal restrictions for using land for flood retention • *What are success and fail factors in upstream-downstream relations?* • *How to assess a fair compensation for using land for flood retention?* • *What are often overlooked issues of getting the land?*	Hard conflicts on fertile and valuable land (upstream) • *What are successes and failures of getting farmers on board?* • *Is local dialogue better/ worse than nation-wide policies?* • *Shall we make beneficiaries pay – is that the way forward?*
Resilient cities	**CHAPTER 8**	**CHAPTER 9**	**CHAPETR 10**
	Measures & civil engineering constraints • *Where should NBS measures be targeted within (crowded) urban areas?* • *What hydrological principles should be applied to future city designs?* • *Could a resilient city help to mitigate extreme events?*	The levee effect and clumsy floodplains • *Why are people settling in flood-prone areas?* • *Is this irrational or is it an efficient use of investments in flood protection that made the places inhabitable in the first place?* • *What are moral hazards, free-rider issues etc regarding the resilient city?* • *How to balance the remaining risk and enforced measures for flood adaptation?*	Intervention in the built-up area • *Does zoning regulation interact with compensation policies?* • *Shall it do that?* • *Isn't "resilient recovery" an oxymoron?*

transaction-cost problem when bargaining for upstream and downstream flood risk mitigation strategies. The distribution of these costs over time may have an impact on the effectiveness of economic instruments with respect to acceptance of small-scale retention by private landowners.

Chapter 5 by Pohl and Bezak summarizes the pros and cons of different types of retention measures along rivers from the hydrological and hydraulic perspectives. They highlight the cutting-the-peak function as the main benefit of retention. Kis, Schindelegger, and Zupanc (Chapter 6) focus on a comprehensive overview of the economic logic of financial compensations and legal restriction for land dedicated for flood retention purposes. This contribution is complemented by Hartmann, Löschner, and Macháč (Chapter 7) dealing with applicability and implementation obstacles of particular instruments for flood retention (such as land readjustment, subsidies, voluntary upstream-downstream compensations and tradable development rights (TDR) or payments for ecosystem services (PES)).

The resilient city section redirects the attention to urban areas that need to adjust to changing global environmental conditions. In Chapter 8, Rinnert, Thaler, and Jüpner offer examples for possible individual measures in cities aiming towards a resilient (re)construction organized according to so-called ‘functional units’. Halbac-Cotoara-Zamfir and Tempels in Chapter 9 focus on transformation processes towards resilient cities. They highlight existing challenges connected with the distributions of responsibilities, property rights, knowledge and skills in managing flood risks in urban areas. Finally, Hudson and Slavíková (Chapter 10) conclude with discussing (dis)incentives given to citizens via risk transfer mechanisms (recovery compensation schemes) and spatial planning policies. They focus on how such incentives (if properly designed) may contribute to resilient city production.

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NOTE

1. Ditches and drains are in this context considered part of the hinterland storage approach.

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PART I

Water retention in the hinterland

2. Nature-based solutions for flow reduction in catchment headwaters

Mary Bourke, Mark E. Wilkinson and Zorica Srdjevic

2.1 INTRODUCTION

The implementation of nature-based solutions (NBS) for flood hazard has grown in popularity across Europe. While initially programmes were applied at reach scale and demonstrated efficacy for smaller catchment areas and lower magnitude flows, data that demonstrated their efficacy at larger scale was not widely field tested (Lane, 2017; Tekidou et al., 2015). Across Europe we are now moving to catchment-scale adoption of measures. In this phase, we need to consider fully the connectivity (or lack thereof) within catchments for the operation of NBS implementation. What happens upstream will have important feedback for the plan of implementation downstream. A whole catchment approach is required, and we would recommend that it begins at the stream source where there are often low populations but high potential for slowing down the flow.

Chapters 2–4 focus on the hinterland. Hinterland is a German word meaning ‘the land behind’ (a city, a port, or similar) (Chisholm, 1908). It has been used to describe an area of land that is far from the coast, a region remote from urban areas. Here we focus our discussion on the catchment headwater. In Chapter 1, hinterland is depicted as being synonymous with the catchment headwater. In this chapter we use the term headwater.

To define the headwater, we use the longitudinally zoned approach to the drainage basin which identifies a headwater-production zone, mid-basin transfer zone, and downstream-depositional zone (Schumm, 1977). Like all reaches of rivers in a given catchment, headwater river characteristics are dependent on the nature of the watershed they drain. Important controls include climate, vegetation, geology and hydrology. In headwaters that are located in and above uplands, the length of first- and second-order streams are estimated to be >73 per cent of the basin stream channel length (Leopold et al., 1964). This larger proportion offers more opportunity for nature-based interventions in headwaters than elsewhere in the basin.

The specific NBS measures to be implemented will be dependent on the hillslope and channel characteristics and heterogeneity therein. Headwater characteristics differ within and between catchments. In general, they typically comprise: (1) hillslopes (unchannelized slopes dominated by slopewash and/or diffusive transport); (2) unchannelled hillslope concavities (serve as sediment storage and often are the source of mass movements). The first- and second-order channels may include: debris-flow channels (non-fluvial processes dominate the sediment dynamics and channel geometry); bedrock-alluvial channels (bedrock exposed or at shallow depth, alluvium is mobilized during higher flows); coarse-bed alluvial channels (unconsolidated coarse sediment); or fine-bed alluvial channels (alluvial channel bed and banks) (Wohl, 2014).

Importantly, the headwater is typically a zone where the slopes and channels are coupled as are the tributaries and mainstem. This facilitates a rapid and often continuous transfer of sediment from hillslopes to channels and results in a mass movement which may dominate sediment supply. The predominant process in the headwater zone is therefore sediment production (but can include sediment transfer and deposition). Close to the source, there is little or no stored alluvium or floodplain. Where it does occur further downstream, floodplain development is limited and occurs as longitudinally disconnected pockets. Longitudinal sediment transfer in catchment headwaters is efficient, organic matter input is direct from headwaters and channels can be dominated by large woody debris. In strongly coupled slope-channel systems, much of the sediment supply entering stream networks comes from slope failures, as well as from fluvial erosion of slopes and streambanks. In some landscapes, headwaters may run through inherited glacial deposits. In these landscapes, peak flows are unable to move the largest clasts and the channel flows around those larger rocks and pieces of wood, which increases channel roughness. Steeper headwater channels often have step-pool morphologies. However, lower gradient, meandering channels occur where finer grained sediments dominate (Church, 2013).

Source waters may originate from precipitation, glaciers, snowpacks, springs, wetland or lakes. The timing of discharge depends on the timing and type of precipitation. Snowpack storage can result in low winter discharge, rising as snow melts. Rain-on-snow events result in large peak flows.

The discharge rates of headwaters can display high spatial and temporal variability. This is dominated by the variation in inputs of precipitation, storage capacity, and the flowpaths through which shallow groundwater moves. Soil permeability exerts a strong control in headwaters as the infiltration capacity of glaciated and volcanic landscapes may be high. This contrasts with fine-grained (clay-rich) slowly draining soils that may lead to overland flow. The storage capacity of headwater basins can be exceeded if the antecedent conditions lead to saturated soils and/or precipitation intensity exceeds infiltration capacity. In these situations, runoff directly into streams results in higher peak flows during periods of long duration or intense precipitation. As contributing areas are relatively small, the instantaneous stream discharge can change quickly and peak flows can be flashy. There is limited groundwater storage and, at certain times of year, or indeed during years of lower than average precipitation, surface flow may cease.

2.2 NATURE-BASED SOLUTIONS IN HEADWATERS FOR DOWNSTREAM FLOOD REDUCTION

The specific measures that are suited to upland headwater areas depend on their geology, soils and topography. However, there are some measures that have higher efficacy in headwaters relative to the mid-basin or downstream depositional zone. Readers are directed to Environment Agency (2017) and EU (2015) for a wider description of measures suited to headwaters. Due to space limitations, we focus on peatland restoration, forests, large wood in rivers, and agricultural practice.

2.2.1 Peatland Restoration

Most European countries contain peatlands. For the greater European region, they comprise almost 10 per cent of land surfaces (1,000,000 km^2; Tanneberger et al., 2021). Their distribution shows a strong latitudinal dependency for cooler and wetter locations, with most occurring in the higher latitudes, especially in north-western Europe. Finland, Ireland and Estonia have the largest proportions, exceeding >20 per cent of their country area (Tanneberger et al., 2017). The European data have not yet been differentiated on the basis of their location within catchments, so these data do not describe the distribution in upland headwaters exclusively.

Peatland landscapes are in crisis. In a study of peatland sites in Ireland, Scandinavia, Britain, and Continental Europe, the onset of climate change (climatic drying, warming) along with human impact (burning and artificial drainage for grazing and afforestation and/or peat extraction for fuel and garden supplies) has seen a marked decline of peatlands in the late Holocene and especially in the past 300 years (Swindles et al., 2019; Tanneberger et al., 2021). This has had significant environmental impacts that include an increase in flooding. While countries such as Germany record that 95 per cent of peatlands are degraded, most other peatland-rich countries are about 50 per cent degraded.

Evidence is growing that sustainable agriculture, flood control and carbon sequestration can be attained with better management of peatlands (Evans et al., 2021). In some cases, this can be achieved in less than three years (Grand-Clement et al., 2015) by raising the peatland water table and reduction in runoff. In the past decade, several experimental peatland restoration measures in catchment headwaters – such as damming or blocking of artificial drains and gullies, grazing exclusion drain/gully stabilization using heather brash, plastic and wooden dams and re-seeding – have been deployed successfully across Europe (Parry et al., 2014; Pilkington et al., 2015) (Figure 2.1). Intensive monitoring has demonstrated that these measures have increased storm flow lag times, reduced peak storm discharge and attenuated the storm-hydrograph shape (Shuttleworth et al., 2019). Catchments become wetter following re-vegetation (exemplified by decreased depth to the water table and increased frequency of overland flow). There is no change in catchment storage during storm events but storm-flow from peatlands is attenuated (Shuttleworth et al., 2019). Additional ecosystem services are also attained, such as an increase in plant diversity and bare peat cover along with a reduction in particulate and dissolved organic carbon and water colour (Pilkington et al., 2015).

2.2.2 Forestry

One third of European territory is covered by forests (2.1 million km^2) (Tekidou et al., 2015; UNECE/FAO, 2011). The distribution is variable; Finland and Sweden have almost 80 per cent forest cover, while Slovenia has 60 per cent and Estonia, Spain and Latvia around 55 per cent. Other jurisdictions remain very low (e.g., Ireland <11 per cent). Biogeographically, Boreal and Alpine regions support 65 per cent of total European forest resources (Tekidou et al., 2015). It is estimated that 25 per cent of all European rivers flow through forested areas and therefore NBS associated with forests and large woody debris have catchment-wide potential under certain conditions. If we are to generalize, forests in Alpine and Continental regions provide the highest water-retention potentials, Atlantic and Mediterranean regions are lower (in part, due to poor data availability). Coniferous forests have the largest impact on runoff across Europe along with mixed forests in Alpine regions and broadleaved forests in the Continental region (Tekidou et al., 2015).

In a recent review, Ellis et al. (2021) highlight several areas where more field observational data and measurements are required to support modelling efforts, particularly at the larger scale. In addition, they note that a wider geographical distribution of studies is required in addition to the largely NW European focus that has emerged to date (Connelly et al., 2020).

Notes: Ground view of peat drain block at Tullychurry (completed January 2021). The forestry site was felled in 2020. Image shows sphagnum regrowth and recolonization due to raising of the water table.
Source: Kennedy (2021).

Figure 2.1 Example of NBS measures in peatlands, Ireland

2.2.2.1 Water retention in forests

The water-retention potential of forests is well documented (e.g., Stratford et al., 2017). It can lead to increased evapotranspiration, greater canopy interception, increased hydraulic roughness from forest floor woody debris and understorey vegetation. Forest soils may see an increase in soil macropores and infiltration pathways along roots. Such forests influence soil infiltration and storage capacity and can alter the amount and timing of water delivery to streams and groundwater. This can both attenuate flow peaks and provide base flow during dryer periods. In addition, if correctly managed, they can improve water quality (Nisbet et al., 2011; Robinson et al., 2003).

The characteristics of individual forests dictate their water-retention performance. Important factors include the forest area (km^2), tree species and density, leaf-area index and length of growing season, forest age and vertical height profile. Effectiveness is also dependent on the presence of semi- to permeable soils overlying permeable bedrock. In very highly permeable soils and bedrock (e.g., loess overlying fractures sandstone), forests will not make a measurable contribution. Planting on organic (peat) soils is not advised for flood reduction. In Ireland, discharge during rainfall events from a high gradient, peaty catchment with mature conifer planted forest was found to be significantly higher than in a comparable non-forested peatland (Kelly-Quinn et al., 1996).

Headwaters have many characteristics that are suited to the effective impacts of afforestation on reducing flood hazards. Where headwaters have been deforested for early and continued agricultural activities, reforestation may yield beneficial outcomes. Data suggest that the afforestation of former pasturelands has measurable and relatively rapid (i.e. less than 10 years) effect on soil infiltration capacity (e.g., Pontbren catchment, Wales, UK; Marshall et al., 2014). For the headwaters of river catchments, where forest cover is greater than 50 per cent, forests can have a strong influence in regulating runoff. Elsewhere in the basin where forest cover is greater than 30 per cent, there is potential for increased water retention, but more research is needed to clarify this threshold.

Certain slope angles (i.e., those typical of upland headwaters: 8–30°) are suggested to be most effective for afforestation. Steeper slopes approach the angle of repose and generally have shallower soil cover which trees struggle to thrive on. Riparian areas (that do not get waterlogged) can improve water quality by absorbing diffuse nutrients from agriculture and plantation forestry, reduce channel bank erosion as well as trap sediment that runs off land into streams thereby reducing channel capacity and destroying aquatic habitats.

Where forest cover is more than 50 per cent of upstream small sub-basins, it has a strong regulating role in runoff and is most effective at intercepting intense rainfalls and slope runoff (Tekidou et al., 2015). Indeed, with strategic placement on the appropriate slope angle, soil type and condition, use of specific native species, and grown to a managed density, afforestation can also effectively intercept runoff that is delivered from upstream to the forest (Chandler et al., 2018; Jost et al., 2012; Murphy et al., 2021). Maximum increased infiltration and concomitant reduction in local flood risk is gained if tree areas in silvopastoral settings are fenced off from grazing (Lunka and Patil, 2016). This is important as agroforestry schemes gain momentum in application across Europe (Elbakidze et al., 2021) due to EU agricultural funding support (e.g., EIP-AGRI).

2.2.2.2 Hydraulic roughness in riparian forests

As floodplain flows are relatively shallow, they have the potential to be modified by floodplain vegetation. This includes the forest stand and the exposed roots and organic debris. Large wood deposited or fallen on floodplains increases hydraulic roughness and influences patterns of erosion and deposition during inundation (Thomas and Nisbet, 2007). The hydraulic impacts of floodplain vegetation are strongly controlled by planting density, stem diameter, height, structure and phenological phase (Kiss et al., 2019). Feedback between flows and floodplain roughness may shelter its surface or expose it to further hydraulic action. This can control future floodplain morphology (e.g., by the erosion of channels, and deposition of debris dams, and sediment splays) (Reesink et al., 2020).

It is important to note that appropriate forest management is essential as there are several negative environmental effects from poorly managed riparian and hillslope forests. These include eutrophication, sedimentation and acidification (see Bullock et al., 2014 for a review of these and other potential negative impacts). We note that a common thread through the literature is the recommendation for a bespoke approach for new afforestation projects. For further reading on this we recommend Marapara et al. (2020) and references therein. The effectiveness of NBS at larger scales is still under investigation and there is a large degree of uncertainty in the evidence.

2.2.2.3 Large wood in rivers

Large wood is increasingly used in European river rehabilitation projects. However, centuries of riparian deforestation and river management practices has led to a low abundance of large wood in channels (Gurnell et al., 2019; Kail, 2003). Therefore, engineered log jams or 'leaky' dams have been built along with local afforestation (Addy and Wilkinson, 2019; Thomas and Nisbet, 2012) to mimic the benefits of natural large wood.

Large wood may be transported to headwater channels through the slope failure of forested slopes (Abbe and Montgomery, 2003). More direct supply is found where riparian trees fall directly across the channel due to bank erosion, windthrow, wildfires or disease (Wohl, 2020). Across Europe, beavers coppice riparian trees to construct beaver dams. We do not discuss beaver dams in this chapter; however, several papers discuss the debate around their efficacy at flood-peak reduction and increase lag time (Larsen et al., 2021; Neumayer et al., 2020; Wohl, 2015).

Naturally occurring in-channel large wood has an important influence on channel sediment and water storage, channel planform, bedform and sediment size. Catchment headwaters are areas of limited in-channel wood mobility where individual pieces are relatively more important. Large wood in headwater channels increase flow resistance, and cause flow deflection and channel bed and bank scour (Curran and Wohl, 2003; Grabowski et al., 2019).

Low velocity areas associated with large wood cause enhanced deposition of fine-grained sediment and organic particulates (Elosegi et al., 2017). Scour and deposition around large wood increase the abundance and diversity of aquatic habitat for a variety of organisms (Al-Zankana et al., 2021; Deane et al., 2021; Thompson et al., 2018). In highly permeable gravel channels, effective wood dams enhance hyporheic flow (Hester and Doyle, 2008), which is known to improve water quality (Fernald et al., 2006). Large wood can lead to the formation of multi-thread channels, and enhance channel-floodplain connectivity and patterns of overbank erosion and deposition (Gerhard and Reich, 2000; Gregory et al., 1985; Kail, 2003).

Studies of large wood in headwater streams (e.g., Gurnell et al., 2019) have demonstrated that it is the higher ratio of channel width to riparian tree height (e.g., 10 m wide channels and 30 m tall trees) found in headwater streams that ensures a higher frequency of large wood remains *in situ* to form wood dams. Nevertheless, the headwaters is an area where individual pieces are relatively more important. In general, as stream width increases downstream, the role of wood in rivers for flood mitigation decreases.

Modelling efforts have demonstrated that effective flood mitigation (i.e., a mean reduction to peak discharge of 10 per cent) is achieved after 25 years of forest growth at a sub-catchment scale, i.e., where 22–47 per cent of channel network is permitted to develop large wood dams naturally with no wood removal (Dixon et al., 2016). In addition, a significant increase in lag time (2.6–7.3 hours) between peak rainfall and runoff has been measured in small (less than 26 km^2) headwater catchments in the UK where large wood and riparian planting had been emplaced (Black et al., 2021).

2.2.3 Agricultural Practice

Around 40 per cent of land in the European Union is farmed (Brandmüller and Önnerfors, 2020). Farming practices have an important impact on natural environments yet a range of current practices exacerbate environmental issues such as water quality, scarcity and flooding, soil erosion and compaction, landscape and biodiversity preservation.

Headwaters are subjected to prescribed burns to generate a mosaic vegetation distribution of varying ages, promoting the habitat of game birds, where the effects on runoff are similar to those of grazing. Grazing affects many aspects of catchment headwater hydrology. Conventional agriculture practices are known to increase soil compaction and reduce soil-water storage capacity through the use of heavy machinery and livestock trampling. In tillage, the formation of a plough pan in the subsoil changes the direction of water percolation by impeding vertical infiltration and enhancing interflow (Alaoui et al., 2018). These practices lead to enhanced and earlier occurrence of saturated excess overland flow on hillslopes. This may increase downstream flood risk (Pattison and Lane, 2012). Heavy grazing may reduce protective cover as sheep and cattle may eat and trample vegetation. This can reduce surface roughness and accelerate overland flow movement that lead to flashy flows (Guo et al., 2017).

The potential for NBS on e.g., grasslands is poorly understood. Despite efforts to improve grasslands, they are known to exhibit low hydraulic roughness. This is because they tend to support monocultures such as rye grass (Ellis et al., 2021). Poor management causes high levels of compaction (and, subsequently, low infiltration and through flow) and low hydraulic roughness (Bilotta et al., 2008). This results in many grasslands contributing to sources of enhanced overland flow, limited water-holding capacity and erosional processes. Improved grassland management can lead to more ecologically and hydrologically diverse grasslands that are important for reducing overland flow and delaying peak flows across upland headwaters (Ellis et al., 2021). However, seasonal cycles of surface roughness in grasslands strongly modify overland flow, potentially having a large impact on downstream flood peak and timing (Bond et al., 2020).

This is also true for tillage where so-called 'muddy-floods' occur in catchments with large areas of arable land adjacent to freshwater systems (Boardman and Vandaele, 2016). Soil surface infiltration of water is a function of pore-size distribution and the continuity of pores and flow paths. During heavy rains, water may not infiltrate into the ground due to high soil saturation or low hydraulic conductivity, and moves over the soil surface as runoff (Skaalsveen et al., 2019). It is likely to carry nutrients and sediments that can cause diffuse pollution to receiving water bodies, as well as flooding (e.g., Mellander and Jordan, 2021).

Boardman and Vandaele (2020) suggest a combined soft-engineered and land-use management approach. Their data from the Molenbeek catchment (~5,000 ha) in Flanders suggest a significant decline in erosion following implementation of measures to prevent runoff generation (e.g., cover crops during the dormant period, conservation tillage); reduce runoff along topographically concentrated runoff pathways (e.g., grassed waterways); increase infiltration (e.g., grass buffer strips at the bottom of fields); and use of sediment traps (earth dams and retention ponds) (Boardman and Vandaele, 2020).

While the aim of surface and subsurface land drainage is to increase potential soil storage capacity by removing excess surface water from agricultural land, research indicates that sediment erosion can be significantly higher compared to undrained land (Bilotta et al., 2008). Water draining rapidly from grasslands may result in a more rapid transfer to the river system and contribute to downstream fluvial flooding (Ellis et al., 2021). In Ireland, generations of farmers have installed complex subsurface drainage systems that are not mapped (Figure 2.2). Mitigating the effect of field drainage on downstream flow hydrographs is a future research challenge.

Agricultural practices that aim to *disconnect sediment and water flux* through soil and water conservation measures (Keesstra et al., 2018) include grassed waterways, vegetation strips, contour planting, and the use of soil and stone bunds to create temporary storage areas (e.g., Novara et al., 2013; Wilkinson et al, 2010, 2019). Mulching, intercropping and the use of cover crops protect the soil surface from erosion (e.g., Rodrigo-Comino et al., 2020).

Many NBS for grasslands aim to *increase biodiversity*. The assemblage of different species habits encourages a surface roughness that intercepts more rainfall and reduces overland flow more efficiently (e.g., Haselberger et al., 2021; Osterkamp et al., 2012).

Although these practices have been used for many years, they have been deployed at small scales and the ‘cascade of strategies’ at scale is not well understood (e.g., Parras-Alcántara et al., 2016).

Tepes et al. (2021) have identified 22 different soil protection practices. Soil strategies that are deployed to increase infiltration rates and lower runoff and erosion focus on improving soil health. While topsoil compaction is reversible (e.g., soil aeration), results vary across landscapes. There are no effective remediation options for subsoil compaction – it is persistent and cumulative (Thorsøe et al., 2019).

While soil aeration and subsoiling may reduce soil compaction and increase organic matter accumulation (Ellis et al., 2021; Wallace and Chappell, 2020), organic farming systems also achieve this (Keesstra et al., 2018). There has been significant effort through EU-level policy in recent decades to increase the adoption of organic farming (Brzezina et al., 2017). This has led to important sector growth (e.g., between 1985 and 2019 organic farming in utilized agriculture areas grew from 0.1 per cent to 8.5 per cent). Agroforestry landscapes in Europe currently occupy 9 per cent of the utilized agricultural area (Augère-Granier, 2020). They are systems involving the practice of deliberately integrating woody vegetation (trees or shrubs) with crops and/or animal

Notes: Note the (breached) soil drainage pipe, located 70 cm under the field surface. These anthropogenic subsurface soil drain systems are unmapped in many jurisdictions and serve to increase water routing from agriculture land to channels.
Source: M. Bourke.

Figure 2.2 Image of freshly excavated sediment trap and earthen bund in Co. Wexford, Ireland systems. The undergrowth and canopy are managed so that the surface is protected by different layers of vegetation that grow at different times. Emerging evidence suggests that agroforestry can be effective in reducing floods (van Noordwijk et al., 2017). The conflicting interests between intensive farming and protection of aquatic systems has been a driver for European strategies and frameworks such as the Water Framework Directive (WFD) (Skaalsveen et al., 2019).

2.3 SCALING UP NATURE-BASED SOLUTIONS

There is an international paradigm shift that has seen more consideration of NBS for managing flood risk alongside technical solutions. Whilst we can store and attenuate flood waters on our larger rivers and floodplains (see chapters related to rivers and floodplains), we also need to store and attenuate storm runoff on the land around headwaters (e.g., peatland, farmland, small ditches and channels which feed larger rivers). Wilkinson et al. (2019) highlight that, in the early decades of the twenty-first century, there has been a rapid rise in the use of NBS in managing runoff in catchments. However, whilst knowledge on the functioning of these measures is increasing, the evidence is more focused at the local scale and there remains much uncertainty on the effectiveness of NBS approaches at the catchment scale (Dadson et al., 2017; Environment Agency, 2017; Lane, 2017; Priest and Wilkinson, 2019). Does this lack of evidence mean that we should not proceed with installing these measures at larger scales in our catchments? Here, we review this question identifying the opportunities and challenges in scaling up the measures and approaches outlined in this chapter. This is viewed through the lens of a physical sciences perspective therefore looking at large-scale processes and wider ecosystem services.

2.3.1 Large-scale Catchments

Firstly, there is a need to define ‘large scale’. This is a terminology which can vary in the country or region which may be considering a catchment-based NBS approach. Large scale could refer to the full catchment scale of a river basin. Therefore, the full catchment scale behind a town or city can vary substantially across Europe spanning several orders of magnitude (area) and cross many political/management boundaries. Managing floods in the cities at these larger scales usually involves considering grey engineering approaches. However, catchments are constructed of sub-catchments containing many settlements. Again, the scale of a sub-catchment within a river basin can span several orders of magnitude (area). Therefore, when considering NBS in catchments it is worth considering the scale they are applicable to. The Natural Water Retention Measures website (see EU, 2015) consider these scales to be 0–0.1 km^2, 0.1–1 km^2, 1–10 km^2, 10–100 km^2, 100–1000 km^2 and >1000 km^2 when assessing the applicability of measures. However, many measures (e.g., buffer strips, hedgerows, leaky barrier/woody debris in ditches, smaller wetlands) are suited to the smaller scale range (EU, 2015).

Priest and Wilkinson (2019) highlight that in some cases where NBS has been implemented, flooding still occurs to towns and settlements. On these occasions, the floods are more extreme which highlights that those catchments require a large volume of available storage for flood waters prior to the event with available capacity during the storm (Priest and Wilkinson, 2019). Large catchments will require large volumes of available flood storage (Bokhove et al., 2019) and a range of flood risk management techniques. Whilst we can store on rivers and floodplains, we also need to attenuate flood runoff in the wider catchment landscape (i.e., before it enters larger streams and rivers).

2.3.2 Placement of Measures

The effectiveness of NBS for managing hydrological extremes can vary spatially and temporally. Therefore, in larger scale catchments it is important to consider their placement within individual sub-catchments to avoid creating new flooding issues such as synchronizing flood peaks. Also, at larger scales (e.g., >100 km^2) the issues surrounding (de-)synchronization are influenced by how rainfall moves across the catchment (Lane, 2017) and the size (e.g., convective vs. frontal system events), intensity, depth of rainfall and duration of the storm (Wilkinson and Bathurst, 2018). Equally, acknowledgement must be given to the temporal scales of effectiveness of NBS approaches. For example, leaky barriers (Leakey et al., 2020) and soil bunds (Boardman and Vandaele, 2020) are point-based interventions which are effective immediately whilst afforestation can cover larger areas but has a longer temporal effectiveness lag time (Stratford et al., 2017). There is no one-size-fits-all approach, and each catchment needs a bespoke strategy which is suited to the catchment characteristics and flood risk. It is widely acknowledged that NBS are currently suited to small-scale catchments and for managing small- to medium-sized flood events (Dadson et al., 2017; Environment Agency, 2017). However, if NBS is considered as part of a suite of measures in a catchment (e.g., traditional grey infrastructure) then the combined effect can aid in mitigating large-scale/extreme events. Hewett et al. (2020) describe how a Catchment Systems Engineering (CSE) technique can be used to successfully address water management issues at the catchment scale. The approach considers both NBS and technical solutions throughout the catchment system. It highlights how water can be stored in small, dispersed volumes in catchments (e.g., agricultural areas, peatlands, forests, small ditches and channels) whilst larger strategic volumes can be placed along larger rivers and floodplains (Wilkinson et al., 2019).

The effectiveness of NBS at larger scales is still under investigation and there is a large degree of uncertainty in the evidence (Dadson et al., 2017). Whilst science continues to improve estimates of effectiveness, the trends suggest that measures could help to mitigate some flood peaks at certain scales. However, this uncertainty can sometimes lead to conflicting solutions when practitioners are trying to develop a flood scheme and need to assess the cost-benefit ratio of catchment-based interventions (i.e., living with the uncertainties surrounding the benefits). Evidence on measure performance is needed to perform an accurate cost-benefit analysis but this can be challenging owing to uncertainties (Priest and Wilkinson, 2019). It is therefore vital that we do not consider these NBS approaches as just flood risk management measures but acknowledge that these measures deliver wider ecosystem services (Hartmann and Slavíková, 2018) and therefore, value these extra services.

2.3.3 Integrated Catchment Management as a Desirable Objective

It is vital to take an integrated catchment management approach when considering NBS approaches in catchment headwaters. Valuing the wider multiple-scheme benefits is important to achieve a positive cost-benefit priority score (Priest and Wilkinson, 2019). NBS delivers a wide range of other benefits to large-scale catchments. For example, large-scale peatland restoration and the planting of trees in the correct locations (Friggens et al., 2020) can help to sequester carbon and therefore mitigate climate change.

Uncertainties remain and therefore the public and implementors may not be comfortable with this. Generally, there is a perception that the public feel safer and more protected from flooding when traditional grey infrastructure measures are implemented (Mourato and Ferreira, 2019). However, if one of these traditional schemes is complemented with NBS approaches, public confidence can be increased, at least during the initial stages (Mourato and Ferreira, 2019). Marshall et al. (2019) interviewed several Scottish communities at risk of flooding and found there was an interest in NBS approaches for mitigating flood risk. Here, public support for NBS measures can be enhanced by providing information about NBS measures, promoting community engagement in the process when considering measures, and building and maintaining trust in and around the flood risk management processes.

NBS need to be carefully located and suitably designed to achieve maximum efficacy for flood mitigation. An integrated catchment management approach will require an assessment of catchment connectivity (e.g., connectivity mapping; Kalantari et al., 2020) and an approach that uses systems thinking (Keesstra et al., 2018) for landscape, hydrological and sediment processes along with biodiversity. This approach will improve prediction of how a given catchment will respond downstream to upstream NBS system implementation. We suggest that any NBS plans for flood mitigation should begin in the headwaters.

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3. Legal challenges of restricting land use for natural flood protection in the hinterland

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3.1 INTRODUCTION

There are many options for improving water-retention potential in the landscape. We can distinguish different categories of measures, such as agricultural and forestry measures, restoration of ecosystems, and technical measures in settlements (see Richert et al., 2007; Rieger and Disse, 2010; Wahren et al., 2011; Albrecht et al., 2017; see also Chapter 2 by Bourke et al., and Chapter 8 by Rinnert et al., in this volume). While agricultural measures are first of all aimed at adapted soil cultivation, increased structural diversity and extensification of farming, forestry measures concern afforestation and forest restructuring. Examples for renaturation measures are the development of water-parallel wooded, reedbed and/or tall shrub borders along and between watercourses, the extension of flow paths (meanders), and the creation of retention troughs in the floodplain. In the vicinity of sealed areas, desealing measures and technical measures of urban water management can delay or reduce rapid runoff.

The above measures often require changes in the use of land, which is usually in private ownership. They have to be implemented on larger areas in the river basin, which are used as agricultural land, forest land or settlement areas. In contrast to retention measures along the rivers like polders and dike relocations (see Albrecht and Hartmann, 2021), retention measures in the hinterland do not necessarily require ownership of the land but call for land-use restrictions and obligations imposing limitations of ownership rights. For example, the agricultural measures may come with decreased crop yield. The restoration of ecosystems and set-aside can reduce the arable area to be farmed or make it more difficult to use large agricultural machinery. Unsealing measures are very cost-intensive. From this it becomes clear that it is not always in the interest of landowners to implement such measures voluntarily.

Therefore, a legal obligation to implement such measures should be considered. But how and to what extent can ownership rights be limited in order to apply restrictions and obligations for water-retention measures? And what role do funding programs play in this context? To answer these questions, section 3.2 explains the requirements for and restrictions on land uses. It uses the category of flood generation areas ("Hochwasserentstehungsgebiete") provided in German water law as an example. This regulation is of great interest for the problem at hand as the German legislator has already presented a regulative approach with this, which is not yet to be found in any other country and can serve as a model. The designation and protection of such areas will protect and improve water-retention potential in the hinterland, providing obligations and restrictions for land users, in particular permission and compensation obligations.

In section 3.3, the compatibility of land-use obligations and restrictions with property rights is discussed. In this context, property rights in various European countries and possibilities of limiting them are described. The example of flood generation areas is used to examine whether and to what extent such obligations and restrictions are proportionate. In this context, the distinction between negative and positive obligations is relevant. Since the state's ability to intervene in the property rights of land users is limited, the legal instruments have to be supplemented by funding measures. Therefore, in section 3.4, the possibilities offered by funding programs and especially the instruments of EU agricultural policy to implement the necessary retention measures are examined. Finally, some conclusions are drawn concerning the obstacles of implementing water-retention measures in the hinterland and possible solutions from a legal perspective (section 3.5).

3.2 REGULATIVE APPROACH: FLOOD GENERATION AREAS IN GERMANY

An innovative regulative approach to manage water retention in the hinterland is the instrument of flood generation areas provided in Section 78d Federal Water Act in Germany (WHG, 2009, "Hochwasserentstehungsgebiete"). Flood generation areas are situated in the area of the headwaters, where the increased probability of heavy precipitation coincides with a morphology of the terrain (particularly characterized by steep gradients) that promotes rapid runoff. The protection of these areas aims at improving water retention in the hinterland where floods occur.

Flood generation areas are to be protected by decree. Their protection was newly introduced into the Federal Water Act by the Flood Protection Act II of 30 June 2017 (Flood Protection Act, 2017). The restrictions in the area covered by the decree are intended to prevent the risk of flooding from increasing further as a result of construction or other measures that promote runoff and hinder infiltration. The regulation on flood generation areas in Section 76 Saxon Water Act (SächsWG, 2013), which has been regulated in the Saxon Water Act since 2004, served as a model.

The state government may determine flood generation areas by decree in accordance with the criteria laid down in Section 78d para. 2 Federal Water Act. In contrast to Section 76 para. 1 Saxon Water Act, according to which the water authorities are obliged to designate flood generation areas, Section 78d para. 2 Federal Water Act places the designation of the flood generation areas at the discretion of the federal states. The reason for this weak formulation is that the federal states (with the exception of Saxony) viewed the instrument with skepticism from the outset (Bundesrat, 2016, pp. 13 ff.). They feared an enormous administrative enforcement effort, costs for authorities and citizens for the approval procedures as well as a restriction of municipal development. Moreover, the exact delimitation of the areas is methodologically difficult. If restrictions are to be imposed on the land users in the areas concerned, the flood-reducing effect must be clearly demonstrable. Added to this is the fact that the topographical conditions for flood generation areas are not present in all federal states. Accordingly, the regulation has so far only been used in Saxony.

The methodology for determining flood generation areas is not defined by law, but is to be determined by the states. In this context, the hydrological and topographical conditions, in particular the ratio of precipitation to runoff, the soil properties, the slope, the settlement structure and the land use are to be taken into account (Section 78d para. 2 Federal Water Act). The Saxon State Office for Environment and Geology has developed a two-step methodology (Grafe et al., 2007). First, the expert system WBS FLAB[1] was used to identify areas with equal runoff formation based on available spatial data on soil/geology, slope, land use, and water network. These areas were subsequently combined with precipitation distribution data. Only areas where flood-triggering heavy precipitation (>50 mm per day) occurs with a frequency of ≥0.35 (equivalent to 3.5 times in 10 years) were considered.

By this procedure, 1,760 km² of the area of Saxony (corresponding to 9.5 percent of the area of the Free State or 8.4 percent without localities) were identified as flood generation areas, of which 52 percent are forest areas, 31 percent grassland, 14 percent arable land and 11 percent localities (inner areas) (Walther, 2008, slide 20; Müller, 2010, p. 318). These are primarily areas in the Ore Mountains, the Lusatian Mountains and the Zittau Mountains in the border triangle of Saxony, Poland and the Czech Republic (see Figure 3.1, 'specialist proposal' areas). This area map is the technical basis for the legal designation of the areas.

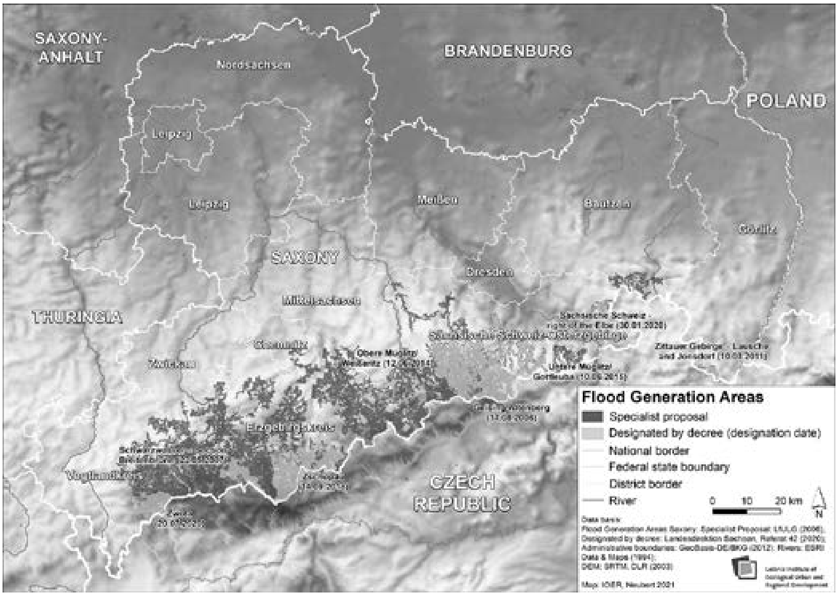

Figure 3.1 Geographical location of the flood generation areas in Saxony

The legal designation of flood generation areas is carried out by decree of the higher water authority (Landesdirektion of Saxony), which clearly describes their boundaries and presents them in map form (Section 76 para. 1 sent. 2 SächsWG). When designating the area, the authority has a technical margin of judgment regarding the concrete demarcation of the border. In total, a maximum of +/-10 percent may deviate from the area coverage which was determined by the Saxon State Office for Environment and Geology (Regierungspräsidium Chemnitz et al., 2007, p. 6). So far, a total of eight areas have been designated by decree of the higher water authority in Saxony (see Figure 3.1, ‘designated by decree’ areas).

The designation triggers the validity of the protection regime regulated in Section 78d para. 3 to 6 Federal Water Act: Section 78d para. 3 Federal Water Act establishes a general principle that, in order to prevent or reduce flood hazards, the water infiltration and water-retention capacity must be maintained or improved in designated flood generation areas (Köck and Maier, 2015, p. 808). In particular, the soil should be unsealed as far as possible and suitable areas should be sustainably afforested.

In addition, Section 78d para. 4 provides a permit requirement for certain projects that may significantly affect the natural water infiltration and water-retention capacity, which are: 1. the construction or substantial alteration of building structures, including ancillary facilities and other areas with a total area to be sealed of 1,500 square meters or more, 2. the construction of new roads, 3. the removal of forest or the conversion of forest to another type of use, or 4. the conversion of grassland to arable land. This preventive control is intended to prevent a further deterioration of the current situation (Staatsregierung, 2004, p. 49). In accordance with Section 78d para. 6 Federal Water Act, the avoidance or compensation of an impairment of the water infiltration or water-retention capacity has also to be taken into account in the municipal planning of new build zones.

The projects under para. 4 and the plans under para. 6 may only be permitted if they do not impair the water infiltration or water-retention capacity of the soil or if they are adequately compensated by measures such as the creation of forests or the creation of retention areas in the designated flood generation area (Section 78d para. 5). To fulfill this obligation, first of all, it must be examined whether an impairment of the water infiltration and retention capacity can be *avoided*, for example by constructing the roof of a building as a green roof or by fixing the surface with loose gravel, gravel lawn or lawn grid stones.

If an impairment of the water percolation or water-retention capacity of the soil cannot be avoided, Section 78d para. 5 requires an appropriate compensation through the implementation of retention measures elsewhere. The law does not specify which measures are to be considered with regard to an improvement or an appropriate compensation of the water infiltration and water-retention capacity. An indication is given in Section 78d para. 5 sentence 1 No. 2, which mentions as examples the "creation of forest" and the "creation of retention areas". However, the actual spectrum is much broader (see section 3.1).

3.3 RESTRICTIONS OF LAND USE: COMPATIBILITY WITH PROPERTY RIGHTS?

The example of flood generation areas shows how the implementation of water-retention measures can be enforced. In order to apply those measures in practice, different land-use restrictions and obligations have to be imposed, which implies intervention in property rights of land users (see Tarlock and Albrecht, 2018 regarding the regulation of floodplain development). Private land users, especially farmers and private forest owners, are particularly affected.

In contrast to larger measures in floodplains (e.g. the construction of polders or dike relocations), which are concentrated along rivers and which often require the acquisition of land by the state (see Albrecht and Hartmann, 2021), the special feature of water retention in the hinterland is that it requires many smaller measures distributed over the entire area (see Chapter 4 by Ungvári and Collentine in this volume). This means that a large number of landowners are affected. On the other hand, there is usually neither reason nor interest for the state to get ownership of these areas. Instead, the responsible water authorities must ensure that flood protection-adapted management is carried out on private land. But also in this respect, the question of compatibility with fundamental rights arises, especially with the property rights of the land users.

3.3.1 Property Rights in European Countries and Their Restrictability

Right to property is one of the fundamental rights that is guaranteed in international documents and conventions (see: Article 1 of Protocol No. 1 to the European Convention on Human Rights; Article 17 of Charter of Fundamental Rights of the European Union). Most civil codes and constitutions of European countries guarantee the right of property/ownership (Nikolić Popadić, 2021, p. 216). Ownership right gives the owner the widest right on things in his/her ownership (Sutter-Somm, 2014, pp. 23-24; Stojanović, 1963, p. 29). However, ownership right is not an absolute right (Sutter-Somm, 2014, p. 24). It is possible to restrict it. Examples of provisions that guarantee and protect ownership right, and provisions that allow restrictions to be imposed, can be found in many constitutions and civil codes.

One of the examples is the property right guaranteed in Article 14 Basic Law for the Federal Republic of Germany (Grundgesetz – GG, 1949). Para. 1 sent. 1 prescribes that its “content and limits shall be defined by the laws”, which means that the manner in which the owner may use the object of property right/ownership right can be determined by law. So their freedom in that regard can be restricted. Paragraph 2 of Article 14 Basic Law also forms the basis for introducing the restrictions of ownership right: “Property entails obligations. Its use shall also serve the public good.” This means that general interests must be taken into account when determining content and limits, i.e. justify restrictions on use. Expropriation must be distinguished from the content and limitation provisions of Art. 14 paras. 1 and 2. It is regulated in Art. 14 para. 3 and requires the complete deprivation of the existing property position by a sovereign act of the state, which is permissible only against compensation (Czybulka, 2020, p. 75).

Provisions which are similar to those contained in the German Basic Law can be found in the Constitution of the Republic of Croatia. Namely, it is prescribed that ownership shall be guaranteed. Besides that, “Ownership shall imply obligations. Holders of the right of ownership and its users shall contribute to the general welfare” (Art. 48 Constitution of the Republic of Croatia – URH, 1990). It is also prescribed that ownership right can be restricted by law, so the owner is free to use his/her object of ownership within limitations determined by the law (Art. 30–33 Law on Ownership and Other Real Rights – ZOVDSP, 1996; Art. 50, 52 URH).

Other European countries also have provisions in their legislation which guarantee ownership right, but also allowing its limitation. In the Federal Constitution of the Swiss Confederation, guarantee of ownership is listed as one of the fundamental rights (Art. 26 BV, 1999). It is possible to restrict fundamental rights (such as ownership right) if there is a legal basis for restriction and if that would be for "justified public interest or for the protection of the fundamental rights of others" (Art. 36 BV). It is possible to limit or abolish a certain way of use and there is also the possibility of disposing of property rights (Waldmann et al., 2015, p. 521). The conclusion about possibility of limitations can also be drawn from the Swiss Civil Code, as it is stated that the owner is free to dispose of the object of ownership right at his/her will, but "within the limits of the law" (Art. 641 (1) ZGB 1907, amended 2016).

In France, the Civil Code contains similar provisions. It is prescribed that "Ownership is the right to enjoy and dispose of things in the most absolute manner, provided they are not used in a way prohibited by laws or regulations" (Art. 544 Code civil des Français – CC, 1804). According to the Austrian Civil Code when exercising ownership right, the owner cannot interfere with rights of a third party and he/she cannot "violate the restrictions prescribed in the laws for the preservation and promotion of the common good" (Section 364 (1) ABGB, 1811).

In Slovenia, right to private property is guaranteed by the Constitution according to which the manner of enjoining and acquiring property should be determined by the law "in such a way as to ensure its economic, social and ecological function" (Art. 33, 67 Constitution of the Republic of Slovenia – URS, 1991). The Law of Property Code contains a provision stating that ownership is the right to own, use, and enjoy the thing in the most extensive way, and restrictions of that right can be determined only by the law (Art. 37 SPZ, 2002).

Right to peaceful tenure of a person's own property is guaranteed also in the Constitution of the Republic of Serbia. Ownership right can be restricted or revoked only in public interest established by the law, and the manner of its using can be prescribed by the law (Art. 58 URS, 2006). The Law on Foundations of Property Law Relations prescribes that the owner is entitled to possess, use and dispose of their property, but only within the limits determined by the law (Art. 3 ZOSPO, 1980).

Practice of the European Court of Justice is also supportive when it comes to limitation of property rights in the general interest (see Nikolić Popadić, 2021, p. 218). In the decision on the case *Liselotte Hauer v. Land Rheinland-Pfalz* (C 44/79) regarding the prohibition on the new planting of grape vines in the

EU, the court concluded that limitations were not against Article 1 of the First Protocol to the European Convention for the Protection of Human Rights, as a State has the right "to enforce such laws as it deems necessary to control the use of property in accordance with the general interest" (European Court of Justice, 1979). The scope of that (property) right should be measured in relation to its social function; "the substance and enjoyment of property rights are subject to restrictions which must be accepted by each owner on the basis of the superior general interest and the general good" (European Court of Justice, 1979).

The necessary degree of legal operationalization of the property right by the legislator cannot be determined in general terms. In relation to the sustainable use of agricultural or forest land, for instance, legal norms are required that define the most important duties of the owners in the management of the land and provide the administration with a legal basis for measures if these obligations are not fulfilled (Czybulka, 2020, p. 75). Various control approaches and instruments are conceivable here, also side by side or cumulatively, for example with the help of economic incentives (Czybulka, 2020). This is also the case in terms of protecting various aspects of the public good, such as nature conservation or flood control. The restrictions laid down in German water law for flood generation areas are an example of the legal concretization of property rights.

3.3.2 Proportionality of Measures

From the previous, we can conclude that although property/ownership is guaranteed and the ownership right is the widest right on a thing allowing the owner to use it in the most extensive way, there is a legal basis for introducing limitations.

By assigning the legislature the task of defining the content and limits of property (see for example Art. 14 para. 1 sent. 2 of the German Basic Law; Art. 544 Code Civil des Français; Art. 362, 364 of the Austrian Civil Code; Art. 37 of the Law of Property Code of Slovenia; Art. 58 of the Constitution of the Republic of Serbia, Art. 3, 4 of the Law on Foundations of Property Law Relations of Serbia), the guarantee of property is under a legislative proviso ("Gesetzesvorbehalt"). However, not all restrictions are justified. The restrictions must pursue a legitimate objective and be appropriate and necessary to achieve that objective. Finally, the measure must be proportionate, i.e. the intended purpose must not be disproportionate to the severity of the interference with the fundamental right to property (Epping, 2019, margin number 480). The interests of the general public must be taken into account in the weighing process (see Art. 14 para 2 GG).

But what does this mean for the permissibility of land-use restrictions in the hinterland for the purpose of water retention? First of all, the land-use restrictions must pursue a *legitimate objective* and be appropriate and necessary to achieve that objective. These conditions are likely to be fulfilled as a rule: after all, flood protection is undoubtedly a legitimate purpose.

Measures to promote water retention in the area must also be *suitable* for flood protection, i.e. flattening the flood wave. In order to justify interventions in the property rights of landowners, water authorities must be able to show a clear correlation between flood-retention measures and their positive impact (Albrecht and Hartmann, 2021, p. 37). The flood-reducing effect of retention measures in catchments has been confirmed in principle in various research projects (Niehoff, 2002; Feger et al., 2010; Albrecht et al., 2017, pp. 372ff. with further references). Reforestation and forest conversion measures as well as technical flood-protection measures have the strongest effect with regard to water retention. Structurally enhancing renaturation measures have a higher impact than purely agricultural measures. An optimal effect can be achieved by a targeted combination of measures and by avoiding interventions that strongly increase runoff (deforestation, sealing). However, the aforementioned measures are generally only effective with moderate precipitation and soils that are not yet pre-saturated (Feger et al., 2010, pp. 41ff.). Also, flood-reducing effects turn out to be much higher in smaller catchments than in large river basins, where they are hardly measurable (Kirn and Weiler, 2019, p. 28). This should be taken into account when assessing the suitability of the measures.

The *proportionality* of the measure depends on the weight of the pursued purpose and the severity of the interference with the fundamental right. In order to assess the proportionality, we have to classify different types of measures for improving water retention. In doing so, we can distinguish between negative obligations to refrain from action (so-called ‘prohibitions’) and positive obligations to take certain actions (so called ‘commands’). Negative and positive obligations represent different approaches in restricting ownership/property right, and they can be used to classify water-retention measures.

3.3.2.1 Negative obligations

A prohibition is a request for the owner to refrain from certain activities, which can also be qualified as a negative obligation. This can be, for example, prohibition to use agricultural land for construction purposes, or prohibition to use agricultural land for certain production like genetically modified organisms (GMO), prohibition to use pesticides near protected watercourses, etc. A distinction can be made between preventive prohibitions subject to permission (präventives Verbot mit Erlaubnisvorbehalt) and repressive prohibitions subject to exemption (repressives Verbot mit Befreiungsvorbehalt) (Heugel, 2018, Sect. 22 marginal no. 15).

In the case of preventive prohibitions, certain actions – which are basically permitted – are subject to a permit requirement so that the authority can check whether they impair the protective purpose of the area or object. An example is Section 78d para. 4 Federal Water Act, providing a permit requirement for certain projects that may significantly affect the natural water infiltration and water-retention capacity. If this is the case, the deterioration must be compensated. This compensation requirement is crucial as it imposes a prohibition of deterioration on land users. Such regulations do not appear disproportionate: it is not an unreasonable burden for the owner to apply for a permit before any possible deterioration of the status quo caused by him or her. Furthermore, it is in the public interest (and also in line with the polluter pays principle) that deteriorations caused by the intervention are compensated.

In the case of repressive prohibitions, on the other hand, certain actions are generally prohibited, as they commonly impair the protective purpose of the area or object. Exceptions can only be permitted in exceptional cases by way of an exemption, for example to avoid cases of hardship. Such a repressive prohibition represents a stronger encroachment on property rights than a preventive prohibition. It is neither contained in the Saxon regulation (Section 76 Saxon Water Act) nor in the federal regulation (Section 78d Federal Water Act) on flood generation areas.

3.3.2.2 Positive obligations

Commands require the owner to apply certain activities, to use his/her object of ownership right in a certain way (Nikolić, 2018, p. 59; Stojanović, 1963, p. 39). In contrast to prohibitions, commands are not directed at an omission, but at an action, whereby the boundaries can be fluid in individual cases (Heugel, 2018, Sect. 22 marginal no. 15). They can also be referred to as positive obligations. That can be, for example, obligation to use the land in a certain way, to apply certain agricultural methods or a certain composition of tree species in forestry use, etc. (Fischer-Hüftle et al., 2011, Sect. 22 marginal no. 26).

Examples for positive obligations are provided by Section 78d para. 3 sent. 1 Federal Water Act, establishing the obligation that in order to prevent or reduce flood hazards, the water-infiltration and water-retention capacity must be maintained or improved. This command is specified by sentence 2 of Section 78d para. 3 Federal Water Act, after which, in particular, the soil should be unsealed as far as possible and suitable areas should be sustainably afforested. Such obligations are associated with enormous burdens for the owner. Thus, unsealing and reforestation measures are very cost-intensive and, moreover, also associated with the change of the previous land use. Such positive obligations appear normally disproportionate because the owner cannot be expected to implement certain (costly) measures on their land that are primarily in the public interest (Köck and Maier, 2015, p. 808).

If we take a closer look at the regulation, however, we notice that the wording of the obligation is quite vague. In contrast to Section 78d para. 2 Federal Water Act of the first Federal Government's draft bill, according to which the competent authority can "oblige owners and beneficiaries of land to maintain or improve the natural water-infiltration and water-retention capacity of the soil", the adopted version of Section 78d does not contain any powers of intervention against private parties. Corresponding obligations can therefore at best be based on the general powers of water supervision according to Sect. 100 para. 1 sentence 2, which is doubtful, however (Köck and Maier, 2015, p. 809). It follows that the regulation is not readily enforceable, but rather a general principle (Bundesregierung, 2017, p. 31).

This is also consistent with the state of discussion in nature conservation law, according to which, for reasons of proportionality, maintenance, development and restoration measures in protected areas (in contrast to prohibitions), cannot generally be addressed to private parties (Heugel, 2018, Sect. 22 marginal no. 15). Rather, implementation is in the responsibility of the competent authorities, which usually fulfill their obligation through contractual agreements with the affected property owners or by commissioning third parties (Hendrischke, 2012, Sect. 22 marginal no. 23). Cost-intensive obligations to property owners would only be possible under the condition of compensation payments. The legislature can avoid the disproportionate nature of such an obligation by providing the obligation with a compensation provision in favor of the owner (see BVerfG, 1981). Such compensation regulations are of particular importance in environmental law in order to ensure the constitutionality of certain regulations.

3.4 INCENTIVES FOR VOLUNTARY MEASURES THROUGH SUPPORT PROGRAMS

An instrument of implementing measures on private land is funding programs of the government. Such measures can contribute to improve the water-retention potential in the hinterland. These measures are voluntary, i.e., the land owners may decide whether they apply for funding. Therefore, such measures are not in conflict with property rights.

In Saxony, for instance, several funding programs have been adopted in the fields of water management, nature conservation, agriculture and forestry, which can be used to support measures for the improvement of water retention in the hinterland. One example is the funding directive for water bodies/flood protection (RL GH/2018), which provides financial support for, among other things, measures to improve or restore water-retention capacity in flood generation areas (see No. 2.2.5 of the Directive). Under this directive, unsealing measures, for example, are eligible for funding. Funding recipients are, among others, natural persons and legal entities under private law (No. 3.2 of the Directive). The preservation and development of ecologically valuable water bodies as well as the renaturation or improvement of the ecological potential of semi-natural, developed water bodies are also the subject of funding (No. 2.1.1 of the Directive). Such measures also have a positive effect on the water-retention capacity.

An important source of financial support for water-retention measures is the EU's common agricultural policy (CAP), which can be used for financing measures to improve water-retention potential in the whole European Union. Funds made available through the CAP support both farmers and rural regions. Through the means of agricultural subsidies, land use is influenced over a broad area. This corresponds with the spatial scale of decentralized flood protection, which requires water retention in the hinterland. From the perspective of flood protection, the aim is to direct land management in such a way that it contributes to water retention, e.g. by promoting special farming methods and forms of cultivation.

The starting point is the basic premium scheme for farms/single-area payment scheme under the first pillar of the CAP. It regulates certain positive and negative limitations regarding the way of use of agricultural land and measures that should or should not be applied within agricultural practice. Farmers should respect prescribed minimum standards without special compensation (see Art. 93 Regulation (EU) No. 1306/2013: "good agricultural and environmental condition of land"). If the beneficiaries of the area and livestock payments do not fulfill these obligations, the payments can be reduced or even completely cancelled.

In addition to the basic premium or single-area payment scheme, each farm receives an additional payment per hectare for the application of certain climate and environmentally friendly land-management practices ("greening") (Regulation (EU) No. 1307/2013). Member States must mandatorily allocate 30 percent of their national envelope to the financing of these "greening premiums". Three measures are envisaged in this context: crop diversification, maintenance of existing permanent grassland, and maintenance of land used in environmental interest (i.e. field margins, hedges, trees, fallow land, landscape features, biotopes, buffer strips, wooded areas, nitrogen-fixing plants) (Art. 44, 45, 46, Regulation (EU) No. 1307/2013). These measures can also have a positive effect on water retention. Any violation of the greening obligations entails extremely high penalties for the land users (Massot, 2020).

For measures that exceed the above-mentioned ecological minimum standard, different support/compensation schemes are prescribed within the second pillar of the CAP. One of the ways to "preserve and promote the necessary changes to agricultural practices that make a positive contribution to the environment and climate" are agri-environment-climate payments (Art. 28

Regulation (EU) No. 1305/2013). Such funding regulations could be established by all Member States of the EU. They are co-financed by the European Agricultural Fund for Rural Development and by regional or national funds. The implementation is carried out through rural development programs designed by the Member States. The programs are based on a package of measures to be combined from a catalog of European measures, the details of which are laid down in the Rural Development Regulation (Regulation (EU) No. 1305/2013).

The above-mentioned agri-environmental and climate measures (i.e. maintaining as well as promoting the necessary changes in agricultural practices that have a positive impact on the environment and climate) are a mandatory part of the programs. Financial support can also be provided for organic farming and the implementation of Natura 2000 and the Water Framework Directive. Forestry measures can also be funded by the European Agricultural Fund for Rural Development. This includes, among others, investments in the development of forest areas and improvement of forest viability (afforestation and planting of forests) as well as payments for forest environmental and climate services and forest conservation. As mentioned above, such measures also have a favorable impact on water retention. That model might be further developed in order to expressively integrate measures that can contribute to improvement of water-retention potential in the landscape.

The upcoming CAP funding period (2021–2027) may hold further potential for funding measures to strengthen water retention in the hinterland. One of the changes triggered by the CAP reform is the introduction of eco-schemes. The states should "establish the list of agricultural practices beneficial for the climate and the environment" which should be designed to meet at least one of the prescribed objectives: to "contribute to climate change mitigation and adaptation, as well as sustainable energy; foster sustainable development and efficient management of natural resources such as water, soil and air; contribute to the protection of biodiversity, enhance ecosystem services and preserve habitats and landscapes" (Art. 6, 28 COM(2018) 392 final). This results in a wide scope for the definition of measures. This system could give more flexibility to Member States to adapt the measures to their national and regional needs (Meredith and Hart, 2019, p. 19).

In the new CAP funding period starting in 2023, 20–30 percent of direct payments from the first pillar are earmarked for eco-schemes (Michel, 2020). The eco-schemes are voluntary for the farmers, which means that they are not a prerequisite for receiving the basic premium. This distinguishes the eco-schemes from the greening requirements (Michel, 2020). Payments should be annual and should cover commitments that go beyond a standard of good agricultural and environmental condition and minimum requirements for the use of fertilizers and plant protection products (Art. 28 COM 2018).

These commitments should also be different from agri-environment-climate commitments in the second pillar of the CAP. Member States can choose to grant this payment as an additional payment to the basic income support, or as a compensatory payment for all or for part of the additional costs and forgone income (Art. 28 COM 2018; Meredith and Hart, 2019, p. 21).

By January 1, 2022, the Member States are to submit a national strategy plan to the EU Commission on the design of future CAP support and the implementation of the eco-schemes. Discussions include, for example, the establishment of flower strips, multi-unit crop rotations, grassland extensification or an increase in non-productive areas, in addition to the minimum share prescribed by conditionality (Michel, 2020). There is overlap between measures that can contribute to water retention in the hinterland (on agricultural land) and the environmental requirements of the new CAP. This is due to the fact that the retention-improving measures in the hinterland do not only help to improve flood protection, but also benefit nature, soil, and water conservation and contribute to climate adaptation (Albrecht et al., 2017, p. 375). Accordingly, fulfillment of the ecological requirements under CAP and funding of measures that are beneficial for water-retention purposes are often congruent. The new eco-schemes should be used to more strongly integrate environmental aspects in general and water aspects in particular into agricultural land-use practices.

There are views in the literature that the minimum standard of environmental protection and good agricultural practice should be an integral part of the farmer's property right and that therefore the farmer's activities that comply with the basic environmental requirements do not involve compensation, while measures which exceed that minimum standard require compensation, including compensation for the reduction in yield resulting from the application of environmental protection measures (Rodgers, 2016, p. 45). This argues in favor of already setting a demanding basic level of ecological requirements within the framework of the conditionality of EU direct payments in the first pillar of the CAP and to tie the further payments of the eco-schemes and the second pillar to more ambitious ecological targets. This aspect should be considered in the decision of how to integrate flood protection purposes in the CAP.

3.5 CONCLUSIONS

Restrictions of ownership right are necessary in order to implement water-retention measures on private land. Constitutions and civil codes of European countries allow limitations of ownership/property rights in order to serve the public good. But the challenge is to establish to what extent the use of the land can be limited in conformity with property rights and when and which kind of compensations/payments should be involved. In accordance with constitutional law, the restrictions of ownership/property rights must fulfill certain criteria in order to be allowed. Restrictions must pursue a legitimate objective and have to be necessary and appropriate to achieve this objective. Flood protection is certainly a legitimate purpose for introducing limitations of ownership right and the measures that promote water retention can contribute to flood protection. The proportionality of the measures has to be assessed in a weighing process in the individual case. The interests of the general public for an intact environment and for flood protection must be taken into account in this process.

The regulation of the instrument of flood generation areas in German and Saxon water law is an example of how to identify, designate and protect the water-retention potential in areas where floods arise. The aim of the legal provisions is to maintain and improve the water-retention capacity in these areas. All land uses are affected, especially agriculture and forestry, but also the use of the areas for settlement purposes. Protection is achieved through permit and water-retention compensation obligations for measures that impair water retention, as well as improvement requirements. While the permit and compensation obligations represent a proportionate restriction of the fundamental property right, this is not readily the case for costly improvement measures such as unsealing and reforestation measures. This requires the use of financial incentive and financial compensation to enforce such measures in a constitutionally compliant manner.

Challenges in implementation of water-retention measures might be overcome with different funding programs. As far as water-retention measures should be implemented on agricultural land, we can refer to CAP in search for potential solutions. Some of the measures that farmers should respect as minimum standards without special compensation, like in the case of good agricultural and environmental condition of land, are also beneficial for water-retention purposes. We suggest that minimum standards that should be followed within the CAP can also include more measures that will direct the land use in order to achieve objectives in the field of water retention for flood prevention. Environmental protection and climate-change mitigation/adaptation are part of the CAP and that scope can be expanded towards the integration of flood-prevention measures. This is supported by the fact that agricultural land use is directly connected to issues of all these three fields.

Unfortunately, to date water policy is only partially integrated into CAP, and the measures mostly focus on the protection of water against pollution (European Court of Auditors, 2014), although they might be further developed in order to also integrate measures of natural flood protection. Payments within the CAP are one of the ways for funding implementation of measures that go beyond the minimum standard and therefore need compensation to be compatible with property rights. The challenge under the new CAP is to draw the line between this minimum standard that does not require compensation and more extensive measures that have to be compensated. The minimum standard should not be set too low and compensation payments should be linked to ambitious targets. That also applies with regard to water-retention measures.

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NOTE

1. *W*issens*b*asiertes *S*ystem *Fl*ächen gleicher *Ab*flussbildung (Knowledge based system areas of equal runoff formation) (Seidler and Merta 2005).

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4. Implementation of measures in the hinterland: transaction costs and economic instruments

Gábor Ungvári and Dennis Collentine

4.1 INTRODUCTION

Reducing flood risk by implementing measures upstream to "keep rain where it falls" will require adaptation in the landscape of the hinterlands (see also Bourke et al., Chapter 2 in this volume). In order to have a meaningful impact on the rate of water discharge, the sites of these hinterland measures will, in all probability, have to be both spatially distributed and numerous. This large number of small, distributed measures is in contrast to the more concentrated and extensive flood plain measures which serve to temporarily store water during extreme events. All types of land-use changes for implementation of diverse flood risk reduction measures will require agreements with landowners with respect to the distribution of both benefits and costs. However, in the hinterlands the different features of these measures places further emphasis on understanding the nature of the barriers which arise for landholders and the wise use of economic instruments to overcome them.

While successful risk reduction programs will provide benefits to multiple downstream stakeholders, the implementation of measures will impose costs on multiple landowners due to changes in how their land is used (see also Hartmann et al., Chapter 7 in this volume; Bark et al., 2021). It may be possible to achieve coordination of direct costs and benefits efficiently through economic instruments, but to be successful a proposed program of measures also needs to address indirect costs to landowners. These indirect costs are those that fall on individual landowners as a result of their possible participation in a program in addition to the costs associated with land-use change or risk reduction. These kinds of indirect costs are one type of transaction costs, i.e. costs associated with designing, implementing and maintaining an institutional structure capable of achieving the specified goal (McCann et al., 2005).

This chapter sheds light on the intertwined specifics of transaction costs and the use of economic instruments in flood risk mitigation strategies (see also Hartmann et al., Chapter 7 in this volume). Transaction costs will have an impact on the willingness to accept/adopt economic instruments. The incidence (burden of costs) may be to a large extent determined by spatial relationships between those exposed to damage from flooding and those landowners where upstream mitigation measures may be implemented. In addition, the distribution of these costs over time may have an impact on the effectiveness of economic instruments with respect to acceptance by private landowners. The price for a change in land use in a voluntary contractual agreement (transaction) will be subject to a private landowner's subjective evaluation of not only the direct costs but also the indirect costs of a contract. The subjective evaluation of both costs may be influenced by the trust between the two parties to the transaction (Zandersen et al., 2021).

This chapter focuses on the role of transaction costs associated with participation of landholders in the hinterlands in a program of measures to reduce the risk of flood damage to stakeholders downstream. Acknowledging and evaluating transaction costs ex-ante will allow policy makers to make more informed decisions when comparing policy alternatives (Shahab et al., 2018; Larcom and van Gevelt, 2017; Mettepenningen et al., 2011). Several previous studies have described transaction costs with respect to land-use planning (Shahab et al., 2018, 2019). There have also been a number of studies which look at transaction costs in the design of programs for environmental land management (Pannell et al., 2013). In addition, there have also been studies which seek to understand participation by landholders in flood risk management (Bark et al., 2021; Zheng et al., 2014) and in environmental driven land-use change (Rolfe et al., 2018; Mettepenningen et al., 2011). However, none of these studies have analyzed how transaction costs relate to the decision by landholders to participate in a program with respect to economic instruments.

The next section describes an overview of transaction costs and the incidence of these over space and time for upstream landholders. The following section describes the use of economic instruments in the hinterlands and the impact of transaction costs on these. The last part of the chapter discusses the effectiveness of these instruments in the hinterlands to achieve reductions in downstream flood risk and draws conclusions from the analysis.

4.2 TRANSACTION COSTS IN LAND-BASED FLOOD MITIGATION POLICY

Transaction costs are persistent. The range of discussion with respect to transaction costs covers a wide range of economic behavior. Coase (1960) suggested that transaction costs can explain how firms are organized, while economic historian North (1990) uses the concept to trace the evolution and development of the American economy. Both of these writers won Nobel prizes in economics for their work. A great deal of the early literature has focused on the costs associated with the transfer of ownership of a private good and, as a corollary to this, property rights. Stavins (1995) suggests that transaction costs are always present in markets “and can arise from the transfer of any property right because parties to exchange must find one another, communicate and exchange information” (p. 134). This concept of communicating and exchanging information is also central to evaluating transaction costs associated with instruments for achieving coordination of multiple upstream and downstream stakeholders’/landowners’ interests in a flood risk reduction program.

An evaluation of the cost efficiency of alternative flood risk mitigation strategies with a focus on measures in upstream hinterland areas should take into consideration not only that there are transaction costs but that there are also time and space dimensions to these costs. This principle is true not only for flood mitigation programs but has been extensively addressed and acknowledged in the broad literature on the analysis of transaction costs in environmental policy. Krutilla and Krause (2011) start their review with a comprehensive definition of transaction costs, but focus this definition on environmental policy. They write that “environmental regulation … defines a distribution of environmental or quasi-ownership rights for polluters and other stakeholders” and that “transaction costs are the ex-ante costs of establishing environmental policy in all of its aspects” (pp. 267–268). The costs of executing the policy are distinct from transaction costs as these are the costs associated with achieving the aim of the policy. McCann et al. (2005) point out that there are even transaction costs associated with the measurement of transaction costs and that there is then a tradeoff between the need for accuracy and the costs of acquiring data (see also Rørstad et al., 2007).

Much of the early work and development of the conceptual basis for transaction cost analysis took place within the field of organizational economics. This is particularly true for a concept developed by Williamson (1985) to analyze transaction costs, which he called “asset specificity”. This concept has been useful for illustrating how specific characteristics of an investment can affect the level of transaction costs in connection with the asset. “Asset specificity affects the transaction costs for both the public and the private parties … via activities such as information collection, implementation and contracting, support and administration and monitoring” (Coggan et al., 2010, p. 1780). Krutilla and Krause (2011) point out that “asset specificity [is] less relevant to the formation of ‘public contracts’ (laws and regulations) than to the private contracts associated with market activity” (p. 270). This may be because asset specificity may be expected to have the greatest influence on information costs and that a set of rules and regulations reduces the need for gathering information for private parties.

The organizational-economics literature recognizes the importance of the frequency/timing of a transaction. In general, the more standardized a transaction is, the lower the costs will be that are associated with it. In addition, a high frequency of transactions between the same parties should also result in decreasing transaction costs. In part, this effect can be attributed to lower costs for information gathering or a learning effect for parties to the transaction. Falling transaction costs may also be expected the longer a particular policy has been in place (Shahab et al., 2018).

The effect of uncertainty is considered by Coggan et al. (2010) to be of three types: uncertainty of the future state of nature, uncertainty about what a party to a contract is required do, and uncertainty about how a party to a contract will behave (p. 1781). All three types of uncertainty may affect the magnitude of transaction costs and the willingness to enter into a contract. For example, for policies which include contractual agreements between private landholders and a public administrator or collective institution, uncertainty about the level of transaction costs may be a reason for the lack of participation by landowners (Zandersen et al., 2021).

The final two sets of factors identified in the organizational-economics literature refer to characteristics of the parties involved in the transaction. The first of these comes from the limited ability of actors to process information (bounded rationality) which limits the possibility of achieving the potential economic efficiency of transactions in response to environmental policy. Coggan et al. (2010) note that this effect will be "magnified when the transactions or the good being transacted is complex, such as the case with highly asset specific goods" (p. 1781). Rolfe et al. (2018) suggest that participation by landholders in a conservation tender is limited if the policy is perceived as complex as this leads to higher transaction costs in the decision process. The other factor has to do with opportunism, where "providing false information or withholding important market information from other market participants" is rewarded (Coggan et al., 2010, p. 1781). Where the potential for opportunistic behavior exists (due to incomplete contracts for example), the public administrator could experience an increase in monitoring and enforcement costs. In the case where potential market participants believe that they are in competition for limited resources, this may lead to higher transaction costs not only for administrators but also for participants.

To take into account the effect of timing, Krutilla and Krause (2011) emphasize the viability of taking an analytical approach based on the use of stages to estimate the incidence of transaction costs. They suggest there are three policy stages. In Stage 1, the policy is formulated (planned, defined and decided). Stage 2 is the period of implementation when the "policy is decided, regulations and guidelines are developed to implement it" (p. 273). Even in this stage there may be high transaction costs associated with rule making and in particular as stakeholders attempt to define guidelines and rules for implementation of the policy. Stage 3 is referred to as one of policy operation. It is in this stage that actual abatement costs are incurred, but there are also transaction costs associated with record-keeping, accounting and reporting. They do not pay much attention to the boundaries that define these three stages as they see stage delineation as a tool to help structure and analysis. It is not important when costs occur in the process but rather estimating the cumulative sum of transaction costs that occur over the life span of the policy.

Coggan et al. (2010) focus not only on time but also on the factors that have an influence on the magnitude of transaction costs and suggest a framework which includes both a cost typology as well as a time perspective. In this chapter, we consider the following three categories of transaction costs: information costs, legal costs and administrative costs.

Information costs are the costs for downstream stakeholders and upstream landholders in a program to reduce flood risk by using land-based mitigation measures. This includes landholders learning what is required and permitted as well as searching for and gathering the information needed to engage in negotiations with program administrators. The level of transaction costs is affected by the design of the program and definition of the role for the managing authority and the guidelines for program participants. These types of transaction costs include costs associated with research and data collection, ongoing management and contract design.

Legal costs may be incurred in the design of the guidelines for a program, challenges to the program guidelines/decisions or with respect to contracts entered into. These include costs from the opportunity cost of time and legal representation, time and resources to negotiate and finalize contracts, opportunity cost of waiting for program finalization and clarity of allowable actions and understanding policy amendments or application in different circumstances.

Administrative costs depend on the specific institutional structure to be adopted and the allocation of responsibility between stakeholders and landholders. These costs include the need for managing the information and legal activities described both at a program developmental level and at an operational level. These types of costs include those for time and resources to understand policy, to evaluate compliance strategies and execute technological decisions, for application review and for keeping records of transactions.

The costs associated with these three activities are spread over a time dimension divided into three periods in our analytical model; program design, adoption and operation. Although these activity costs may be analyzed as separate transactions at each stage as suggested by Shahab et al. (2018), we have chosen to treat these as a single transaction of a particular policy at different stages in a program in line with the method proposed by McCann et al. (2005). This latter treatment is more in line with the focus of this chapter, the expected incidence of costs between two groups; downstream stakeholders (program administrators/public interests) and upstream private landholders under different policy alternatives.

The first stage, the program design stage, may also be described as "coming to an agreement". This involves taking the strategy from an idea to an institutional structure. This stage begins at a point when the interest in a program is established and ends when a time is set for the start of implementation. In the second stage, adoption or implementation, landowners know the details of the program and evaluate their set of choices to participate. The final time stage, operation, is when the policy can be considered to be mature, defined as when the program has a stabilized set of routines. For example, the number of measures established in the hinterlands is considered to be sufficient and transaction costs are primarily those associated with contract renewals, monitoring and information necessary for maintenance.

4.3 ECONOMIC INSTRUMENTS AND TRANSACTION COSTS

Involving the concept of transaction costs into the thinking of natural, enhanced land-management induced water retention measures has two aspects. The first one was reflected in the previous section, that transaction costs can be substantial and may even influence the cost-benefit balance of a flood risk mitigation scheme. The other aspect belongs to the way in which agreement is reached between compensating for costs and the benefits of implementation. Other chapters in this book describe some of the growing set of cases where robust estimations show that there is an overall gain if land is used in a multi-purpose way to be able to contribute to flood risk mitigation. However, this potential in itself does not pave the way to the necessary agreements for realizing the changes. This section evaluates the suitability of economic instruments for realizing this aim and the cost of the necessary information for their proper application.

Economic policy instruments belong to tools that foster modification of individual activities, as opposed to other policy instruments such as an outright ban or other regulation of activities. The distinguishing feature of economic instruments lies in their relativity. Individual actors have the room to adapt their choices according to the costs or benefits of the instruments attached to a particular activity, either raising costs to deter detrimental activities or providing additional benefits to promote beneficial ones. The prior group usually consists of fees, charges and taxes, the latter one of subsidies.

The use of economic instruments presupposes a legal clarification of rights and duties that stakeholders hold or bear, such as property rights (see Albrecht and Nikolić Popadić, Chapter 2 in this volume). This provides not only a basis for transfer of ownership (a transaction) but also determines on whose shoulders the burden of modifying individual activities is placed when taking into account externalities. Externalities are benefits or costs which arise in connection with an activity, but which are not reflected in the decision to perform the activity. Externalities are pervasive. However, the basis of this legal clarification is not necessarily supported by a formally arranged set of rules or institutions. In the absence of formal property rights, transactions may still take place as long as there are no legal objections to the transaction. In this latter case, these quasi-property rights may establish precedents which lead to the establishment of formal complete property rights. This process of clarification reflects a constantly evolving sphere of interest resolution because private actions have an impact on others. This partly scientific, partly legal and partly political clarification of a transaction between two interests results in steering the aggregation of individual activities toward a social optimum where an ever wider set of impacts are taken into consideration. Unlocking the flood mitigation potential of measures in the hinterland through transactional economic instruments to a large degree also establishes a set of property rights.

There are two main types of positive opt-in transactional economic instruments, subsidies and payments for ecosystem services (PES). Subsidies are payments for positive externalities. If there are benefits associated with production of a particular good that are not considered in market decisions, these goods provide social marginal benefits and providing an additional financial incentive will increase the production of these. Subsidies tend to be general, based on a predefined offer for existing production outputs. PES are agreements on land management with a specified set of land users with respect to the provision of agreed non-market ecosystem services. These may also be a predefined offer but in many cases are a price that is set by negotiations between a buyer and a seller, for example between a downstream stakeholder and an upstream landholder.

It is important to distinguish the role that economic instruments, such as subsidies or PES, can play in the sequential phase of creating a scheme for the implementation of flood risk measures in the hinterlands (see also Hartmann et al., Chapter 7 in this volume). In the implementation phase of a project to reduce flood risk, the focus should be on the costs of alternative strategic policy choices. How feasible is the realization of project goals? How cost-effective would a program of measures be compared to (or complementary to) other alternatives further downstream? The transaction costs of information also need to be taken into consideration. How effective is an instrument in obtaining the necessary information for the underlying negotiations on the price and size of land that is available for the scheme? Is the instrument effective in supporting the process?

For nature-based solutions such as mitigation measures in the hinterlands, their individual and aggregate contribution to flood reduction need to be calculable. This quantification is needed to integrate these into multi-party solutions or to be comparable to grey infrastructure solutions. The quantification refers to a threshold volume of flood-reduction services (measures) that must be obtained through the schemes and not to the amount of mitigation services in general. In addition, a flood mitigation scheme on private land needs not only an agreement with the owners on the land coverage for the scheme but also the price to provide the service. The price and the land size on offer to provide flood mitigation service are connected through the spatial pattern of land exploitation productivity in the area. Land-use productivity that defines the value of a land parcel is information known only by the owner. Without a clear picture of the supply curve of land for mitigation, the price for the necessary attenuation effect cannot be determined.

Voluntary subsidies with a predefined opt-in price are not suitable to solve this challenge. Mountainous terrain is diverse in both the productivity of land uses and the scale of roughness that drives runoff from the parcel. An assumed flood-mitigation effect downstream could be aggregated from a great variety of land groupings with very different economic effects on landowners. Applying subsidies for providing a pre-calculated threshold effect on runoff attenuation would require the knowledge of land productivity across a whole landscape and an effective monitoring network (along several converging valleys). If this information were available, an optimal level of a subsidy could be determined for initiating the necessary coverage of adaptation in land use.

Runoff attenuation efficacy by one pathway depends on how steep the terrain is and how that area is hydrologically connected to the watercourse system. To attenuate the same runoff from sources with high hydrological connectivity, these could be subsidized at a higher rate than those with less direct connectivity to compensate for the greater impact on risk downstream. If an average subsidy is proposed for both sources, then the source with high connectivity will change less than optimal and the low-connectivity ones will overperform; this lowers the cost efficiency of the subsidy. This type of effect can be compensated for by designating sources in zones with similar connectivity and then setting a subsidy level appropriate for each zone. However, using averages even for zones will result in some inefficiency and designing and managing such zone systems would in all likelihood have a great effect on information transaction costs (Rørstad et al., 2007).

A pre-declared opt-in price level of a PES scheme may not result in the supply of a sufficient area of land to provide a critical impact. Geography-driven spatial diversity and site-specific micro-conditions among hinterland conditions make the effectiveness of measures much more reliant on local knowledge and the willingness of landholders to adopt measures and much less on even more advanced remote simulation and planning tools. Although these technical instruments may be useful for the challenge in the design phase of a scheme creation, there need to be financial vehicles to connect stakeholder benefits to landholder costs.

The widely used expression landowner or stakeholder cooperation is euphemistic. Agreement takes place after a successful process of bargaining over competing interests about how land should be managed. Reaching agreement must address both sides, recognizing the validity of their opposing interests. If this does not take place, then there may not be a breakthrough and the transaction is not realized. Álvarez et al. (2019) describe this decision in a game theory frame, albeit the authors argue for a cooperative methodology that "differs from non-cooperative game theory in that the allocation can be made from a centralized point of view, rather than through non-cooperative bargaining among the players" (p. 2). This decision point is really a tough bargaining situation for the parties.

Landholders are (naturally) driven by the economic impact of changing land use that affects them not just directly but along the many interdependent processes of related production activities as is often the case in farming. Holstead et al. (2017) describe farmers as being well aware of the different productivity potential of each parcel of land included in the farm. A farm's production practices as a whole can be the end product of long sequences of optimization. If they were engaged in negotiation about changing it, there may be a preventive action to avoid possible harmful outcomes for them. This may also be led by mistrust based on the track record of the government in dealing with flood development issues (Roth and Winnubst, 2015). It is also important not to assume inter-regional (downstream) solidarity as a given. McCarthy et al. (2018) found that "Rather than attempting to gain partnerships between spatially dislocated stakeholders in upper storage and lower impacted catchments, success resides on the storage land and persuading landowner co-operation" (p. 85). Their finding also underscores that "A clear enforced legal framework of ownership of land and funding mechanisms is also viewed as essential" (p. 85). Although Holstead et al. (2017) list several other aspects that have an influence on farmers' attitudes towards flood mitigation measures on their land, it is helpful to approach it as a business case. Morris et al. (2016) approach the issue of reaching agreement in a businesslike manner where a price for delivering the mitigation service is considered as a bargain between the (maximum) willingness of downstream beneficiaries to pay for the service and the landowners' (minimum) willingness to accept providing the service based on its true cost for the owner.

Thaler et al. (2016) elaborate on the aspects of proximity and the level of integration in what they describe as a cooperation process in creating inter-regional flood management partnerships. In that context, hinterland specifics in providing a risk mitigation service downstream reflect low-proximity feelings with all of its hindrances on reaching agreements, or it can be described as a high-transaction, cost-ridden process. This distance between the beneficiaries (usually high-value urban areas) and the area of service provision may also make the use of transferable development rights less relevant from the flood perspective. The value of development rights will be higher within the close-periphery of urban centers where the high value and the scarcity of land for further development creates the necessity of buying out other parcels' right to development in a mutually efficient manner (Crabbé and Coppens, 2019; Kis and Ungvári, 2019).

In order to provide the land necessary for flow control – as in many other economic sectors with similar information asymmetries – this should be based on economic instruments that reach their goals by establishing a platform or institution for resolution of competing interests. The perceived benefit is the primary incentive inducing subjective evaluation by potential service providers in their willingness to retain water on their land. Only a specific set of economic instruments includes the feature that their own work, in and of itself, reveals the information for setting an appropriate price for the mitigation service provided. What this chapter argues is that transaction costs, information availability and "willingness to share information" constrain land provision efforts for flood mitigation in the hinterland. Effective policy should focus on schemes that are able to efficiently single out the necessarily large pool of the most willing participants; reverse auctions do this.

Reverse auctions are a tender-type trading mechanism where one buyer and many potential sellers face each other. Sellers turn in their bids with the prices and the quantity of the service or asset they are willing to provide to the buyer. The offered quantities that have been made can then be arranged according to a ranking of bid prices from lowest to highest. The buyer starts by accepting the lowest bids up to a targeted cumulative quantity. This competitive decision framework results in the ability to select the lowest bids and is an incentive for sellers to adjust their offer price close to the real cost of the service provided.

Reverse auctions have gained momentum and have been used extensively in recent years in nature conservation tenders (Rolfe et al., 2018), land stewardship programs (Elliott et al., 2015) and for different compositions of watershed services (Bennett, 2016). There are fewer examples about the use of reverse auctions for flood mitigation services (Morris et al., 2016). A review article found that the lack of comprehensive performance assessment of the different sub-services is a serious drawback (Gordon et al., 2018). A successful online reverse auction scheme that took place on the Parrett and Tone catchments in Somerset, UK in 2018–2019 (Somerset Rivers Authority, 2020) focused on flood mitigation measures with erosion control impacts that have local relevance, while the involvement of a cumulative, watershed-wide flood mitigation aspect was not described.

Neuvel and Van Der Knaap (2010) view spatial planning in a similar manner to offer the revealing aspect of reverse auctions, writing that: "spatial planning should not only be regarded as an instrument for regulating the land required for flood reduction, but also as an important substantive perspective through which participation can be facilitated" (p. 285). Economic instruments should not only be regarded as instruments for regulation but a toolkit that can provide substantial information that facilitates the participants in reaching agreement to unlock efficiency gains of advanced landscape planning and management. Using tradable and auction-type instruments not only offers the possibility of low information transaction costs, but is the only solution that is able to provide a mutually justifiable price from both the landholder's and the stakeholder's perspectives (Jack et al., 2008).

4.4 CONCLUSIONS

Successful implementation of hinterland measures depends more heavily on managing and minimizing transaction costs of the process than any other measures along the flood pathway. There are two groups that accrue transaction costs, downstream stakeholders and upstream landholders. Previous studies have focused on the types and scale of transaction costs for downstream stakeholders, while little attention has been placed on the types and scale of transaction costs that fall on landholders. The focus of this chapter has been on the incidence of transaction costs for landholders in the hinterland.

Landholders in the hinterlands are spatially distant from downstream stakeholders. This distance has an effect not only on the choice of economic instruments but also on the subjective evaluation of transaction costs by individual landholders. This evaluation can be seen as a continuum between two positions, full compensation or no compensation for transaction costs. In the latter case, landholders that regard the costs from making changes in land management to be a social responsibility in their broader community may expect not to receive compensation beyond the direct costs of the measures. On the other hand, landholders that consider their interests to be independent from downstream stakeholders may expect all their indirect and direct costs to be included in the payment for implementation. The degree to which landholders regard themselves as "distant" to stakeholder beneficiaries may also be determined by their level of involvement in the design and operation of a program of measures. In addition, the geographic diversity of the hinterland terrain requires prior evaluation of the flood risk reduction that defines the contribution of each parcel to the overall mitigation potential across different flood scenarios. The early involvement of landholders (including farmers) with local knowledge of the terrain and the occurrence of previous floods helps to narrow down the complexity of this task and consequently the costs of preparation.

Transaction costs for landholders in the hinterlands may vary depending on when they are included in a program of land-based mitigation measures and for what costs they are compensated. One of the features of natural flood reduction measures is that they are often great in number and can be implemented at alternative sites. If landholders are included in a program only after it has been fully developed, then their role is simply one of providing services at a particular site in return for payment. In the case of an auction, they would need to determine at what price they would be willing to participate and initiate the proposed land-use change. In the case of a payment determined by stakeholders, they would need to decide whether the price offered was sufficient to cover costs. Both of these decisions themselves carry transaction costs and if the evaluated transaction was not completed (the offer not accepted) the landholder would not be compensated for these costs. In addition, in an auction process a higher bid which included the landholder's transaction costs may not be successful in competition with alternate sites (bids) which in turn could lead to a downward pressure on offer prices in order for the landholder to be partially compensated for their transaction costs. These factors taken together may lead to lowering interest in landholders' participation in a program. If landholders were included earlier in the process and their time for participation (transaction costs) was fully compensated, then this may lead to a higher degree of participation in bids or positive applications with respect to implementation of measures. Not only would some of their compensation costs not need to be included in the price of the transaction, but also there may be less uncertainty about the outcome of their bid/application.

There are specific economic instruments that can genuinely support the creation of a scheme that provides land for flood mitigation service among hinterland circumstances at different stages of the process. The information asymmetry between providers and beneficiaries of the land-use changes that unlock the provision of these services suggests the use of auction-based PES or TDR instruments as part of the planning process to determine the price of the service. These instruments can provide both of the necessary conditions of an agreement: financial viability from the landholders' perspective and the efficient use of financial resources from the beneficiaries' (stakeholders') perspective.

The knowledge and experience gap we consider most important to fill in order to enhance the realization of successful hinterland schemes lies in the nexus of developing reliable risk-based metrics to describe the performance of the potential hinterland measures. This requires the advanced simulation of the catchment processes in relation to the transformation of the different floods and their effects. Incorporating local knowledge would not only support the planning of physically possible and effective measures, it would also narrow down the set of feasible measures that the complexity of the geography makes difficult to manage. This nexus exercise can lead to lower transaction costs and set the stage to support the multi-stakeholder negotiations including the use of fit-for-purpose economic instruments. While it is in its infancy, the inclusion of flood risk mitigation into the bundle of watershed services promotes the coherent use of advanced hydrologic, legal and economic approaches.

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PART II

Flood storage along rivers

5. Technical and hydrological effects across scales and thresholds of polders, dams and levees

Reinhard Pohl and Nejc Bezak

5.1 INTRODUCTION

Floods are a natural hazard that can result in large economic losses and endanger human lives all over the world. Global annual flood losses are estimated to exceed US$100 billion (Desai et al., 2015). Climate change together with other changes such as urbanization or economic growth is expected to additionally increase flood losses (Winsemius et al., 2016). A recent study has indicated that flood risk in Europe is increasing in north-western Europe and decreasing in southern and eastern Europe (Bloeschl et al., 2019). Therefore, society needs to adapt to a changing environment (Clark, 2006; Han, 2011).

There are multiple options available for flood risk management and these include both grey infrastructure measures, such as levees, and also blue or green infrastructure approaches such as the use of small ponds that have recently gained the attention of various scientific disciplines (Hartmann et al., 2019; Schanze, 2017; Simm et al., 2013; Bourke et al., Chapter 2 in this volume). Depending on the specific catchment properties such as size or topography, there are also multiple options as to where to locate the flood protection measures including the hinterland (Bourke et al., Chapter 2 in this volume), locations on the floodplains along rivers, and flood protection within resilient cities or urban areas (Popp-Walser, 2013; Rinnert et al., Chapter 8 in this volume). This chapter provides an overview of the hydrological, hydraulic and technical concepts of flood protection measures along rivers where traditional and nature-based flood protection measures are discussed and evaluated from the flood risk perspective.

5.2 MAIN HYDROLOGICAL CONCEPTS

The focus of this chapter is on flood water storage along rivers. Catchment headwaters tend to be more forested and hilly (Bourke et al., Chapter 2 in this volume) compared to mid-catchment reaches which often have lower slopes. Consequently, flow velocity is lower. This needs to be taken into consideration when planning flood protection measures. Additionally, these downstream catchment reaches are more frequently instrumented for flow stage and discharge and resultant modelling can be more confidently treated.

The basic concept used for the design of the flood protection measures is the so-called design discharge concept (Bornschein and Pohl, 2018). Every hydro-technical measure or structure is designed taking into consideration the design discharge value, which is a discharge with a given return period (e.g., 50 or 100 years). The return period for which the structure needs to be designed is usually determined by the national legislation or by national guidelines. Less important structures, such as culverts, are designed using smaller return periods. For example, in Slovenia the design discharge with a 100-year return period is used for culvert design in case of roads within the cities and roads with design speed higher than 60 km/h while a 20-year return period is used in all other cases. Moreover, objects that are more important are designed using higher return period values (i.e., low probability events, extreme event scenarios). For example, the levees used to protect the Krško Nuclear Power Plant are designed using the probable maximum flood (PMF) concept (LaRocque, 2013), which is the highest discharge that is expected to occur at a given location. Other concepts are risk-based (R), considering the flood probability (P) and the consequences (C) expressed by:

$$R = P \cdot C \tag{5.1}$$

The next step would be resilience-based design methods additionally including the time to recover (Pohl, 2020). Thus, a first and very important step in the design of any measure used for flood protection is the definition of the design discharge or water level. In cases where a relatively long series of measured discharge is available (>30 years; series should at least cover one-third of the length of the recurrence period) the most frequently conducted approach to defining the design discharge is the flood frequency approach (FFA) (Bezak et al., 2014). In the process of conducting the FFA based on the defined sample of discharge values (i.e., the most frequent annual maximum method is used, which is one of the hydrological concepts), one relates the return period concept with the discharge estimation (Bezak et al., 2014). Different distribution functions can be used for fitting to the observed values and multiple methods are available for the estimation of the distribution parameters (Bezak et al., 2014). It is desirable to test multiple distributions and select the one that gives the best fit to the measured data based on the results of statistical tests and goodness-of-fit criteria (Bezak et al., 2014). There are several sources of uncertainty in the design discharge estimation, such as uncertainty related to the rating (i.e. discharge-water level) curve extrapolation or uncertainty related to the limited accuracy of high-flow measurements. Therefore, uncertainty and sensitivity estimation should be included in the design discharge definition (Meylan et al., 2012).

In some cases, the information about the design discharge is not sufficient for the planning purpose and an entire design hydrograph is needed. One example would be the planning of a flood reservoir where the complete hydrograph needs to be routed through the reservoir to evaluate the impact of the changed hydrological conditions on flow along the river. In such cases, hydrological (i.e., rainfall-runoff) models are most frequently applied for the definition of the design hydrograph (Bezak et al., 2018; Sezen et al., 2019). There are numerous rainfall-runoff models available; each has its own parameters that need to be calibrated using measured data. Moreover, the model performance should be evaluated before further applications. The main hydrological processes that affect runoff generation, such as rainfall loss due to rainfall interception, infiltration into groundwater or transformation of effective rainfall into runoff, are incorporated into these types of models, which can be done semi-empirically, conceptually with the consideration of water storage concepts, or using a physical basis. There are considerable differences in the concepts used between models.

The most common input variables used by hydrological models are: precipitation, air temperature or potential evapotranspiration data (Sezen et al., 2019). Depending on the size of the catchment area, a sufficient network of meteorological stations should be used for the definition of the input data. In case of smaller catchments (<50 km^2), the most relevant station can be used. However, in larger catchments (>50 km^2) data needs to be interpolated. Another important component for the design hydrograph is the design hyetograph (i.e., distribution of the rainfall amount over time for the design rainfall event). The hyetograph can also be determined using a variety of methods (Bezak et al., 2018; Dolšak et al., 2016). Therefore, by using a calibrated model and a design hyetograph (i.e., rainfall event) one can determine the design hydrograph. There are also other approaches developed for the design hydrograph definition and these are mostly based on the regionalization methods using the similarity concept (Bloeschl et al., 2013).

In case that measured discharge data is not available, which is common in many catchment headwaters (Bourke et al., Chapter 2 in this volume) and across semi-arid and arid regions, catchments are regarded as ungauged. In these cases, alternative approaches are used for the design discharge and hydrograph definition (Bloeschl et al., 2013). Different types of methods are developed for the prediction in case of ungauged catchments, from simple empirical equations for discharge estimation to more complex methods that can be based on the statistical methods and the similarity concept of the nearby catchments (Bloeschl et al., 2013 with more detailed information for further reading).

5.3 HYDRAULICS FOR FLOOD ROUTING AND FLOOD PROTECTION

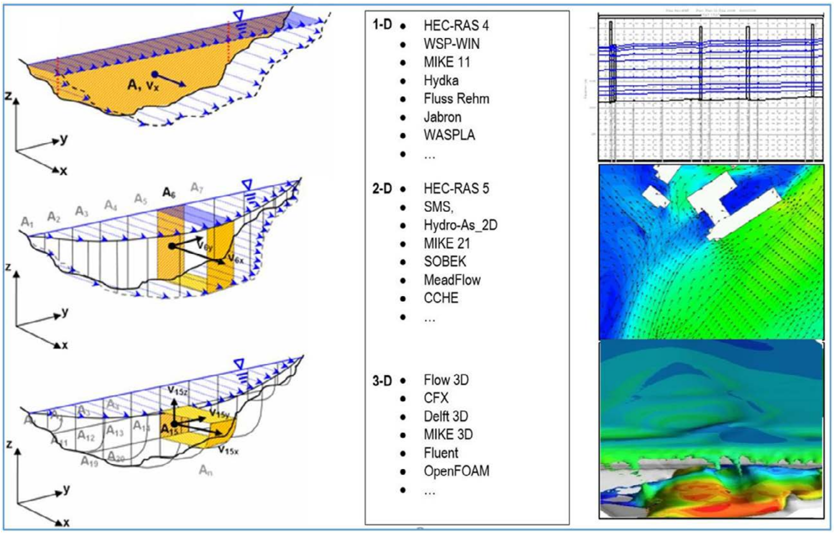
Finding the relation between water depth and flow rate is one of the basic issues in hydraulic engineering. Two questions arise from this issue: first, how much water can be conveyed at a given water level under certain boundary conditions and channel properties (channel and floodplain roughness, cross section, longitudinal slope) and second, which water level will result from a certain discharge at a certain point. The first answer enables the design of the dimensions of a channel and the second is important for flood protection and the estimation of inundation areas.

In the special case of a channel with constant cross section, roughness and longitudinal slope along the flow path (uniform flow) and constant discharge over time (steady flow), the so-called normal flow (depth) will be observed. In this case, the relation between the discharge and the water depth can be expressed, for example, using the Manning-Strickler formula (Chow, 1959):

$$Q = A \cdot \frac{1}{n} \cdot r_{hy}^{\frac{2}{3}} \cdot \sqrt{s_e} = A \cdot v \tag{5.2}$$

with A – flow cross-section area, n – Manning's roughness coefficient, r_{hy} – hydraulic radius (i.e., ratio between cross-section area and wetted perimeter), s_e – longitudinal energy slope, v – mean flow velocity. This also applies to very gradually changing time-dependent (i.e., quasi-steady) flows in prismatic channels (e.g., a trapezoidal-shaped channel). The roughness coefficient was originally derived for 1D-flow calculations. Its application in 2D hydro-numerical models requires experience and expert knowledge and can be confirmed by calibration and verification of hydraulic models.

In the more general case, the channel properties and, consequently, the flow velocity vary along the flow path. Furthermore, the discharge varies over time due to variations in rainfall, water utilization and snowmelt. This non-uniform, non-steady flow can be described by differential equations on the basis of the principles of conservation of energy (i.e., Bernoulli's equation) and mass (i.e., continuity equation) which were introduced by Saint-Venant (Graf, 1998). Especially in lowlands and areas with large floodplains (reclaimed land), a one-dimensional calculation using the above-mentioned approaches is not sufficient. For these applications, two- or three-dimensional numerical software programs have been developed in order to provide a realistic modelling of the flow characteristics. Figure 5.1 summarizes different methods of discretization and shows some examples of numerical software programs that can be used for hydraulic modelling.



Note: Names and abbreviations written in the middle panel represent hydraulic model software names.

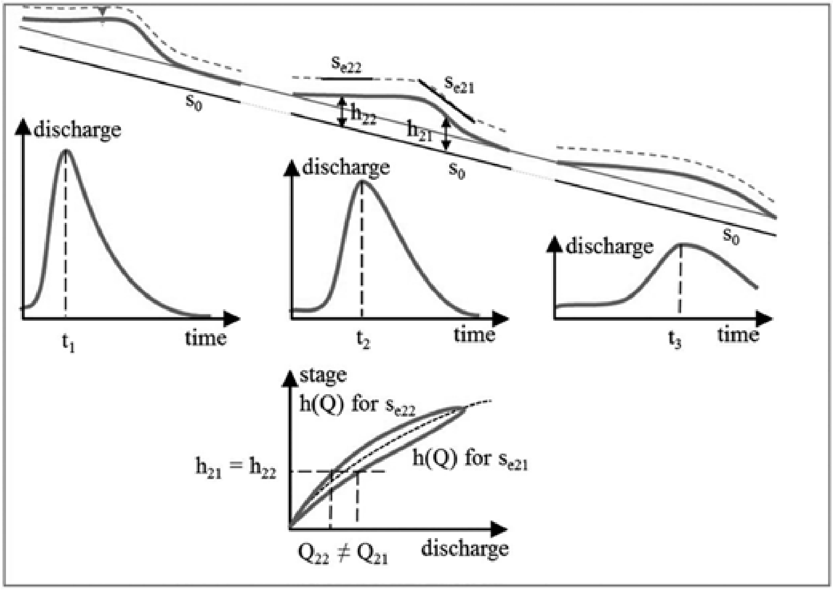
Figure 5.1 Discretization of calculation elements for one-, two- and three-dimensional hydraulic models and some examples of such models

The results of the hydro-numerical hydraulic models can be displayed using hydraulic profiles or inundation maps (Figure 5.2).

Due to the steeper energy slope on the flood wave front, there is a higher flow velocity than at the rear of the wave. The higher velocity of the advancing wave and the lower velocity behind the wave peak result in a flattened wave peak with a reduced peak discharge (Figure 5.3). This is particularly so where there is no confluence or surface water input to feed the flood wave entering the considered control section of the river.

Note: From left to right: terrain model, aerial photo, topographic map.

Figure 5.2 *Inundation maps displaying the water depth on different map layers*



Notes: Top: water level as a function of the flow path (profile h = h(x)). Mid: discharge as a function of time (hydrograph Q = Q(t)). Bottom: hysteresis of the stage (water level)-discharge-relation (different discharges at the same depth in front and behind the flood wave peak).
Source: Pohl (2012).

Figure 5.3 *Flood wave at three points of a river/open channel under the assumption of a prismatic channel without additional confluences or precipitation along the considered reach*

This retention effect can be intensified by large floodplains or other retention areas. However, for very long-duration floods (i.e., over several days or weeks), which may be common in perennial large river basins, this effect is almost not perceptible due to a very large water volume. This can result in a quasi-steady flow. In this case, very large storage volumes (S) are needed in or alongside the river to reduce the inflow Q_{in} into a considered river section.

The change of the water storage volume dS within a control section of a river reach, reservoir or polder equals the difference between the section/reservoir inflow Q_{in} and outflow Q_{out} during a period and can be written as a differential equation for small time steps dt:

$$\frac{dS}{dt} = Q_{in} - Q_{out} \tag{5.3}$$

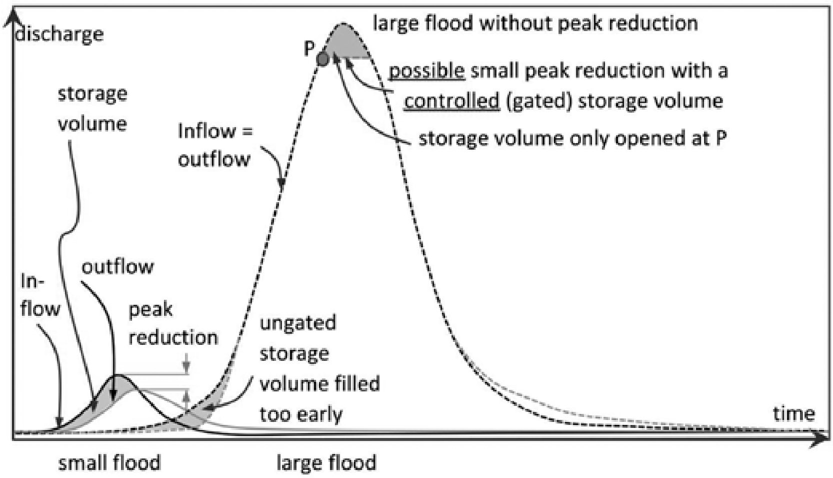
The inflow includes the upstream river inflow as well as the overland runoff from the sides as well as precipitation within the control section itself in the river channel. The outflow is the downstream discharge or the flow through outlets in the case of controlled polders or reservoirs.

The often-proposed levee setback is another flood risk management option that might also improve ecological parameters (Bozkurt et al., 2000). Filling the wider forelands with the arriving flood wave can retard the wave propagation and reduce the peak discharge. However, the latter does not work when the flood wave fills the retention volume before the peak has arrived (Figure 5.4).

In the case of large flood waves, only controlled polders or reservoirs can reduce the peak when their inlet structure is opened at the appropriate point in time shortly before the expected passage of the peak. This flood management requires a rather good flood prediction, which usually involves a combination of measurements and modelling to find the right moment for opening the gates (Acreman et al., 2002).

Another secondary effect of levee setback along relatively short flow paths is the development of the water level. Assuming subcritical flow conditions (i.e., Froude number smaller than 1, which indicates a flow with lower flow velocity and bigger depth compared to supercritical flow that is characterized by Froude number larger than 1 possessing higher flow velocities and lower depths) and applying the Bernoulli's-Theorem:

$$z + h + \alpha \cdot \frac{v^2}{2 \cdot g} = const. \tag{5.4}$$



Notes: The image shows a comparison of a small flood (solid lines) and a large flood (dotted lines). Inflow hydrograph: black line, outflow: grey lines. Hatched area: storage volume. Hydrographs of a small flood (i.e., 2-yr flood) and a large flood (i.e., 100-yr flood) are shown as an example. All areas in the chart indicate water volumes because the vertical diagram axis represents the discharge and the horizontal axis depicts time. For the small event, a peak reduction is possible; however, for the large event, controlled reservoir storage is required. Only when its inlet gates are opened at point P can the expected peak reduction be reached.
Source: Pohl (2019).

Figure 5.4 Effect of a small flood retention measure

with z = elevation above a datum (e.g., mean sea level), h = water depth, α = kinetic energy correction factor, v = mean flow velocity and g = acceleration due to gravity, together with the principle of continuity:

$$Q = v \cdot A = const. \quad (5.5)$$

This shows for the same discharge that a wider flow cross section after a levee setback causes a lower flow velocity and hence a slightly increasing water depth at least at the lower end of the setback reach upstream of a reduction of the flow cross section area. The requested minimum length of levee relocation to get a lower water level has been investigated by Gilli (2010).

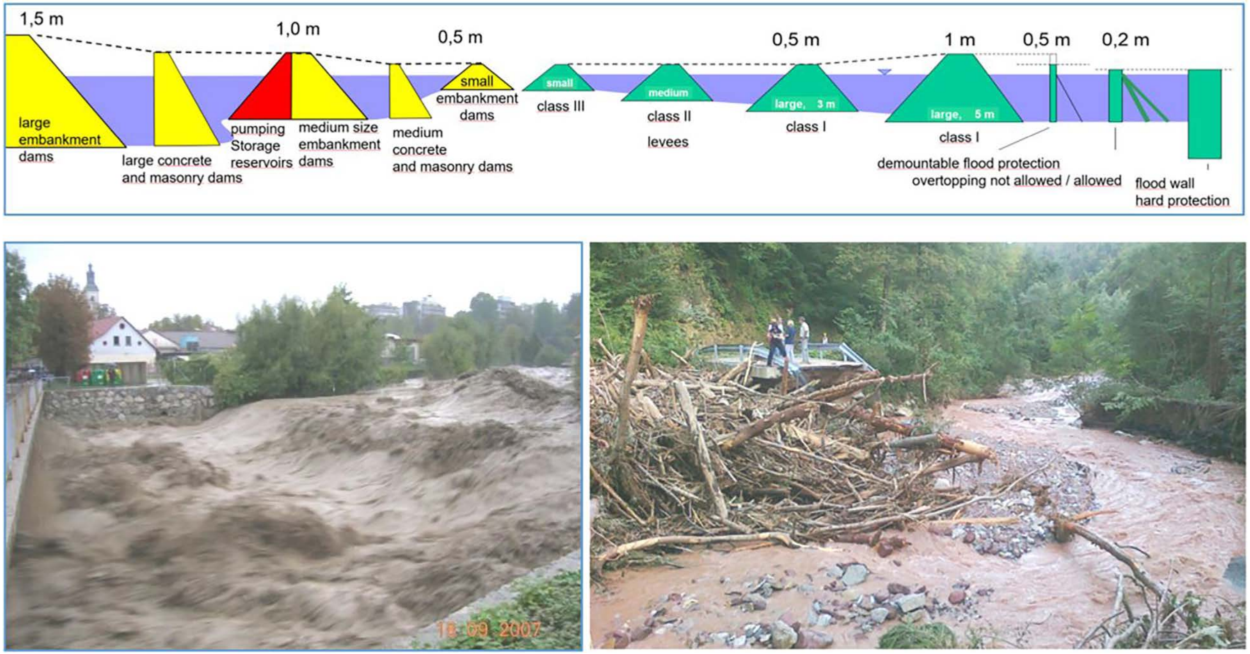
5.4 DESIGN WATER LEVELS

For effective planning of flood protection measures, the design water level must be defined along the entire flow path. As mentioned above, a design discharge can be determined based on the hydrological analysis (gauge observation series extrapolation or precipitation-runoff model). Settlements, industries and important infrastructure are often protected against a 100-year flood $(P \leq 0.01)$ according to the regulations and guidelines in many countries. Using the design discharge, the water level profile along the open channel is usually found by means of a hydro-numerical calculation. In very simple cases (approximately quasi-steady, uniform flow), at small streams the application of eq. (5.1) might be sufficient. For the majority of cases, a hydro-numerical model is recommended since the calculations can be done in this way more easily for larger river reaches and because these models use different computation methods that go beyond eq. (5.1). For valleys with clearly identifiable flow paths, a one-dimensional model (Figure 5.1) might be sufficient. For rivers in lowlands with unclear flow paths during floods, two-dimensional models are preferred (Figure 5.1). For very complicated flow situations, e.g., proximal to physical structures, abrupt flow changes, rapids or obstacles, three-dimensional hydro-numerical models can help to understand the flow pattern and to find the wetted perimeter of the channel (Figure 5.1). Furthermore, in the most critical examples, a physical model can be constructed to obtain required information for the optimal planning of structures such as outlets or gates (Bombač, 2012; Novak et al., 2016).

For the design of the bank, embankment or elevation of flood protection measures, a freeboard is usually designed to cope with waves (run-up height calculation), settlements and uncertainties. In some countries, a minimum freeboard allowance is given, whereas elsewhere only recommendations exist (Figure 5.5). These freeboard allowances are normally sufficient when the fetches (wind interaction length) are less than 100 metres, the water depth under five metres and the bank slopes lower than one in three (approx. 18°).

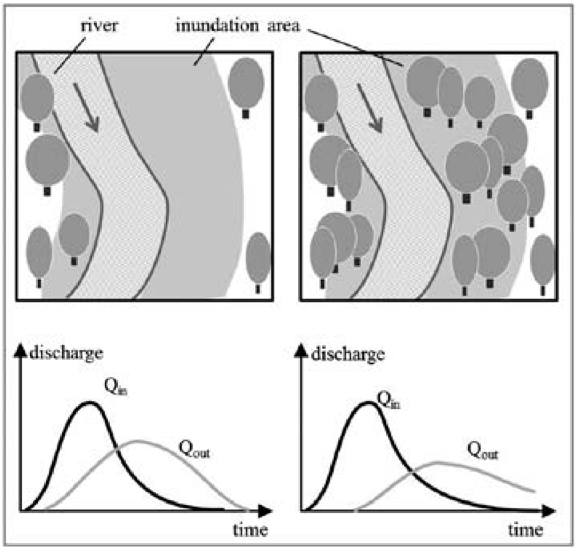
When a floodplain is covered with high or dense vegetation (resulting in a higher roughness coefficient, Mannings n), the downstream peak discharge can be reduced and the flood wave duration increased (i.e., compared to the upstream section) (Figure 5.6). Accordingly, water would remain longer within the inundation area and the flood water level may be higher (Gilli, 2010). Nevertheless, these effects have a lower impact on extreme and rare (i.e., catastrophic) floods than on smaller and more frequent floods. In addition, the roughness could be increased by the entrapment of large floating woody debris which is stuck between upright trees during a flood event. The floating (e.g., woody) debris can also enhance infrastructure damage (e.g., bridge openings or culverts) (Figure 5.5).

This relationship between floodplain roughness and flow hydrograph was confirmed by an experiment when modelling the flood control function of floodplain woodland in a 2.2 km-long reach of the River Perrett, United



Notes: The figures in the lower panel show a situation during a flood event (the left figure shows standing waves upstream of the bridge structure and was taken during the 2007 flood in Slovenia on the Sora river, while the right figure shows the destruction of a bridge due to the transport of woody debris during the 2014 flood in Slovenia on the Gradaščica river) where it is evident why consideration of freeboard is essential (i.e., processes and events can occur that cannot be predicted or prediction is very uncertain).

Figure 5.5 Proposed minimum freeboard allowance (upper panel)



Notes: Left figures: lower roughness. Right figures: higher roughness.
Source: Bornschein and Pohl (2018).

Figure 5.6 Flow hydrographs (Q_{out}) at the end of a river reach with the same inflow hydrograph Q_{in} but different land use

Kingdom (Nisbet, 2006). The setup of a 133 ha wet woodland within this area would increase the flood storage by 71 per cent and delay the flood peak arrival downstream by 140 min in case of a 100-year flood event. It is also noticeable that the influence of vegetation on flood propagation differs seasonally as vegetation in winter is often less dense and/or lower. Hydraulic models that were calibrated using a winter flood event should be modified before forecasting flood water levels for a summer flood event (Heyer et al., 2015).

5.5 FLOOD RISK MANAGEMENT CONCEPTS

Flood risk management concepts may have different objectives. One objective can be a lower peak water level. Another aim could be a later arrival of the flood wave. Sometimes upstream measures can be carried out to protect downstream people and property. In other cases, the measures can only be organized in the floodplain areas and not upstream. Sometimes the removal of downstream obstacles, blockages or sediments can help to avoid backwater effects (i.e., higher upstream water level).

From these issues, different measures and hydro-technical structures can be derived. As mentioned above, the retention capacity in the catchment area can be improved by rough terrain surfaces (crops, bushes, trees, forest). In addition, other measures include forming troughs and hollows in the landscape, by ploughing parallel to the elevation contours (and not downhill), by meandering streams and rivers and more groundwater recharge instead of surface runoff. These 'soft-engineered' structures use natural materials, but do involve design and construction. The more frequently deployed technical approach for regular flood protection is the construction of flood defences ('hard' engineering).

There are three main kinds of flood defences: levees, flood protection walls (so called 'hard' engineered structures) and demountable (i.e., temporary) elements. For individual building solutions, stop logs and plates are often used to seal doors and windows. Some examples are provided in Table 5.1 with possible objectives. Additional examples can be found in Chapter 8. Thus, it can be seen that specific measures in almost all cases can have some negative effect (e.g., negative effect of upstream levee on downstream flood conditions). Therefore, a holistic approach should be used when planning flood protection measures and planned measures should be evaluated from the upstream-downstream perspective (Rinnert et al., Chapter 8 in this volume). Furthermore, Figure 5.7 shows some examples of hard engineered flood protection measures.

5.6 FLOOD RISK AND RELIABILITY OF MEASURES

The objective of flood protection should be chosen in such a way that the overall financial benefit of the measure is greater than the investment. There are several guidelines and publications available about cost-benefit analysis in hydraulic engineering and water management (Dittrich et al., 2018; DVBU, 2008; DVWK-M10/1985; LAWA Leitlinien 1979; LAWA Grundzüge 1981; LTV Erstellung von Hochwasserschutzkonzepten, 2003). This approach can be applied using the flood risk management concept with the basic eq. (5.1) where the consequences are the (avoided) costs per year and the probability refers to an arbitrary year. However, this equation implicates the zero-times-infinity-problem with numerical instability for extreme values of both variables. Very rare events (i.e., catastrophic floods) with low probability normally cause very huge consequences and vice versa. When displaying the consequences (ordinate) as a function of the probability (abscissa) in a coordinate system (Figure 5.8), the area between the curve and the abscissa is the risk being represented by the integral over all possible events.

$$R = \int_0^1 C(P).dP \qquad (5.6)$$

Notes: From left top to right bottom: 1. Levee with flood wall at Jessnitz, Germany. 2. Flood wall under construction (2013) on the right Rhone bank in Arles, France. 3. Levee with flood wall and openings for demountable flood protection elements at the Elbe River in Dresden, Germany. 4. Leveed river with smoothed bed: Weisse Elster south of Leipzig, Germany. 5. Flood bypass cutting a meander of the river Elbe, Dresden, Germany. 6. Flood bypass using the artificial channel (i.e., Gruber channel that was constructed in 1780) that is used to protect the Ljubljana city centre.
Sources: First five photographs: R. Pohl. Final image: Atlas okolja (2021).

Figure 5.7 Six flood protection measures

Table 5.1 Examples of different hard-engineering flood protection objectives and measures with possible implications

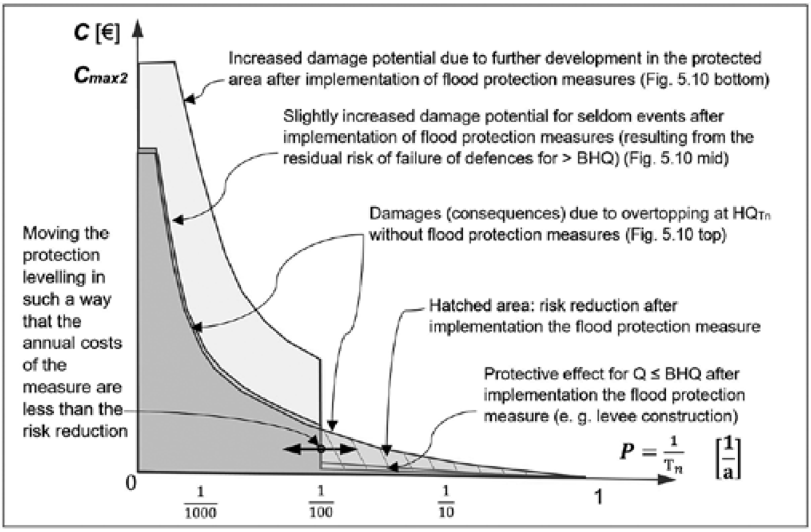
Objective	Measure	Issues and possible implications
Lower flood water level	Reducing channel roughness	Loss of natural river bed, erosion along the channel, earlier downstream arrival of flood peak
	Flood bypass cutting meanders	Increased hydraulic gradient, earlier downstream arrival of flood peak
	Removal of sediments	Disturbance of sediment balance, required bed load disposal, loss of aquatic habitat
	Deepen the river bed	Disturbance of sediment regime and groundwater flow, upstream erosion, downstream sedimentation, loss of aquatic habitat
	Upstream flood retention to cut the discharge peak	Upstream inundation or reservoir needed, large storage for relative small peak reduction downstream, inlet-, outlet structures for polders
Later flood peak arrival	Raise channel roughness	Higher water level, more upstream inundation
	Upstream flood retention	Upstream inundation or reservoir needed, outlet structures
Protection of people and properties	Structural flood defences (levees, walls, demountable flood protection elements	Structures in the landscape, reduction of retention area affecting downstream reach (i.e. higher water level downstream)
	Individual object protection, flood-adopted buildings	Flood-protected isles in an inundated area

Assuming full (100 per cent) protection against all events which occur more frequently than after periods of T_n years, the remaining risk could be reduced to the value:

$$R = \int_0^{1/Tn} C(P) \cdot dP \tag{5.7}$$

In case of additional building activities in the protected area after completing the flood risk management measures (Figure 5.10), the potential consequences would rise and therewith the risk. Furthermore, a higher risk than without protection might be thinkable, which can be read from the larger area below the revised curve in Figure 5.8. That such activities really occur, one can see in Figure 5.9.

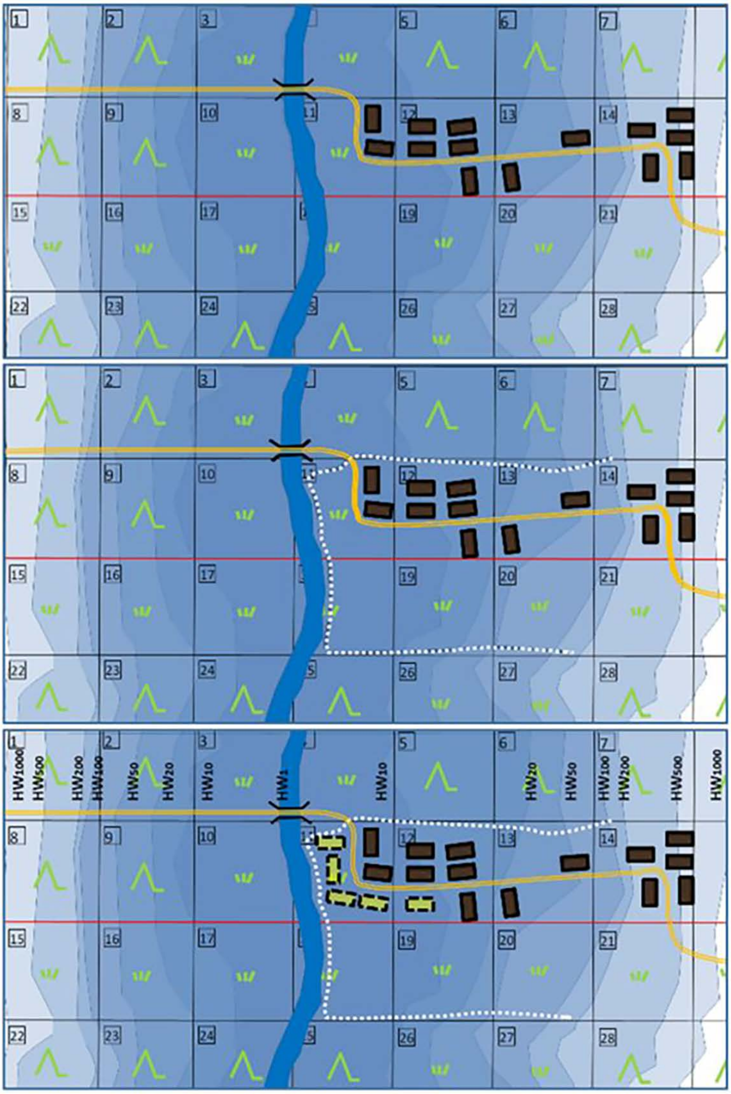
When the consequences of flood events can be expressed as monetary damage (e.g. €), the risk gets the unit €/a and represents the expected annual damage.



Notes: Schematic diagram not scaled: Q = discharge, C = consequences, costs, P = exceedance probability, BHQ = design flood, HQ = flood with a certain recurrence period.

Figure 5.8 *Risk of inundation of the area behind a flood defence compared with the situation without protection and with additional property after having built the defences*

Figure 5.9 *Real estate brokers are offering building lots directly behind the levee that has been refurbished after the hurricane Katrina 2005 (Highway 23, Belle Chasse, New Orleans, LA, USA)*



Notes: Originally without flood protection (top), then leveed (white dotted line, mid) and later further developed (light grey houses, bottom).

Figure 5.10 Example of a flood-prone housing development

5.7 EXAMPLE OF GOOD PRACTICE: DRY RETENTION BASINS

Dry retention basins are one of the examples of a water retention hydro-technical structure. In the case of this type of structure, the area inside the retention structure is flooded only during high-stage events. During low and mean-flow conditions, the area can be used for other purposes, e.g., agricultural production or recreational amenities (e.g., grass area or partly forested, although forest reduces the capacity). It should be noted that floods can have a negative effect on the soil properties if the area is used for agriculture (e.g., Glavan et al., 2020). Despite this, they are frequently used in Slovenia in order to improve flood safety. An example of such an object is the Prigorica dry-retention reservoir located on the Ribniščica river (southern part of Slovenia) in order to ensure flood safety of the nearby Ribnica settlement. The dry-reservoir was constructed more than 30 years ago and is in operation during high-flood conditions (Figure 5.11). The reservoir can retain up to 12×10^6 m^3 or, during catastrophic floods, up to around 15×10^6 m^3. When the reservoir is completely full, it covers an area of 270 ha. The hydro-technical elements include an embankment dam, outlet, gate and emergency spillway. During more than 30 years of operation, this basin has been in operation several times. However, it should be noted that regular maintenance is required to ensure optimal performance during high-flow events. Such measures are regarded as an example of good practice that combine elements of green (i.e., area inside basin can be used for agricultural production) and grey infrastructure and most importantly can be used to reduce the flood damage. However, as pointed out by Nester et al. (2017), the effect of such retention reservoirs decreases with scale. Thus, for large catchments the effect of multiple reservoirs can be small. For example, Nester et al. (2017) showed that use of 130 alpine retention measures with total volume of 21×10^6 m^3 located in the Inn river would only reduce flood peak by 2–3 per cent compared to the situation without these retention measures. Thus, it is clear that in such a case some other flood protection alternative should be used.

5.8 CONCLUSIONS

More space for flowing waters can help to reduce the flood peak and to delay the arrival of the flood peak downstream. Small measures can in some cases only affect small floods or have a local effect. Nevertheless, they can help to reduce the frequency of inundations downstream. The reduction depends on the scale. If a considerable cut of high flood peak is desired or needed, large storage volumes are required which should additionally be gated so that the

Notes: Upper two photos show the area inside the retention reservoir during high- (left) and low- (right) flow conditions. The lower image shows reservoir outlet flow during a high-flow event.
Source: Ribnica24 (2021).

Figure 5.11 Wet retention reservoir in operation

storage is not filled before the arrival of the flood peak. Therefore, some other measure could be more suitable in such cases.

Hydrological and hydraulic models can help to assess the effects of flood mitigation measures. Hydraulic models are applicable to extrapolate stage (i.e., water level)-discharge-curves for large floods that were not recorded in the past. Roughness coefficients like Manning's n or Strickler's k_{st} were originally introduced into 1D-flow calculations so that their application in 2D-hydro-numerical models needs experience and expert knowledge. That is why calibration and verification of hydraulic models are very important for the reliability of the modelling results. The same applies for the hydrological models where model calibration and evaluations should be done before further use of the models. Therefore, the modeller should also keep in mind the drawbacks and limitations of the model.

Often it is postulated that a couple of small protection measures is better than one large measure. As the economic and hydraulic efficiency depends on many factors, it cannot be said in general and without profound individual analysis whether one large or several smaller flood protection measures will bring the better effect. When speaking about nature-based solutions or non-structural methods, we must confess that also these projects need a lot of construction work at least during the phase of project implementation but in many cases also during their later lifetime (i.e., maintenance). Furthermore, these measures are structural measures too, including earthworks, excavation, reinforcement of embankments, building pathways and roads and in some cases also bridges, inlet/outlet structures, and flood defences. In the end, it is important that all flood risk management actions and protection measures should be evaluated from a cost-benefit perspective in order to ensure that public money is spent in an effective way to protect people, property and the environment.

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6. Financial compensation and legal restrictions for using land for flood retention

Andras Kis, Arthur Schindelegger and Vesna Zupanc

6.1 INTRODUCTION

Flood retention to control flood runoff and cut flood peaks is considered to be an efficient flood protection measure (Munich Re, 2014). Typically, retained water in a technical understanding is not the flood runoff between dike lines but instead floodwater within (controlled) polders. The idea of orchestrating controlled flooding into designated retention areas upstream of vulnerable areas often leads to highly specialized and mono-functional technical constructions (Patt and Jüpner, 2013).

Retention areas for temporary flood storage can typically only be allocated to non-occupied areas (i.e. not constructed), which are usually occupied by agricultural areas. Furthermore, land for the construction of necessary accompanying technical structures (inlet, outlet, levee) is needed. As allocation of retention measures can sometimes be met with reluctance in local communities (Glavan et al., 2020), suitable financial mechanisms (Slavíková et al., 2020) must be established to encourage cooperation of local stakeholders and private owners to avoid long-term mistrust (Raška et al., 2019) in order to ensure successful implementation of retention measures. It is therefore essential to take a look into the theoretical as well as practical considerations of financial compensation to land owners providing retention services as well as land-use restrictions (Slavíková et al., 2020). The notion of property is not a universal one but rather specific for every national and constitutional context – as discussed by Albrecht and Nikolić Popadić (Chapter 3 in this volume). Planning interferes with property permanently as development options are granted or restricted (Van der Veen et al., 2010). Compensation is not granted for every planning-related depreciation. The OECD frames three triggers that should be taken into account here: (1) the degree of interference with property rights, (2) the character of governmental measures (purpose, context) and (3) interference of the measure with reasonable and investment-backed expectations (OECD, 2004). If compensation is indispensable, it therefore depends on the degree of property interference and the specific legal context. Compensation for retention services that come with development restrictions are common in Europe but differ in detail among countries (Tarlock and Albrecht, 2016).

The chapter aims to disclose how 'fair' financial compensations for retaining water on (private) land can be calculated and how they are linked to legal titles to land as well as land-use restrictions. While some aspects besides economic ones such as personal attachment, substitutional areas and cultural value may also play a role in practical arrangements, they fall outside the scope of this chapter.

Firstly, the foundation of calculating compensation for individual assets and the different possibilities to disburse compensation via (a) buyout, (b) one-time payoff with additional payments on a yearly basis or connected to events or (c) in relation to actual events will be explained. As a second aspect, the chapter looks into the question of the composition of financial means. Financing can be secured from public funds according to a distributive scheme among public and private stakeholders or by private financiers only. Any compensation for granting property or usage rights goes typically with either a change in ownership, easements or land-use restrictions. For logical reasons, areas dedicated for flood storage need to maintain this service long-term. Therefore, the control of land use, construction or land transfer is a core issue of any retention project, yet often neglected.

The chapter aims to provide a systematic overview of the characteristics and role of compensation payments in flood retention projects and their connection to land-use restrictions. First, a theoretic section illustrates the underlying principles complemented with a desktop research-based presentation of relevant examples from European countries. It is therefore a descriptive secondary analysis to provide an introductory reading. The reader will receive a systematic overview on compensation and land-use restriction in connection with flood retention, an exemplary insight into the actual practice of European countries and an outline of essential aspects that need to be considered in designing compensation schemes (social, economic, environmental criteria).

6.2 GOVERNING LAND FOR FLOOD RETENTION

6.2.1 Costs and Benefits of Flood Retention

Similar to other types of flood risk management measures, retaining floodwater requires a long-term perspective on economic costs and benefits. In the planning stage, short-term constructing costs are immediate and visible, while long-term benefits of reduced flood risk are less tangible. Flooding private land to provide retention services raises the question of compensation, as the benefits generally accrue to others than those who face the costs. Deciding on the rationality of the investment and calculating the compensation both require a good understanding of different types of costs and benefits related to designating a given piece of privately owned land for floodwater storage (Hartmann et al., 2019).

Project costs consist of several items that can be divided into short-term costs – including expenses for construction or land easement (Grčman and Zupanc, 2018) – and long-term operational costs. Costs for construction operations cover infrastructural development, which is almost always needed, whether it is building an inlet or outlet structure, a levee section, channel system adaptation or some other construction. Operational costs cover maintenance of the infrastructure and damages occurring in the event of flooding and losses connected to restrictions of land use. For most flood-retention sites, damage due to flooding the land will occur at times, but not every year. Potential cropland flooding may necessitate an adjustment in agricultural practices that may be unsuitable for certain crops or cultivation methods. Also, the use of specific pesticides may be forbidden. For example, in the case of hop production as described by Glavan et al. (2020), there is a complex system that the compensation of agricultural production strategy entails. From an agricultural perspective, four aspects need to be included in cost evaluation of compensation during the pre-flood management planning: (1) soil management (e.g. monitoring of soil quality, a technical manual for removal of flood slurry and debris), (2) management and maintenance of agricultural infrastructure (e.g. hop wires, drainage and irrigation systems), (3) tillage operations oversight (warning systems, farm economic analysis, dry detention reservoirs scheduling) and (4) adaptation to microclimate changes (frost protection, pest control, crop rotation adaptation). The change in possible land uses entails costs – via reduced profitability – for farmers, and in some cases, permanent loss of livelihoods due to decreased quality or size of arable areas. Less frequently, non-agricultural land is used for flood retention, such as football fields, parking lots and playgrounds. In these cases, much of the costs are related to cleaning the field and reconstruction or repair of damaged assets. Especially construction land is seldom considered for nature-based solutions for flood protection, as compensation costs of such areas would be extremely high.

The various benefits generally take the form of lower flood defense related costs and reduced flood damages, also to agricultural land which is usually exempt from flood protection plans (Holstead et al., 2017). There is a need for less dike development and maintenance, fewer people and sand bags for actual defense operations, and just as importantly, there is a lower risk that a costly flood event happens. Quantifying flood risk is a complex effort as it requires hydrological modeling as well as sound economic estimates of damages in affected areas (Ungvári and Kis, 2018), but it is critical to be able to judge the economic merits of any flood risk related interventions. If land-use change is part of the floodwater storage-related arrangement, ecosystem services may emerge which offer other kinds of benefits that may be more difficult to quantify, and the private land owner can neither benefit from nor relate to it (Raška et al., 2019). Ecosystem services may consist of, for example, improved local hydrology, enhanced biodiversity, carbon sequestration and opportunity for recreational activities (Kiedrzyńska et al., 2015).

Some costs are immediate, others will occur in the future, and most benefits will also register with a delay, in connection with future flood events. To be able to compare costs and benefits, it is indispensable to bring them all to a common denominator. Present value is one such measure; annualized value is another. If projected benefits significantly exceed costs, then it makes sense to carry on with the idea of floodwater storage.

Under most flood-retention schemes, benefits will accrue mainly to settlements, while costs will register primarily with farmers and private land owners that provide the service of flood risk reduction. The latter generally demand compensation even if that is not always ensured by national regulation. In addition, some water retention measures may count as good agricultural practice that is already subsidized, therefore claims for additional compensation may not be legitimate (see Albrecht and Nikolić Popadić, Chapter 3 in this volume). The farmer survey of Posthumus et al. (2008), nevertheless, highlighted that farmers typically insist on compensation payments for their flood risk reduction services. The authors inspected both runoff control measures on upstream farms and water storage on farms in the lower parts of a catchment. If a measure constitutes a good farming practice, serving the interests of both the farm and the community, then farmers might be willing to carry it out without compensation. However, for any activities that entail costs for the farmers, there is unanimous agreement on the need for compensation. One of the findings of McCarthy et al. (2018) is that in England and Wales the availability of funding for compensation was the main driver for successful flood storage arrangements with farmers. A historic example for water management related compensation in the Netherlands is provided by Bos and Zwaneveld (2017). When the Zuiderzee (a bay of the North Sea) was closed off over a century ago by one of the largest ever water infrastructure projects, affected fishermen lost their income and had to choose new occupations. They were granted individual compensation which made up almost 5 percent of the total projected development cost.

Using a simplified scheme, it is feasible to assume that there is one group of beneficiaries and one group of service providers. Equation 6.1 illustrates the economic precondition of an operational arrangement:

$$B >= C_{comp} + C_t >= C_s \quad (6.1)$$

where: B is the risk reduction enjoyed by the beneficiaries (minus the cost of infrastructural measures paid by them); C_{comp} is the compensation paid to service providers; C_t is the transaction cost of concluding the agreement; and C_s is the total cost faced by service providers as a result of storing floodwater on their land (including the cost of infrastructural measures paid by them).

If the above formula holds, then there is a possibility for all players to benefit from the scheme – depending on the actual compensation arrangements. Putting this theoretically sound precondition into practice encounters difficulties with the uncertainty of valuing costs and benefits, e.g. the financial value of flood risk reduction. The asymmetry of information on costs and benefits can further complicate the analysis: farmers may know but not disclose the level of potential damage on their land. Therefore, the value of B and C may not be available as discrete figures, only as estimated ranges. However, as Collentine and Futter (2018) describe, flooding urban areas is generally costlier than flooding rural land, thus there is a lot of room for the formula to hold in case of upstream rural and downstream urban relations. The practice of the Environment Agency in England shows that benefits outweigh costs at a large number of farms (McCarthy et al., 2018).

From here on, we will concentrate on the compensation (C_{comp}), how it can be structured, what some of the pros and cons of its specific variations are, and which parties possibly contribute to its payment. We will also consider the transaction cost (C_t) when feasible.

6.2.2 Compensation Payments in Europe

Based on the introduced scheme, determining a compensation seems rather simple. However, in reality this can be a complex and sophisticated task, as it depends on the services provided, how risk is shared among involved stakeholders, how payments are structured, what kind of events trigger payments of the compensation, etc. In addition, there are difficult to monetize aspects such as personal attachment to a piece of land, lack of substitutional areas and the presence of cultural values. Each of these items may make it more difficult to reach an agreement or drive the level of compensation up.

As shown in Figure 6.1, payment may originate from various stakeholders. Payments by direct beneficiaries are frequently supplemented by local, regional or central government instalments; in fact, they often carry the bulk of the burden. Besides, beneficiaries from retention measures are often not only downstream property owners but also infrastructure operators (e.g. highways, railway) that might help fund such prevention schemes. In general, monetary funding is used for compensation, but there are also examples of offering land in other locations in exchange for the land dedicated for flood retention, while sometimes the land itself is purchased by authorities, municipalities, etc. Concerning the timing of payments, there are various practices, none of which is dominant. Compensation payments might be disbursed event based, on an annual basis, in connection with establishing retention services in a one-time payoff or use a mixed scheme. And finally, there is a risk that increasingly frequent floods generate higher overall costs. Depending on the compensation scheme, these costs may increase the burden of either the beneficiaries or the service providers.

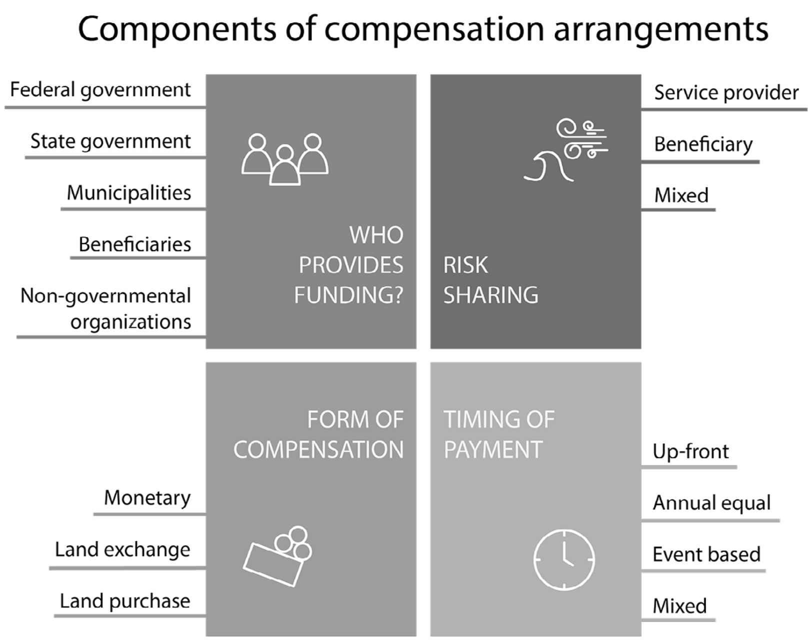

Figure 6.1 Typical building blocks of compensation agreements

Next, examples are drawn from European countries illustrating that various compensation schemes can work effectively, depending on local conditions.

In Hungary, following the record-breaking floods of the 1998–2001 period on the river Tisza, the government decided on the construction of a string of emergency polders along the river to avoid the exceedingly expensive continued heightening of the dikes. Until today, 6 major polders have been developed with a combined storage capacity of 720 million m^3, covering a total land area of 250 km^2. The polders are intended to mitigate infrequent, extremely large floods that occur only a few times in a century. The related damage, however, can be astronomic, justifying the costs associated with the construction and operation of the polders (Ungvári and Kis, 2018). The predominantly agricultural land inside the polders continues to be cultivated. Only the land area necessary for the construction of the locks and other structures, as well as the dikes surrounding the polders was purchased by the government through a process of expropriation. At the time of the construction, land owners with land inside the polders received a one-time payment to compensate for the inconvenience associated with the construction and future operation of the polder. The actual value of this compensation depended on the soil quality of the farm in question; on average it was about 390 EUR/hectare, corresponding to 10–20 percent of the value of land at the time (Weikard et al., 2017). In addition, in case floodwater is released into the polder, full damage compensation is guaranteed by regulation. So far this has happened only once, when the Tiszaroff polder was put to use in 2010. Both the initial, one-time payment and any event specific compensation is paid by the central government – which is also in charge of most flood protection infrastructure and operations in Hungary; in essence, the government bears all flood risk. Downstream beneficiaries consist of many different settlements and they do not take part in financing the compensation.

Also in Hungary, a dike relocation project is currently under execution along the river Tisza, at Fokorúpuszta just north of the city of Szolnok. Over 300 hectares of former agricultural land is being added to the floodplain, targeting flood risk reduction and enhanced ecosystem services. Following the relocation of the dike, this area will be under water about 10 per cent of the time and thus it will no longer be available for crop production (REKK, 2020). The land area is purchased by the government and turned mainly into meadow, with a patch of forest. The government offers a price to land owners that is approximately 20 percent above market prices. If this offer is refused, then expropriation is applied, resulting in higher transaction costs, but potentially a lower price premium. Recently, the majority of land owners come to an agreement with the government and expropriation happens relatively infrequently. As agricultural activities will cease in the area, no party will have to face the risk of flooding.

In the case of the Seymaz river renaturation in Switzerland – targeting flood risk reduction, habitat improvement and water-quality recovery – agricultural land was converted into natural area (NWRM, 2013a). As a result of the project, 800,000 m^3 of water can be retained. Farmers initially opposed the idea, but their resistance was eased through involving them in the process, and engaging with them in negotiations which resulted in alternatives for compensation for their lost farming opportunities. Farmers had a choice of either selling their land at a price of 16,000 EUR/ha or keeping and managing it based on the principles laid out in a 'nature contract'. In the latter case, the compensation was set at a rate of 819 EUR/ha and year. Additional compensation was offered to mitigate the disturbance during the construction period and participating farmers also benefited from a tax advantage. The funds came from the government (the canton and the state), while downstream beneficiaries of reduced flood risk did not directly contribute to financing.

Austria might be a small state in the heart of Europe but it has established a complex flood risk management framework and practice (Rauter et al., 2019). Compensation payments do not only play a role in buyouts that are necessary for protection infrastructure. Especially in controlled retention areas, farmers receive compensation for an increased flood risk. A well-researched case is located in the alpine municipality of Altenmarkt on the river Enns. Flood evaluations revealed a serious flood risk for the main village leading to the development of an integrative protection scheme with a river widening, dams and the construction of a controlled retention basin. Initial project costs were split between federal and state funds (84 percent) and contributions coming from the municipality of Altenmarkt and the private beneficiaries (16 percent) that were organized in a water cooperative. The 12 affected private land owners that provide in total 20 ha for retention purposes receive a yearly payment of EUR 0.25 per square meter, a total of about EUR 50,000 per year, financed by the water cooperative. This compensation covers the restrictions concerning the land use and damages occurring due to flooding. Land owners are still eligible for compensation from the federal disaster relief fund (Löschner et al., 2019). This case demonstrates that running costs can also be taken over by beneficiaries themselves.

In Slovenia, dry detention reservoirs are frequently used as a measure to alleviate flood risk (Glavan et al., 2020). When implemented on agricultural land, policymakers assume the agricultural use will continue. In case of extensive land use, such as meadows, this may be possible. However, the potential consequences of flooding present a threat to the productive capacity of a rural landscape through negative impacts to the soil properties, consequent decrease in crop quality and quantity, and in case of more intensive agricultural areas, potential damage to the existing agricultural infrastructure (i.e. irrigation equipment). The Slovenian government prepared a Detailed Plan of National Importance to ensure flood safety in the Lower Savinja Valley, an area subjected to many floods in the past due to the torrential nature of Savinja river tributaries. The proposed plan foresees the implementation of a chain of 10 dry reservoirs (520 ha of agricultural land) to provide a higher level of flood protection for the downstream cities of Celje and Laško. Organized in a civil initiative, private land owners financed a study with potential alternative locations for smaller dry detention reservoirs in the upstream, hilly areas of the Savinja tributaries. The study was not considered and was dismissed. As there is intensive hop production, losing areas would necessitate intensification of hop production in other areas not in dry detention reservoirs, in order to compensate for the loss of income. This would be possible through an additional water source for irrigation that is hampered in summertime through low discharge of surface waters, and the civil initiative proposed wet reservoirs would be constructed as a source of water for irrigation. Thus, in this case, 'in-kind' compensation may be the solution, but negotiations with private land owners are still ongoing.

In the case of the dike relocation project on the river Elbe close to Lenzen in Germany, former farming land was acquired by the state and turned into a floodplain area. To ensure the continued livelihoods of the farmers, instead of simply purchasing or expropriating the land, plots of land were offered in exchange (NWRM, 2013b). The transaction was managed by the German Federal State of Brandenburg. Some of the offered land was already state-owned, and some land was purchased as land to be exchanged for farmland. Altogether, 420 hectares of land were acquired by the state from 60 land owners. The project was financed mainly by the Federal Government, and contributions by the State of Brandenburg, Burg Lenzen e.V, and also by some nature conservation NGOs. Besides construction costs related to the dike relocation, and the cost associated with land purchase, additional compensation was paid to the relocating farmers for the inconvenience caused.

In the United Kingdom there are various examples of compensation (Penning-Rowsell and Priest, 2015). In Scotland during the 2000s, the Rural Stewardship Scheme offered £25/ha per year to land owners if they agreed that their land would not be protected in case of floods. In some instances, environmental and nature protection NGOs supplement the payments of the state in exchange for additional ecosystem services, e.g. adopting grazing instead of crop management, or planting specific shrubs or hedges. The additional payment may tip the farmer's decision to engage in an agreement (Scottish Executive, 2005). A similar case can be seen in for England, where the Royal Society for the Protection of Birds (RSPB) is willing to co-finance schemes with a habitat restoration component (McCarthy et al., 2018).

In England along the river Trent, land was purchased by the River Boards back in the 1930s and 1940s, and subsequently rented out to farmers. The rental agreement defines no flood compensation; thus farmers carry the risk of flooding and they adjust their practices accordingly (Scottish Executive, 2005).

During the last three decades the Environment Agency of England has concluded agreements with farmers to allow flooding their land ('flowage easement'). These negotiated agreements consider flood return periods, current land value derived from land-use activities and business reorganization costs when applicable. Negotiations tend to be lengthy, requiring substantial transaction costs, but estimates for these costs are not available. Depending on the agreement, compensation payment may be up-front in one sum, or an annual payment for the floodwater retention service regardless of whether a flood actually takes place in a given year. Up-front payment is preferred by the Environment Agency as that reduces transaction costs (McCarthy et al., 2018). It also provides enhanced opportunities for farmers for business readjustment or buying a new piece of land with a low risk of flooding. While flowage easement is the preferred and more frequently used arrangement in England, if an agreement with a farmer cannot be reached, then in justified cases compulsory purchase is also a legal option. For example, if there are a number of interconnected farms that can only be flooded together, and all farmers agree on flowage easement except for one, then compulsory purchase can be exercised for that farm.

6.2.3 Usage Restrictions for Retention Areas

Land that is dedicated to flood retention in controlled (or sometimes also uncontrolled) polders needs to be the target of a restrictive land-use policy. There are three fields of action to be distinguished here: (a) the control of agricultural land use and cultivation, (b) the control of any construction activity and (c) the control of land transfer. For uncontrolled polders and/or simply inundation areas between dike lines, there might be a less restrictive approach as flood probabilities and intensities are not directly changed by measures; nevertheless, all of these restrictions eventually mean a decrease in land value and therefore are causally linked to applied compensation schemes.

The rationales behind regulation of floodplain development were categorized by Dunham (1959) in three cases: (i) regulating development to minimize flood damages that provide a public benefit to citizens – those who are burdened receive compensation; (ii) regulation that prevents a property owner from using his/her property in a way that damages other property owners; and (iii) where building in flood-prone areas is a moral hazard behavior. If land owners can rely on the compensation of losses, there is no incentive to be risk sensitive (Dunham, 1959). While the compensation discussion tackles especially the first rationale, the discussion of usage restrictions targets the other rationales. Undesirable and detrimental behavior should be avoided and managed by strict regulations.

Discussing usage restrictions, a distinction between controlled and uncontrolled retention, as well as flood runoff areas is essential. Restrictions for the latter are typically already included in general provisions of planning regulations aiming to prevent and control development in flood areas and manage them as low-risk areas. Such regulations are very common in European countries that link building bans or zoning restrictions directly to flood hazard classifications (e.g. Nordbeck et al., 2019). Controlled and uncontrolled polders, though, mean an increased flooding probability and/or inundation depth as well as the need for a (strict) control of land use.

6.2.3.1 Control for cultivation

Agricultural production or forestry in uncontrolled and even more in controlled polders can have considerable impacts on flood events – of course depending on the scale of the flood event. Generally, plants in flood runoff and retention areas can have a positive impact by decreasing the velocity of runoff. However, their volume is in direct competition for space with flooded water and can, if the vegetation is not considered in hydraulic calculation, have a negative impact. Furthermore, vegetation debris can cause problems with technical infrastructure, such as inlet and outlet structures of controlled polders or bridges. Smaller tributaries are more sensitive to debris clogging. Filling of controlled polders should be strictly scheduled (Glavan et al., 2020) in order to successfully relieve flood peaks and operate smoothly at any time. Another important aspect in controlling cultivation is the damage potential. For example, seawater intrusion or waterlogging can cause severe damage to cultivation or even a complete loss of yield that triggers a compensation demand.

Formal spatial planning instruments are typically limited to regulating zoning and building development. Therefore, these instruments have little leverage on agricultural and forestry land that typically makes up most of the land in uncontrolled and controlled polders (Löschner, 2019).

Unless owners are compensated for the land-use restrictions, it is difficult to regulate cultivation of green areas, designated for retention, and interestingly little research or approaches in practice can be found. Low intensity agricultural land use, such as meadows, is encouraged. Typically, the traditional cultivation is already adapted to flooding but especially controlled polders bring additional limitations. There exist theoretically different approaches to tackling this question: (i) setting incentives or (ii) legally enforcing a certain cultivation. Incentives for a certain use can especially be realized using subsidies. This would be actually rather complex and expensive in its administration and would need a control mechanism as well. Costs might exceed the potential cost in case of a flood event. The second option faces the complexity of public administration and competences. Typically, the decision on the type of cultivation is up to land owners and cannot easily be prescribed. Furthermore, flood management is not closely linked to agricultural aspects in public administration and there are hardly any ways to legally oblige farmers to a specific use (see also Albrecht and Nikolić Popadić, Chapter 3 in this volume). At the same time however, it is possible to link compensation payments to a certain use and exclude others. This sets a clear incentive but might be politically difficult to enforce.

6.2.3.2 Control and restrictions for development

The control and restriction for development in the context of flood retention has two main problems to solve: (i) dealing with existing building stock – especially in uncontrolled polders – and (ii) prohibiting new development that would lead to a risk increase. In the realization of flood management or retention projects, the existing building stock might even sometimes face relocation, such as depicted in examples from Austria (Löschner et al., 2019; see also Löschner and Schindelegger, 2019). This regulatory assignment can be typically addressed by spatial planning instruments such as zoning and development plans.

Firstly however, the actual knowledge about frequently inundated areas leads to the designation of hazard areas via hazard maps that imply land-use restrictions. It is a common practice in many European countries to link the expected severity and frequency of flood events with development and building bans. This is normally included in national/federal water acts that foresee such bans or at least the necessity to apply for special permits within such areas. Even without further consideration in planning instruments, a restriction based on hazard zones can be enforced. Typically, essential uncontrolled as well as controlled polders are disclosed in hazard maps and are linked to binding or at least recommending restrictions for any development.

A challenge in establishing and managing retention areas is the existing building stock. While controlled polders are meant to be flooded more often, which strongly opposes any residential or commercial use, uncontrolled polders might feature existing buildings such as farmhouses, sheds or community infrastructure. Here, the control of the actual internal usage, and any additional construction or reconstruction, is essential.

6.2.3.3 Control of land transfer

This aspect might appear somewhat odd in light of the previous discussion. Any flood protection infrastructure is based on technical projects and therefore land acquisition or the securing of rights of disposal is an essential baseline for a project realization. Land acquisition as preparation for the implementation of a technical project can be based on negotiations, expropriation titles or also pre-emptive rights. The latter enables water authorities responsible for protection infrastructure to acquire full property. Land consolidation schemes can also be applied in such a context as is the case in Germany (Drees and Sünderhauf, 2006). So, there are multiple ways for authorities to acquire land but in some cases public authorities might also consider interfering with land transfer and aim for a long-term buyout instead of paying yearly instalments and compensations in case of events to farmers in retention areas. Here, pre-emptive rights can secure a prior position for authorities to buy land and use it for specific purposes in flood management (riparian vegetation, etc.) or lease it to farmers for cultivation.

Overall, usage restrictions for retention areas are generally harmonized within the planning of technical projects and typically rely on individual agreements and arrangements with land owners. A challenge within this perspective is the consideration of compatible or multifunctional land use. Protection projects do not have the objective or title to include such aspects in their schemes which might lead to diked areas with low-risk agricultural use. One interesting example comes from Israel with the widely known Ariel Sharon Park. The area used to be a landfill and has now been adapted to be a metropolitan park that also serves as a controlled retention basin for the river Yarkon that poses a major threat to essential infrastructure in Tel Aviv (Alon-Mozes, 2012). Nonetheless, it makes a huge difference for development restrictions on what legal land title is established by public authorities. In the case of full buyouts, normally no additional restrictions are needed. Long-term leaseholds and land charges might also enable smooth management. Private land with an increased flooding probability is the target of such regulation. Practice shows that (re)allocating development rights through government-based initiatives with financial compensation is still considered the most feasible approach (e.g. Crabbé and Coppens, 2019).

6.3 DISCUSSION

The presentation of compensation mechanisms and legal restrictions concerning land designated for flood retention purposes clearly shows how closely determining the land use and rights of disposal are linked to economic aspects of valuing land as well as usage rights and thereby to deciding upon compensation. This is an essential linkage as regulation and compensation need to be in line with constitutional requirements, otherwise it would be an actual expropriation (Tarlock and Albrecht, 2016) which occurs in the first place for physical structures but not for land in a retention area. Compensation and usage restrictions differ for land according to its function in flood management. Compensation is typically highest for land needed for technical infrastructure (levee, dike, inlets, outlets – because the alternative uses of that land cease) and in controlled-flood polders, while land that is only affected randomly by rare flood events is rather a target of compensating the actual loss of crops as events are considered to be a force majeure. This mechanism is similar for any legal restrictions enforced on flood-retention areas.

Overall, the perspectives of farmers, who mostly supply land for retention purposes, need to be considered. Especially essential here are long-term incentives with simple administration, the particular context of the farmers (cultivation, ecological production, water rights for irrigation) whose livelihoods depend on the land availability and the framing of a joint effort in flood risk management (Holstead et al., 2017). At the same time, there is not much research available that takes a closer look at the role of spatial planning and development restrictions in floodplain management generally and management of retention areas more particularly (Tarlock and Albrecht, 2016).

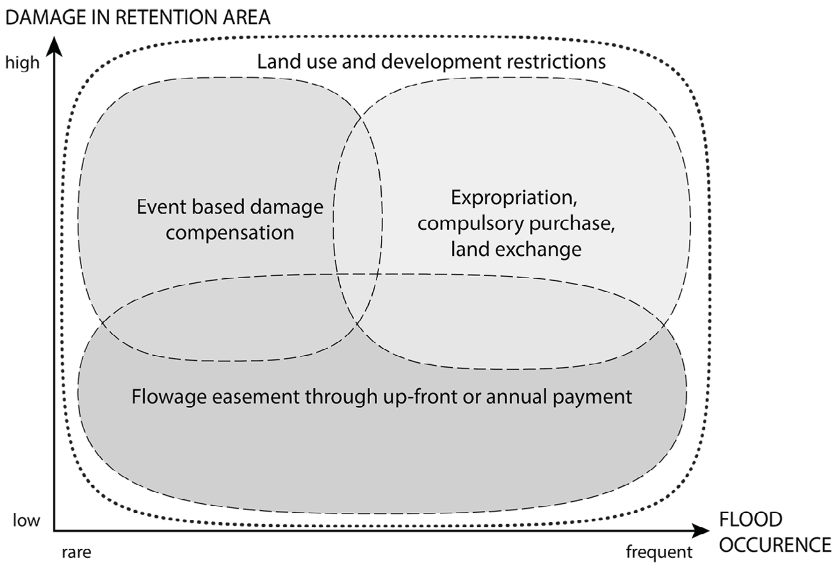

Figure 6.2 Compensation and usage restrictions in relation to flood occurrence and damage potential

Figure 6.2 illustrates the rationale behind different compensation approaches and the linkage to land-use and development restrictions. In fact, compensation for retention services is mostly designed dependent on the likelihood of flood events and the damage expected in retention areas. Especially high damage potential within retention areas (loss of yield) justifies an event-based damage compensation or even a compulsory purchase or similar to simplify the operation of retention areas. In any case, land-use and development restrictions will be enforced. While the formulation of restrictions and conditionalities for land use and development depending on flood hazard maps are common around Europe, retention areas are typically not development zones to safeguard retention services at all times. Land management, though, often struggles to control cultivation in retention areas and this demonstrates that an integrative and comprehensive approach to compensation and land-use and development control in retention areas is an imperative.

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7. Upstream-downstream schemes and their instruments

Thomas Hartmann, Lukas Löschner and Jan Macháč

7.1 INTRODUCTION

In Europe, a series of major flood events in the 1990s and early 2000s triggered a turn towards spatial flood risk management (Haupter et al., 2007; Löschner, 2018; Thaler, 2014; van Ruiten and Hartmann, 2016). The EU Floods Directive,[1] a common regulatory framework for flood policies in the EU, was developed in response to the devastating floods in 2002. It highlights, among others, that "measures to reduce [the risks associated with flooding] should, as far as possible, be coordinated throughout a river basin if they are to be effective" (European Parliament and European Council, 2007), thus institutionalizing the concept of a catchment approach to flood risk management (Hartmann and Jüpner, 2014). The coordination of measures across the catchment hints at the principle of upstream-protects-downstream, which builds on the widely accepted notion that flood waters should be retained in less valuable upstream areas and to reduce downstream flood risk by 'keeping the rain where it falls' (Collentine and Futter, 2016; Milman et al., 2017).

In populated areas, riparian land is often valuable land that is used intensively, e.g. for agricultural production, commercial or residential purposes. Storing flood water to protect vulnerable downstream land uses, however, requires a lot of land. Chapter 5 by Pohl and Bezak in this volume illustrates how much space is needed and which measures need to be implemented. They conclude that the costs and benefits of implementing flood retention measures need to be evaluated in order to identify beneficiaries as well as parties that might even be disadvantaged by certain measures. Once the costs and benefits are known, the next logical step is to set up an upstream-downstream scheme to finance the respective measures while accounting for the respective gains (such as reduced risk of inundation) and compensating the affected landowners.

The relation of upstream and downstream in flood risk management has been discussed in the scholarly debate for a while (Jüpner, 2018; Scherer, 1990; Strobl, 2006). Often, technical aspects of emissions or pollutions (e.g., Groll et al., 2015), cross-border aspects (e.g. Bracken et al., 2016) or a catchment perspective on governance (e.g. Rouillard et al., 2015) are explored and discussed. Explorations on the relationship between upstream and downstream from the aspect of policy interventions and economic trade-offs are rare (Löschner et al., 2019; Macháč et al., 2018). Hartmann (2011), for example, discusses various policy interventions in an explorative way – ranging from schemes like land readjustment, to land trusts or insurance-based schemes. In their study on game theory, Macháč et al. (2018) point at some theoretical issues regarding upstream-downstream relations. Thaler et al. (2016) show empirically the lack of regional cooperation between local authorities and other stakeholders, such as landowners, in flood risk management across catchments and Seher and Löschner (2018) argue that upstream-downstream schemes cannot be entirely achieved by public policy instruments alone, but they need to be complemented by governance frameworks.

This chapter explores such upstream-downstream schemes and instruments and policies to implement them. It begins with a general theoretical overview of the upstream-downstream debate, then presents the main types of instruments in addressing upstream-downstream relations in flood risk management and showcases some practical examples before concluding with some discussion points and issues for future research.

7.2 UPSTREAM-DOWNSTREAM RELATIONS

The literature on environmental policies can help better understand the reciprocal and often complex relationship between upstream and downstream. Environmental policy distinguishes three basic principles to deal with negative externalities – and a flood event that is not retained upstream can be considered as such an externality.

First is the precautionary principle. It aims to prevent or mitigate events in advance of an impact. The second principle is the polluter-pays principle. It aims at compensation for damages produced by the externality, and it sets incentives to prevent them from happening in the first place. The third is the principle of common burden. It is usually applied in cases where a polluter cannot be identified (Hartkopf and Bohne, 1983). The three principles should be enacted in this order of priority. What do they imply for upstream-protects-downstream? To apply the precautionary principle in a proportional way, it is necessary to define which impact should be prevented, and which impact is still tolerable. At its extreme and applied to car safety, the precautionary principle could imply reducing the speed of cars in general to e.g. 10 km/h. This of course would not be proportional, and the costs of such a measure would outweigh the benefits. In flood risk management, in many countries a centennial flood, one that statistically occurs once in 100 years, is defined as tolerable. Applying the precautionary principle to retention upstream thus requires balancing the costs and benefits of a measure – as Pohl and Bezak rightly point out in their conclusion. What is considered a tolerable risk, however, is a socio-political issue and it is not static (due to climate change but also changing public opinion). Enforcing the precautionary principle to realize measures upstream to reduce the risk downstream thus requires an agreement between all parties on the tolerable impact and proportionality of the measures.

An alternative to the precautionary principle is the polluter-pays principle. It assumes that there is a polluter – or for flood risk management – someone who caused the externality, i.e., the flood discharge, who can be made liable for the damage it incurs. The polluter then needs to pay for the damage, which at the same time could set an incentive to reduce the impact (i.e., by implementing retention measures). However, identifying this polluter in this context proves to be very difficult and also marks an issue of justice: flood risk at a given place on a river is to a considerable extent dependent on the situation in the upstream catchment (Scherer, 1990). "Only ships and salmon stream upstream" (Hartmann, 2011) – everything else, pollution, nutrition, and also floods flow downstream. The dependency of the downstream on the upstream makes it logical to establish some sort of solidarity scheme between the parties within a catchment. Yet the relationship is not mutual. Usually, an upstream location has only one direct downstream, but a downstream can have multiple upstreams. The polluter cannot be easily identified and even if this was the case, then the question is who is liable – the one who put vulnerable uses in harm's way (downstream) or the one who could realize measures that might reduce flood risk? This makes the establishment of a solidarity scheme difficult – as Macháč et al. show in a theoretical thought experiment involving game theory (Macháč et al., 2018). The internalization is, however, connected with evaluation of all costs and benefits connected with flood damages and flood protection (see also Kis et al., Chapter 6 in this volume). Using cost-benefit analysis, it is possible to evaluate and include both flood risk management costs and benefits. Results of cost-benefit analysis are vital inputs for decision-making and setting of appropriate instruments (Macháč et al., 2021). The process of economic evaluation is described in detail in the 'Multi-Coloured Manual' (Penning-Rowsell, 2013).

In addition, the situation becomes even more complicated if we acknowledge that most downstreams are upstreams to someone else, and most upstreams are downstream to yet another upstream. This complexity relates to the third principle of environmental policy: the principle of common burden. If no polluter can be identified, the public bears the costs for externalities. However, this principle is ineffective from several viewpoints. First, if the general public is responsible for the risk reduction, the resources are not available for other common tasks; second, there is no incentive for risk-reducing behaviour, as Hartmann found out for the case of clumsy floodplains (Hartmann, 2011), where the public support for victims of flood risk management nurtures inertia for risk-adaptation. This is even embedded in many financial flood-recovery schemes (Slavíková et al., 2020).

The relation between upstream and downstream and their consequences for policy solutions frames the following discussion on instruments.

7.3 INSTRUMENTS FOR UPSTREAM FLOOD RETENTION

An instrument can be considered a public policy intervention that aims "at modifying the behaviour of social groups presumed to be at the root of [...] the collective problem to be resolved (target groups) in the interest of the social groups who suffer the negative effects of the problem in question" (Knoepfel, 2007, p. 24). Translated into the issue of upstream retention, this means that we are looking for public policy interventions that can realize retention measures as outlined in Chapter 5 by Pohl and Bezak on land upstream. The target group is the landowners of the potential retention areas, whereas the social group that suffers the negative consequences would be the (valuable and vulnerable) downstream area.

Public authorities have a huge variety of instruments available that aim at getting access to the land in question, such as land readjustment, land consolidation, pre-emption rights, freehand purchase, or expropriation (Albrecht and Hartmann, 2021; Löschner et al., 2021; Nikolić Popadić, 2021). The instruments differ in the way they treat landowners and their property (van Straalen et al., 2018). Therefore, finding a legitimate and proportional balance between the defence of private property rights and public interests is a challenge (Booth, 2016; Gerber et al., 2018a). In principle, we can distinguish four intervention paths (i.e., instruments) that deal in different ways with this balance (Hengstermann and Hartmann, 2018; Knoepfel et al., 2011). First, instruments that use public policy without impacting property rights (such as incentives or regulations); second, instruments that impact the scope and the content of use or disposal rights via public policy (such as land-use planning or land consolidation schemes); third, instruments that redefine property rights and that impact the scope and the content of use or disposal rights (e.g. pre-emption rights); and fourth, instruments that redistribute property rights (expropriation or strategic land banking). The choice of the appropriate instrument is merely neutral. "The selection and use of policy instruments is often presented functionally, as though the choice only depends on mere technical questions (Lascoumes and Le Galès, 2007). However, instruments are not axiologically neutral; they correspond to a particular understanding of the public problem, to a specific interpretation of the role of the state and/or its private partners" (Gerber et al., 2018b, p. 21).

7.4 ECONOMIC POLICY INSTRUMENTS

A very important driver for upstream retention is landowner motivation. Beside the above-mentioned instruments, there is a set of financial instruments which deserve focused attention as they can be used to incentivize upstream riparians to retain water and protect downstream vulnerable areas. This approach is based on positive and negative externalities related to flood management and their internalization. As mentioned by e.g., Seher and Löschner (2018) or Macháč et al. (2018), interventions upstream can cause positive effects (e.g. retaining of floods) or negative effects (e.g. accelerating floods by the building of dykes) in downstream areas. The case is usually that upstream actors neither receive nor pay any compensation for their impact on the downstream (Dorner et al., 2008). The reason for this externality is mainly the absence of the market, which leads to an inefficient allocation of resources (see also Kis et al., Chapter 6 in this volume, on calculating compensations). In this case, flood protection and mitigation measures distribution between upstream and downstream parties.

According to Schanze (2006), the aim of financial instruments is either to support the implementation of measures or to restrict flood risk related activities. From the perspective of catchment-oriented flood risk governance, financial instruments represent mechanisms for risk sharing (Seher and Löschner, 2018). In the upstream-downstream relation, it is important to encourage the different parties and stakeholders to collaborate (Chang and Leentvaar, 2008). Besides current instruments such as general public budget or subsidies, the emphasis should be put on instruments utilizing negotiation between different groups of stakeholders/upstream-downstream such as tradable development rights (TDR) or economic policy instruments (EPI) such as payments for ecosystem services (PES) (Macháč et al., 2018). These instruments lead to an alternative market, which encourages effective investment of resources in flood protection and motivates the upstream to implement measures. According to Filatova (2014), private investments, non-perverse subsidies, flood insurance and other market-based instruments provide flexibility and efficiency and engage stakeholders to cooperate.

In the case of general public budget and subsidies, the government finances the implementation of flood mitigation and protection measures directly or provides resources to other subjects such as water boards, municipalities or regional governments for financing implementation of these measures from different types of taxes (Thaler and Hartmann, 2016). In the case of subsidies, the government covers either the complete cost or co-financing is required from public resources. It is a centralized approach based on the principle of common burden, in which state government takes responsibility for the implementation and financing of the measures.

The other above-mentioned economic instruments (private investments, TDR and PES) are based on market mechanisms and agreement of different stakeholders (Kis and Ungvári, 2019). Private investments are usually not a common instrument to tackle the upstream-downstream relation without additional incentives in the form of e.g. compensation. Private investments without any compensation are typically used rather at the site of the flood to eliminate risk and thus possible damages.

7.5 UPSTREAM-DOWNSTREAM INSTRUMENTS IN PRACTICE

To illustrate some of the complexities surrounding the implementation of upstream-downstream schemes, this section takes a closer look at two practical examples from Austria. In both cases, it was appropriate to provide more room for the river and retain flood water on open agricultural land as much as possible to protect vulnerable settlement areas located downstream.

7.5.1 Voluntary Agreements to Balance Upstream-Downstream Interests (Mittersill, Austria)

Following a series of devastating floods in the early 2000s, Mittersill – an alpine municipality in the Austrian province Salzburg – developed a flood protection scheme for 100-year design floods, featuring a horizontal dam and a controlled flood-storage basin. The protective dam generated a classic upstream-downstream situation, whereby upstream agricultural land is flooded to protect downstream settlements. While downstream 'beneficiaries' reap the benefits of reduced flood risk and appreciated land value, the upstream 'providers' of the flood retention service face higher flood damage, reduced yields as well as a depreciation in the value of their agricultural land (Löschner and Schindelegger, 2019).

Given this imbalance, a fund was set up to compensate upstream landowners. The entire project costs, including the compensation for the upstream landowners, were pre-financed by the public, with the intent to demand financial contributions from the downstream beneficiaries based on a complex scheme that assesses the expected benefits based on inundation depth and taxation value of the property. This compensation scheme, however, led to severe opposition including legal charges from beneficiaries, some of whom considered flood protection a public responsibility, while for others the taxation value underestimated the 'real' market value of properties. The municipality consequently decided to limit the beneficiary contributions to land-value capture (from re-zoning open land into building land). Based on these revenues, a ‘solidarity fund’ was established for the compensation of the upstream landowners in case of a future flood event.

This case of a beneficiary-pays scheme was by design an innovative approach. In retrospect, local decision-makers acknowledged that (i) a legal framework (e.g. a water cooperative) should have been established to involve both the providers and the beneficiaries in a common organizational structure and (ii) the compensation scheme should have been developed in closer cooperation with the affected stakeholders in order to ensure broader acceptance.

7.5.2 Regional Regulatory Spatial Plans to Preserve Floodplains (Upper Rhine Valley, Austria)

In 2005, the Upper Rhine Valley in Vorarlberg – a densely populated and dynamic economic area bordering Switzerland, Germany, and Liechtenstein – suffered a severe flood event. One of the key challenges for flood policy makers following the flood events in 2005 was providing space for flood-alleviation measures and preventing urban development in potential hazard areas. Faced with a lack of appropriate regulatory zoning instruments to secure large-scale areas for flood protection measures, state officials in water management and spatial planning engaged in an inter-sectoral coordination process to identify and delineate suitable areas. In 2013, following another large flood event, the Vorarlberg state government issued the ‘Blauzone Rheintal’ (Blue Zone Rheintal), a legally binding regional land-use plan to preserve areas for flood runoff and flood retention, including emergency runoff corridors to mitigate future flood impacts. The ‘Blauzone’ covers an area of 5,400 hectares in 22 municipalities and predominantly includes areas with low damage potential, such as agricultural or forestland (Löschner et al., 2019).

Given its character as a regulatory planning instrument, the ‘Blauzone’ was issued as a legally binding directive, which obliges the affected municipalities to amend their local land-use plans and (re)zone areas located within the ‘Blauzone’ as so-called open-space reserve areas. This means that no development is permitted in those areas with the exception of enlarging existing agricultural facilities. In addition to protecting settlement areas against future floods by preserving open areas for flood retention and flood discharge, the ‘Blauzone’ also secures areas for future flood control measures, such as the intended relocation of the Rhine outlet into the Bodensee (due to sedimentation) and thus preserves the necessary decision scope to meet the needs of future generations.

7.6 DISCUSSION

This chapter provides an overview of financial and public policy instruments to realize upstream-downstream schemes. Following classical economic theory, it is possible to design suitable instruments for upstream-downstream relations based on input analyses (e.g. cost-benefit analysis to evaluate the externality).

Private investors could be motivated to implement measures upstream using some financing schemes such as PES or TDR (Collentine and Futter, 2016; Crabbé and Coppens, 2019). In case of payments for ecosystem services, the provision of flood retention could be compensated by the beneficiaries downstream. So far, this is more of a theoretical approach. In practice, it takes place only partially, when the payer of compensation is a public authority that provides landowners with subsidies. There are two barriers which limit the application of economic policy instruments or PES to a greater extent: (i) high transaction costs and (ii) a free rider problem. These two problems are related, as stated by Coase (1960). The agreement between two private entities is an alternative to government regulations. However, such agreements are only feasible if administrative costs of organizing transaction between investor and downstream are low. In case of negotiation between upstream and downstream, however, the transaction costs are often very high, i.e., the transaction costs can only be low for small-scale solutions (Seher and Löschner, 2018). Free riding is also a relevant phenomenon, as some affected stakeholders might refuse to pay, but would be protected (i.e., receive benefits). The implementation of payments is thus more realistic if the implementation and payment is negotiated by the municipality or an association of municipalities in the downstream representing the common interest in flood risk reduction (Macháč et al., 2018).

TDR are very similar to PES. In this case, the subject of negotiation/payment does not provide flood protection itself, but flood risk trading in the context of land use and development. TDR can ensure a change of land use in flood buffers of flood-prone areas which are preserved for specific use due the flood risk (Chang, 2017). Development is possible when the flood risk is reduced due to implementation of measures in another place. As presented by Chang and Leentvaar (2008), both places could benefit from this trading. The place increasing the flood retention is in the position of the seller providing the reduction of flood risk to another place in the position of buyer.

Experiences from practice show that the success of such upstream-downstream schemes and their respective instruments depends on a number of more complicated aspects which can be summarized in some lessons learned, and which point at gaps in research.

- *Transaction costs must not be underestimated*. One of the most important aspects is the transaction costs connected with agreement of all stakeholders. It is possible to find a solution with one administrative body in which the stakeholders know each other. The close relationship supports the willingness to cooperate. As is evident from the case study in Mittersill, inter-municipal cooperation is possible on a small scale. The role of the municipality is primarily to ensure coordination, raise awareness, and enforce the agreement. One of the basic steps is to find and modify appropriate instruments which will be acceptable in local conditions.
- *Small scale is more successful.* It is more challenging to use instruments across administrative boundaries within the same catchment. This is not only because of administrative or legal issues, but also due to different cultures (Albrecht and Hartmann, 2021) and multiple interests (Löschner and Schindelegger, 2019) as well as free rider problems. A larger scheme is associated with a greater redistribution of costs and benefits. So, one of the key problems is to identify and define the area for installing an upstream-downstream scheme. Each upstream has one big downstream area, but one downstream can have multiple upstream parties involved. The negotiation and coordination are thus very complicated. In large schemes, the neighbourhood relations are characterized by anonymity and the willingness to pay, and providing enough motivation to upstream is limited. So, although large-scale schemes might be more efficient in terms of the peak reduction capacity, the chances of success are bigger on smaller scales and within one jurisdiction (e.g. within municipalities).
- *Financial resources are generally not the limiting factor*. The implementation of measures is in most cases subsidized by national or even supranational bodies (such as the European Union). Also, the water sector is in general better financed than many other public bodies (such as land-use planning). The compensation schemes are often generous (Albrecht and Hartmann, 2021). In addition, PES or TDR promise to support financing measures from the beneficiary side.
- *Upstream-downstream schemes fail not due to a lack of instruments*. Although the implementation of many instruments is partly limited by legal and institutional constraints and state regulation often does not allow individual agreements between upstream and downstream parties, evidence also shows that it is possible to do it on a small scale in one municipality body with relatively low transaction costs. Also, besides the availability of instruments, it is crucial that decision-makers are willing and able to activate certain instruments. According to the two presented case studies,

> there is not a lack of instruments. To achieve the goals, persistence and strategic long-term land management are important. Investments in flood risk management need to address and cover not only the implementation of measures but also preparation, planning and governance of land for flood risk management. So, regulatory and economic instruments are a limiting factor of upstream-downstream schemes, but it is as important that the public administrative bodies embrace the implementation of such schemes.

Finally, while the range of instruments discussed in this chapter is still limited and leaves out some instruments that are explored in practice (see e.g. Albrecht and Hartmann, 2021, but also Löschner et al., 2021), this chapter shows the variety of possibilities for realizing upstream-downstream schemes. Still, the willingness and ability to use them is crucial. Stakeholders mostly prefer to apply the principle of common burdens and implement the measures only using a general public budget or obtaining subsidies. This leads to the conclusion that one of the open questions that this chapter also leaves open is to discuss how municipalities, and regional or state authorities can organize and formalize cooperation. Such cooperation and its associated governance scheme can be an essential precondition for the implementation of most of the regulatory and economic instruments. Introducing other instruments is thus often politically unfeasible.

One conclusion that can be drawn is that such schemes are always tailor-made and often small-scale solutions. There is not one instrument that prevails or hinders such schemes in general, but upstream-downstream schemes can be realized with a huge variety of instruments.

Exploring the way these instruments are used in practice strategically, understanding the motivations and interests of all stakeholders and revealing the contextual factors of success of such schemes are academically some of the most intriguing and societally most pressing open research questions in this context. This requires continuing studying and monitoring such schemes in practice while refraining from transplanting solutions from one location to the next.

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NOTE

1. Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks.

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PART III

Resilient cities

8. Individual measures for adaptive cities

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8.1 INTRODUCTION

'Resilient' cities play an increasingly important role in scientific research (Liao, 2012; Gersonius et al., 2013; Zevenbergen et al., 2017; Pathirana et al., 2018) as well as practice due to changing global environmental conditions such as climate change. In the past, floods caused by rivers or extreme rainfall often demonstrated their potential to cause extensive damage, as evidenced by various recent events: the United Kingdom summer floods of 2007, and pluvial flood events in Germany and recent flood events across the United States (Pitt, 2008; Chatterton et al., 2010; Schmitt and Scheid, 2019). The occurrence of such events with an increasing intensity is significant (Viavattene and Ellis, 2013; Fekete et al., 2019; Schmitt and Scheid, 2019). The target of reducing to a minimum the extent and degree of negative consequences caused by floods can be directly linked to the need of adaptation for exposed residential and non-residential buildings (Pohl, 2020; Kuhlicke et al., 2020).

Cities offer especially enormous challenges. In recent decades, there has been intense pressure to build new and more buildings in urban areas. At the same time, areas suitable for further urban expansion are often rare (Liao, 2012; Pathirana et al., 2018; Schmitt and Scheid, 2019), which is why redevelopment of land such as former industrial and port areas (so called 'brownfield areas' or 'waterfront developments') offers new and beneficial options (Pearsall, 2009; Aerts and Botzen, 2011). Since such areas are attractive to both investors and private individuals due to their desirable waterfront locations, prices for such residential or business properties tend to be high. Significantly, these 'new' building areas are usually planned in flood-prone areas (Aerts and Botzen, 2011).

From the perspective of flood risk management (FRM), such restructuring into residential and business areas risks a significant increase in potential damage (Bernet et al., 2017; Miller and Hutchins, 2017; Spekkers et al., 2017; Rözer et al., 2019). Therefore, the mitigation of potential loss constitutes a key responsibility in the process of planning, constructing, and later using such restructured waterfront areas. Usually, flood risk management strategies and policies recommend the implementation of structural engineering solutions, property-level flood risk adaptation measures or nature-based solutions (Sörensen et al., 2016; Attems et al., 2020; Huang et al., 2020). However, due to the singular circumstances surrounding urbanization, concepts regarding flood hazards must be innovative due to practical constraints: limited availability of space to implement structural and non-structural measures and private ownership of land (see also Chapters 9 and 10 in this volume). These conditions require a tailored approach consisting of structural and organizational concepts, strategies, and especially instruments (Patt and Jüpner, 2020).

International initiatives to encourage and implement resilient cities have been established in recent years, notably the 2013 '100 Resilient Cities (100RC) Programme' project pioneered by the Rockefeller Foundation (The Rockefeller Foundation, 2021) and the creation of the 'Resilient Cities Network' (Resilient Cities Network, 2021). Furthermore, frameworks like 'PARA' (protect, accommodate, retreat or avoid), which Doberstein et al. (2019) associated with flood resilience and the reduction of flood risk, and 'FLORES' (Flood Resilience Systems Framework) presented by Magnuszewski et al. (2019) have been published. Apart from these, scientific papers dealing with the operational aspects of resilience have recently been published (Davidson et al., 2016; Hernantes et al., 2019; Heinzlef et al., 2020; Lamaury et al., 2021). Nonetheless, the transformation of a theoretical concept into a practical application remains a major challenge, as does the question of scale and temporal aspects, areas in which further study and research is needed (Chelleri et al., 2015; Serre et al., 2018; Bayerisches Staatsministerium für Umwelt und Verbraucherschutz, 2014; Heinzlef and Serre, 2020).

This chapter fills this lacuna by offering examples for possible individual measures for a resilient (re)construction of so called 'functional units' placed at waterfronts. This will be undertaken by considering strategies for FRM according to the EU Floods Directive (EU 2007/60/EC DIRECTIVE) with a special focus on prevention, protection, mitigation, and precaution, as well as recovery measures and strategies.

8.2 RESILIENCE AND FLOOD RISK MANAGEMENT: RE(THINKING) FRM FOR FLOOD RESILIENCE

The legal framework for European Flood Risk Management is provided by the EU Floods Directive (EU 2007/60/EC DIRECTIVE) issued in 2007. The LAWA, a Working Group on water issues of the Federal States and the Federal Government of Germany, illustrates the main aspects of the EU flood risk management within a flood risk management cycle, including phases before, during, and after a flood. Furthermore, a categorization into four sectors, each with particular measures contributing to the overall FRM, was made: prevention, protection, precaution and recovery/regeneration/report (see LAWA, 2019). But by taking a deeper look at 'common' structural flood protection measures like dike systems, the functionality of such instruments offers an interesting point of departure for further discussion. One of the main characteristics of such measures is that they are designed for a specific load (see Chapter 5 in this volume) or rather for specific exposure. In other words, such structural/technical measures are characterized by a 'threshold of functioning', a situation that leads to the topic of overload. What if the external impact during a flood exceeds the robustness of the dike system? In light of the above discussion, it is clear that 'traditional' flood risk management as implemented in past years is increasingly reaching its limit regarding functionality. This situation leads to the urgency of embracing beyond-design thinking.

To face future challenges, a (re)thinking of the current flood risk management is crucial – and currently taking place in scientific discussions. Publications currently exist that deal with 'flood resilience' (Hegger et al., 2016; McClymont et al., 2020; Disse et al., 2020; Kuang and Liao, 2020) and address resilience in smart planning (Moraci et al., 2018) or in the context of urban flooding (Sörensen et al., 2016). This indicates that implementing resilience for cities – especially for waterfront areas – should not be executed by a single group of experts. Rather, it should constitute a collaborative effort that involves civil engineers, urban planners, and stakeholders. In this light, integrating resilience into considerations regarding the adaptation and (re)development of waterfront areas offers the potential for cities to strengthen their ability to face future (flood) challenges more effectively and efficiently. Still, when it comes to putting principles of resilience into practice, the first challenge is determining and agreeing on what exactly is meant by resilience. Since there exists a wide variety of resilience definitions (see Matzenberger et al., 2015; Zhou et al., 2010), we shall refrain from applying a single definition. Rather, according to the 'three pillars of resilience' – RECOVERY, RESISTANCE and ADAPTIVE CAPACITY – discussed in Chapter 10, we offer the following characteristics as the key qualities of resilient systems:

- resistance,
- buffer capacity and flexibility as part of adaptive capacity, and
- recovery time.

To connect these to the question of how to implement and improve the resilience abilities of cities, especially their vulnerable waterfronts, we offer a brief (and to be continued) overview of mitigation measures that would contribute to strengthening cities' flood resilience. Further on, a special focus is on urban systems as a functional unit. There, we offer a brief example of a restructured former port area in Germany which considers a flood resilience approach. The conclusion summarizes cities' challenges regarding changing climate conditions and addresses main aspects for further research for developing resilient systems like cities or functional units.

8.3 MITIGATION MEASURES WITHIN FRM: THEIR CONTRIBUTION TO 'FLOOD RESILIENT CITIES'

Flood risk management aims at decreasing the vulnerability of residents in urban areas. Cities usually implement a wide range of 'classical' and 'innovative' structural and non-structural measures in order to avoid and control water penetration, including the undercutting and washout of residential and non-residential buildings. Urban communities must address the static as well as the dynamic load of flood events based on different types of flooding (river, pluvial, groundwater, torrential mountain floods). Risk-reducing measures can either be built alongside the river, adjacent to buildings at risk, or directly implemented in a building's structure (Holub et al., 2012). Potential options include single solutions for privately owned buildings toward the larger goal of robust, redundant, and flexible systems for critical infrastructure networks. In addition, urban flood risk management strategies must integrate societal goals and needs, such as well-being and biodiversity. Consequently, urban systems usually request implementation of a 'bundle' of measures – not one single solution, such as flood storage – because of the lack of space, different types of flooding and risks, and a wide range of different needs and interests within an urban system.

8.3.1 Mitigation Measures

There are two main types of mitigation measures: structural and non-structural. Structural mitigation measures comprise physical systems whose purpose is to protect structures from natural hazards. Non-structural measures on the other hand have the goal to identify hazard areas and thereafter limit this area either permanently or temporarily (Holub and Hübl, 2008). Additionally, flood risk mitigation measures can be applied permanently or temporarily in a mobile manner. Temporary hazard protection is created by installing removable protection barriers. These are put in place during an event and removed afterwards (Ogunyoye et al., 2011). They represent a low-cost option for households (Bowker, 2007). Hazard protections that can be disassembled, a moved protection system, installed before an event, usually require control during the event. They have the additional advantage that they can be partially installed before an anticipated event. But it should be mentioned that due to the reaction and installation time needed, such systems are more suitable for river floods, where a forecast can be used, than for floods caused by extreme rainfall. In general, these are often used as additional protection for permanent protection systems. Such systems include temporary and permanent elements (Ogunyoye et al., 2011). Permanent hazard protection is a system that does not need required supervision during an event because it is already fully in place (Ogunyoye et al., 2011).

Permanent solutions are often more costly than temporary measures (Bowker, 2007). There exists a wide range of mitigation measures (Table 8.1). There are three main types: (1) property-level flood risk adaptation, (2) nature-based solutions and (3) engineering solutions (O'Donnell et al., 2019; Attems et al., 2020; Patt and Jüpner, 2020; also see Chapter 3 and Chapter 5 in this volume). Each entails varying costs and effectiveness for flood risk reduction. Some measures, such as wet-flood proofing, allows water to enter and exit, thereby reducing residual risk (Shaeffer, 1960; US Army Corps of Engineers, 1995; ODPM, 2003; FEMA, 2014). The following overview of the possible flood risk reduction measures in urban areas shown in Table 8.1 is organized by using the above-mentioned three main types. Here, it is noted that some measures, within for example the 'nature-based solution' category, also include parts of engineering solutions or works (see Chapter 5 in this volume).

8.3.2 Urban System as a Functional Unit

Urban systems play an important role around the world. Metropolitan areas function as central hubs for national economies, are the seat of a country's political power, and attract new residents due to greater availability of jobs and possibilities for education. They also attract many businesses, often in highly productive sectors such as biotechnology, software, and information and communications technologies (ICT). At the same time, cities are leading actors in developing, adapting, and implementing innovative solutions to various challenges, such as extreme weather events, air pollution, and terrorist attacks (Smailes, 1971; Hommels, 2008; Rosenzweig et al., 2010; Turok and McGranahan, 2013; Muñoz-Erickson et al., 2017). Urban systems are highly interconnected and rely on a robust critical infrastructure since thousands of people use public transport systems to reach their workplace and rely on food-distribution (supermarket) systems to obtain food and because most urbanites have no access to private gardens. In addition, developments such as the unpredictability of the impact of a warmer climate and demographic shifts affect human behaviour. Furthermore, an expected increase in network complexity (for example smart cities) will increase complexity in the near

Table 8.1 Overview of possible flood risk reduction measures in urban areas

Type of impact on building	Measures	Temporary/ Permanent
Property level flood risk adaptation		
Deflection of flood discharge	Drainage for surface water	Permanent
	Design and shape of building	Permanent
	Elevating building	Permanent
Dry floodproofing	Raising the ground floor level	Permanent
	Buildings on partially elevated areas	Permanent
	Floating/amphibious buildings	Permanent
	Sealing building openings	Permanent/ Temporary
	Elevated light shafts	Permanent
	Check valves (non-return valves)	Permanent
	Backup valves	Permanent
	Overhead sewers	Permanent
	Toilet pan seals	Permanent
	Waterproof cellar using Bitumen sealing	Permanent
	Waterproof cellar using waterproof concrete	Permanent
Wet floodproofing	Situate important rooms on a higher level, e.g. moving kitchen to the first floor	Permanent
	Move electrical appliances above likely flood level	Permanent/ Temporary
	Pump to remove water (sump pump)	Permanent
	Floor drain standpipes	Permanent
Barriers	Free-standing barriers, mobile elements	Temporary/ Semi-Permanent
	Levee/Berm	Temporary
	Floodwalls	Temporary
	External flood door	Permanent
	Tubes (air filled/water filled)	Temporary
	Filled containers (permeable/impermeable)	Temporary
Other measures	Anchorage of oil tanks	Permanent
	Emergency supplies	Temporary

Type of impact on building	Measures	Temporary/ Permanent
Nature-based solutions		
Retaining water	Land use change, such as increased permeable areas and surface storage like green roofs or green car parks	Permanent
	River restoration, such as channel realignment	Permanent
Providing more space for rivers	Water storage areas, such as impoundment reservoirs	Permanent
	Wetlands, such as wetlands re-creation	Permanent
	River restoration/retraining, such as river re-profiling	Permanent
	River and water course management, such as vegetation clearance, channel maintenance and riparian works	Permanent
	Floodplain restoration, such as reconnecting rivers and floodplains	Permanent
Flood prevention and protection measures		
Technical flood protection	Construction of new flood protection lines	Permanent
	Increase the flood protection lines	Permanent
Flood prevention	Power generators	Permanent/ Temporary

Source: Based on Dadson et al. (2017), Attems et al. (2020), Patt and Jüpner (2020).

future, especially in urban areas (Markolf et al., 2018). Thus, urban systems are highly complex. However, current adaptation to these extreme developments is often techno-centric, with a strong focus on system robustness, such as reducing vulnerability through strengthening structural measures (Markolf et al., 2018). Techno-centric approaches are advantageous in response to extreme weather events, but also involve limitations (McPhail et al., 2018). We consider cities and urban systems as dynamic social-ecological-technological systems (SETS) (McPhearson et al., 2016; Grimm et al., 2017; Markolf et al., 2018). The social-ecological-technological systems framework is based on the social-ecological system (SES) but extends it by incorporating the importance of infrastructure within urban areas (Markolf et al., 2018). The SETS assess vulnerability and resilience of urban areas in a broader, more holistic perspective, a more effective approach than considering flooding as an event for which there is a one-fits-all solution (Chang et al., 2021). The SETS approach allows us to evaluate and to understand how urban areas, especially their infrastructure, can be resilient against future flood-hazard events, improve life satisfaction of the urban population, provide ecosystem services as well as exploit innovations in urban areas. Therefore, the aim is to change the current biophysical and institutional environment (McPhearson et al., 2016; Grimm et al., 2017; Markolf et al., 2018). The SETS concept provides the bridge between social-ecological systems and socio-technical systems, integrating social science, environmental science and engineering concepts. The inclusion of the technology perspective allows extending our current knowledge of system thinking as technology is often understood as apolitical or determinist (Ahlborg et al., 2019).

8.3.3 'Resilient' Cities: Restructuring Former Port Areas to Functional Units that Consider Flood Resilience

As noted earlier, cities are challenged by the conflict between a desire for expansion and a limited number of suitable available areas. This challenge has been addressed in redeveloped former industrial and port areas as in New York City or HafenCity Hamburg. Another example is the 'Zollhafen Mainz' project in Germany, a restructured former port located on the waterfront (and within the floodplain) of the river Rhine. Not all individual particularities of this project can be discussed here, but some general information will be given.

The project began in 2010 and is scheduled for completion in 2025. Approximately 2,500 inhabitants will live in the new city quarter. Furthermore, approximately 1,400 residential units and 4,000 new jobs are estimated to be created by 2025. The project occupies 30 hectares, including 8 hectares of port basin (Zollhafen Mainz GmbH & Co. KG, 2021). Importantly, the project area is exposed to the Rhine due to its location within a floodplain. As part of the *FloodResilienCity* project (*Improved integration of increased urban development and flood risk in major cities*) within the Interreg 2007–2013 North-West Europe Programme (Webler et al., 2010; Keep.eu, 2021), planners, engineers, and others intend a redevelopment of this former harbour area in a flood-resilient way. To achieve this, new measures, requirements, and strategies are necessary. But as Redeker (2013) points out, besides the aim of flood-adapted, or rather flood resilience and construction compliance with requirements due to the floodplain location, awareness of the existing, even if rarely occurring, flood risk is a key issue addressed in this pilot project. The plan is guided by the 'Project Developers' Guide' (PDG) and the 'Flood Risk Management Guide' (FRMG). The former is intended as a flood-resilience framework for developers. Besides information on inundation scenarios and planned measures for flood protection, this guide provides developers with construction requirements and reference projects. The second guide, the FRMG, addresses the future inhabitants or employees in 'Zollhafen Mainz'. The FRMG provides answers to questions such as: "What does the local authority do to protect me?", "How do I have to prepare myself for an approaching flood?" and "What do I have to do after the flood has arrived?" (Webler et al., 2010).

In general, the development of an area within a floodplain contradicts the main objective of the EU Floods Directive to reduce "the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods" (EU 2007/60/EC DIRECTIVE). As noted in recital 2, an increase of "human settlements and economic assets in floodplains [...] contribute[s] to an increase in the likelihood and adverse impacts of flood events" (EU 2007/60/EC DIRECTIVE). Nonetheless, the 'Zollhafen Mainz' project could be realized and serves as one example of a flood-resilient waterfront (re)development.

8.4 CITIES' CHALLENGES AND THE WAY FORWARD

Despite existing knowledge about flood risk management in general, and prevention, protection, and adaptation strategies against natural hazards in particular, currently existing strategies in urban areas mainly focus on the present state of the art. Nevertheless, urban systems require new ways of thinking that accommodate changing climatic conditions. Even though the concept of resilience is a promising approach for cities, and scientists, engineers, planners, and many others are working on its further development and implementation, the way to resilient (re)structuring of cities and waterfronts remains a challenge. But cities' pressure on further urban expansion and the challenge to find or generate suitable areas for that (see section 8.1 above) could be seen as a chance to force resilient (re)structuring or rather development of certain areas.

Focused on rebuilt or reused areas like 'Zollhafen Mainz', a locale characterized by exposure to floods, the functionality of such 'units' is paramount. Since these new areas include residential and business structures, it is essential to guarantee access to living and working spaces and the functioning of infrastructures in the event of a flood. But what if a medical emergency occurs during a major flood? Or a fire? Functionality in the event of various hazard scenarios should be a main consideration during the planning and construction stages of such projects, as well as afterwards, during their use and maintenance. In this context, questions arise about accessibility in and out of the affected area and must be answered in order to realize resilient development.

Furthermore, flexible reactions to and learning processes of systems during and after flood events are other aspects that contribute to greater resilience. For example, are there redundant systems or components within a system that support a flexible reaction to major floods? Or, how might a systems' learning process be initiated without the (active) involvement of a human being? Could artificial intelligence (AI) provide an option for self-learning and self-adapting systems within buildings, for example?

Further research work is needed to find appropriate answers to these questions. Above all, it is essential to translate the concept of resilience into practice and promoting further progress in the operationalization of resilience is the key solution to strengthening cities' resilience in our rapidly evolving world.

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9. Institutionalizing the resilient city: constraints and opportunities

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9.1 INTRODUCTION

Urban lands have increased in the last decades, generating fundamental challenges as well as an unprecedented necessity and opportunity to enhance the resilience of urban systems. As human-dominated, constructed landscapes supplied with urban infrastructure and a series of urban-specific services, urban areas are prone to the consequences of climate change regardless of their wealth or geographical location (Hough, 1995; Kelly, 2004; Alberti, 2008).

Considered to be critical in meeting environmental challenges like growing exposure to flooding, the interest in adopting and implementing adaptation and mitigation measures has increased greatly (see Chapter 8 in this volume), with more strategic and long-term planning decisions becoming necessary (see Chapter 10 in this volume). As urbanization rates are increasing rapidly worldwide, living with floods by alleviating their consequences is becoming more important. Therefore, it is assumed that built areas will have to be transformed to withstand rising surface-watercourses and rainfall levels in order to keep damage low when flooding occurs. Resilient cities should be able to withstand, adapt to and eventually transform under the influence of shocks in order to maintain the functioning of their economic, socio-cultural, institutional and ecological services as well as to develop and provide new opportunities for their residents regardless of the nature of the shocks, pressures or changes to which they must respond.

But how this transformation can happen and how the resilience of urban areas can be achieved is not that straightforward, as it challenges existing distributions of responsibilities, property rights and availability of knowledge, skill and resources in managing flood risks. It is known that resilience initiatives emerged as efficient short-term actions that can be taken to reduce climate-related vulnerabilities (e.g. flood risk). However, the success of implementing resilience in urban areas prone to flood risks depends on a series of factors such as efficient leadership, cities' economic growth, social policies, infrastructure development, environmental policies, participatory learning, stakeholders' involvement, and a sustainable planning and urban land management system.

This chapter aims to unravel the institutional challenges related to this transformation. First, we describe what role urban lands and developments (could) play in the light of the resilient city. Then we go into the challenges related to urban land management systems on a legislative, institutional and spatial level. Finally, we discuss some opportunities to deal with these challenges. As such, this chapter contributes to the understanding of the thresholds for the implementation of the resilient city.

9.2 URBAN LANDS FOR A RESILIENT CITY

In many areas, public protection is provided through traditional flood protection measures, mainly based on grey infrastructure (i.e. dikes, dams, etc.). However, these alone may not be sufficient to cope with increasing overall flood risks and flood extremes in particular in cities. Urban lands can absorb shocks, in this case floods. Therefore, integrating urban lands in public protection strategies through land-use measures offers a promising contribution to flood resilience.

We discuss here two ways in which urban lands can contribute to flood resilience: multifunctional land use and Nature Based Solutions (NBS). These concepts contribute to the key principles on which cities' resilience is based, i.e. redundancy, flexibility, capacity to reorganize and capacity to learn (Dodman, 2010; Hordijk and Baud, 2010). In what follows, we discuss how these concepts can contribute to flood resilience from the urban land perspective.

Urban lands should and can have the ability to substitute other urban systems in terms of flood protection. The development of multifunctional areas that can buffer flood waters or offer flood protection can reduce the vulnerability of urban areas to flood risk. Examples include the retention and/or infiltration of flood waters in water squares, multifunctional flood-defence zones such as terraced quay-walls that combine less vulnerable functions on the lower levels with better protection for the more vulnerable functions on the higher levels, or even integrating buildings as part of the flood-defence system. Fostering the implementation of multifunctional urban lands is complex as it requires accurate information on the contribution of these lands to flood protection but also the ability of local authorities to implement them, and therefore a better connection between academic interdisciplinary knowledge and real-world policy formulation and decision-making.

Crossing sectoral borders and recognizing the inter-linkage between cultural traditions and urban land use is a prerequisite to initiate dialogue on urban land-use change, water excess storage and infiltration and flood risk reduction management.

However, despite considerable efforts in managing flood risk in urbanized areas, the implementation of multifunctional urban lands, able to increase retention and promote resilience in urban areas, is still in its infancy, both in research and in practice (Knieling and Mueller, 2015). The lack of collaborative approaches burdens the ability to identify potential substitutions between different urban systems in managing flood risk and, furthermore, in using lands as an institutional factor in developing a resilient city.

Mitigation measures tend to be potentially more efficient and more sustainable solutions to water-related problems in cities, redirecting the focus from traditional, technical and engineering-dominated protective measures towards measures based on NBS, including natural water-retention measures. NBS and urban-ecosystems restoration can serve as buffers against flooding, leading to a diversification of flood risk management approaches (Driessen et al., 2018). These NBS types of measures not only serve to reduce risk and provide more robust urban flood protection. They also provide additional environmental services, including increased biodiversity and recreation opportunities, as well as other environmental benefits such as improved water quality and aquatic habitats. However, a common characteristic of green infrastructure measures is that they often claim more land than traditional methods do. Land already in use for other purposes is often privately owned. Mobilizing private urban land for temporary flood storage means having to coordinate different actors and institutions in water management. This particularly includes engaging landowners and land-users actively in developing and implementing management plans (Hartmann, 2011). However, it also implies that managers employ a more transdisciplinary perspective and create governance mechanisms for transferring benefits from the downstream urban beneficiary to the upstream, often rural, provider (Macháč et al., 2018). There are few, if any, working models for such transfers of benefits and their development will require collaboration from all communities of end-use implementers – those who must benefit from the implementation on the ground level. This includes municipal and other governmental stakeholders, but also the landowners/users who will benefit from the reduced flood risks in return for some level of compensation for those benefits. Such a benefit transfer policy will be extremely difficult to impose from the top. Therefore, what is particularly needed are dialogue tools which policy makers can use to encourage the effective adoption of such nature-based technologies.

NBS for resilient cities – such as green roofs – can only be effectively implemented on a larger scale if land and building owners agree on implementing them. Further, such measures can raise conflicts around land-use issues (Van Straalen et al., 2018). Thus, making land available and getting the landowner/

user to implement the measures is one of the key challenges for NBS to contribute to mitigating and adapting to water-related risks in urban areas.

For the implementation of both multifunctional land use and NBS, the capacity to reorganize and learn are necessary conditions. There will be situations when critical decisions must be taken about where flood protection can be offered and where not. Therefore, it is important that as a society we are able to internalize previous experiences and use them for the future planning of urban areas.

The urban hydro-social system is a chain which includes not only the natural resources of an urban area, but also the human beliefs, activities and policies which affect the functioning of that system. Implementation of specific measures for gaining a resilient city in terms of flood risk (see Chapter 8 in this volume) requires extensive dialogue processes in order to 'bring everyone onboard' – to assure that the local 'payers' for the implementation of these services see the benefits they are paying for and that, by changing their practices, they can gain significant protection from flooding and other consequences of climate change. As such, the shift towards flood resilience is not just a shift towards different types of measures, but a societal shift towards learning how to live with floods in urban areas.

9.3 CHALLENGES FOR URBAN LAND MANAGEMENT SYSTEMS

In the following paragraphs we will discuss the link between urban land management systems and flood risk management, and in particular the spatial, legislative and institutional challenges. Which challenges can we meet in our efforts to ensure cities' resilience against flooding? And how can urbanized areas be transformed to withstand rising surface-watercourses?

9.3.1 Spatial Challenges

Land use and zoning may exacerbate or limit the exposure and vulnerability of urban dwellers and infrastructure to the growing threat of climate change (flooding). Therefore, developing an integrated urban land-planning framework is a major issue in the process of implementing the resilient city.

New building activity poses important challenges to urban flood resilience. Exponential growth and aggressive development of peri-urban areas often conflicts with environmental aspects and climate change effects. Rapidly increasing urbanization rates worldwide are resulting in a deterioration of environmental quality. Uncontrolled urban development might lead to increased soil sealing and thus increased flood risks on the one hand and building activity in flood-prone areas that is not designed to withstand flooding on the other.

Even in planned urban developments, challenges lie in uniting urban planning with flood risk management (see also Chapter 10 in this volume). Urban planning has relatively short planning horizons and focuses on normal day-to-day flood conditions, whereas flood risk management takes the long term into account while also focusing on extreme flood conditions. According to Zevenbergen et al. (2008), matching these temporal scales is key to maintaining and improving urban flood resilience.

Also, the existing urban fabric often does not sustain flooding well. Due to increasing flood risks and the heavy reliance on engineered flood protection in the past, areas that were previously considered safe from flooding are increasingly affected by floods. Accommodating flooding in such areas would require high investments. As buildings affected by flooding become less valuable, vulnerable populations might move into flood-prone parts of the city, not only increasing overall vulnerability, but also inciting unjust situations (Nagenborg, 2019).

Therefore, the spatial challenge lies in regulating extensions to develop in a resilient way and retrofitting existing structures to accommodate flooding and thus become more resilient. Tackling these challenges requires thorough consideration of the distribution of responsibilities among all parties involved, i.e. legislative and institutional challenges.

9.3.2 Legislative Challenges

Legislative aspects play a crucial role in implementing efficient urban land management in order to obtain resilience to floods. Ensuring property rights over urban land and securing these rights, adopting a set of policies governing access to and use of land in the city under changing climate conditions and planning and managing cities all require a coherent and efficient legislative framework.

However, there are several challenges in securing this legislative framework. We can mention here the cities' bureaucracies, the frequency of political transitions in city leadership, financial policies and the access to technical assistance and knowledge resources.

The legislative capacity to combat the effects of climate change (including reducing the risk of floods in urban areas) is affected by the major focus of property rights on the market-oriented economy (especially in developing countries) to the detriment of ecological aspects. Restoring this capacity may, however, require government regulations in the public interest that will restrict private property rights (Freyfogle, 2003; Goldstein, 2004), which triggers the question of adequate compensation (see Chapter 3 in this volume).

Unfortunately, these issues are inevitably influenced by bureaucracy and political transitions in leadership. The integration in the legislative framework of all stakeholders implies an interdepartmental cooperation between different institutions, working groups and committees, as well as key concepts such as participatory processes and public governance. In addition, the importance of the respective education level as well as the existence of easily assimilable sources of knowledge must be emphasized here. Cities with easily readable and understandable bureaucratic procedures and people who are able to understand bureaucratic procedures recover more quickly (Blaikie et al., 1994; Buckle et al., 2001; de Bruijn, 2005).

However, technical assistance and knowledge resources are not always easily accessible and may require special attention. In many cases, cities' fiscal systems are based on local collection of different taxes which may generate inequities. The absence of a sustainable source of revenues for local authorities is a major liability in the efforts of enforcing a legislative plan effective in achieving the state of resilience (Razin, 2000; Raphaelson, 2004). Resilient cities have succeeded in implementing a robust fiscal system capable of supporting the development and implementation of regulations on efficient urban land use at a local level in order to mitigate climate-change effects or planning adaptation.

Political transitions are also a significant challenge. Even if the resilience of a city represents a political commitment for all political orientations, political transitions are usually characterized by changes in agendas on the environment, land taxes, the level of bureaucracy and economic strategies. Political instability and inefficient leadership (which unfortunately almost inevitably occur especially in developing countries with a higher degree of corruption) will only exacerbate the difficulties of obtaining a resilient city.

As resilience is not an easily visible short-term goal, there is generally no interest in using political capital to implement specific resilience measures. However, a strong and committed political framework for urban land management systems is crucial for institutionalizing resilient cities.

9.3.3 Institutional Challenges

The institutionalization of different urban land policies and strategies aiming to reduce flood risk in urban areas within local administration and their integration with other sectoral plans is a key issue in implementing the resilient city. It has been proven that institutionally well-organized cities have a privileged position in developing measures for urban land management and their implementation (Blanco et al., 2011; Otto-Zimmermann, 2011). The regulation of urban land usually includes institutional processes for planning, subdivision of undeveloped land, zoning, and building codes for private and public development to ensure an appropriate approach to different challenges threatening the resilience status.

Worldwide, cities' institutions have created a range of mechanisms to implement flood risk-related policies. Unfortunately, there are several factors that threaten the effectiveness of these mechanisms: insufficient capacity and expertise, lack of devolved authority or appropriate responsibility, and decentralization level and financial resources.

Adapting institutional capacity to the complexity of urban land management to promote the concept of resilient city is a complex process. It involves a harmonious integration of three factors: human resources, financial resources, and capacity and decision-making power. In addition, the human component involves addressing an additional factor: expertise. Numerous situations have been documented in which the institutions involved in reducing the risk of floods have proved unable to achieve their objectives due to the lack of adequate staff with appropriate technical and socio-economic knowledge (Blanco et al., 2011; Otto-Zimmermann, 2011). In terms of financial resources, a challenge is to shift public investments from flood-protection to flood-resilience measures, which requires a wider range of actors to be involved and is much harder to realize.

An effective implementation of flood risk reduction mechanisms in urban areas requires a dedicated local authority with clearly assigned responsibilities. Unfortunately, in many OECD countries it has been documented that the local authorities from urban areas lack sufficient jurisdiction over aspects that significantly affect flood risk reduction (OECD, 2009, 2010).

Empowering local authorities from both political and financial perspectives could be a silver bullet in overcoming several institutional challenges regarding the institutionalization of resilient city. McCarney (2006) mentioned that cities could develop and implement more efficient planning and management functions if the local authorities are considered as key partners in national governmental structures and if they have significant financial power (see also McCarney et al., 2011). These aspects are strongly linked with decentralization processes that ensure the ability to take and implement decisions from the governmental sphere (in a manner closer to the citizens) in urban areas for mitigating flood risk. Decentralization also provides local authorities with the responsibility for the management of their urban lands. Efficient urban land-use planning, a process that is not easy to develop and implement, is a key aspect for institutionalizing the measures for achieving a resilient city.

9.4 OPPORTUNITIES FOR THE FLOOD-RESILIENT CITY

A wide range of structural and non-structural measures exist to accommodate flooding in cities. Structural measures are physical constructions aimed at reducing or avoiding impacts of floods, such as dikes, barriers and dams, while non-structural measures use knowledge, practice or agreement to reduce flood risks, such as building codes, awareness raising and early warning systems. In what follows, we discuss some of the spatial, legislative and institutional opportunities that might arise to advance the development of the flood-resilient city.

9.4.1 Spatial Opportunities

Different flood-proofing measures are available, in terms of different types of development (new vs. existing structures), scales (building vs. neighbourhood vs. city vs. region), distribution of responsibilities (individual vs. collective) and type of solution (engineered vs. NBS). Most of these measures have been or are being tested for soundness and cost-efficiency, proving to be promising opportunities to achieve flood resilience through redundancy and flexibility. Especially individual adaptation measures are believed to contribute substantially to the resilient city by contributing to urban planning objectives such as attractive waterfronts (see Chapter 8 in this volume). As Zevenbergen et al. (2008, p. 87) explain "This is because they do not have to hinder urban development, unlike some collective, resistive measures (e.g. large embankments), and can provide simultaneous short-term societal benefits (e.g. high amenity value of attractive waterfronts)".

The choice between these different measures is not merely a technical one. It raises important political questions on the distribution of risk and the costs and benefits among the different stakeholders involved, especially the people exposed to flood risks. For example, while individual adaptation measures might be promising, this also means that responsibilities for flood protection are shifted from collective (principle of solidarity) to individual, challenging existing distributions of responsibility. Considering the already existing potential issues with fairness and justice (Fainstein, 2015), it is important to carefully consider efficiency, effectiveness and distribution of responsibility when proposing flood-resilience measures.

Technical solutions can be found to almost any flood problem. However, in order to achieve the flood-resilient city, the challenge lies in implementing these measures (Hartmann and Jüpner, 2020). Depending on the specific nature of the preferred flood-proofing measures, different stakeholders are involved in the implementation. To create the right momentum or window of opportunity for the implementation of flood-resilience measures, different types of resources need to be available. While it might be hard to pursue flood resilience under normal day-to-day conditions, moments of new developments or redevelopment and renovation signify a real opportunity to develop resilient cities. In the (re)development phase, financial capital and technical expertise gather around a specific area or building(s), representing a window of opportunity for the resilient city to be implemented.

It is often easier to flood-proof buildings and areas as part of the initial design than retrofitting measures into existing spatial structures. Indeed, "opportunities created by urban transformation and restructuring can be used to implement additional or even new flood mitigation measures and thus deliver resilience" (Zevenbergen et al., 2008, pp. 86–87). For existing spatial structures, flood-resilience measures can be retrofitted into existing structures during a renovation phase.

Aside from the presence of capital and momentum, also some kind of motivation for the implementation of flood-resilience measures is needed. After all, it is highly unlikely that the implementation of the flood-resilient city will happen spontaneously. Therefore, structural flood-resilience measures need to be flanked by non-structural measures promoting the implementation of these measures. These include land-use regulations (making the implementation of flood-resilience measures mandatory) or other rules and regulations, for example to mediate costs through subsidies or tax reductions.

9.4.2 Legislative Opportunities

It is difficult to identify truly legislative opportunities that can support the process of institutionalizing the resilient city. Instead of pursuing a bureaucratic process for legislative changes, the focus should be on a more accessible approach based on often-overlooked issues like participatory governance, public consultation and participatory process. Involving citizens in the decision process regarding urban land use, flood risk mitigation, and spatial planning within the broad objective of achieving city resilience is a must since these decisions will have direct and indirect effects on them. Thus, participatory process is a key aspect in institutionalizing the resilient city (Lovan et al., 2017; Schauppenlehner-Kloyber and Penker, 2016; Marana et al., 2018).

In addition, successful implementation of specific measures for achieving urban resilience demands a broad range of stakeholders at the local level to support, internalize and adapt to strategies in order to produce successful results. Using dialogue-based and action research-adapted techniques to build community capacity in order to facilitate future implementation of flood risk reduction management strategies which are sustainable economically, environmentally and socially can represent an alternative to overcome potential legislative obstacles.

Another key concept used at the European policy level in this context of rapid environmental and social changes that are threatening and/or impeding urban resilience is co-creation. This concept integrates participatory governance and the process of bottom-up innovation for development. It involves the active contribution of citizens to delivering flood-resilience measures, an action that can lead to more resilient cities (Heron and Reason, 1997; Lemos and Morehouse, 2005; Ruiz-Mallén, 2020).

Aside from pursuing development and coordination, spatial planning also has an important regulatory function. In this function, land-use policies could enforce a minimal degree of flood resilience. Available instruments are zoning plans and ordinance, development controls for land use and density and building codes, for example for elevated (infra)structures, flood-proofing and NBS (Burby, 2000). As such, the implementation of the flood-resilient city could be legally enshrined in spatial planning law.

9.4.3 Institutional Opportunities

The integration of the resilience concept in the urban planning processes implies the inclusion of cultural, environmental, social and economic factors in innovative planning and design solutions.

In many cases, the development of new infrastructure to increase cities' resilience can be particularly costly so that a more affordable and less bureaucratic alternative may be the process of renovating existing infrastructure. The process of renovation or retrofitting should be conducted in ways that respond to current societal challenges such as the need for increased liveability and sustainability, reducing the impact of natural hazards and risks, and ensuring the conditions for a fast and efficient post-disaster recovery (see also Chapter 10 in this volume).

As local communities are often the main contributors to increasing the resilience of urban areas, the implementation of a system of subsidies and facilities for contractors could help to mitigate financial pressures. Renovation and/or retrofitting for resilience is challenging, but within a sustainable dialogue-based approach it can catalyse positive energies across communities and improve quality of life.

Mobilizing private and public urban landowners for implementing flood-resilience measures that also allow urban development means coordinating different actors and institutions. This particularly includes engaging building owners, landowners and land-users actively in developing and implementing flood risk management plans, but it also implies that managers employ a more trans-disciplinary perspective and create governance mechanisms for transferring risks and benefits (Hartmann, 2011; Macháč et al., 2018). There are few, if any, working models for such transfers of benefits and their development will require collaboration from all communities of end-use implementers – those who should benefit from the implementation on the ground level. These include municipal and other governmental stakeholders, but also the building owners, landowners and land users who will benefit from the reduced flood risks, in return for some level of compensation for those benefits. Such a benefit transfer policy will be extremely difficult to impose from the top. What is particularly needed are dialogue tools which can be used to encourage the effective adoption of innovative solutions like nature-based technologies.

9.5 DISCUSSION AND CONCLUSIONS

Transforming urban lands to withstand rising surface-watercourses and rainfall levels in order to keep damage low when flooding occurs offers a promising contribution to enhancing flood resilience of urban systems. However, this transformation process requires changes at institutional, legislative and spatial levels as well as the participation and coordinated action of multiple stakeholders. These changes should ensure and support the integration of urban lands in public protection strategies through land-use measures, enhancing overall resilience to flooding.

The capacity of urban lands to absorb climatic shocks and to replace certain functions of urban systems in the area of civil protection must be addressed in an inter- and multi-disciplinary fashion, securing effective cooperation between various stakeholders involved in developing urban land management systems for achieving resilience.

However, the implementation of these urban land management systems involves overcoming certain obstacles of a legislative, spatial and institutional nature. Developing an integrated urban land planning and management framework is a major issue in the process of implementing the resilient city. This process is threatened in many situations by rapidly increasing urbanization rates, insufficient capacity and expertise of local and regional authorities, lack of devolved authority or appropriate responsibility, inadequate decentralization, insufficient financial resources and policies, bureaucratic aspects, frequent political transitions in city leadership, insufficient access to technical assistance and knowledge resources, and unsuitable market-oriented approaches in urban land management.

Overcoming these obstacles is an issue of responsibilities allocation across scales of governance and among different categories of stakeholders. The distribution of risk and the costs and benefits among the different stakeholders involved within a cooperation framework based on participatory governance, public consultation and participatory process will facilitate future implementation of flood risk reduction management strategies, which are sustainable economically, environmentally and societally. The overall coherence and alignment of resilience policies is based on valuable dialogue-based and action research-adapted techniques which encourage co-creation and effective adoption of innovative solutions like nature-based technologies (Yohe and Strzepek, 2007; Revi, 2008).

In conclusion, urban land planning and urban land management systems are key adaptive institutions in the process of adapting to unavoidable impacts of climate change and reaching resilience status. Institutionalizing resilient cities is a matter of several urban policy issues including governance efficiency, effective planning capacity, agile planning and land markets, and sustainable planning strategies.

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10. The role of risk transfer and spatial planning for enhancing the flood resilience of cities

Paul Hudson and Lenka Slavíková

10.1 INTRODUCTION

How urban areas are designed will become an increasingly important topic in flood risk management (Raška et al., 2020; see also Chapter 9 in this volume). For example, planning regulations (see Box 10.1) can aim to lower flood risk or prevent the creation of flood risk. This is known as risk-sensitive, or strategic, planning. This can be achieved by requiring building owners to employ property-level measures that minimize flood risk (e.g. elevating buildings above expected flood depths), while neighbourhoods can be designed around green infrastructure (see Chapter 8 in this volume), or ensuring that development only takes place if there is a sufficiently low flooding probability (Hudson and Botzen, 2019). However, urban planning is not the only potential instrument for urban risk management. Another instrument is risk transfer (see Box 10.2). Unlike planning instruments, risk transfer does not aim to lower disaster impacts but rather supports the recovery process. This is by providing the resources needed to kick-start post-disaster recovery. The archetypal examples of risk transfer are, ex-ante, insurance (Hudson et al., 2020), and ex-post, government compensation (Slavíková et al., 2020). Both instruments come at the end of a chain of stakeholders' activities, considerations, and interactions. Risk-sensitive planning manages flooding by balancing competing agendas (Thaler et al., 2020), much like risk transfer (Surminski, 2018), across various interested and/or antagonistic social groups (e.g. property-price changes if the provision of flood information is mandated). Each step of this chain needs to be considered for successful and sustainable flood risk management (Golnaraghi et al., 2017). This similarity creates potential synergies in how these instruments can be used.

BOX 10.1 SPATIAL PLANNING MECHANISMS

Spatial planning mechanisms vary in different institutional contexts. In principle, they intend to reconcile private interests of developers (or landowners and land users in general) with different types of common interests. In flood risk governance, such common interests are potential flood damage reduction, increased community resilience, and community prosperity.

Spatial planning regulation usually embodied in spatial plans and followed by construction requirements tells people what changes they can (or cannot) adopt on their properties – it has the form of direct regulation without (financially) incentivizing people. In high flood risk areas, new development of properties can be fully prohibited. Renovation of existing properties can be burdened with standard retrofitting requirements. In areas with lower flood risks the development is possible under specific construction conditions. This situation is mainly true for European spatial planning reality within which property rights may be (and are very often) limited with society regulations. However, the complexity of combined flood risk management and spatial planning can create loopholes in this approach. The main regulators are national institutions and local governance authorities responsible for spatial plans development.

Limiting flood impacts via these instruments (risk transfer and urban planning) requires the instruments to be collaboratively integrated into increasingly proactive risk-management paradigms. Proactively limiting flood risk requires all stakeholders to act in accordance with their abilities as successful flood risk management is beyond the scope of a single actor (Rauter et al., 2020; Snel et al., 2020; Suykens et al., 2019). This focus allows both risk transfer and risk-sensitive urban planning to fit within the risk-management paradigm of resilience (Disse et al., 2020; Masnavi et al., 2019). Our conceptualization of resilience uses three core pillars: recovery (the ability to return to the pre-flood state or to minimize the disruption to well-being), resistance (the ability to lower potential flood impacts proactively), and adaptive capacity (the ability to learn and positively transform the system). These pillars have been used in several studies (Hudson et al., 2020; Thieken et al., 2014). It is beyond the scope of this chapter to introduce these pillars in detail. However, they succinctly express the three main areas proactive risk management seeks to act within. In this paradigm of proactive risk management, we must strengthen each pillar as part of the overall system. A systems-thinking approach is required as resilience can be worsened and undermined if there is an overly strong focus on a single resilience pillar or instrument (Cremades et al., 2018;

Lucas and Booth, 2020). Therefore, for society to be resilient, we must consider multiple instruments, outcomes, and interactions.

BOX 10.2 RISK TRANSFER MECHANISMS

Risk-transfer mechanisms come in many forms. For example, public/private insurance transfers risk by converting an unknown potentially large disaster loss into a known smaller fixed loss (the premium), with predetermined compensation expectations. This pre-finances losses through a combination of premiums and the insurer's capital reserves. Government compensation schemes on the other hand use post-disaster cash transfers to alleviate a disaster's impact. Often, such schemes have unclear compensation criteria and are financed via taxation, borrowing, or budgetary reallocation. Additionally, we can directly engage with financial markets via insurance-linked securities (ILS), such as catastrophe bonds. Catastrophe bonds are short-term bonds, for which the principal capital does not need to be returned to investors if a disaster occurs and meets pre-agreed conditions (e.g., hurricane category, earthquake magnitude). The capital is used instead for reconstruction or compensation. While different, they share many of the same concerns and core objectives. This is to provide an influx of resources to those impacted to kick-start the recovery process and minimizing the overall well-being loss.

In principle, there are no limits to how these mechanisms can be used. Other than that, the relative risk appetites of the person accepting the risk and the person transferring risk must overlap for a mutually beneficial exchange. The more often and extreme a disaster risk the more resource intensive (i.e., expensive) it becomes to transfer. This can be because, e.g., premiums must grow to maintain solvency or more capital must be kept in reserve, or imposes greater opportunity costs on budgets. Therefore, limitations are often placed on who can access risk-transfer mechanisms, such as excluding new developments in floodplains, floodplains with too high an occurrence probability, or those who do not want to retrofit their property, to create an overall viable mechanism. These accessibility conditions are argued to incentivize risk reduction and compliance with resilience boosting activities. This is because people are rewarded for acting in line with risk management policies.

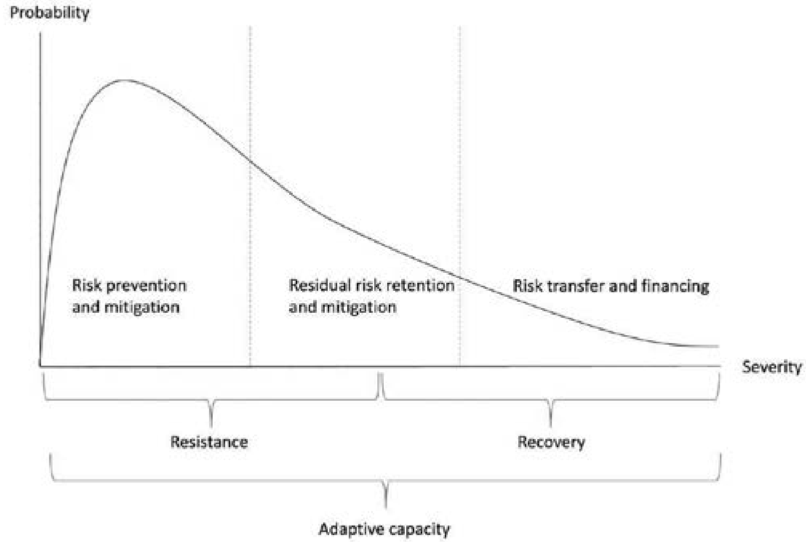
Key actors and stakeholders are difficult to determine. This is because risk-transfer systems evolve from a series of public policy choices and cultural determinants. This evolutionary process creates different core key actors and stakeholders. For example, in the private sector-led UK the main stakeholders are private actors (citizens or companies), insurance companies, Flood Re (a reinsurance pool), international reinsurance companies, and the government as a provider of structural risk reduction. While in the public sector-led France, we see main stakeholders are private actors (citizens or companies), insurance companies (as distribution channels), the public reinsurer, and government as the guarantor of the system and provider of structural risk reduction.

This is appropriate as flooding is a complex problem requiring multiple instruments to address different aspects. In this light, this chapter presents a series of examples of how to boost urban flood resilience by using risk-sensitive urban planning and risk transfer (in general rather than through specific mechanisms). The boost in resilience occurs through the creation of positive synergies if both instruments are considered equally important in flood risk management. This is because the recovery process creates the opportunity to improve both resistance and recovery capabilities (Slavíková et al., 2020). This is done through the potential to transform cities and risk-management approaches through improved adaptive capacity. The scope of this debate is larger than can be contained within a single chapter. We hope that our examples and interconnections spark a wider discussion and consideration on how the two instruments can be proactively interconnected rather than working in parallel.

10.2 URBAN FLOOD RESILIENCE AND RISK MANAGEMENT

The process generating flood risk is complex. Moreover, there is a large range of uncertain potential impacts. For example, higher-occurrence-probability floods are less impactful than those with lower occurrence probabilities. Therefore, to account for this, multiple instruments must be used across the entire risk profile. This leads to risk-layering, segmenting the risk profile for efficient management via targeted activities (see Figure 10.1). The frequency and severity of potential flood events guide the layers into risk prevention and mitigation, risk retention and mitigation, and risk transfer. Moreover, we would argue that each layer is also best served by a different resilience pillar. This is because each pillar focuses on specific activities, where socio-economic instruments can be targeted for a specific goal. One example is the use of planning to disincentivize floodplain development (risk prevention). These resilience pillars interact with the risk layers, creating overlapping segments of and impacts on the risk profile faced. This can lead to positive synergies.

For instance, consider the first risk layer. This risk layer is best managed via prevention and risk reduction as these are typically low-severity and



Source: Authors.

Figure 10.1 Risk-layering and resilience diagram

high-frequency events that can be cost-effectively reduced and prevented (e.g., via hinterland retention areas as discussed in Chapter 2 in this volume). This layer also includes actively preventing new risks (e.g., development bans in areas with occurrence probabilities of 1 per cent or higher where socially relevant). The residual risk retention and mitigation layer covers lower probability and higher severity risk that can be self-financed as it represents a risk level that is not cost-effective to prevent completely. This layer of risk is within the capacity of a household or company (for example) to limit (e.g., property-level retrofitting with flood barriers or resistance materials; see Chapter 8 in this volume). These are aspects of the resistance resilience pillar for which we aim to limit the impacts that are within our capacity to reasonably do so. We posit that these are activities where planning mechanisms are best suited to act due to their focus on the physical city.

This has the resulting implication that flood risk cannot be eliminated as certain events are not warranted to fully prevent. This is either because they are so rare and we have more socially productive investment opportunities, or they are impossible to prevent. Therefore, there remains risk that must be borne and absorbed if we are to act in a socially responsible manner. This risk layer contains risk retention (e.g., the use of savings or resources at hand to absorb impacts) and risk transfer (e.g., insurance or ILS), which fall under the recovery-resilience pillar. The risk-transfer layer consists of events that go beyond the actor's ability to absorb, thereby requiring an influx of resources from specialized institutions, such as insurers.

How the risk layers are split across these two pillars has significant implications. The division in effect draws the line between where risk reduction is deemed possible and where risk must be accepted and absorbed. Where this line is drawn has significant impacts on risk-transfer mechanisms. For example, if the line is drawn early in the risk profile, more risk is transferred, rendering the mechanism more resource intensive (e.g., expensive). This increase in expense can reach the point where individual mechanisms are no longer viable, reducing the ability to recover from events that exceed protection standards. Similarly, if no risk is expected to be transferred (i.e., that all risk must be prevented by the state), we create a paradox whereby preventing risk leads to more risk being created (Haer et al., 2020) and a self-reinforcing unfamiliarity with risk transfer. Therefore, it is clear that to be proactively resilient, a combination must be employed. Flooding must be prevented via protective infrastructure, potential impacts mitigated via protective behaviours (see Chapter 8) or via upstream-downstream agreements (see Chapter 4), and the remaining risk must be transferred.

Maintaining the ability of the system to act on each risk layer and resilience pillar in an accessible, effective, and sustainable manner can be considered as adaptive capacity. Adaptive capacity is the ability to learn and improve the system, so it produces effective risk management. For example, a system whereby risk is allowed to grow so large that risk transfer becomes prohibitively expensive does not display adaptive capacity as we lose access to the full range of resilience-boosting instruments. However, a system whereby after a flood risk-transfer instruments incentivize and inform on the use of property-level adaptation indicates a higher level of adaptive capacity, for at least one aspect of the system.

10.3 EXAMPLES OF SYNERGIES BETWEEN PLANNING AND RISK TRANSFER

10.3.1 The Recovery Pillar of Resilience

This sub-section presents several examples of how risk-sensitive planning supports risk transfer to build greater resilience.

The first example of synergy within the recovery pillar regards accessible risk-transfer financing. For insurance (or ILS), the premium partially determines its accessibility. The higher the premium, the less accessible it is. For insurance, this is because it is more expensive, or for ILS it represents a riskier product which may not be attractive. A premium or price linked to the underlying risk creates the strongest incentives for additional risk management. This is because successful policyholder risk management can lower the price charged (Hudson et al., 2020). However, the more expensive the price is, the more it consumes resources. Spending more resources on accessing risk transfer can undermine a household's/business's capacity to achieve other resilience pillars. For example, after paying the premium, they no longer have the resources to employ the risk-reducing measures. Similarly, public compensation must be funded. This can be via taxation, as occurred in the Czech Republic (Slavíková et al., 2020), or resource diversion, e.g., from infrastructure maintenance. In these examples, the greater the potential threat, the greater the potential compensation that must be paid, and the greater these problems become. Planning instruments such as sponge-city developments lower risk (see Chapter 8) thereby reducing the pressure placed on risk transfer and forgoing potential increases in premiums, taxation, or the opportunity cost of changing the use of earmarked monies. Therefore, the synergy created through risk-sensitive urban planning is the production of a suitable marketplace for sustainable and affordable risk-transfer mechanisms.

A related synergy between planning and risk transfer is how urban development in flood-prone areas can be sensitized to who is located there. For example, developing social housing in floodplains has implications for risk-transfer affordability as compared to high-end developments. Moreover, more socially vulnerable households in general may not be as able to absorb disaster impacts due to the subjectively larger impacts they suffer from a disaster, potentially worsening the recovery process and resulting in a potentially higher likelihood for negative mental-health outcomes. The strategic integration of concerns outside of direct monetary losses supports risk-transfer mechanisms in bolstering community resilience. This is because community recovery potential is bolstered by only allowing floodplain development if its residents can handle the consequences of a flood and access risk-transfer measures, making these requirements known.

A further synergy on how planning supports risk-transfer mechanisms is the creation of a larger insurance market. Public/private-led risk-transfer mechanisms must have participants from both high- and low-risk areas. In covering both areas, greater diversification is achieved. This helps the risk-transfer provider to remain solvent or to manage premiums through an implicit cross-subsidy between areas. Planning regulations can require the purchase of insurance. This requirement creates a more stable and larger participant pool. A second planning approach is mandating that all buildings within disaster-prone areas are constructed or retrofitted so that they reach and maintain a sufficiently low level of vulnerability. Therefore, planning instruments and development help to counteract two fundamental problems with risk-transfer mechanism: moral hazard and adverse selection. Moral hazard is where individuals protected by risk-transfer instruments employ fewer risk-management behaviours. In turn, this leads to a higher risk level than would otherwise occur. This negative outcome can be mitigated by building requirements that lower risk. Adverse selection is, effectively, where only the highest at-risk demand access to the risk-recovery mechanisms. Mandated coverage expectations reduce this potential as neither high- nor low-risk people can leave, helping the overall pool to be sustainable.

A related issue is the concept of 'buy-outs' or 'planned relocation' relevant for repetitive property loss (Tate et al., 2016). This action increases resistance as there are fewer properties to damage. This reduces the burden placed on the risk-transfer provider as there is a lower geographically concentrated need for compensation. Additionally, as the finance sector is increasingly taking climate change into account, it is possible that there will be places where only those unable to move away remain in disaster-prone areas (de Koning and Filatova, 2020). Buy-outs can address this problem by creating a market which would otherwise not exist. This allows a planning instrument to directly boost resistance, and thereby indirectly support risk transfer.

10.3.2 The Resistance Pillar of Resilience

This sub-section presents several examples of how risk transfer supports risk-sensitive planning to build greater resilience.

Risk-sensitive planning must note that risk is generated by a series of interacting decisions placing externalities upon one another. Therefore, one person's decisions can impact the risk profile for other people, creating a potential ripple effect. For instance, the installation of protective infrastructure can effectively move flood water from one area to another, an outcome often not considered in the decision-making process of an individual. Therefore, alterations in the burden of providing or accessing risk-transfer mechanisms in a socially equitable way can provide an indication of these externalities and their magnitude. Additionally, known troubles in gaining access to risk-transfer mechanisms in specific areas can help redirect activity. This creates a wider space for coping with changes in risk by providing a third-party indication of how risk is changing. This creates a new mechanism that either supports the original planning intent or helps to identify where a problem has been created.

Urban planning must achieve multiple objectives of which flood risk is only one. Therefore, it is possible that the generation of new risk cannot be avoided due to wider social objectives. In this case, risk transfer (especially insurance) can help incentivize vulnerability reduction. For example, in France, communities can be asked to retrofit buildings after a flood to return to laxer public insurance conditions (Poussin et al., 2013). This is to incentivize complying with flood-sensitive building codes. However, in the case of

France, these measures do not have to be implemented, but merely included in a risk-prevention plan (Poussin et al., 2013). Therefore, it is important that flood risk management is suitably mainstreamed into urban planning in a way that generates tangible, rather than tokenistic, action.

A related issue is the 'betterment' concept. Betterment is where, during the recovery process, funds provided by insurers (for example) can be used to enhance resistance directly rather than returning it to the previous status quo. In Canada, for example, from 2008, mitigation clauses and innovative recovery solutions have been incorporated into the rules of the federal disaster relief distribution provided to affected households. This means that additional financial resources might be provided on top of disaster relief pay-outs to mitigate disaster risk. The introduction of the extra disbursement has been considered as the first step toward sustainable disaster recovery. Critiques pointed out that the limited disbursement reduces the range of choices for mitigation options and that only measures on already damaged property are reflected (Sandink et al., 2016). Similarly, in Australia from 2007, the betterment principle has been incorporated into government-funded disaster relief to provide missing linkage between recovery and mitigation. However, in many justifications, the potential for such investments is currently limited without a reconsideration of the nature of insurance as a tool for a return to the status quo. A relaxing of the resistance against betterments can aid in achieving zoning regulations that require property-vulnerability reduction. For instance, in the case of France, zoning-mandated property-level measures do not need to be implemented if deemed too expensive. However, the post-disaster recovery phase offers the second-best opportunity to retrofit the property in a way that meets the wider disaster-management regulations from risk-sensitive planning.

A further example of synergy comes directly from enhancing the recovery pillar. Unterberger et al. (2019) note that risk-transfer coverage for local governments (e.g., insurance or ILS) can boost fiscal resilience. This is important for cities as budget irregularities can inhibit the repair of physical environment/infrastructure, or other expected services. A city that is unable to provide suitable infrastructure or services weakens the recovery-resilience pillar, increasing indirect economic impacts, e.g., longer business interruption costs (Botzen et al., 2019). The protection offered by integrating risk-transfer mechanisms into infrastructural needs helps planners securely achieve their other social objectives, thereby allowing a city to provide its needed services as soon as possible after a disaster event.

10.3.3 The Adaptive Capacity Pillar of Resilience

Creating synergistic outcomes is adaptive capacity as such interactions create a more productive outcome. For example, when recovery is supported by more proactive risk-sensitive planning, risk-transfer mechanisms are more affordable and sustainable, freeing cognitive and financial resources for other resilience boosting activities or insights. One example comes from the synergy generated by both instruments requiring in-depth local knowledge. The entire set of required knowledge is beyond the capacity of a single actor to know or generate, thus creating a movement towards detailed data sharing and modelling (Surminski et al., 2015) in order to generate new insights from closer collaboration. For instance, insurers and city planners in Copenhagen have come together to understand better how flood water and damage occur after pluvial flood events. This is achieved by using the urban planners' more detailed knowledge of the city at an engineering level and insurers' detailed knowledge of what, where, and how damage was incurred (Hudson et al., 2020). Additionally, coordination among jurisdictions is also necessary as a large number of stakeholders are needed to share information and coordinate action while ensuring accountability (Jha et al., 2013). This is due to the nature of flood risk as an externality. However, creating the national platforms and governance structures required to facilitate this generates transaction costs. The problem of transaction costs is discussed in Chapter 4 in this volume.

Addressing social justice or equality concerns helps to build a resilient city as both risk transfer and risk-sensitive planning interaction is another aspect of adaptive capacity. The distribution of flood risk is inherently unfair, but there are mechanisms in place to support social equity and deliver fair flood risk management in terms of the distribution of resources and that without careful consideration development may create or preserve inequalities. Failing to account for social justice concerns can lead to conflicts and mistrust (see, for example, Wamsler and Lawson, 2011), which can be overcome through inclusive collaborative environments that go beyond consultation. Forming these inclusive collaborative environments can lead to more community-led actions and more productive activities now and in the future (Slavíková et al., 2020).

Finally, including risk-transfer-specific stakeholders at all stages of the planning process boosts adaptive capacity because it is a group whose primary concern is limiting flood risk to remain sustainable instruments. This creates an implicit pressure group to maintain flood risk standards and not to generate unprotectable or unabsorbable risks. This is through the expertise they acquire through interaction with individual loss claims. For instance, Flood Re in the UK aims to provide affordable insurance but will not insure any newly constructed buildings. Rather, the users of these buildings must instead buy insurance directly off the private market rather than the subsidized pool. The potentially high premiums can prevent access to insurance which is often a requirement for being able to gain a mortgage (for example). This creates a tangible incentive for planners to consider flood risk because if a property cannot be sold or financed, the development cannot offer a net benefit to society. This thereby helps to enforce bans on developing in floodplains. Moreover, for regulation to be effective, it requires enforcement or the creation of other incentives that encourage people to act in line with the regulations (e.g., zoning regulations), which is an increasing focus of flood risk management even if this movement needs to be communicated better (Snel et al., 2020). Achieving this movement creates reinforcing expectations between the needs for risk reduction and recovery mechanisms. Similarly, planning stakeholders can and should be involved in the chain developing risk-transfer mechanisms so that risk-transfer providers remain sensitive to the social implications of their services.

10.3.4 Barriers to Synergies

However, despite many examples of positive synergies between planning and risk transfer, several hurdles remain to be overcome. These predominantly relate to stakeholder expectations and perspectives (see, e.g., Thaler et al., 2020). The above sections indicate that the synergies between planning and risk transfer come from the observations that fundamentally all instruments within disaster-risk management play into the following considerations for a resilient society: coverage or protection exclusions; minimum protective standards; limitations of what can be compensated; and retrofitting buildings after a disaster (Slavíková et al., 2020). However, these considerations need to be mainstreamed into decision-making as important and actionable outcomes (Golnaraghi et al., 2020). This is because, while there are many different risk-transfer styles and objectives, e.g., private sector insurance (e.g. Germany), public sector insurers (e.g. Spain), or by public compensation funds (e.g. Austria), disaster risks are often poorly considered in urban planning (Golnaraghi et al., 2020). This means that, while many countries have rules against floodplain development, there are often multiple exemptions due to disasters receiving lower priorities as compared to more tangible issues. Moreover, approaches must be proactive ex-ante strategies rather than more politically attractive ad hoc solutions. For example, in the V4 countries there is a low willingness to commit to ex-ante integrated arrangements due to the perceptions of how stakeholders are expected to behave within the system. This can also be seen in the approaches of the Netherlands and Germany. The Netherlands takes a risk-based approach indicating that the resistance measures can fail, while in Germany the predominant perspective is that of safety (Bormann et al., 2020). This perspective difference implies that in safety-oriented approaches recovery mechanisms are not actively considered as measures that should not fail. No instrument will provide certain outcomes. Additionally, ignoring the experiences of stakeholders specialized in other instruments presents a foregone opportunity for improving resilience.

Therefore, the two instruments must be mainstreamed. This is because the complex problem of flooding generates less resilient risk-management outcomes when approached from only one perspective or need. Siloed approaches occur because of institutional incentives that must be overcome or reorganized into new structures.

A related issue regarding the different perceptions of correct behaviour occurs because the two mechanisms operate at different scales/scopes. Risk transfer operates at the national and international scale, while planning is intensely local even with national guidelines. This creates conflict as different perspectives lead to different priorities and expectations. This is especially relevant if flood risk governance is also fragmented. For example, in Germany, flood risk management is the responsibility of the individual federal states (Thieken et al., 2016) as compared to Lithuania's single authority (Mikša et al., 2021). This increases the cognitive distance between those involved, inhibiting cooperation, and leading to siloed and potentially conflicting approaches. Therefore, while the European Floods Directive calls for greater inclusivity in flood risk management, achieving the required polycentric involvement is difficult due to the 'cultural' differences across stakeholders. Moreover, given that planning occurs at the local to regional level, in this, unlike in risk-transfer schemes, there can be substantial transaction costs or social inertia to overcome as more stakeholders must be involved. However, this might be weakened when we consider a publicly provided mechanism (Seifert-Dähnn, 2018).

However, similar perspectives can also inhibit successful cooperation between the instruments. Glaas et al. (2017) note that in Norway the insurance industry lobbies national/local government to make climate-change-related risks a higher priority. However, they also note that both act upon short time horizons because of politics (governments) or the annual nature of insurance (insurers). This means that while both have an incentive for proactive resilience building, there is a continuing focus on immediate/tangible issues matching their cognitive time horizons. This short-run focus can easily lead to maladaptive outcomes via immediate unconnected incremental changes in the risk-management system. This can be corrected by reducing the unfamiliarity with working along a longer planning horizon, but the incentives to deviate from this must be counteracted. Successful collaboration is required to overcome this barrier because risk transfer itself is not inherently transformative but absorbs risk so other actors can be transformative.

10.4 CONCLUSION

Promoting urban resilience must not only consider how the creation and management of physical assets alters the risk profile of an urban area but also must consider how we can increase the capacity of a range of stakeholders to keep both the physical and socio-economic environment suitably robust and resilient. A holistic approach across multiple instruments creating synergies in turn promoting inclusive collaboration across stakeholders is important. These structures should be aimed at proactively coping with the entire risk profile by targeting the layer of risk most suitable while preventing one mechanism from becoming the overall crux of an urban resilience strategy allowing the system to become maladaptive. This is because planning and risk transfer can best operate if they can focus on the resilience pillar that they are most suited to acting upon: resistance in the case of planning and recovery in the case of risk transfer. The opportunity to specialize in these specific roles creates synergies between the two instruments as we see they require many similar underlying features, criteria, and expectations. This thereby creates an environment where one instrument can succeed allowing the other to flourish by creating a supporting environment.

In this chapter we have presented a series of examples where when working together both mechanisms, embracing a systems-thinking approach, create synergies in creating more proactively resilient and risk-limiting cities rather than a system attempting to maintain the status quo. To achieve this, several barriers still need to be overcome to create the required resilience improving partnership. Achieving this requires a systems-thinking approach that involves the active consideration of all the elements discussed in this book.

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PART IV

Conclusion

11. Challenges of spatial flood risk management

Thomas Hartmann, Lenka Slavíková and Mark E. Wilkinson

Flood risk management is still a rather young paradigm. About 30 years ago, flood protection was the prevalent approach in dealing with riverine floods. For example, in Europe, the river Rhine floods in 1993 and 1995 initiated a change towards a more risk-based approach instead of mainly defending against flood waters (Jüpner, 2005). The flood events in the early twenty-first century further pushed the implementation of the shift from flood protection to flood risk management (Patt and Jüpner, 2020; Hartmann and Albrecht, 2014; Schanze et al., 2006), up to the institutionalization in the European Floods Directive (Hartmann and Jüpner, 2014). As a result, flood water had to be 'accommodated' (Wesselink, 2007), the term 'space for the rivers' was coined (Warner et al., 2012), and measures behind the defence lines of dikes have become increasingly relevant (van Ruiten and Hartmann, 2016). This has also led to a greater consideration of taking a 'catchment-based approach' to flood risk management, for example, considering nature-based solutions (NBS) alongside established technical solutions. The contextual features, such as political evolution, wealth and flood memory, affect the particular directions and speed of this transition (Nikolić Popadić, 2021; Kapović Solomun et al., 2020). Nevertheless, flood risk management has become the standard in dealing with floods within Europe, but also beyond Europe (Dai et al., 2019; Ferdous et al., 2019; Jacobson, 2019; Suykens et al., 2019; Milman et al., 2017).

However, flood risk management is also changing. Flood protection and the years of the flood risk management at the beginning of the century have similarities in that they assume a prevalent role for water management authorities, who are often formally responsible for flood risk management. Both presume a sectoral-management approach, while flood risk management acknowledges that other sectors and comprehensive spatial planning need to be integrated in one way or another. Still, the water authorities in the early years of flood risk management also had a key and coordinating role. In the last decade, this dominant role is increasingly questioned (van den Brink, 2009), and the notion of governance is becoming increasingly important (Hartmann and Spit, 2015, 2016; Mees et al., 2014; Wiering and Driessen, 2001). “Governance implies the involvement of various actors that are independent of a central power and operate at different levels of decision-making” (Kluvánková-Oravská, 2010, p. 60). Flood risk governance has developed increasingly as a field “where implemented flood mitigation measures should be diversified among actors, top-down and bottom-up decision-making should be balanced, and the involvement of multi-actor networks including active participation from citizens should be promoted” (Slavíková et al., 2019). Multiple stakeholders, sectors, and disciplines need to collaborate to deal with the higher intensity and frequency of flood events that we experience as a consequence of climate change and increasing vulnerabilities in flood-prone areas (IPCC, 2018). The management paradigm still has its relevance, but it is thus complemented by governance.

The most recent twist in flood risk management – or flood risk governance, as suggested by some authors (Alexander et al., 2016) – is the recognition that flood risk management requires addressing land as a biophysical (Ferreira et al., 2022), socio-economic (Hartmann et al., 2019a), and instrumental resource (Hartmann et al., 2018) across the whole catchment, including the hinterland, along the rivers and in urban areas. “Making this land available and persuading land users to implement the measures are thus two key challenges for implementing measures to mitigate or adapt to water-related risks. Usually, flood risk management deals first with technical and hydrological issues before addressing land management. Implementation of flood risk management is often hampered by the lack of land management approaches” (Hartmann et al., 2019b, p. 6). This ‘spatial turn’ highlighting the need of bridging land-use and flood risk governance regimes (van Ruiten and Hartmann, 2016) is explored in this volume by bringing together these notions under the term ‘spatial flood risk management’. Accordingly, this volume has been organized in three parts, addressing decentralized water retention in the hinterland, flood retention in polders or washlands, and resilient cities from three notions of land-environmental conditions, socio-political contexts and stakeholders and interests. Ultimately, spatial flood risk management entails two aspects: first, it manifests a catchment-based approach to flood risks across the different spatial areas described in the three parts, and second, it embodies the relevance of addressing land comprehensively in flood risk management, i.e., with all its different notions of land as a biophysical resource, land as a socio-economic asset and land as a representation of interests of plural rationalities of stakeholders. These two aspects can be described in a 3×3 matrix as introduced in Chapter 1, and the chapters discuss the content of this matrix.

Each chapter thereby identified specific challenges and future research questions for the concept of spatial flood risk management.

The first chapters of each of the three parts – Bourke et al., Pohl and Bezak, and Rinnert et al. – explore the environmental conditions of land for flood risk management. One conclusion that can be drawn for both hinterland-retention and flood-polder chapters is that large volumes of available storage are required in larger-scale catchments prior to a flood event occurring. Bourke et al. show that certain NBS measures can temporarily hold and attenuate water during flood events and could offer smaller-scale dispersed-water retention across a catchment (there are many local-scale studies which have promising results). Pohl and Bezak highlight storage measures along rivers where large storage volumes are required to significantly reduce flood peaks. These need to be engineered and managed at the right time. Therefore, both chapters highlight the different management options for managing flooding in a catchment (at varying scales) ranging from nature-inspired methods to more traditionally engineered approaches both with the common theme of attenuating flood water within a catchment. This is a first challenge of spatial flood risk management: It requires land on a large scale to realize measures across the whole catchment, while at the same time the socio-economic component of land and the respective interests represented in land point at smaller scales.

Another challenge of spatial flood risk management, which is related to the dilemma on scale, is the issue of causality of measures. Bourke et al. emphasize that the effects of NBS on the large scale are uncertain and still need to be further investigated. The lack of proof of causal effects for someone else of measures on one piece of land can provide a serious legal constraint for implementing measures, as Albrecht and Nikolić Popadić point out in their contribution. Kis et al., but also Ungvári and Collentine, support the need to be able to prove the effects of measures for beneficiary parties from an economic angle. Ungvári and Collentine identify the issue of monetary evaluation of retention-related benefits. It seems that the issue of causality is more difficult for hinterland retention measures, where the effects are often less transparent and potentially there are still some unknowns, but causality and cost and benefits are essential for retention with polders along rivers (Pohl and Bezak). While technicalities and engineering seem to be less of a problem, uncertainties of hydrological and hydro-numerical models can be challenging to thoroughly evaluate measures (Pohl and Bezak). It is especially important to prove positive and negative effects of measures for the downstream area. One way to overcome this is to think beyond the area of flood risk management goals. Bourke et al. conclude that many NBS approaches in the hinterland provide many other ecosystem services such as providing new ecological habitats. Therefore, when considering this approach, it is important to work more widely (out of the flood risk management sphere) with other stakeholders who are also thinking about how to manage catchments in a more sustainable way. By doing so, we can deal with other global issues (e.g. addressing wider

UN sustainable-development goals). This is a second challenge of spatial flood risk management: The causality is necessary to justify measures, both economically and legally, but at the same time there are large uncertainties with the flood effects of measures, and they are side-benefits addressing non-flood related issues.

Both of these challenges are fully relevant for urban areas, where land is scarce and possibilities for flood storage are limited. Cities themselves, often situated more downstream, have constrained options for flood-damage potential reduction on their own, especially when considering options beyond traditional flood protection. Still, multiple measures and governance strategies are available to transform them into flood-resilient cities.

Rinnert et al. show that there are many measures that can be implemented to make cities more resilient, covering better resistance, increased buffer capacity and more flexibility as part of adaptive capacity and improved recovery time. The measures include structural and non-structural approaches. However, many of the measures need to be realized on private land of a significant monetary value. Halbac-Cotoara-Zamfir and Tempels discuss the spatial, legislative, and institutional challenges of realizing the resilient city. The chapter illustrates that there is huge potential for the resilient city, but it requires well-functioning collaboration of many stakeholders – foremost landowners and spatial planning. Hudson and Slavíková confirm the potential and show how financial schemes can help foster flood-adaptation measures through individuals by avoiding moral-hazard behaviour and increased costs of inaction. At the same time, they point out the need to identify clear benefits that allow (financial) risk-transfer and trigger measures. This is in line with the conclusions of Bourke et al., Pohl and Bezak, Kis et al., and Ungvári and Collentine, and others in this volume on the need to have provable causality of measures with flood risk reduction. Ultimately, the resilient city is dependent on the measures in the hinterland and along the rivers upstream. However, the more precise the proof of causalities gets, and the better schemes between upstream and downstream that can be installed, the more difficult it could be to simultaneously realize adaptive behaviour of households in cities (due to a false sense of security). This is an issue of risk communication, but also of financial and legal instruments. This forms a third challenge of spatial flood risk management: activating citizens – or rather landowners – to realize respective measures requires shared risk perception and the setting up of allocation mechanisms that link those providing retention services with those who benefit from them.

What to conclude from the knowledge brought together in this volume? The three challenges point at the key issues of spatial flood risk management, highlighting the problems of scale, connectivity and governance. By no means does this book attempt to resolve them. At best, we can conclude that while spatial flood risk management is needed and bears high potential – as explained by the various contributions especially on the environmental conditions (Bourke et al., Pohl & Bezak, Rinnert et al.) – it entails many new challenges regarding the socio-economic and instrumental notions of land, assessment of NBS co-benefits and options for multi-functionality of land uses in general. The links between the contributions in this book also hint at the need to approach challenges of spatial flood risk management not in a mono- or multi-disciplinary fashion, but in an interdisciplinary way. Solutions are between the disciplines, where the issues are addressed collaboratively from multiple disciplinary angles.

Though this might seem a simple conclusion for a complex issue; the work on the topic over the past years, and in particular in the European-Union-funded LAND4FLOOD COST Action (www.land4flood.eu), encompassing multiple disciplines from almost 40 countries in Europe and beyond, demonstrates that there is a huge need and potential for communication across disciplines and countries.

If one can derive policy lessons from the contributions and findings from this volume and LAND4FLOOD as a whole, they lead to three main **policy messages**:

- Start working on the small scale: Comprehensive river-basin plans are impressive, but they will not come to fruition without working with individual parcel owners. Activation of landowners is vital and generates a domino effect regardless of the situation of the most efficient retention site.
- Money for flood storage measures implementation is not enough: Multiple instruments and strategies – land for land swaps, production-loss compensations, conservation easements, tax exemptions – must be activated.
- Take time to get landowners on board: Land-use changes purposefully decreasing land productivity are painful. Careful and continuous balancing of individual views with societal benefits is needed.

These three messages are derived from the three challenges above. They can be at best provisional and need to be further explored, validated, and refined in the future.

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