

The ‘Flood Resilience Rose’: A management tool to promote transformation towards flood resilience

Leena Karrasch^{1,2}  | Britta Restemeyer^{1,3} | Thomas Klenke¹

¹COAST – Centre for Environment and Sustainability Research, Carl von Ossietzky University of Oldenburg, Oldenburg, Germany

²Department of Ecological Economics, Carl von Ossietzky University of Oldenburg, Oldenburg, Germany

³Department of Planning, University of Groningen, Groningen, The Netherlands

Correspondence

Leena Karrasch, Carl von Ossietzky University of Oldenburg, COAST – Centre for Environment and Sustainability Research, Oldenburg, Germany.
Email: leena.karrasch@uol.de

Funding information

European Regional Development Fund, Grant/Award Number: 38-2-9-16

Abstract

Coping with the growing impacts of flooding in EU countries, a paradigm shift in flood management can be observed, moving from safety-based towards risk-based approaches and holistic perspectives. Flood resilience is a common denominator of most of the approaches. In this article, we present the ‘Flood Resilience Rose’ (FRR), a management tool to promote harmonised action towards flood resilience in European regions and beyond. The FRR is a result of a two-step process. First, based on scientific concepts as well as analysis of relevant policy documents, we identified three ‘levels of operation’. The first level refers to the EU Floods Directive and an extended multi-layer safety approach, comprising the four different layers of protection, prevention, preparedness and recovery, and related measures to be taken. This level is not independent but depends both on the institutional (second level) and the wider (third level) context. Second, we used surveys, semi-structured interviews and group discussions during workshops with experts from Belgium, Denmark, Germany, the Netherlands and the United Kingdom to validate the definitions and the FRR’s practical relevance. The presented FRR is thus the result of rigorous theoretical and practical consideration and provides a tool capable to strengthen flood risk management practice.

KEYWORDS

flood defence measures, governance and institutions, integrated flood risk management, resilience

1 | INTRODUCTION

Floods are one of the most severe natural hazards in Europe, posing serious threats to inhabited areas (Feyen et al., 2012; Kaufmann et al., 2016; Kundzewicz et al., 2013). Climate change and continuous urbanisation are likely to even further increase flood risk and socio-economic damage potential (Vousdoukas et al., 2018). Acknowledging the growing risks and increasing

frequency of flood events, a paradigm shift in European flood risk management can be observed, moving from safety-based towards risk-based approaches (Heintz et al., 2012; Klijn et al., 2008; van Herk et al., 2014). This requires the adoption of holistic perspectives (Hall et al., 2003; Meijerink & Dicke, 2008; Scott, 2013), which consider a diverse set of flood risk management measures including active stakeholder participation, communication, and awareness-raising (Aerts et al., 2008; Hegger

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.

© 2021 The Authors. *Journal of Flood Risk Management* published by Chartered Institution of Water and Environmental Management and John Wiley & Sons Ltd.

et al., 2014; Wardekker et al., 2010). Resilience is considered a promising approach to deal with risk and uncertainties arising from climate change, intensified land use and increasing human vulnerability (Davoudi et al., 2012; Scott, 2013; White et al., 2010). To increase resilience in coastal zones, three key characteristics are central: (i) robustness and the ability to absorb or withstand disturbances, (ii) adaptability of the system to reduce vulnerability and (iii) transformability as a transition to a new system when ecological, economic or social structures make the existing system untenable (Restemeyer et al., 2015).

The European Floods Directive (Directive 2007/60/EC, n.d.) is a legal tool for flood risk management that aims to increase flood resilience in European countries. It contributes to the reduction and management of the risks of flood damage, in relation to human health, the environment, cultural heritage and economic activities. The Floods Directive requires the development of flood risk management plans (European Commission, 2013). With respect to the implementation of the Floods Directive on regional and local scales, the flood risk management cycle comprises four types of measures: (i) prevention (e.g. avoiding construction in flood-prone areas, adapting buildings to flood risk, and promoting appropriate land use), (ii) protection (e.g. structural and non-structural measures such as dikes or water management), (iii) preparedness (e.g. flood forecasting and warning, emergency response planning, public awareness) and (iv) recovery and review (e.g. clean-up, restoration, recovery and lessons learned).

Different countries have developed different national approaches to the implementation of the Floods Directive. In the Netherlands, for example, a so-called 'multi-layer safety approach' is used as formulated in the Dutch National Water Plan (2009) and Delta Programme. It is a risk-based approach that integrates three layers: (i) flood prevention (e.g. dikes and dams), (ii) spatial design (based on e.g. flood risk maps) and (iii) disaster management (e.g. evacuation plans). The multi-layer safety approach has initiated new discourses about flood risk management, the development of integrated flood risk management plans and the cost-effectiveness of measures (De Moel et al., 2014; Gersonius et al., 2011; Kaufmann et al., 2016; van Herk et al., 2014). A prominent example of its implementation is in the City of Dordrecht, as described in Hegger et al. (2014).

Although the Floods Directive has the potential to form a basis for a transboundary common framework to improve flood risk management (Priest et al., 2016), there is no consistent use of terms and types of measures in the literature. Terms relating to the multi-layer safety approach are used interchangeably and sometimes in

contrast to the Floods Directive (see De Moel et al., 2014; Gersonius et al., 2011; Kolen & Kok, 2013; van Herk et al., 2014). For example, the first layer 'prevention' includes structural flood protection measures, such as dams and dikes, but in terms of the Floods Directive these types of measures relate to 'protection'. The focus in existing programmes is placed on structural protection measures, whereas recovery has the lowest priority (European Commission, 2019a). Local measures to reduce flood risk are often considered individually instead of holistically, especially synergies and combinations of different measures are lacking in management practice and lower adaptive capacities (Cosoveanu et al., 2019).

In this article, we present the 'Flood Resilience Rose' (FRR) as a management tool to promote transformation towards flood resilience. The underlying notion is that when a social-ecological system is disturbed by a flood event, returning to the state prior to the disaster is undesirable, as that would put the area at the same risk. Instead, the imperative is to learn from this experience and to transform to a less vulnerable state. The FRR is a result of a two-step process. First, based on literature and scientific concepts, we defined three 'levels of operation'. The first level refers to an extended multi-layer safety approach, comprising the four different layers of protection, prevention, preparedness, and recovery, and related measures to be taken. This level depends both on the institutional context (second level) and the wider context (third level). Second, we used surveys, semi-structured interviews and group discussions during workshops with experts from Belgium, Denmark, Germany, the Netherlands and the United Kingdom to validate the definitions and the FRR's practical relevance. Additionally, the needs of the local practitioners were included in the development of the FRR. The presented FRR is thus the result of rigorous theoretical and practical consideration and provides a tool to strengthen flood risk management practice.

2 | MATERIAL AND METHODS

The FRR was developed by the authors in the context of the Interreg VB North Sea Region project 'FRAMES – Flood Resilient Areas by Multi-layer Safety'. Operating from 2016 to 2020, FRAMES aimed at increasing the resilience of flood-prone areas and communities by working with the multi-layer safety approach. Pilot areas were in Belgium, Denmark, Germany, the Netherlands and the United Kingdom. Each pilot area was coordinated by experts in flood risk management (so-called 'pilot coordinators') and researchers from each country. We used a two-step process to design and apply the FRR.

TABLE 1 Participants and their affiliation

Country	Region	Participants		
Belgium	Flanders	Pilot coordinator, Policy Assistant, Province of East-Flanders (Survey 1 and Interview 1) Expert, Spatial Planning, Province of East-Flanders (Survey 1) Expert, Civil Engineering, University of Ghent (Survey 1 and Interview 1) Expert, Civil Engineering, University of Ghent (Survey 1)		
Denmark	City of Vejle	Pilot coordinator, Coastal Science, Danish Coastal Authority (Survey 2 and Interview 2) Expert, Coastal Engineering, Danish Coastal Authority (Survey 2) Expert, Climate Management, Vejle Municipality (Survey 2)		
Germany	Wesermarsch	Pilot coordinator, Hydrological Modelling, Jade University of Applied Science (Survey 3 and Interview 3) Pilot coordinator, Hydrological Modelling, Jade University of Applied Science (Survey 3 and Interview 3) Expert, Coastal Management, Consultant (Survey 3)		
The Netherlands	Ablasserwaard	Pilot coordinator, Policy Advisor, Province of South-Holland (Survey 4 and Interview 4) Expert, Water Management, Rijkswaterstaat (Survey 4)		
	Zeeland	Pilot coordinator, Policy Advisor Water, Province Zeeland (Survey 5 and Interview 5)		
	Zeeland	Expert, Electricity Grid, Water Management Consultancy & IT Company (Survey 6)		
The United Kingdom	Kent	Pilot coordinator, Adaptation Programme, Kent County Council (Survey 7 and Interview 6) Pilot coordinator, Adaptation Programme, Kent County Council (Survey 7 and Interview 6) Expert, Health, Family and Social care, Kent County Council (Survey 7 and Interview 6) Expert, Health, Family and Social care, Kent County Council (Survey 7) Expert, Sustainable Business and Communities, Kent County Council (Survey 7)		
		Great Yarmouth	Pilot coordinator, Chief Executive, National Flood Forum (Survey 8 and Interview 7) Pilot coordinator, Project Officer, National Flood Forum (Survey 8 and Interview 7) Expert, Flood and Water management, Norfolk County Council (Survey 8) Expert, Supply Manager, Anglian Water (Survey 8) Expert, Flood Partnership Manager, Anglian Water (Survey 8) Expert, Lead Asset Planner, Anglian Water (Survey 8)	
			Lustrum Beck	Pilot coordinator, Trust Manager, Tees Rivers Trust (Survey 9 and Interview 8) Expert, Agriculture and Fisheries Project Manager, Tees Rivers Trust (Survey 9)
			Medway Catchment	Pilot manager, Natural Flood Management Coordinator, South East Rivers Trust, (Survey 10 and Interview 9) Expert, Project Officer, South East Rivers Trust (Survey 10) Expert, Flood Advisor, Environment Agency (Survey 10) Expert, Acting Overview and Scrutiny Manager, Kent County Council (Survey 10)
			Southwell	Pilot coordinator, Project Officer, National Flood Forum (Survey 11 and Interview 7) Pilot coordinator, Chief Executive, National Flood Forum (Survey 11 and Interview 7) Expert, Project Manager, Trent Rivers Trust (Survey 11)

Note: Pilot coordinators and experts who took part in the surveys and interviews in the studied regions.

- The first step focused on theoretical aspects. We reviewed literature describing the Dutch multi-layer safety approach (i.e. National Water Plan, 2009; De Moel et al., 2014; Gersonius et al., 2011; Hegger et al., 2014; Kaufmann et al., 2016; van Herk et al., 2014; Wiering & Winnubst, 2017). Additionally, an overview was produced of measures being introduced in Belgium, Denmark, Germany, the Netherlands and the United Kingdom in response to the EU Floods Directive (Directive 2007/60/EC, n.d.). Related policy documents and flood risk management plans in the respective countries were analysed (i.e., Environment Agency and DEFRA, 2011; European Commission, 2019b, 2019c, 2019d, 2019e, 2019f; Flemish Government, 2013; Ministry of Infrastructure and the Environment and Ministry of Economic Affairs, 2015; The Federal Government, 2008). Then we defined the three levels of operation of the FRR. For the first level, we used the flood risk management cycle and incorporated the different layers of the Dutch multi-layer safety approach (Hegger et al., 2014) as well as strategies to harmonise urbanisation and flood risk management (Oosterberg et al., 2005). To complete the FRR, we also added two levels of contextual embedment. The first one relates to the ‘institutional context’, looking at actors, networks and partnerships responsible for and/or affected by flood risk management. The second level is about the ‘wider context’, comprising regulatory, normative, social-ecological and economic aspects.
- The second step focuses on input from practical aspects and relates to the character of the FRR as a tool to support management practice. Eleven on-the-spot surveys, each combined with semi-structured interviews, were conducted with pilot coordinators and other experts in each country covered by FRAMES (Table 1). The participants in the surveys and interviews have profound knowledge particularly with respect to coastal protection, climate adaptation, policy advice, water management, hydrology, project management and/or social care. We spent 2 or 3 days in the pilot areas to guide the participants through the survey and undertake semi-structured interviews. The questionnaire was structured based on the three main aspects of the FRR: (a) context and flood risks of the respective areas and future developments; (b) the goals, measures and instruments of multi-layer safety and (c) the ingredients for managing change in line with the multi-layer safety approach.

After the surveys and semi-structured interviews were completed, nine additional semi-structured interviews were conducted with selected pilot coordinators and experts (Table 1), to discuss open questions and gather

more in-depth information. The main aim of the surveys and connected interviews was to validate the FRR in terms of its practicability, inclusiveness and comprehensibility. The surveys and interviews provided important input informing the implementation of the multi-layer safety approach in regard to resilience. The theoretical foundation of the FRR was reconciled with the results of the surveys and interviews to create a practice-informed management tool to realise multi-layer safety locally. The insights gained by the surveys and interviews were especially important in informing the second level (institutional context) and third level (wider context) of the FRR. The resulting first version of the FRR was discussed in workshops between FRAMES partners, and suggestions emerging from these workshops were adopted in the final version of the FRR presented in this article. Thus, an iterative generation of the FRR was ensured, adapted to the needs of practice.

3 | RESULTS: THE FLOOD RESILIENCE ROSE

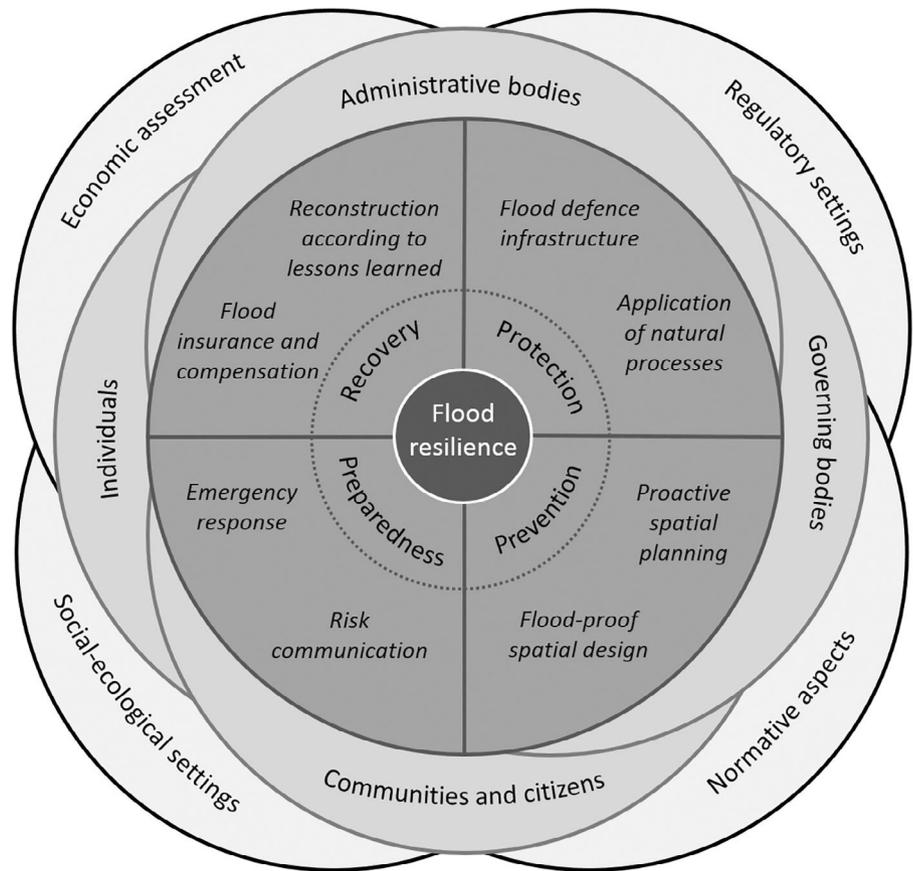
The FRR is a practice-informed management tool that addresses, in particular, actors and institutions working in the field of river and coastal zone management. It has the overall goal to operationalise the Floods Directive and make flood risk management more resilient. It provides not only a list of measures but also helps to consider the respective context. That way, it supports practitioners in how different measures can be combined in order to reach a more holistic flood risk management strategy. Thus, the FRR helps practitioners both to arrange new flood risk management measures and to reflect on measures already taken. The different layers and levels together allow a comprehensive consideration of structure and potentials of different measures. In practice, the application of the FRR may nevertheless be hampered by limitations in relation to time frames, the scope of different measures and the willingness of practitioners either to make use of the tool or to reflect on measures more generally.

The FRR helps to increase flood resilience on three different levels of operation (Figure 1).

3.1 | Goal: Increase flood resilience

We understand flood resilience as an amalgamation of engineering resilience and socio-ecological resilience. The concept of engineering resilience includes technical flood protection measures, especially constructions and infrastructure (i.e. dams, dikes, sluices). In this

FIGURE 1 The Flood Resilience Rose. Flood resilience can be increased by operationalising the multi-layer safety approach (level 1, dark grey) within the institutional context (level 2, grey). Both are embedded in the wider context (level 3, light grey). The multi-layer safety approach has four layers of action taking, namely protection, prevention, preparedness and recovery. The institutional context involves collaboration of administrative bodies, governing bodies, communities and individuals. The wider context comprises regulatory settings, normative aspects, social-ecological settings and economic assessment



view, resilience refers to technical functioning, efficiency, constancy and predictability. It describes resistance to technical disturbances and the restoration of stability and equilibrium after such disturbances occur (Bruneau et al., 2003; Holling, 1996). Engineering resilience focuses on the robustness of technical and structural systems.

Social-ecological resilience goes beyond the idea of equilibria and the idea that there is a stable state that can be restored. The concept of social-ecological systems considers non-linear, complex and constantly changing environments: all parts of the social-ecological system evolve not only by themselves but also through their interaction with each other (Adger et al., 2005; Berkes et al., 2000; Davoudi et al., 2012). Social-ecological resilience focuses on the adaptability and transformability of social-ecological systems.

Flood resilience should consider a diverse set of flood risk management measures, including not only technical but also social-ecological aspects. The aim is to both reduce the probability and mitigate the consequences of flooding. The FRR, including the multi-layer safety approach, combines the aspects of robustness, adaptability and transformability to produce the integrated objective of increased flood resilience (Figure 2).

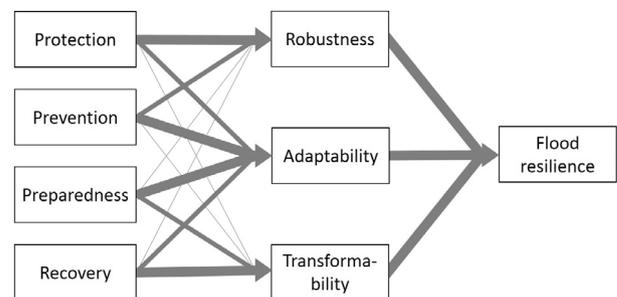


FIGURE 2 The Flood Resilience Rose's multi-layer safety (level of action taking) is connected to characteristics of resilience (robustness, adaptability, transformability) that increase flood resilience in flood risk management. That is, protection contributes to technical robustness, whereas prevention and preparedness focal points are on adaptability, and recovery target at transformability

3.2 | Flood Resilience Rose: Theoretical considerations

3.2.1 | First level: Multi-layer safety

In the first level, processes of action-taking occur, often on the local and regional scale. To increase flood resilience, it is important to understand opportunities for

combining the four different layers of protection, prevention, preparedness and recovery. Our definitions of these different layers are based on the Floods Directive, Oosterberg et al. (2005) and Hegger et al. (2014).

'Protection' aims to reduce the impacts of floods by keeping floods away from people and areas susceptible to damage. Measures for increasing flood resilience can be related to flood defence infrastructure (structural measures) or the exploitation of natural processes (non-structural measures, eco-engineering approaches such as building with nature). Flood defence infrastructure includes technical measures and physical interventions; these can include channel, coastal and floodplain interventions and surface water management (i.e. dikes, dams, barriers, locks, spillways and dredging, artificial drainage systems, pumps). The exploitation of natural processes for protection, as in eco-engineering approaches, comprises physical interventions involving the management of natural floods, runoff and catchment, and water flow regulation (i.e. natural drainage systems and bypasses, natural water storage facilities and retention polders, floodplain works and restoration of natural systems to regulate water flow, compartmentation of floodplains and water systems).

'Prevention' aims to reduce damage and other negative consequences in the event of a flood by keeping floodwater away from people and areas susceptible to damage. This often requires proactive spatial planning and flood-proof spatial design. In terms of proactive spatial planning, avoidance, removal or relocation of constructions in flood-prone areas and an appropriate transformation of land-use can be considered (i.e. flood risk zoning, new locations for urban expansion, de-urbanisation, land-use planning policies and regulations, flood risk modelling and assessments). Proactive spatial planning focuses on broader areas and is landscape-oriented. Flood-proof spatial design implies the adaptation of existing and future constructions (i.e. adaptive buildings, adjustments to individual houses and infrastructure, public networks). This approach is location-based and asset-oriented.

'Preparedness' aims to reduce the vulnerability of people and areas susceptible to damage by increasing awareness about flood risk and appropriate behaviour – before, during and after a flood event. This implies active risk communication and emergency response. Active risk communication can be enhanced by flood forecasting and warning systems and increased public awareness and preparedness (i.e. flood risk maps, communication plans, emergency schemes, adaptive capacity of inhabitants). Emergency response refers to both emergency event response and contingency planning (i.e. institutional emergency response planning, disaster management

plans, adaptive capacities of authorities, evacuation routes and shelters).

'Recovery' aims to reduce the vulnerability of people and areas susceptible to damage by mitigating social and economic impacts and facilitating the return to 'normal liveable' conditions after flood events. Measures and programmes can include flood insurance, compensation and reconstruction efforts. Flood insurance and compensation are important for individual and societal recovery (i.e. financial assistance and reimbursement, recovery funds, insurance policies). Reconstruction of individual, societal and environmental assets is determined by clean-up and restoration activities (i.e. build-up, re-construction plans, health-supporting services, storage of hazardous materials in containers, well-water safety). Additionally, lessons learned are an important aspect of transformation in terms of resilience. Transformation towards innovative courses of action can lead to reduced vulnerability.

3.2.2 | Second level: Institutional context

Flood risk management is highly institutionalised (Wehn et al., 2015). Often, governance arrangements are very complex, as shown for example in Mees et al.'s (2018) analysis of the complex and specific government system in Belgium, and Forrest et al.'s (2018) investigation of flood groups in England. Table 2 provides a simplified summary of the responsible groups tasked with addressing flood risk in Belgium (Flanders), Denmark, Germany, the Netherlands and the United Kingdom.

The institutional context relates to the institutions responsible for implementing the Floods Directive and realising the multi-layer safety measures described above. This second level includes actors, networks and partnerships across four interlinked groups: administrative bodies, governing bodies, communities and individuals. 'Administrative bodies' include institutions and authorities responsible for flood management. All EU member countries must fulfil the obligations of the Floods Directive and flood risk management, as the EU Floods Directive is embedded in the countries' national law. Administrative bodies implement different instruments and governance tools to achieve multi-layer safety, including plans, laws and guidelines.

'Governing bodies' addressing flood risk management include many different interest groups and actors, in areas ranging from spatial resources to technical building, and including water and coastal management, nature conservation, agriculture, policy, industry and tourism actors as well as researchers and citizens. Participatory settings should include these governing bodies, particularly practitioners,

TABLE 2 Implementation of the Floods Directive in Flanders, Denmark, Germany, the Netherlands, and the United Kingdom (European Commission, 2019b, 2019c, 2019d, 2019e, 2019f)

EU Floods Directive	Responsible for implementation at national level	Responsible for implementation of measures
Belgium (Flanders)	Committee on Integral Water Policy	Local water managers (provinces, municipalities, polders), Flanders Environment Agency, Landowners (unclassified watercourses)
Denmark	Danish Coastal Authority, Ministry of Environment	Municipalities, Specific stakeholders (fire brigade, police, drinking water providers, energy providers), Landowners (co-financing of dikes)
Germany	State ministries, German Working Group on Water Issues of the Federal States and Federal Government	District authorities, Lower authorities Associations (i.e. water boards, dike boards), Municipalities and communities
The Netherlands	Ministry of Infrastructure and Environment (Rijkswaterstaat)	Regional water authorities (water boards), Provinces, Municipalities (Safety Regions)
United Kingdom	Department of Environment, Food and Rural Affairs	Environment Agency, Lead Local Flood Authorities (county councils), District authorities, Individual level (preparedness)

experts, managers and decision-makers working at different local, regional and national levels.

The involvement of ‘communities and citizens’ in the flood risk management cycle is one requirement of the Floods Directive. This public participation aims to enhance community responsibility and participation in development processes. Examples include local flood action groups that develop and share good practice, train community volunteers and help to prepare flood action plans (Mees et al., 2016).

‘Individuals’ (households, private actors) can take prevention and preparedness measures to reduce vulnerability and risk of individual properties by, for example, elevating vulnerable structures, reinforcing foundations and flood-proofing with sandbags. The financial management of impacts poses a particular challenge. Measures can include loss-reducing measures and contracts with flood insurance.

3.2.3 | Third level: The wider context

The ‘wider context’ is determined by four factors that influence flood risk management: regulatory settings (objectives of framework legislation such as the EU Floods Directive or national climate adaptation strategies), normative aspects (culture, history, traditions), social-ecological settings (regional impacts of climate change, geography, ecosystem-based management),

and economic assessment (pre- and post-disaster costs).

‘Regulatory settings’ are determined by legislative obligations. On an EU level, the Floods Directive determines how each country should design flood risk management. This more general guidance provides the wider legislative context, which has to be embedded in national law (Table 2). The overall objective is to reduce the negative consequences of floods in each country, but the challenges posed by temporal aspects and finding the means to achieve goals are hardly addressed (European Commission, 2019a). The foci of each country are summarised in Table 3. The European Commission’s (2019a) investigation of specific and measurable objectives of the Floods Directive shows that such measures are reported generally and not specifically defined. Denmark, Germany and the United Kingdom have also formulated objectives in rather general terms, without measurable quantitative targets. Only the Netherlands has defined national safety standards up to 2050 that are part of the Delta Programme. In general, measures to reduce flood risk concentrate 41% on protection, 26% on prevention, 24% on preparedness and 8% on recovery; 1% involve other or no actions (European Commission, 2019a).

‘Normative aspects’, including traditions, are strongly intertwined in ideas of flood resilience. The influence of culture on people living in riverine and coastal landscapes is often immense. They can have a strong sense of belonging and regional identity, experiencing an emotional connection to these landscapes (Gerkenmeier &

TABLE 3 National law, foci and measurability of Floods Directive objectives in Flanders, Denmark, Germany, the Netherlands and the United Kingdom (European Commission, 2019b, 2019c, 2019d, 2019e, 2019f)

EU Floods Directive	National law	Focus of objectives	Specific and measurable objective
Belgium (Flanders)	Flemish Decree on Integrated Water Policy (2003, 2013)	Sustainable reduction of flood risk with sufficient protection for people, economic activity, ecology and cultural heritage, Reduction of the adverse consequences of floods, Set at regional level	Estimation of flood risk based on the severity of the consequences in relation to the likelihood of flooding, Indicators (e.g. reduction of number of affected people)
Denmark	Assessment and Management of Flood Risk from Watercourses and Lakes (2009, 2013), Assessment and Risk Management for Floods from the Sea, Fjords or Other Parts of the Sea Territory (2010)	Reduction of the adverse consequences of flooding, Reduction of the likelihood of flooding, sometimes referring to non-structural measures, Set at municipal level	Objectives are neither fully specific nor measurable, No quantitative targets
Germany	Federal Water Act (2009)	Mitigation of new risks prior to a flood event, Reduction of existing risks prior to a flood event, Reduction of adverse consequences during a flood event, Reduction of adverse consequences after a flood event, Reduction of adverse consequences of floods and likelihood of flooding, sometimes referring to non-structural measures, Set at strategic level	Objectives are very general and neither fully specific nor measurable
The Netherlands	Water Act (2009)	Protection against floods, Prevention of consequences, Crisis management, Reduction of adverse consequences of floods and likelihood of flooding, sometimes referring to non-structural measures, Set at national level	Objectives are general, but overall targets are specific and measurable (national 2050 safety standard)
The United Kingdom	Flood Risk Regulations (2009) Flood and Water Management Act (2010)	Reduction of the adverse consequences of floods, sometimes referring to non-structural measures, Set at strategic level	Some objectives are measurable, No quantitative target

Ratter, 2018; Verbrugge et al., 2019). The landscapes have developed through centuries of human–nature interactions, in relation to, for example, sea-level rise and decline, destructive storm surges, land reclamation and the building of embankments, and extensive dike building (Knottnerus, 2005).

‘Social-ecological settings’ include regional impacts of climate change, geographical conditions and ecosystem-based management. In the North Sea countries, key observed and projected impacts of climate change include sea-level rise, increasing frequency of extreme precipitation events, and winter storms, connected to a higher risk of

river and coastal flooding (EEA, 2017). Efforts are being made to make climate science and data more available for decision-makers and wider society. This field, which is still emerging, is referred to as ‘climate services’ (Vaughan et al., 2018). Instruments, such as ecosystem-based management focus on inter- and transdisciplinary processes and rely on an integrated and adaptive management of human and natural resources (Long et al., 2015). With regard to increasing flood resilience, the concept of ecosystem services is gaining increasing attention (Halbe et al., 2018).

‘Economic assessment’ is important for flood risk assessments and is featured in the Floods Directive’s

recommendations, especially with regard to prevention measures. Pre- and post-disaster costs regarding expected damage (mapping), effects on water management (water retention, discharge and ecology) and special vulnerabilities (risk to life, protection of heritage) can be calculated, as well as benefit–cost ratios (avoided damage relative to costs) (Meyer, 2018).

3.3 | Flood Resilience Rose: Application in the FRAMES pilot areas – input from practice

3.3.1 | First level: Application of the multi-layer safety approach

The surveys and interviews employed the above-described definitions of the multi-layer safety approach's four layers. We found no discrepancies in implementation, but the

extent of measures taken differed from case to case. In most pilot areas the existing measures could be assigned to the protection and prevention layers, while preparedness and recovery were less strongly developed (Table 4). We could see that most pilot coordinators wanted to broaden the mix of measures and approaches in their pilot area. Most pilot activities were targeted at the preparedness layer, either through improving societal resilience to floods or improving disaster management (Table 4).

3.3.2 | Second level: Application of the institutional context

Results from the surveys, interviews and group discussions reveal that local and regional actors are main drivers behind the transition towards multi-layer safety. Examples with a special focus on disaster management are given in Table 5. All interviewees agree that the FRR

TABLE 4 Examples of existing types of measures described by the pilot coordinators for each layer (results of the surveys)

Country	Protection	Prevention	Preparedness	Recovery
Belgium (Flanders: Ninove, Denderleeuw)	Weirs, embankments, improved water discharge, flood retention zones	Signal-areas (no developments in flood- prone areas), compensation requirements for new building permits, 100% water collection and infiltration at own property	Classical measures by crisis services (sandbags, pumping), citizens' own precautionary measures (pumps, barriers), Be- Alert and SMS services, improved communication between water managers, subsidies for property-level protection	Flood damage is reimbursed through fire insurance, the Disaster Fund reimburses agricultural loss
Denmark (City of Vejele)	Sluice and pumps, dikes, river management	Flood-proof spatial design of new buildings, meetings with locals on awareness	Emergency response plan	None
Germany (Wesermarsch)	Dikes, dams, barriers, locks, pumps, drainage system	Individual measures, polder, retention basin	Flood warning system, disaster management, evacuation route	People depend on private insurance, in case of national disasters recovery is supported by donations
The Netherlands (Ablasserwaard)	Dikes, sluices, pumps, room for the river	Impact analysis, natural sand dynamics	Evacuation plan	None
The United Kingdom (Kent council)	Flood defence management plans, property protection, sandbags	National planning policy, local plans	Emergency and flood plans, flood and weather alerts	Kent Resilience Forum multi-agency recovery plans and governance structure, SWIMS system to record impact and response and improve future resilience

TABLE 5 Institutions responsible for implementing flood protection measures according to pilot coordinators (in addition to institutions named in the Floods Directive, see Table 3)

Pilot area	Actors that are main drivers behind the transition towards multi-layer safety: Examples from the local pilot areas
Belgium (Flanders)	Provincie Oost-Vlaanderen, De Vlaamse Waterweg, Municipalities Ninove and Denderleeuw, Fire brigade, Residents
Denmark	Vejle Municipality
Germany	With focus on disaster management: NGOs (Red Cross), County government, Police, Dike and water boards, Federal armed forces, Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency (NLWKN)
The Netherlands	Provincie Zuid-Holland, Waterschap Rivierenland, Veiligheidsregio Zuid-Holland Zuid, Municipalities
The United Kingdom	Kent County Council

is a helpful management tool for local and regional institutions and actors to increase flood resilience. The main differences between the different pilot areas are that in Belgium, Germany and the Netherlands a diverse set of institutions are responsible for flood risk management, whereas in Denmark and the United Kingdom the responsibility rests with the municipalities and councils.

3.3.3 | Third level: Application of the wider context

Our analysis of the pilot areas has shown that the consideration of the wider context is crucial to enable the adoption and implementation of the multi-layer safety approach. The following examples indicate how regulatory settings, normative aspects, social-ecological settings and economic assessment play a role in flood risk management.

‘Regulatory settings’: Possible measures to climate-proof vulnerable areas in terms of flooding are named in national climate adaptation strategies, such as the Flemish Climate Policy Plan 2013–2020 (Flemish Government, 2013), the German Strategy for Adaptation to Climate Change (Federal Government 2008), the Dutch National Waterplan 2016–2021 (Ministry of Infrastructure and the Environment and Ministry of Economic Affairs, 2015), and the UK’s National Flood and Coastal Risk Management Strategy (Environment Agency and DEFRA, 2011). These strategies often focus on sectoral challenges and courses of action. Additionally, they strongly emphasise prediction and control of impacts of climate change and related protection and prevention measures. Such national strategies can set out a certain course of action, which can give more or less room to pilot coordinators to experiment with multi-layer safety approaches. For example, the Belgian pilot coordinators

indicated that a cost–benefit analysis in Flanders had shown that a combination of protection, prevention and preparedness measures is the most efficient and cost-effective, whereas a similar assessment in the Netherlands came to the result that a focus on protection is most cost-efficient. The Dutch pilot coordinator therefore felt like there was more room to work on the preparedness layer than the prevention layer, because that would involve less costs and also fitted with the increasing role of ‘safety regions’ in emergency response.

‘Normative aspects’: Normative aspects relate to norms and values that are part of culture within specific areas. In the pilot areas, we could for example see that most pilot coordinators and experts had to operate in areas where traditional safety-based approaches have been dominant for decades (see Table 4). As became clear from our interviews, all pilot coordinators were open to innovate and add new measures and new ways of working together in the pilot areas. Some of them, however, indicated that the long-term legacy of technical safety measures limited their innovation capacity. The place-based relationships and connectedness of coastal inhabitants influence decision-making processes. The interviewees have stressed that it is increasingly important to raise awareness of alternative measures in flood risk management and encourage an integrated consideration of protection, prevention, preparedness and recovery.

‘Social-ecological settings’: Responses in the surveys and interviews stressed that social-ecological settings are important for increasing flood resilience. The low-lying, flood-prone areas are vulnerable to impacts of climate change and sea-level rise, particularly in terms of increased frequency of storm and extreme events, coastal erosion, and coastal squeeze, along with the loss of intertidal habitats and shifts in precipitation patterns. As described by Pontee (2013), loss of intertidal habitats due to coastal squeeze occurs through the concurrence of

landwards migrating low-water levels (exacerbated by e.g. sea-level rise) and fixed high-water levels (by e.g. a coastal protection system). Pilot coordinators and experts are increasingly aware of climate change. But there is a lack of understanding of the ways cumulative effects of climate and anthropogenic changes combine with often specific geographical conditions of flood-prone areas. Ecosystem-based management can contribute to flood protection by considering ecosystem services such as hazard reduction, wave attenuation, reduction in current velocity and avoidance of erosion, carbon sequestration, nutrient retention and recycling or food webs. The German pilot coordinators consider ecosystem-based management including nature-based solutions as very appropriate measures for the future.

‘Economic assessment’: Economic assessments can be important for calculating pre-disaster or post-disaster costs. Pre-disaster costs emerge due to new investments, development costs in various flood protection measures, and cost-effectiveness measures, including funding schemes or compensation measures. Socio-economic information such as number and age of inhabitants or buildings can be used for developing flood risk maps. For example, the Kent pilot carried out an advanced GIS vulnerability analysis for the flood risk of social care homes to provide recommendations which social care homes should be adapted, and in what way. Post-disaster costs relate to flood damage to property and agricultural products, business interruption and/or development of emergency services. In Denmark, for example, the focus was more on the recovery and rebuilding process in Roskilde after a storm surge in 2013 took place and which general lessons could be learned to improve recovery and rebuilding plans in the future.

4 | DISCUSSION

The FRR (Figure 1) advances the shift from safety-based to risk-based approaches in flood risk management practice. The risk-based approach is a holistic one that integrates multi-sector and multi-purpose perspectives including alternative, adaptive management perspectives. It aims to be more environmentally friendly, sustainable, and, above all, to increase the safety levels in times of increasing risks and uncertainties. Noting that widespread implementation in practice is still being hampered by various factors (Heintz et al., 2012; Klijn et al., 2008; van Herk et al., 2014), the FRR promotes an integrated coordination of the multi-layer safety approach (level 1), institutional context (level 2), and wider societal and environmental context (level 3). Since the 2000s, this ongoing transition has been increasingly associated with

the term ‘resilience’ (De Bruijn, 2004; Scholten & Hartmann, 2018; Scott, 2013; Wardekker et al., 2010; White et al., 2010). But this concept is also described as ‘fuzzy’ (Pendall et al., 2010, p. 80), ‘contested’ (McEvoy et al., 2013, p. 291), and difficult to operationalise and implement (Klein et al., 2003). There have been various attempts to design assessment frameworks, but they are often detached from practice. Additionally, resilience often does not cover governance or institutional context of power, actor-relations, and knowledge generation (Evans, 2011; Olsson et al., 2015).

Flood resilience can be improved by increasing robustness, adaptability and transformability of flood-prone areas (Figure 2, Restemeyer et al., 2015). The FRR combines two concepts of resilience – engineering resilience and social-ecological resilience. Both concepts influence various measures being taken to mitigate flood impacts in terms of protection, prevention, preparedness and recovery. On the one hand, engineering resilience aims to achieve stability, foreseeability and efficiency, with a focus on technical and physical measures (Gunderson, 2000; Holling, 1996). Engineered flood control increases the robustness of the system. It is currently the most common type of flood protection in practice; popular defence measures include dikes and barriers. Especially in Germany, dike protection provides a high feeling of security, even though absolute protection cannot be guaranteed. On the other hand, social-ecological resilience rejects the idea that the world can be predicted and controlled (Chandler, 2014; Davoudi et al., 2012). Thus, a general shift can be observed in flood risk management, from ‘bounce back resilience’ to ‘bounce forward resilience’ (Davoudi et al., 2012; White et al., 2010). In the context of FRR, adaptability and transformability go beyond maintaining a robust system and support the notion that vulnerability is reduced by taking adaptive measures, especially related to prevention, preparedness and recovery. Particularly from the perspective of transformability, flood events can be regarded as opportunities to re-design and innovate flood risk management, for example by making more room for water. Increasing assets and developments in flood-prone areas leads to increased vulnerability and damage potential (Tempels & Hartmann, 2014). To increase flood resilience, both concepts and schools of thought of resilience are equally important.

Since flood risk management within the dynamic context of flood-prone areas calls for innovative, cost-effective and environmentally friendly measures, an integrated consideration of measures is required, as described in the FRR. The FRR advances the Dutch multi-layer safety approach with the addition of a fourth layer, called recovery, which particularly targets transformability. The

inclusion of this fourth layer as a cornerstone of the approach fulfils the requirements of the Floods Directive.

Thus, the four layers of the FRR's multi-layer safety approach can be regarded as design parameters for increasing flood resilience and can help implement the Floods Directive in national settings. The FRR contributes to a shift towards a more comprehensive flood risk management, despite the diversity in implementation and application of the Directive among EU member states (Heintz et al., 2012; Klijn et al., 2008; Krieger, 2013). The FRR's design parameters suggest some measures and objectives but do not attempt to evaluate these; nor are the four layers separated from each other. As described in Ran and Nedovic-Budic (2016), current planning and flood risk management practices tend to implement measures relating to the different layers in isolation, and coordination between measures is lacking, resulting in reduced efficiency and effectiveness. The FRR, however, allows for an integrated consideration of the respective layers and, therefore, a sound consideration of possibilities and opportunities. The goal is to help practitioners and researchers acknowledge connections and communicate flood risk management in a holistic way rather than advocating particular measures in isolation.

As a capacity-building and management tool, the FRR allows administrative and governing bodies, communities, and individuals to understand the linkages and overlaps between the four layers. As stressed in Folke et al. (2005) and Cosoveanu et al. (2019), actors often have incomplete knowledge, and the inevitability of uncertainties has created an urgent need for more adaptive and dynamic forms of governance. The main goal of the FRR is to raise awareness that flood risk management should include various measures, and that these measures should build on each other. Existing structural measures can be used to improve the system and new, non-structural measures can be added. For example, an existing dike line can be designed as an evacuation road, or new settlement developments can be planned while taking prevention and preparedness measures into account. The combination of traditional and new components to increase flood resilience results in more sustainable approaches in flood risk management (Huiteima & Meijerink, 2010).

The FRR can be used as a communication tool to inform different actors and institutions about measures to increase flood resilience. By communicating diverse measures with different objectives to multiple stakeholders, views are broadened and sectoral thinking can shift to cross-sectoral thinking, taking the multi-functionality of specific measures into account and

increasing efficiency in flood risk management. The inclusion of multiple sectors and stakeholders is a time- and resource-intensive process, sometimes restricted by financial or institutional settings (Begg et al., 2018). Nevertheless, it is crucial for awareness-raising and sound decision-making. Such participatory processes are becoming more common and case studies related to stakeholder engagement and empowerment in flood risk management are gaining greater attention (e.g. Gerkenmeier & Ratter, 2018; Grecksch, 2013; Karrasch et al., 2017; van den Brink et al., 2019; Winkler et al., 2018).

Often, stakeholder networks are very complex, and relationships can be formal, institutionalised, informal, sporadic or non-existent, relating to different types of influence, such as legal, political or financial (Winkler & Hauck, 2019). A shift of responsibility from government to individuals, and towards adaptive behaviour, is observable (Haer et al., 2017). Participatory approaches, as striven for in the FRR, represent a necessary attempt to acknowledge different interests. In such approaches, mutual learning and capacity building can be observed to lead to better-informed decision-making. As described in Brown et al. (2017), management tools, like the FRR, that consider diverse adaptation options, multi- and cross-scale governance arrangements and inclusive multi-dimensional assessments are key for increasing flood resilience.

The FRR can help to realise sound procedures in flood risk management, taking the wider context into account. It includes important normative aspects, permitting the development of tailor-made processes and increased trust between actors. Stakeholder involvement is strengthened because participants are not given the feeling that they are providing only 'external' ideas but rather are engaged in finding joint solutions during inclusive participatory processes. The FRR improves understanding of cumulative or cascading effects relating to climate change by communicating, for example, the effects and interactions of sea-level rise, increased water run-off, erosion, and saltwater intrusion in relation to their economic impacts (Gallina et al., 2016; Nones & Pescaroli, 2016; Schaper et al., 2019). Additionally, explaining the contribution of ecosystem services to flood resilience, such as the function of flood and storm protection in providing natural buffers against hazards (Carus et al., 2016), raises awareness of non-structural and ecosystem-based measures. These are particularly important in terms of regulating ecosystem services. Prominent examples are water-flow regulation, erosion control, wave attenuation, or hazard regulation by water retention. Often, decision-makers and the wider society are unaware of climate services, cumulative effects or the provision of ecosystem services. The FRR promotes an

understanding of the different drivers and measures that increase flood resilience.

5 | CONCLUSION

The FRR is a management tool designed for and with practitioners to capture the complexity of flood risk, increase flood resilience and promote a shift towards more comprehensive flood risk management. The main aim of the FRR is to support actors to better understand or communicate how different layers of flood risk management measures (protection, prevention, preparedness and recovery) as well as different levels of operation (multi-layer safety, institutional context, wider context) are interlinked and build on each other. The FRR contributes to the integrative implementation of the EU Floods Directive in national and local settings. In particular, it can serve as a tool that addresses governance within the institutional context. It combines the Floods Directive's requirements with diverse perspectives and needs of stakeholders, taking the multi-functionality of adaptation options into account.

ACKNOWLEDGEMENTS

We are very thankful for the time and effort of the FRAMES pilot coordinators and their active participation during the research process. We would also like to thank the anonymous reviewers for their comments and suggestions, which helped us to improve the manuscript. This study was part of the EU project FRAMES (Flood Resilient Areas by Multi-layer Safety), supported and co-funded by the European Regional Development Fund Interreg VB North Sea Region Programme 2014–2020 (grant number No: 38-2-9-16).

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request. Some research data are not shared and not publicly available due to privacy or ethical restrictions.

ORCID

Leena Karrasch  <https://orcid.org/0000-0002-7722-1720>

REFERENCES

- Adger, W. N., Hughes, T. P., Folke, C., Carpenter, S. R., & Rockström, J. (2005). Social-ecological resilience to coastal disasters. *Science*, 309(5737), 1036–1039.
- Aerts, J. C., Botzen, W., van der Veen, A., Krywkow, J., & Werners, S. E. (2008). Dealing with uncertainty in flood management through diversification. *Ecology and Society*, 13(1), 41.
- Begg, C., Callsen, I., Kuhlicke, C., & Kelman, I. (2018). The role of local stakeholder participation in flood defence decisions in the United Kingdom and Germany. *Journal of Flood Risk Management*, 11(2), 180–190.
- Berkes, F., Folke, C., & Colding, J. (Eds.). (2000). *Linking social and ecological systems: Management practices and social mechanisms for building resilience*. Cambridge University Press.
- Brown, K., Naylor, L., & Quinn, T. (2017). Making space for proactive adaptation of rapidly changing coasts: A window of opportunity approach. *Sustainability*, 9(8), 1408.
- Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., Shinozuka, M., Tierney, K., Wallace, W. A., & Von Winterfeldt, D. (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. *Earthquake Spectra*, 19(4), 733–752.
- Carus, J., Paul, M., & Schröder, B. (2016). Vegetation as self-adaptive coastal protection: Reduction of current velocity and morphologic plasticity of a brackish marsh pioneer. *Ecology and Evolution*, 6(6), 1579–1589.
- Chandler, D. (2014). *Resilience: The governance of complexity*. Routledge.
- Cosoveanu, F. S., Buijs, J. M., Bakker, M., & Terpstra, T. (2019). Adaptive capacities for diversified flood risk management strategies: Learning from pilot projects. *Water*, 11(12), 2643.
- Davoudi, S., Shaw, K., Haider, L. J., Quinlan, A. E., Peterson, G. D., Wilkinson, C., Fünfgeld, H., McEvoy, D., Porter, L., & Davoudi, S. (2012). Resilience: A bridging concept or a dead end? “Reframing” resilience: Challenges for planning theory and practice interacting traps: Resilience assessment of a pasture management system in northern Afghanistan urban resilience: What does it mean in planning practice? Resilience as a useful concept for climate change adaptation? The politics of resilience for planning: A cautionary note. *Planning Theory & Practice*, 13(2), 299–333.
- De Bruijn, K. M. (2004). Resilience and flood risk management. *Water Policy*, 6(1), 53–66.
- De Moel, H., Van Vliet, M., & Aerts, J. C. J. H. (2014). Evaluating the effect of flood damage-reducing measures: A case study of the unembanked area of Rotterdam, The Netherlands. *Regional Environmental Change*, 14(3), 895–908.
- Directive 2007/60/EC of The European Parliament and of The Council of 23 October 2007 on the assessment and management of flood risk [online]. Document 32007L0060. <https://eur-lex.europa.eu/eli/dir/2007/60/oj>
- Dutch National Water Plan – State Secretary for Transport, Public Works and Water Management and the Ministers for Housing, Regional Development and the Environment and for Agriculture, Nature and Food Quality. (2009). National Water Plan 2009–2015 [online]. The Hague, The Netherlands. <http://publicaties.minienm.nl/documenten/national-water-plan-2009-2015>
- Environment Agency and DEFRA. (2011). Understanding the risks, empowering communities, building resilience. The national flood and coastal erosion risk management strategy for England. Presented to Parliament pursuant to Section 7 of the Flood and Water Management Act 2010 [online]. London: The Stationery Office. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/228898/9780108510366.pdf

- European Commission. (2013). Guidance for reporting under the Floods Directive (2007/60/EC). Guidance document No. 29. A compilation of reporting sheets adopted by Water Directors Common Implementation Strategy for the Water Framework Directive (2000/60/EC) [online]. Technical Report 2013-071. https://circabc.europa.eu/sd/a/acbcd98a-9540-480e-a876-420b7de64eba/Floods%20Reporting%20guidance%20-%20final_with%20revised%20paragraph%204.2.3.pdf
- European Commission. (2019a). Commission staff working document. European Overview – Flood risk management plans. Accompanying the document Report from the Commission to the European Parliament and the Council on the implementation of the Water Framework Directive (2000/60/EC) and the Floods Directive (2007/60/EC). Second River Management Plans. First Flood Risk Management Plans [online]. Brussels, SWD (2019) 30 final. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52019SC0030>
- European Commission. (2019b). Commission staff working document. First Flood risk management plans – Member State: Belgium. Accompanying the document Report from the Commission to the European Parliament and the Council on the implementation of the Water Framework Directive (2000/60/EC) and the Floods Directive (2007/60/EC). Second River Management Plans. First Flood Risk Management Plans [online]. Brussels, SWD (2019) 37 final. <https://eur-lex.europa.eu/legal-content/ga/TXT/?uri=CELEX:52019SC0037>
- European Commission. (2019c). Commission staff working document. First Flood risk management plans – Member State: Denmark. Accompanying the document Report from the Commission to the European Parliament and the Council on the implementation of the Water Framework Directive (2000/60/EC) and the Floods Directive (2007/60/EC). Second River Management Plans. First Flood Risk Management Plans [online]. Brussels, SWD (2019) 38 final. <https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:52019SC0038>
- European Commission. (2019d). Commission staff working document. First Flood risk management plans – Member State: Germany. Accompanying the document Report from the Commission to the European Parliament and the Council on the implementation of the Water Framework Directive (2000/60/EC) and the Floods Directive (2007/60/EC). Second River Management Plans. First Flood Risk Management Plans [online]. Brussels, SWD (2019) 41 final. <https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:52019SC0041>
- European Commission. (2019e). Commission staff working document. First Flood risk management plans – Member State: The Netherlands. Accompanying the document Report from the Commission to the European Parliament and the Council on the implementation of the Water Framework Directive (2000/60/EC) and the Floods Directive (2007/60/EC). Second River Management Plans. First Flood Risk Management Plans [online]. Brussels, SWD (2019) 75 final. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52019SC0075>
- European Commission. (2019f). Commission staff working document. First Flood risk management plans – Member State: United Kingdom. Accompanying the document Report from the Commission to the European Parliament and the Council on the implementation of the Water Framework Directive (2000/60/EC) and the Floods Directive (2007/60/EC). Second River Management Plans. First Flood Risk Management Plans [online]. Brussels, SWD (2019) 58 final. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52019SC0058>
- European Environment Agency. (2017). *Climate change, impacts and vulnerability in Europe 2016: An indicator-based report*. EEA Report No 1/2017.
- Evans, J. P. (2011). Resilience, ecology and adaptation in the experimental city. *Transactions of the Institute of British Geographers*, 36(2), 223–237.
- Feyen, L., Dankers, R., Bódis, K., Salamon, P., & Barredo, J. I. (2012). Fluvial flood risk in Europe in present and future climates. *Climatic Change*, 112(1), 47–62.
- Flemish Government. (2013). The Flemish climate policy plan 2013-2020. A summary [online]. <https://www.vlaanderen.be/publicaties/the-flemish-climate-policy-plan-2013-2020-a-summary>
- Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources*, 30, 441–473.
- Forrest, S., Trell, E.M., Woltjer, J. (2018) Flood groups in England: Governance arrangements and contribution to flood resilience. In: Trell, E.M., Restemeyer, B., Bakema, M.M, van Hoven, B. (Eds.). *Governing for resilience in vulnerable places*. Routledge, pp. 92–115.
- Gallina, V., Torresan, S., Critto, A., Sperotto, A., Glade, T., & Marcomini, A. (2016). A review of multi-risk methodologies for natural hazards: Consequences and challenges for a climate change impact assessment. *Journal of Environmental Management*, 168, 123–132.
- Gerkenmeier, B., & Ratter, B. M. (2018). Multi-risk, multi-scale and multi-stakeholder – The contribution of a bow-tie analysis for risk management in the trilateral Wadden Sea Region. *Journal of Coastal Conservation*, 22(1), 145–156.
- Gersonius, B., Verbeek, W., Subhan, A., Stone, K., & Zevenbergen, C. (2011). Toward a more flood resilient urban environment: The Dutch multi-level safety approach to flood risk management. In K. Otto-Zimmerman (Ed.), *Resilient cities: Cities and adaptation to climate change proceedings of the global forum 2010* (pp. 273–282). Springer.
- Grecksch, K. (2013). Adaptive capacity and regional water governance in North-Western Germany. *Water Policy*, 15(5), 794–815.
- Gunderson, L. H. (2000). Ecological resilience – In theory and application. *Annual Review of Ecology and Systematics*, 31(1), 425–439.
- Haer, T., Botzen, W. W., de Moel, H., & Aerts, J. C. (2017). Integrating household risk mitigation behavior in flood risk analysis: An agent-based model approach. *Risk Analysis*, 37(10), 1977–1992.
- Halbe, J., Knüppe, K., Knieper, C., & Pahl-Wostl, C. (2018). Towards an integrated flood management approach to address trade-offs between ecosystem services: Insights from the Dutch and German Rhine, Hungarian Tisza, and Chinese Yangtze basins. *Journal of Hydrology*, 559, 984–994.
- Hall, J. W., Dawson, R. J., Sayers, P. B., Rosu, C., Chatterton, J. B., & Deakin, R. (2003). A methodology for national-scale flood risk assessment. *Proceedings of the Institution of Civil Engineers-Water Maritime and Engineering*, 156(3), 235–248.

- Hegger, D. L. T., Driessen, P. P. J., Dieperink, C., Wiering, M., Raadgever, G. T. T., & Van Rijswijk, H. F. M. W. (2014). Assessing stability and dynamics in flood risk governance: An empirically illustrated research approach. *Water Resource Management*, 28(12), 4127–4142.
- Heintz, M. D., Hagemeyer-Klose, M., & Wagner, K. (2012). Towards a risk governance culture in flood policy—Findings from the implementation of the “Floods Directive” in Germany. *Water*, 4(1), 135–156.
- Holling, C. S. (1996). Engineering resilience versus ecological resilience. *Engineering within ecological constraints*, 31, 32.
- Huitema, D., & Meijerink, S. V. (2010). Realizing water transitions: The role of policy entrepreneurs in water policy change. *Ecology and Society*, 15(2), 26.
- Karrasch, L., Maier, M., Kleyer, M., & Klenke, T. (2017). Collaborative landscape planning: Co-design of ecosystem-based land management scenarios. *Sustainability*, 9(9), 1668.
- Kaufmann, M., Mees, H., Lieferink, D., & Crabbé, A. (2016). A game of give and take: The introduction of multi-layer (water) safety in the Netherlands and Flanders. *Land Use Policy*, 57, 277–286.
- Klein, R. J., Nicholls, R. J., & Thomalla, F. (2003). Resilience to natural hazards: How useful is this concept? *Global Environmental Change Part B: Environmental Hazards*, 5(1), 35–45.
- Klijin, F., Samuels, P., & Van Os, A. (2008). Towards flood risk management in the EU: State of affairs with examples from various European countries. *International Journal of River Basin Management*, 6(4), 307–321.
- Knottnerus, O. S. (2005). History of human settlement, cultural change and interference with the marine environment. *Helgoland Marine Research*, 59(1), 2–8.
- Kolen, B., & Kok, M. (2013). An economical optimal investment strategy in a multi-layer flood risk approach. In F. Klijin & T. Schweckendiek (Eds.), *Comprehensive flood risk management* (pp. 877–887). CRC Press.
- Krieger, K. (2013). The limits and variety of risk-based governance: The case of flood management in Germany and England. *Regulation & Governance*, 7(2), 236–257.
- Kundzewicz, Z. W., Pińskwar, I., & Brakenridge, G. R. (2013). Large floods in Europe, 1985–2009. *Hydrological Sciences Journal*, 58(1), 1–7.
- Long, R. D., Charles, A., & Stephenson, R. L. (2015). Key principles of marine ecosystem-based management. *Marine Policy*, 57, 53–60.
- McEvoy, D., Fünfgeld, H., & Bosomworth, K. (2013). Resilience and climate change adaptation: The importance of framing. *Planning Practice & Research*, 28(3), 280–293.
- Mees, H., Crabbé, A., Alexander, M., Kaufmann, M., Bruzzone, S., Lévy, L., & Lewandowski, J. (2016). Coproducing flood risk management through citizen involvement: Insights from cross-country comparison in Europe. *Ecology and Society*, 21(3), 7.
- Mees, H., Crabbé, A., & Suykens, C. (2018). Belgian flood risk governance: Explaining the dynamics within a fragmented governance arrangement. *Journal of Flood Risk Management*, 11(3), 271–280.
- Meijerink, S., & Dicke, W. (2008). Shifts in the public–private divide in flood management. *International Journal of Water Resources Development*, 24(4), 499–512.
- Meyer, V. (2018). Decision support on flood management in complex urban settings. Is risk assessment the right approach or do we need decision heuristics? In S. Kabisch, F. Koch, E. Gawei, A. Haase, S. Knapp, K. Krellenberg, J. Nivala, & A. Zehndorf (Eds.), *Urban transformations* (pp. 363–373). Springer.
- Ministry of Infrastructure and the Environment and Ministry of Economic Affairs. (2015). National Water Plan 2016–2021. Our Water our Future [online]. Government of the Netherlands. <https://www.government.nl/documents/policy-notes/2015/12/14/national-water-plan-2016-2021>
- Nones, M., & Pescaroli, G. (2016). Implications of cascading effects for the EU Floods Directive. *International Journal of River Basin Management*, 14(2), 195–204.
- Olsson, L., Jerneck, A., Thoren, H., Persson, J., & O’Byrne, D. (2015). Why resilience is unappealing to social science: Theoretical and empirical investigations of the scientific use of resilience. *Science Advances*, 1(4), e1400217.
- Oosterberg, W., Van Drimmelen, C., & Van der Vlist, M. (2005). Strategies to harmonize urbanization and flood risk management in deltas. 45th Congress of the European Regional Science Association: Land Use and Water Management in a Sustainable Network Society, Amsterdam, The Netherlands, European Regional Science Association (ERSA), Louvain-la-Neuve.
- Pendall, R., Foster, K. A., & Cowell, M. (2010). Resilience and regions: Building understanding of the metaphor. *Cambridge Journal of Regions, Economy and Society*, 3(1), 71–84.
- Pontee, N. (2013). Defining coastal squeeze: A discussion. *Ocean & Coastal Management*, 84, 204–207.
- Priest, S. J., Suykens, C., Van Rijswijk, H. F., Schellenberger, T., Goytia, S., Kundzewicz, Z. W., van Doorn-Hoekveld, W. J., Beyers, J. C., & Homewood, S. (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. *Ecology and Society*, 21(4), 50.
- Ran, J., & Nedovic-Budic, Z. (2016). Integrating spatial planning and flood risk management: A new conceptual framework for the spatially integrated policy infrastructure. *Computers, Environment and Urban Systems*, 57, 68–79.
- Restemeyer, B., Woltjer, J., & van den Brink, M. (2015). A strategy-based framework for assessing the flood resilience of cities – A Hamburg case study. *Planning Theory & Practice*, 16(1), 45–62.
- Schaper, J., Ulm, M., Arns, A., Jensen, J., Ratter, B., & Weisse, R. (2019). Transdisziplinäres Risikomanagement im Umgang mit extremen Nordsee-Sturmfluten–Vom Modell zur Wissenschafts-Praxis-Kooperation. *Die Küste*, 87, 75–114.
- Scholten, T., & Hartmann, T. (2018). Flood resilience and legitimacy – An exploration of Dutch flood risk management. In E. M. Trell, B. Restemeyer, M. M. Bakema, & B. van Hoven (Eds.), *Governing for resilience in vulnerable places* (pp. 77–91). Routledge.
- Scott, M. (2013). Resilience: A conceptual lens for rural studies? *Geography Compass*, 7(9), 597–610.
- Tempels, B., & Hartmann, T. (2014). A co-evolving frontier between land and water: Dilemmas of flexibility versus robustness in flood risk management. *Water International*, 39(6), 872–883.
- The Federal Government. (2008). German strategy for Adaptation to climate change adopted by the German federal cabinet on 17th December 2008 [online]. The Federal Government. https://www.preventionweb.net/files/27772_dasgesamtenbfl-63.pdf

- van den Brink, M., Edelenbos, J., van den Brink, A., Verweij, S., van Etteger, R., & Busscher, T. (2019). To draw or to cross the line? The landscape architect as boundary spanner in Dutch river management. *Landscape and Urban Planning*, *186*, 13–23.
- van Herk, S., Zevenbergen, C., Gersonius, B., Waals, H., & Kelder, E. (2014). Process design and management for integrated flood risk management: Exploring the multi-layer safety approach for Dordrecht, The Netherlands. *Journal of Water and Climate Change*, *5*(1), 100–115.
- Vaughan, C., Dessai, S., & Hewitt, C. (2018). Surveying climate services: What can we learn from a bird's-eye view? *Weather, Climate, and Society*, *10*(2), 373–395.
- Verbrugge, L., Buchecker, M., Garcia, X., Gottwald, S., Müller, S., Præstholm, S., & Olafsson, A. S. (2019). Integrating sense of place in planning and management of multifunctional river landscapes: Experiences from five European case studies. *Sustainability Science*, *14*(3), 669–680.
- Vousdoukas, M. I., Mentaschi, L., Voukouvalas, E., Bianchi, A., Dottori, F., & Feyen, L. (2018). Climatic and socioeconomic controls of future coastal flood risk in Europe. *Nature Climate Change*, *8*(9), 776–780.
- Wardekker, J. A., de Jong, A., Knoop, J. M., & van der Sluijs, J. P. (2010). Operationalising a resilience approach to adapting an urban delta to uncertain climate changes. *Technological Forecasting and Social Change*, *77*(6), 987–998.
- Wehn, U., Rusca, M., Evers, J., & Lanfranchi, V. (2015). Participation in flood risk management and the potential of citizen observatories: A governance analysis. *Environmental Science & Policy*, *48*, 225–236.
- White, I., Kingston, R., & Barker, A. (2010). Participatory geographic information systems and public engagement within flood risk management. *Journal of Flood Risk Management*, *3*(4), 337–346.
- Wiering, M., & Winnubst, M. (2017). The conception of public interest in Dutch flood risk management: Untouchable or transforming? *Environmental Science & Policy*, *73*, 12–19.
- Winkler, K. J., & Hauck, J. (2019). Landscape stewardship for a German UNESCO Biosphere Reserve: A network approach to establishing stewardship governance. *Ecology and Society*, *24*(3), 12.
- Winkler, K. J., Scown, M. W., & Nicholas, K. A. (2018). A classification to align social-ecological land systems research with policy in Europe. *Land Use Policy*, *79*, 137–145.

How to cite this article: Karrasch, L., Restemeyer, B., & Klenke, T. (2021). The 'Flood Resilience Rose': A management tool to promote transformation towards flood resilience. *Journal of Flood Risk Management*, *14*, e12726. <https://doi.org/10.1111/jfr3.12726>