Flood-risk reduction: Structural measures and diverse strategies

Z. W. Kundzewicz[a,b,1], D. L. T. Hegger[c], P. Matczak[d], and P. P. J. Driessen[c]

Floods continue to hit many countries, both less developed and industrialized, bringing human suffering and immense economic damage (see floodobservatory.colorado.edu/). Hurricane Florence and Typhoon Mangkhut were just the most recent reminders of the disruption that flooding can bring. Hence, striving to improve the flood-risk governance system has broad relevance. Yet, the reduction of flood risk, understood globally as a combination of hazard, exposure, and vulnerability, is a rather distant goal (Fig. 1).

Several weaknesses of flood-risk management in the United States, recognized in a recent PNAS Opinion (1), generally apply to many European countries as well, despite all the political, economic, and social differences between the United States and Europe. From our European perspective, this panoply of approaches suggests that both social and engineering factors must be further explored and scrutinized across the globe—as should notions of justice related to flooding impacts and responses.

Diverse Strategies

The European Union (EU) has dedicated legislation, called Directive 2007/60/EC, on the assessment and

Fig. 1. In January 2018, the Seine flooded in Paris. When it comes to flood policies around the world, both social and engineering factors must be further explored and scrutinized—as should notions of justice as they relate to flooding impacts and responses. Image courtesy of Shutterstock.com/Ekaterina Pokrovsky.

[a]Institute for Agricultural and Forest Environment, Polish Academy of Sciences, 60-809 Poznań, Poland; [b]Potsdam Institute for Climate Impact Research, 14473 Potsdam, Germany; [c]Environmental Governance, Copernicus Institute of Sustainable Development, Utrecht University, 3584 CB Utrecht, The Netherlands; and [d]Institute of Sociology, Adam Mickiewicz University, 60-568 Poznań, Poland

The authors declare no conflict of interest.

[1]To whom correspondence should be addressed. Email: kundzewicz@yahoo.com.

management of flood risks (2). This "Floods Directive" aims to reduce and manage the risks that floods pose to human health, economic activity, the environment, and cultural heritage. The Directive requires all 28 EU Member States to identify areas at risk of flooding, to map the flood extent as well as assets and humans at risk in these areas, and to take adequate measures to reduce this flood risk. The Directive takes a procedural approach and allows EU Member States policy discretion in designing flood-risk management. The Directive, as well as national obligations related to it, enhances the lasting dedication to flood-risk reduction. Otherwise, national flood-risk–reduction activities (investments, legislation, and research) are triggered by destructive deluges (such as the floods in Poland in 1997 and 2010), but then interest decreases even within a few years after a great flood.

The United States has been the global leader, showing the path of flood-risk reduction. It was the US Flood Control Act of 1936 that enhanced structural defenses as the principal strategy in many countries. However, there is an illusion of perfect safety among populations protected by levees and dams. Residents near these structures clearly ignore their flood risk.

Unfortunately, we manage neither keeping destructive waters away from people at all times nor keeping people away from destructive waters.

Aside from attempts to reduce the water load via structural measures, one can try to enhance the resilience of the system as a whole as well as readiness to live with floods (3). Construction of a fail-safe system is impossible, but we may strive to build a "safe-fail" system that occasionally fails but does so in a safe way (4) and is capable of bouncing back. To enhance flood resilience, three distinct system capacities are required: to resist (e.g., by structural defenses), to absorb and recover (e.g., by spatial planning, disaster management, and insurance), and to adapt and transform by taking advantage of opportunities. A comparative study of flood-risk management carried out in the framework of the STAR-FLOOD project (www.starflood.eu/) in six EU countries (Belgium, England in the United Kingdom, France, The Netherlands, Poland, and Sweden) advocates for considering a roster of flood-risk–management strategies in addition to structural defenses.

It is important to emphasize that floods constitute a hazard only when humans encroach on flood-prone areas, as others have pointed out (5). Hence, preventive measures aim to decrease the consequences of flooding by decreasing the exposure of people and property via prohibiting or discouraging development in areas at risk. Flood-risk mitigation focuses on decreasing the consequences of floods through measures within the vulnerable area. Consequences of floods can also be alleviated by flood preparation (e.g., flood forecasting and warning systems, disaster management, and evacuation plans). Fast recovery after a flood event is enhanced by reconstruction plans (providing a window of opportunity for flood-proofing the new buildings or relocating inhabitants from unsafe to safer areas) as well as compensation or insurance systems.

The flood-risk–management strategies listed above differ in their focus on the reduction of flood hazard, exposure, vulnerability, and consequences. Unfortunately, we manage neither keeping destructive waters away from people at all times nor keeping people away from destructive waters. It is, therefore, necessary to embark on a diversified portfolio of flood-risk–management approaches—flood-risk mitigation, preparation, and recovery, to maximize the net effect of a combination of strategies (6). Physical conditions and existing institutions are highly context specific, and therefore, different mixes of strategies are needed in different sites. Moreover, we have shown (6, 7) that it is important not only to diversify but also to align the strategies and to be aware of the impact that different strategies may have on one another.

Flood defenses may encourage urban development in at-risk areas, and recovery mechanisms might also provide a disincentive for flood-risk prevention. However, smart urban planning enhances flood preparation (e.g., via spatial requirements for evacuation). Compensation and insurance schemes may act as incentives or disincentives to flood-risk reduction. In England, the implementation of property-level measures through risk differentiation and insurance premium reductions—if property owners take mitigating measures—are one such incentive. In contrast, in France, a comprehensive recovery scheme, via the Cat-Nat fund, forms a disincentive for limiting development in flood-prone areas.

Mixed Results

Appropriate elements for a portfolio of nonstructural flood-risk strategies have been known for decades (8–11). Gilbert White's seminal idea promoting the development of a portfolio of "adjustments" of human behavior to reduce flood risk (8) has been around for more than 70 years. Hence, the question arises: Why has it proven so difficult to implement? Perhaps the concept came too early and the world's governments and institutions, dominated by the flood-defense paradigm, were not ready to implement White's ideas. More recently, these notions have been gaining recognition in both Europe and the United States.

Even so, there have been impediments to operation (12), such as a lack of clarity on roles and responsibilities for policy, planning, and implementation; changes in political leadership and national priorities; tradition and predisposition to structural defenses; as well as problems with expertise and willingness to cooperate across disciplines, sectors, and administration levels. In general, resettlement is politically unpalatable. After the 1997 Oder/Odra flood in Poland and in Germany, inhabitants whose houses were flooded, damaged, and destroyed rebuilt better houses in the same floodplain

location, behind stronger and higher dikes (13, 14). However, with spatial planning, zoning, and bans on the development of floodplains, it is possible to control new housing and infrastructure and to try to move the existing infrastructure out of harm´s way.

Here, one can report success stories. For instance, after the Great Flood of 1993 along the Mississippi and Missouri Rivers, the US Interagency Floodplain Management Review Committee (15) recommended that federal, state, and local governments and those who live or have interest in the floodplain should have responsibility for the development and fiscal support of floodplain-management activities. The Committee also recommended that the administration should acquire lands from willing sellers and buy structures at risk in the floodplain. Although definitive numbers are hard to come by, many thousands of buyouts have taken place in the United States since 1993, and households have been relocated to safer places (16, 17).

Another prominent example of a diversification of strategies is the Dutch "Room for the River" program. This $2.2-billion program enabled a transition toward integrated river basin management in The Netherlands, combining structural measures, such as dike strengthening with increased capacity to temporarily store water by removing obstacles (e.g., lowering or eliminating ferry pier banks, widening bridge openings, and removing or lowering quays and flood-free areas) (https://www.ruimtevoorderivier.nl/english/) and dike relocation (among other measures). As part of the program, farms in vulnerable areas have been relocated, and biodiversity has improved (18, 19).

Social Dimensions

The United States and parts of Europe are engaged in a fundamental normative debate on who should be protected, by whom, and at what cost. Unfortunately, these debates are not held in an open and inclusive way, incorporating the views of all stakeholders.

There is little discussion on the risks that a society is willing to accept, nor about the division of responsibilities in dealing with these risks. Engaging the public in behavioral adaptation, aimed at reducing exposure and vulnerability to floods, can help overcome the public perception that floods can and should be controlled only by national flood managers. It requires, however, inclusive societal debates that lead to the establishment of normative principles seen as legitimate and fair (6).

Depending on the national context, policymakers may opt for different principles. From what is sometimes termed a "solidarity" perspective, a fair policy would require that people in low-risk areas also contribute to flood-protection measures in high-risk areas. In contrast, fairness, interpreted as "beneficiary pays," entails contributions based on risks and benefits (20). Yet another principle gives priority to measures that protect the most vulnerable people (21).

The prevailing normative system is also embedded in different flood-risk–management approaches. For instance, an emphasis on flood defense presupposes that some importance is attached to solidarity because governments generally establish flood-defense infrastructures as a public good. To make particular flood-risk–management measures more acceptable, open debates on what is seen as desirable and how and to what extent different strategies may help realize these normative ideas should be held (6, 20). In this sense, flood-risk management always includes normative, political choices.

Tullos (1) postulated a need to overcome the perception that federal managers are in charge of managing flood risks. In Europe, governments play a key role in providing the capacity to resist, through flood-defense measures, as well as flood-risk–reduction measures that cannot be taken by individuals. Governments also take responsibility for flood-risk management, both in the preventive and in the recovery phases. The paternalistic "the government should take care for me" attitude often prevails. Despite this, the involvement of private parties in flood-risk governance is necessary, including businesses and the civic society, to enhance flood resilience. A diversification of flood-risk–management approaches requires the involvement of different sectors (water management, spatial planning, and emergency management) and different governmental levels to provide adequate policy instruments. Enhancing coordination and collaboration between policy sectors and administrative levels helps overcome fragmentation (6) and moral hazard (22).

Flood resilience is enhanced when top-down and bottom-up policy processes are adequately combined and coordinated.

Influencing perception is a difficult task, but there are potential ways forward, for example, by applying more sophisticated communication strategies. For instance, a phrasing of "1% flood probability in any 1 year" appeals less than a phrasing in terms of "26% in the 30 years of a mortgage" (1). It is promising to develop easy visual materials with maps of flood-prone areas (23). A wise centralization could counteract externalization of losses. Yet, this is in conflict with public engagement, which leads to decentralization. Measures implemented locally can strengthen egoistic protection while transferring losses to other (downstream) communities. Again, these are not only technocratic choices; they require strategic, inclusive, deliberations.

Although enhancing risk awareness is important, engaging new actors in flood-risk governance should not end there. Several measures should be taken by residents, not national agencies—these include reducing sealed surfaces on private properties to increase water storage capacity. Also, to ensure legitimate flood-risk–governance approaches, citizens must be included in decision making and implementation. And other (institutional) actors need to be involved, including

local authorities, local land-use planners, and emergency agencies. Institutionalization should proceed through formal rules that balance legal certainty and flexibility.

Other actors, such as private companies, can contribute to flood-risk governance through public-private cooperation, as is the case in the United Kingdom partnership funding scheme. Actors with a financial stake in flood-risk management can enter into the governance strategies at the project level (6). Where private flood insurance mechanisms exist, cooperation between private and public actors is required because the latter are often the reinsurers of last resort.

Flood resilience is enhanced when top-down and bottom-up policy processes are adequately combined and coordinated. Bottom-up activities include drafting flood-risk–reduction plans by local and regional stakeholders (preferably at the river basin level) and supported with funding and expertise from higher-level governments. In a European context, this implies that national governments support regional and local governments, including regional water authorities. At the same time, upstream and downstream measures should be coordinated between municipalities and regions.

Multidisciplinary Collaboration

The principle of sustainable development has been enshrined in the legislation of many states. For instance, it is explicitly mentioned in the Polish Constitution (article 5). The Constitution of The Netherlands states that the protection and improvement of the environment should be key concerns of the authorities (article 21). Hence, flood-risk reduction should be considered in the context of sustainable development and environmental protection, and care has to be taken that decisions do not close off advantageous options for future generations and do not introduce unwarranted disturbances to ecosystems (3).

Within the multidisciplinary European STAR-FLOOD project, participants expanded the research agenda on flood-risk management to include legal, economic, sociological, and geopolitical elements. Legal and social scientists took part, and researchers used an integrated framework for the analysis, evaluation, and design of flood-risk–management practices (6, 7).

Among the outputs were nuanced assessments of legal frameworks that focused on issues such as whether regulatory frameworks allowed actors to deal with change and uncertainty while upholding the rule of law. Also discussed was whether the Floods Directive stimulates changes in governance that lead to risk reduction. As participants observed, balancing legal certainty and flexibility is complicated because of the physical and social infrastructure already in place. Another conclusion was that there should be both a procedural approach (flood-risk–management plans) and requirements regarding the content of these plans (e.g., indicating who is responsible for the implementation of certain measures) added to the directive. This would provide more clarity about the level of protection that inhabitants of flood-prone areas are entitled to (24, 25).

Nonetheless, collaboration between researchers of different disciplines is a challenge because of different perspectives, concepts, and methods. Also, silo thinking, limited sources of financing, project complexity, and different methods of analysis create challenges (26). Comprehensive, multidisciplinary conceptual frameworks enabling collaborative research must be a high priority.

In The Netherlands, where the levees have been constructed over many centuries, there are legally established safety norms and the presence of strong coalitions, including the Office of Public Works (*Rijkswaterstaat*) and related research institutes with a vested interest in flood defense. A shift in thinking about flood-risk management might imply that governance and legal expertise, as well as the ecological expertise necessary in the context of sustainability—to utilize natural processes and provide opportunities for nature (27)—play a stronger role in collaboration with institutions engaged in structural measures. Hence, those institutions that tended to focus on structural measures have to adapt and possibly reconfigure to be open to collaboration.

Finally, questions as to whether, how, and by whom flood governance is debated deserve to be scrutinized further. We should broaden the societal debate and include normative issues more explicitly. What constitutes effectiveness? What is fair? By taking such research routes, social-scientific and legal research into flood-risk–governance strategies has the potential to develop into a set of well-validated design principles that entail a mix of strategies—all while identifying the mechanisms that may facilitate or hamper their increasingly crucial implementation.

Acknowledgments

We thank the international team of researchers with whom we collaborated in the EU FP7 STAR-FLOOD project for the inspiring discussions we had on pathways toward flood resilience. We also thank Gerald E. Galloway and Eugene Z. Stakhiv for thoughtful discussion and providing useful information.

1 Tullos D (2018) Opinion: How to achieve better flood-risk governance in the United States. *Proc Natl Acad Sci USA* 115:3731–3734.
2 EU (European Union) (2007) Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks. *Off J Eur Union* 288:27–34.
3 Kundzewicz ZW (1999) Flood protection—sustainability issues. *Hydrol Sci J* 44:559–571.
4 Hashimoto T, Stedinger JR, Loucks DP (1982) Reliability, resiliency, and vulnerability criteria for water resource system performance evaluation. *Water Resour Res* 18:14–20.
5 Smith K, Ward R (1998) *Floods. Physical Processes and Human Impacts* (Wiley, Chichester, United Kingdom).
6 Hegger DLT, et al. (2014) Assessing stability and dynamics in flood risk governance: An empirically illustrated research approach. *Water Resour Manage* 28:4127–4142.

7 Driessen PPJ, Hegger DLT, Bakker MHN, Van Rijswick HFMW, Kundzewicz ZW (2016) Toward more resilient flood risk governance. *Ecol Soc* 21:53.
8 White GF (1945) Human Adjustment to Floods. Department of Geography Research Paper No. 29 (University of Chicago, Chicago).
9 Leopold LB, Maddock Th, Jr (1954) *The Flood Control Controversy, Big Dams, Little Dams and Land Management* (Ronald Press, New York).
10 Hoyt WG, Langbein WB (1955) *Floods* (Princeton Univ Press, Princeton).
11 Dunne T, Leopold LB (1978) *Water in Environmental Planning* (W.H. Freeman, San Francisco).
12 Sayers P, et al. (2013) *Flood Risk Management: A Strategic Approach* (United Nations Educational, Scientific, and Cultural Organization, Paris).
13 Kundzewicz ZW, Szamałek K, Kowalczak P (1999) The Great Flood of 1997 in Poland. *Hydrol Sci J* 44:855–870.
14 Felgentreff C (2003) Post-disaster situations as "windows of opportunity"? Post-flood perceptions and changes in the German Odra River Region after the 1997 flood. *Erde* 134:163–180.
15 Interagency Floodplain Management Review Committee (1994) *Sharing the Challenge: Floodplain Management into the 21st Century. A Blueprint for Change* (US Government Printing Office, Washington, DC).
16 Multihazard Mitigation Council (2017) Natural hazard mitigation saves: 2017 Interim report (National Institute of Building Sciences, Washington, DC).
17 Salvesen D, BenDor TK, Kamrath Ch, Ganser B (2018) Are floodplain buyouts a smart investment for local governments? Final report for the UNC Policy Collaboratory. Available at https://www.coastalreview.org/wp-content/uploads/2018/09/Project-Report-Floodplain-Buyout1.pdf. Accessed October 25, 2018.
18 Rijke J, van Herk S, Zevenbergen C, Ashley R (2012) Room for the river: Delivering integrated river basin management in The Netherlands. *Int J River Basin Manage* 10:369–382.
19 Straatsma MW, Bloecker AM, Lenders HJR, Leuven RSEW, Kleinhans MG (2017) Biodiversity recovery following delta-wide measures for flood risk reduction. *Sci Adv* 3:e1602762.
20 Pettersson M, et al. (2017) Assessing the legitimacy of flood risk governance arrangements in Europe: Insights from intra-country evaluations. *Water Int* 42:929–944.
21 Paavola J (2008) Science and social justice in the governance of adaptation to climate change. *Env Polit* 17:644–659.
22 Cutter SL, Emrich ChT (2006) Moral hazard, social catastrophe: The changing face of vulnerability along the hurricane coasts. *Ann Am Acad Pol Soc Sci* 604:102.
23 Shaw A, et al. (2009) Making local futures tangible: Synthesizing, downscaling, and visualizing climate change scenarios for participatory capacity building. *Glob Environ Change* 19:447–463.
24 Goytia S, Pettersson M, Schellenberger T, van Doorn-Hoekveld WJ, Priest S (2016) Dealing with change and uncertainty within the regulatory frameworks for flood defense infrastructure in selected European countries. *Ecol Soc* 21:23.
25 Priest SJ, et al. (2016) The European Union approach to flood risk management and improving societal resilience: Lessons from the implementation of the Floods Directive in six European countries. *Ecol Soc* 21:50.
26 Bruzzone S, Larrue C, Rijswick MV, Wiering M, Crabbé A (2016) Constructing collaborative communities of researchers in the environmental domain. A case study of interdisciplinary research between legal scholars and policy analysts. *Environ Sci Policy* 64:1–8.
27 United Nations World Water Assessment Programme (2018) The United Nations World Water Development Report 2018: Nature-based solutions for water. (United Nations Educational, Scientific, and Cultural Organization, Paris).