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OVERVIEW

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Natural flood management: Opportunities to implement nature-based solutions on privately owned land

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Abstract

The implementation of Natural Flood Management (NFM), as an example of a nature-based solution (NbS), is promoted as a risk reduction strategy to support sustainable flood risk management and climate change adaptation more widely. Additionally, as an NbS, NFM aims to provide further multiple benefits, such as increased biodiversity and improved water quality as well as improved mental health. The implementation of NbS often needs private-owned or managed land, yet can create conflicts between the different stakeholders which can undermine the social consensus required for successful implementation. Consequently, a main question is how the multiple benefits and requirements of NFM can be delivered to meet the different goals of the wide variety of stakeholders who must be involved. This article discusses the challenges and potential of implementing NFM as an alternative to the traditional technical mitigation measures in flood risk management. We outline four opportunities in the implementation of NFM: physical conditions of the catchment, social interaction, financial resources, and institutional setting. Their importance is then demonstrated and compared to different examples across the globe. Nevertheless, the core drivers reflect the social interaction and institutional setting and the role of stakeholders in the successful implementation of NFM.

This article is categorized under:

- Engineering Water > Planning Water
- Human Water > Water Governance
- Science of Water > Water Extremes
- Water and Life > Conservation, Management, and Awareness

KEYWORDS

flood risk management, land use management, modes of governance, nature-based solutions, partnership

1 | INTRODUCTION

Across the globe, national, regional, and local flood risk management strategies are often based on the concept of implementing dikes or reinforcing watercourses to protect residential and nonresidential buildings within a human community (Cuillo et al., 2020; Di Baldassarre et al., 2015; Disse et al., 2020; Kuhlicke et al., 2020). Essentially, floods are the product of extreme weather events and catchment characteristics (e.g., morphology, land cover, soil, and geology). Intervention in the land cover and the morphology of a catchment is generally difficult although, coincidentally, agricultural practices such as terracing have the consequence of providing both flood storage and sometimes groundwater recharge. In hydrological terms, the options are to reduce runoff through increase of infiltration, reduce time of concentration, or seek to change the conveyancing capacity of the watercourses (Dadson et al., 2017; Green, 2010a; Waylen et al., 2018). Consequently, the emphasis has shifted to prioritizing measures throughout the catchment to delay the flow through nature-based solutions (Collentine & Futter, 2018; Dadson et al., 2017; Lane, 2017). These strategic changes to flood risk management demand reconsideration of how land use and water management still might consider the needs of individuals and householders but alongside the catchment (Bell, 2020; Green, 2014; Jakubinsky et al., 2021; Lane, 2017; Seddon et al., 2020; Seher & Löschner, 2018; Thaler et al., 2016).

These "new" concepts—also referred to generally as Natural Flood Management (NFM), a sub-set of Nature-based Solutions (NbS)—aim to answer multiple societal needs and goals such as restoration, regulative and supportive services of ecosystems. Indeed, flood risk management no longer exclusively focuses on reducing human losses or protecting infrastructure, but also on supporting recreational and ecological functions caused by future hazard events while enhancing human well-being, biodiversity, climate change adaptation and mitigation (Bell, 2020; Calliari et al., 2019; Cohen-Shacham et al., 2019; Green, 2010a; Iacob et al., 2014). This is in line with the overall movement towards disaster risk management concepts that promote individual responsibility for proactively limiting risk, and an expectation that all of society collectively work toward managing flood risk (Kuhlicke et al., 2020; Matczak & Hegger, 2021; Snel et al., 2021). In the scientific literature, most NFMs are planned and implemented in rural areas (Green et al., 2022; Huang et al., 2020; Thorne et al., 2018) where NFM reduces flood risk through a wide range of different potential interventions (Holstead et al., 2017). Examples include catchment-level landscape interventions (Collentine & Futter, 2018; Dadson et al., 2017; Lane, 2017), upland re-forestry to river restoration, including interventions in the floodplains with wetland or wash land restoration, storage reservoir implementation and changes in agricultural practices (Dadson et al., 2017; Lane, 2017). The aim of the paper is to discuss the challenges and potential of implementing NFM as an alternative to the traditional technical mitigation measures in flood risk management. The paper conducted a critical review of the concept of NFM, presents in the different perspectives. For the selection process of the literature, we used a three-step approach. The first step includes various Scopus-wide reviews of the keywords "Natural Flood Management" (in total 91 documents), "catchment-wide AND flood risk management" (in total 11 documents), and "upstream–downstream AND flood risk management" (in total 6 documents). The review focus on the period between 2006 and 2021. Based on the outcome of step 1, we used a snowballing method (Wohlin, 2014), which includes (a) the reference lists as well as (b) citations by the selected papers. Finally, we evaluated various policy reports from national and international organizations, like the United Kingdom Environment Agency, US Army Corps, World bank and European Commission. This article presents four key opportunities for success that need to be assessed for adoption of NFM. The selection process of the four opportunities is derived deductively from the assessed literature. Additionally, we clustered the different success and failure factors into physical (=environment opportunity) and social aspects (=financial, social, and institutional opportunity). The clustering process oriented himself to similar cluster process like Biesbroek et al. (2013) or Uittenbroek et al. (2013). The inclusion of physical and social factors has been crucial as the literature often focusses only on one of these aspects. We see them as an integrated part, which cannot be excluded from each other. The paper then explores these four opportunities through three selected studies. The studies were selected based on various variables: different types of floods (coastal and river flooding), different political regimes and property rights systems, socio-economic factors, different areas across the globe (global north and global south), and different types of NFM. Finally, all three countries have a long-standing institutionalized flood and coastal risk management system, but with different types of exposure, vulnerability, and risk reduction strategies (Cannon & Müller-Mahn, 2010). The idea behind this is to show the variety and complexity of NFM.

2 | CHALLENGES OF IMPLEMENTING NATURAL FLOOD MANAGEMENT

All physical interventions to reduce the risk of flooding require space and place; however, NFM is spatially extensive while the traditional methods are spatially intensive. Using these strategies requires a catchment-wide framework to achieve noticeable levels of risk reduction and, consequently, NFM must integrate the different spatial, political, and temporal dimensions of flood risk management, such as upstream–downstream co-operation, engaging with different stakeholders (like insurance companies, citizens, land-owners, farmer associations, grassroots organizations, etc.) and coordinating with local authorities, at the same time implementing and maintaining different regulations and financial instruments (Albert et al., 2021; Dunham et al., 2018; Huang et al., 2020; Martin et al., 2021; Rijke et al., 2012; Thaler et al., 2016, 2017). This creates many moving parts that need to be managed and considered in NFM projects. Consequently, public will and consent impact the long-run sustainable implementation of NFM. In addition, NFM measures often cause land-use conflicts as well as upstream–downstream conflicts as they need to be implemented on private-owned land at the upper part of the catchment usually used for farmland or forestry (Holstead et al., 2017; Lundqvist & Falkenmark, 2000; Vitale & Meijerink, 2021). The outcome can be a restriction of use by the landowners. Additionally, NFM often serves to reduce the risk of downstream areas within the catchment; where landowners in the upper part of the catchment who gain no or minor benefits from the NFM (Chang, 2008; Hartmann, 2011; Machac et al., 2018). This is both a strength and a weakness of NFM. It is an approach that aims to provide integrated perspectives and holistically welfare-improving outcomes. Individuals who bear the responsibility to act must either be willing to accept the potential losses caused by flood events and the implementation of NFM for the greater good or be suitably compensated to encourage them to act in a suitable manner.

The complexity of managing a range of different stakeholders adds significant transaction costs to any NFM project, but NFM projects are further complicated in that where NFM measures are implemented primarily as risk reduction measures, the owner of the private land on which they are implemented may not primarily gain from the measures in terms of risk reduction (Blanc et al., 2012; Hartmann et al., 2019, 2022; Seher & Löschner, 2018).

While NFMs introduce some promising concepts, they have rarely been implemented across the globe as a systematic element of mainstream flood risk management strategies (Brillinger et al., 2020). For NFM to be a success it will require radical innovations in how people engage with and manage risks, which will require a more inclusive arrangement of power structures, mindsets, and practices in the co-design and co-implementation of NFM measures. Moreover, they require different sets of knowledge and expertise compared to more mainstream methods of flood risk management. It is not very surprising that often, NFM strategies take the form of a "pilot" or experience project with the open question of how to upscale these single solutions at a mainstream level (Cohen-Shacham et al., 2019; Frantzeskaki & McPhearson, 2021; Werritty, 2006), and the correct scale at which these strategies can be used (Dadson et al., 2017). This question was again mentioned in the European Natural Water Retention Measures (EU, 2014) and European Union Climate Change Adaptation Strategy (EU, 2021). The strategy noted that currently, the activities surrounding nature-based measures are heavily focused on awareness-raising or policy development, rather than physical solutions.

Additionally, when the current evidence base is considered, the implementation of NFM is highly influenced by governance structure and interactions (Cohen & Davidson, 2011) and not only local environmental conditions. For example, property rights have a strong impact on the feasibility of realizing NFM. Private landowners might reject or delay the idea as they have the legal power to do so in that property rights largely protect their private interests and objectives as opposed to the public interests (Potočki et al., 2022; van Straalen et al., 2018). The outcome is that in many cases, the landowner has, to some extent, a stronger position in the negotiation process than does the public administration. As a result, NFM has become increasingly recognized, not only by different governments across the globe (Collentine & Futter, 2018; Hewett et al., 2020) but also by a broad range of other stakeholders like farmers, forest owners, upstream–downstream policymakers, citizens, and so forth. (Hewett et al., 2020; Martin et al., 2021). This can also be clearly seen in the natural overlap between ecosystem-based adaption and community-based adaptation against climate change (Reid, 2016); these measures require that the adaptation process is sufficiently engaged, inclusive, and empowering for all the relevant actors, stakeholders, and citizens at the heart of the NFM measure. While this broad public participation process is considered to be the core of successful nature-based adaptation, it goes beyond the standard consultation process that many government activities must undergo before being implemented, entailing a much deeper degree of "buy-in" for the proposed NFM projects. It is not surprising that NFM is still less known and implemented by public administrations (Brillinger et al., 2020; Connelly et al., 2020) as for many organizations they represent a strong shift away from traditional management approaches. For instance, protection levels are lower, with a greater focus on benefits outside of flood risk management with which flood risk management organizations may not be familiar.

Moreover, not only are there these complications but there are also negative aspects to NFM that must also be remembered. The first is that compared to infrastructural measures or traditional approaches, NFM may not be able to achieve the same level of protection. The degree of flood risk reduction may not meet flood risk management objectives defined by the national government or local communities. The second is that the benefits of NFM are less easily evaluated than the physical damage resulting from flooding, because of its high dependency on the function of the general catchment characteristics and pre-event conditions (Constanza, 2010; House of Parliament, 2011). Moreover, the different streams of benefits may be the remit of different organizations and their funding legislatively restricted to providing specific benefits.

The close collaboration with the various members of the different communities and stakeholders is necessary to demonstrate the value of the individual measures, over any restrictions or alterations that may be required on their lands, as well as an honest understanding of the limitations of any NFM strategy.

3 | KEY OPPORTUNITIES FOR SUCCESS IN IMPLEMENTING NATURAL FLOOD MANAGEMENT

When considering the long-run sustainable implementation of NbS for flood risk management, lessons can be drawn from the wider literature on successful flood risk management, ecosystem-based adaptation, and community-based adaptation. This shows the successful and sustainable implementation of NFM to be at the conjoined nexus of several different sources of influence (Hartmann et al., 2019, 2022; Reid, 2016; Thaler, 2014). One can group such factors into four categories: physical conditions of the catchment, social interaction, financial resources, and the institutional setting.

1. *Physical conditions of the catchment*: Catchment characteristics influence the range of potential NFM and their location as well as the expected outcomes such measures can generate across the relevant objectives.
2. *Social interaction*: NFM, and all NbS, are sensitive to the social context in which they operate. NFM interventions must have either an existing stock of social capital and trust that creates a suitable environment for the required social interaction and negotiation or must be able to generate sufficient levels of trust and social capital during the project development and to maintain this trust and social capital stock afterward. A sufficient degree of solidarity can allow the benefits to be "vicariously" experienced across communities.
3. *Financial resources*: NFM measures require investment and securing of public and private funding to manage them in the short and long term. In essence, the financial viability of complying with and implementing the NFM is a crucial aspect of the realization. For example, a mechanism of compensation for land converted to natural retention areas should be established if productivity is altered temporarily (flooded and short-term indirect impact) or in the long term (opportunity costs associated with a change in production). An additional example will be a consideration of how increased biodiversity and carbon sequestration may support the landowner's business, increasing their profitability in the long run if they comply with the needs of the NFM and other policies. An emergent question is the development of metrics to support the transaction. The central theme of this category is the financial viability for all stakeholders of successfully engaging with the NFM intervention.
4. *Institutional setting*: The institutional setting shows the formal or informal rules regarding how the game must be played by the actors, and the different organizations involved in the implementation of NFM (North, 1990). For example, public administration may not accept NFM implementation if they perceive it does not meet their objectives, they do not recognize the full range of NFM benefits, or are legally constrained in how they must act. The institutional context must be sufficient to create an enabling environment for NFM.

The key opportunities for successful implementation of NFM projects are presented in Figure 1. Figure 1 provides guidance and facilitates both the documentary analysis and discursive interviews with stakeholders. It should be noted that such descriptions and relationships have been found to be dependent on scale and tend to change over time. This is because the long-term success of these NFM methods relies upon an implicit social contract between the relevant actors. We will present each category below, with a consideration of both their individual importance and a consideration of their fungibility across categories for successful implementation. These factors are both individually and

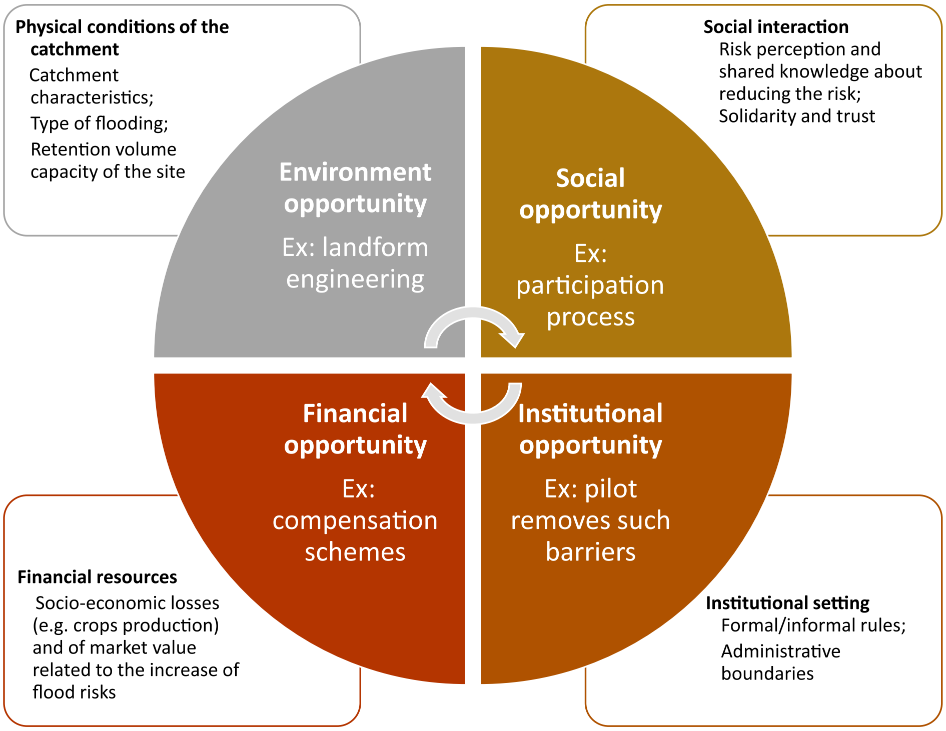

FIGURE 1 Key opportunities of success for implementing NFM

collectively important. This is because in a manner of speaking, the different influences are fungible across categories. For instance, stronger positive relationships between stakeholders may reduce the financial compensation they require or reduce the amount of money that needs to be spent on organizing and transmitting stakeholder knowledge.

3.1 | Physical conditions of the catchment

The prime avenues for NFM are (1) the consideration of another use of land or space, often focusing on soft engineering methods, which includes ponds, wetlands, leaky dams, and so forth (Barber & Quinn 2012; Nicholson et al., 2020) or (2) altering how a land-user interacts with the land, for example by altering tillage and livestock practices (Dadson et al., 2017); so that rather than replacing nature, risk managers work with nature; therefore, natural influences contribute towards an intervention's potential service delivery. Much potential NFM is constrained by the catchment characteristics and its current state (Burns et al., 2015), such as the landscape profile, soil, and the geological elements (Ackers & Bartlett, 2009; EA, 2009). For example, wetlands in floodplains can reduce the peak flow and time to peak of floods; however, the capacity to influence floods depends greatly on the size, location, season, and connection of the wetland areas (Acreman & Holden, 2013). Using multiple wetlands within the floodplain can reduce water flow but there is still uncertainty about the efficiency of multiple sites (Thorslund et al., 2017). Iacob et al. (2017) demonstrated that afforestation can reduce the frequency and magnitude of floods, but with a lower efficiency in the case of "classical" British winter flood events. Reducing the flood peak is certainly possible, but it depends on the scale of the floodplain and catchment (Blanc et al., 2012; Calder & Aylward, 2006). The catchment characteristics, pre-event conditions, and flood peak size are highly relevant to measure efficiency. Based on physical conditions of the catchment, the public administration selects different NFM measures that achieve certain aspects of their flood risk management strategy, within the potential offered by the natural environment. The planned intervention must be synergistic with the local environmental context.

NFM may be associated with various degrees of efficiency to reduce the flood peak. This is especially the case for large flood events and catchments; so far, studies have only indicated a significant effect on a smaller scale (Black et al., 2021; Dadson et al., 2017; Dixon et al., 2016; Nicholson et al., 2020). The study by Wilkinson et al. (2010) showed within the Belford catchment in the Northeast of England that several small-scale NFM measures held runoff and influenced the travel time of the flood peak. Dixon et al. (2016) provide another example where forest restorations in sub-catchments created a positive impact on future flood events. The positive influence occurred at a smaller scale for local areas (van Berchum et al., 2019). A key issue is that most of the NFM examples are pilot studies on a very small scale (Nicholson et al., 2020). NFM needs to be applied at an appropriate scale to attain an efficient influence and establish its effectiveness across larger projects (Blanc et al., 2012).

The preceding description of environmental conditions presents a starting point for determining which NFM measure can be used and how successful in terms of risk reduction that NFM measure is likely to be; however, it is not the only relevant aspect of environmental conditions to assess NFM implementation. The co-benefits provided by NFM (e.g., improved biodiversity, carbon sequestration) can be considered as an investment in the environmental capital stock where the measures are employed or for more widely connected groups. The improved local environmental conditions can provide co-benefits that stakeholders or downstream local authorities are more likely to be willing to pay to receive or complements their regular activities. For example, downstream local authorities may not tolerate increased taxation to fund NFM in a rural area that will lower their flood risk, due to disaster risk management receiving a low priority in their decision-making, but may be willing to pay instead to support the improved biodiversity and recreational quality of the area. Additionally, NFM can also help to reduce soil erosion on farms and hence reduce sediment loads and deposition in water courses. This can be an attractive co-benefit for farmers who may have to give up land upon which to place these measures; as such, benefits can be in line with their business needs.

Finally, when investing in NFM, care must be further taken to make sure that the right type of NFM is developed, as implementing and managing inadequately the NFM can create situations where there is more damage from flooding rather than less. For example, using trees as an option critically depends on forest management (as linked to institutions below), wherein poor management can increase natural disturbance and worsen the risk of flood events, or the realization of forest roads can increase the risk of floods (Calder & Aylward, 2006; Dadson et al., 2017; Scheidl et al., 2020; Sebald et al., 2019). Additionally, the natural limitations of NFM in protecting against smaller flood events must be recognized as well (Dadson et al., 2017).

3.2 | Social interaction

The land needed for NFM can usually be mobilized at lower land values, like low-intensive agriculture areas to protect high-vulnerability areas (Morris et al., 2016). This transfer between upstream and downstream areas sometimes leads to intensive conflicts and a lack of acceptability from different stakeholders; however, social capital, trust, and social norms might increase the acceptance of such a transfer between the different actors and stakeholders. One strategy might be to encourage bottom-up initiative in the planning process (Metcalfé et al., 2017). Bark et al. (2021) showed that stakeholders accept the implementation of NFM if there exists a shared responsibility between public and private sectors.

Private landowners must take an active role in the planning and implementation process (Carina & Keskitalo, 2020). Studies show this to be essential to a successful implementation and management process (Milman et al., 2018). This is especially true, given the natural overlap between NFM and community-led adaptation. Nevertheless, stakeholder engagement can be quite challenging, especially with the wide range of different stakeholders usually involved in NFM implementation (Warner et al., 2014; Waylen et al., 2018; Wingfield et al., 2019). The outcome is that the involvement of different stakeholders can be challenging and intensive because of the different backgrounds and interests involved. As various studies have shown, public administrations need to learn new skills and tools to overcome the barriers to implementation (Thaler & Levin-Keitel, 2016; Waylen et al., 2018). This includes a clear governance problem, where the co-design process increases the complexity of the policy process based on finding new financial resources and different actor networks (Schanze, 2017; Smith et al., 2014; Warner et al., 2014; Watson, 2004, 2015). While suitable engagement can be achieved on an ad-hoc basis per project, in the long-run sustainable and lasting NFM instruments will require a systematic governance system in place that allows for a suitable enabling environment. However, the relative capacities for people to act in these areas can vary across projects and nations as it does require a degree of political will for the government agencies responsible for managing flood risk to give up elements of their power in this area to be sufficiently inclusive and empowering towards local stakeholders and policymakers such that sustainable NFM can be achieved.

The primary avenues through which social interaction should be developed can be argued to be linking and bridging social capital. Linking social capital indicates how closely connected and related different actors are in power hierarchies while bridging social capital is how well-connected actors are horizontal across relevant communities (Putnam, 2001). A significant degree of quality linking capital is required to help create the links and sufficiently high-quality relationships between governmental actors and the on-the-ground communities. Bridging capital is required so that a sufficiently broad coalition of interested parties can be gathered in a meaningful manner, or as a way of transmitting knowledge and vicarious experiences across actors. Satizabal et al. (2022) argue that individuals known as "connectors," or "champions" (Taylor, 2009) are required to suitably build such coalitions. These individuals are those whose "lived experiences and daily practices have granted them in-depth understanding and skills to navigate complex and changing socio-cultural and institutional contexts" (Satizabal et al., 2022, p. 2).

However, care must be taken in maintaining these relationships over time as social connections are dynamic especially when there are potentially significant power differentials across stakeholders. For instance, Satizabal et al. (2022) note that connectors are important, but community engagement is hindered by top-down, state-led approaches to disaster risk management in Australia. Consequently, when investigating which coalitions of stakeholders are to be built for successful NFM to take place, one should pay attention to the true inclusivity of the coalition being built and consider whose voice is not heard. This is because, without the valid consent of the entire community, NFM can become unsustainable in the long run through the increased difficulty of maintaining it or the development of unequal burdens being generated and remaining uncompensated, creating larger, and larger social conflicts. How important this last point is can depend strongly on what type of NFM measure is being used, linking back to the importance of understanding the location's environmental capital in order to correctly determine which NFM measures are suitable and then what is the relevant social context and buy-in that is required.

This consideration can interact with the set of financial influences as well, through its ability to "grease the wheels" of interactions between different stakeholders. Positive feelings and interaction histories between relevant actors can alter the level of compensation or payments people are willing to accept for acting in a positive way for the NFM. A history of negative interaction, on the other hand, can be expected to increase the level of compensation that people require to overcome their distaste for the collaborative efforts.

3.3 | Financial resources

The third category of factors that influence the implementation of NFM is the financial context of the landscape strategy and how the NFM will alter it. For example, NFM interventions that reduce the potential land available for agriculture may end up reducing agricultural incomes (Collentine & Futter, 2018; Wells et al., 2020).

The prime avenue through which this operates is the financial viability of the intervention, both from the perspective of both the implementer and those acted upon. From the perspective of those acted upon, complying with the needs of the NFM must be economically viable for them from a business perspective. For example, if their land must be repurposed for NFM uses and not direct commercial use, the change must offer a beneficial impact to them while for the implementer, the business that they construct must tangibly meet the objectives that they had determined at the start of the project.

One way for this to happen can be compensation mechanisms such as open voluntary negotiation or compulsory compensation (Thaler et al., 2020). For example, Dutch and English legislation relies upon a compulsory compensation system (McCarthy et al., 2018; Thaler et al., 2020). On the other hand, the Austrian flood risk management system relies upon a voluntary, consensus-based approach. Consequently, this latter approach usually demands higher financial compensations, and there is a risk of small groups of private landowners hindering the implementation process—more resources are needed than for a compulsory purchase order (Thaler et al., 2020). The compulsory purchase order allows the legal "purchase and development of the land against the wishes of the landowners" (McCarthy et al., 2018, p. 89). A second way for this to occur is for the additional ecosystem benefits provided by the NFM outside of flood risk reduction to enhance the implementer's business opportunities. For instance, restrictions or alterations to land use can increase biodiversity, which allows their main business activity to be enhanced despite the loss of potential activity. Consider, for example, the conversion of public water areas into a storm-breaker forest in a coastal area; this may reduce the space accessible for fishing but provide more robust fish stocks or the potential for increased eco-tourism opportunities. This financial consideration allows for those upon whom the intervention is imposed to create an internal business case for why complying with the need is a good idea.

Understanding the socio-economic context is important because in order to help move human civilisation towards a more sustainable basis, we will need to leverage a greater investment in nature-based solutions overall to best exploit how their multi-functionality can achieve many of our social objectives. As noted above, however, the type of compensation mechanism required can be expensive, and must be drawn predominantly from governmental coffers. Government budgets are increasingly under pressure from multiple directions, and so appreciate a call for more innovative financing approaches blending public and private financing products for nature-led climate adaptation and overall capacity building. The development of a wider range of financing sources can reduce the budget burden placed on the government, creating a perception that NFM is more affordable. This in turn reinforces the considerations of how we build coalitions for the development of NFM measures and strategies. For example, NFM is one of the core goals of the European Union Climate Change Adaptation Strategy, in that it develops suitable institutional structures and bridges with the private sector; however, the implementation of NFM might also allow new financial opportunities since the private insurance sector might fund them (Paavola & Primmer, 2019). Finally, an underestimated issue is that NFM also might influence (positively or negatively) other socio-economic sectors, such as tourism (Iacob et al., 2014).

NFM strategy development must actively consider this socio-economic context and as a result, the NFM needs will need to match farmers' economic viability. This is a clear argument for how NFM helps to enhance and support the various pillars of sustainable development rather than worsening their level of development. It may require suitable funding or payment schemes to correctly incentivize the acceptance of such measures, as well as limiting the complexity of any bureaucratic requirements. This is especially the case if external funding for the NFM instrument is limited; then, the potential economic variability of the land user must be considered in depth as part of the project's overall objectives within the context of climate change adaptation, stakeholder engagement, multiple benefits, rural land use, trade-off mechanism, and localism agenda.

3.4 | Institutional setting

NFM implementation usually includes different actors and stakeholders. To avoid transparency and inefficiency, there is a need for engagement and interaction to be organized by different rules (Hodgson, 2006; North, 1990; Ostrom, 1986). The rule system, the institutional setting, can be formal or informal as well as also reflecting the social norms and moral understanding of the society (Hodgson, 2006; North, 1990). The understanding of the institutional setting is central to allowing or disallowing NFMs (Garvey & Paavola, 2022; Green, 2014; Thaler, 2014; Wells et al., 2020). In the case of NFM, the institutional setting regulates the social interaction between different actors and stakeholders; the type of compensation; questions about what can or cannot be protected; the role of public administration and the private sector in flood risk management; and the use of property rights in flood risk management (Hartmann et al., 2019; McCarthy et al., 2018). There remains a clear challenge when it comes to the private property rights system, where the implementation of NFM needs voluntary agreement from landowners (Quinn et al., 2010). Obtaining this consent can be quite challenging.

A clear problem is that NFM employs an ad-hoc single solution that allows innovative local solutions but this also creates barriers to upscaling the process (Garvey & Paavola, 2022; Schanze, 2017). A key challenge within the implementation of NFM in Germany appears in Brillinger et al. (2021); that is, there are significant concerns about the implementation of NFM within the public administration—especially from the water managers. Key concerns of the German water managers include uncertainties in terms of effectiveness of NFM and agreement with private landowners to implement measures in rural areas. German water managers usually carry out technical mitigation measures to avoid such challenges. Brillinger et al. (2021) conclude that water managers are the gatekeepers to NFM implementation in Germany. To sum up, the regional institutional setting plays a central role in implementing NFM (Albrecht & Hartmann, 2021; Schanze, 2017), as they will seek to operate within the predefined powers and rules system. These are usually defined by higher levels of governments and behave in the way that their institutional knowledge supports and expects. This contrasts with the adoption of NFM in Germany in urban areas (Green & Anton, 2010; Kiss et al., 2022; Martin et al., 2021) where the institutional arrangements are different, notably in terms of planning controls over land use, responsibilities for flood risk management and resources.

Stronger policy coordination, such as in Europe with the different regulations and strategies like the Common Agricultural Framework, Water Framework Directive, Floods Directive, aspects of the climate change adaptation strategy, or biodiversity strategy, offers significant potential for successful NFM implementation (Rouillard et al., 2015) through the creation of a risk management culture that is more supportive of NFM on the whole. Consequently, an adequate institutional setting allows social innovations in flood risk management, especially as NFM can be often seen because of social innovation (Collentine & Futter, 2018; Frantzeskaki, 2019; Raymond et al., 2017). In this vein, after the UK's exit from the Common Agriculture Policy, there is the possibility that England's system of agricultural subsidies will be refocused towards rewarding farmers for the provision of "public goods" (Bateman & Balmford, 2018). However, this system is in its early days, and it remains to be seen whether it will be successful at both maintaining the financial stability of farms and achieving the government's environmental goals. This, in principle, will greatly support the development of NFM on private land.

As NFM requires privately owned land, like farmlands or forests, different regulations and instruments are needed. This is especially the case if the NFM measures that are implemented and used cross different administrative boundaries (upstream–downstream relationship; Eder et al., 2022; Seher & Löschner 2018; Löschner et al., 2022). This becomes more problematic and challenging in the case of transboundary catchments, where NFM measures might be implemented in a state or country to protect the neighborhood's vulnerable communities.

Finally, given the need to holistically evaluate the benefits of an intervention across different stakeholders, we see that the business case should be developed across different governmental actors as well. For individual stakeholders across a catchment area who must face land-use alterations, they must have an individual business case made for them to act collectively. The same is true for government departments. A single department with a single set of objectives and funding available might not find an NFM intervention a sensible use of the available resources, as it must view the outcome from a single perspective. However, if different departments view the same NFM intervention from different angles, it could be that collectively a suitable business case might be developed if multiple government departments act in concert, further embracing the inclusive nature of the process for developing successful NFM.

There can be additional instructional pressures from the "rules" that must be followed. There can be many informal barriers to the employment of nature as a strategy for flood risk management (Raška et al., 2022). This can be due to uncertainty about its effectiveness for flood risk management objectives (Green et al., 2022) or because the use of nature does not fit within the perceived role of flood risk managers, despite recognition of its importance (Brillinger et al., 2021), and the successful use of nature may require the development of further skillsets and competencies currently outside of the organization's cultural purview (Waylen et al., 2018). These more cultural aspects of the institutional framework can further hinder the implementation of nature on a practical level. However, equally, cultural attributes within an organization could also enhance the capacity to use nature as a risk management solution. For an instance, an institutional allowance for risk-taking in terms of what can be perceived as innovative solutions, combined with resource limitations, can create an institutional atmosphere that encourages the development of cheaper non-gray infrastructure measures rather than a retrenchment of activities.

4 | CASE STUDY EXAMPLES ANALYZED

In this section, we discuss three examples of natural flood risk management from the scientific and gray literature. These studies were not originally designed or analyzed with the conditions discussed in Section 3 in mind, and so we explore the opportunities with the information presented in the three selected studies.

4.1 | Case study 1: Ecosystem restoration in Central Vietnam

The first example, the ResilNam project in Vietnam (see also Hudson et al., 2019; Wolf et al., 2021) focused on the restoration of mangrove forests along the coast of central Vietnam to build climate resilience. The first activity was to account for the physical conditions of the catchment by isolating the areas and communities suitable for mangrove restoration that would provide protection against storms and coastal flooding. Additionally, the ecological conditions of the catchment and the coastline were also considered to determine what type of mangrove would be most ecologically suitable and robust for the area.

The second avenue of the project was based upon enhancing "Social Interactions," as an additional aim of the project was to be an advocate for the increased role of marginalized communities in disaster management plans. It was of prime importance that social influences were correctly developed to improve flood risk perceptions, as well as the ecosystem service benefits provided by the restored mangroves. This was done through training exercises, community outreach, and efforts to produce tangible proof-of-concept evidence on the overall cost-beneficial nature of the project. Through extensive stakeholder engagement, an implicit aim was to build bridges to effectively increase social capital.

Additionally, the implementation of the mangrove restoration was to be led by the community itself to maximize the perception of ownership of the new communal resource. These activities were designed in a way that maximized the ability and incentive to take part. However, it was not completely positive as the development of this NFM method contributed to the development of social capital in one commune but potentially damaged social capital in another. This is because of the emergence of social conflicts due to gender differences in how the lagoon was exploited for economic benefits. The conflict was generated as women were noted to use traditional methods that benefit more readily from the restored mangroves, while the more extractive techniques employed by men tended to interact with the mangroves more negatively in the short term. While there is potential for developing new income streams of the improved ecosystem services, the core conflict is not directly addressed.

This targeted focus on the empowerment of marginalized communities highlights the required role of institutional setting as interconnected with suitable social interaction. The first is that the land given over for the restoration process was part of communal land. The communes selected for the project were ones where the local governments expressed support for the project concept to act as proof-of-concept for the use of NFM measures to build overall economic and climatic resilience. Therefore, the local institutional setting with regard to property rights was considered, and actors with whom there was a high likelihood of success were found and actively engaged with. The second direction in which the institutional setting was developed for this project was the active involvement of the provincial women's union in the project. The women's union was involved to help them build bridges with the provincial Disaster Risk Management Committee as well as helping to train local women in flood risk awareness campaigns and preparedness. The involvement of the women's union brought another official group to further act as a positive pressure group within the official government apparatus.

In terms of financial resources, part of what enhanced the attractiveness of the project for the local actors was that the immediate finance for the NFM efforts came from outside of the local communities due to being funded by the GRP and Zurich Flood Risk Alliance. This directly overcame one of the largest hurdles in implementation, that of who pays for the measure. Furthermore, there was the expected development of community-wide eco-tourism based on tourists visiting the mangroves and the connection of mangrove protection to a community micro-credit scheme. These avenues were proposed to develop a tangible business case for the mangroves.

4.2 | Case study 2: NFM in the Stroud Frome River catchment, UK

Another example is that of six NFM case studies around the Stroud Frome River catchment in Gloucestershire (UK) from 2017 (CMS, 2017). These case studies present different cases where Large Wood Debris (LWD) leaky dams were used as NFM instruments which required successful interaction with local farmers, woodland landowners, and other relevant partners to result in about 21% of the catchment area discharging through the NFM. The idea behind leaky dams is that the LWD employed helps to reduce the volatility of flow rates. When there is light rain, the watercourse water flow will not be impacted by the LWD, while higher flow rates (e.g., after heavy rain) face resistance from the LWD which slows down the flow rate of the watercourse. Moreover, when not used to manage flood risk, the use of LWD also helps to create various other positive biodiversity outcomes in the targeted catchment area. This indicates consideration of the physical conditions of the catchment in terms of where it is to be located and what conditions the nature-led approach would lead to.

In terms of the institutional setting (broadly understood), the land required for the NFM instruments were all located on privately owned land; however, the diversity and complexity in ownership types (for example lease agreement between Trust and private users, private ownership) and land use (woodland, active pasture farming, mixed-use farming, etc.) were recognized. In these interconnected examples, a synergistic outcome was produced as all sets of influences were carefully managed and enacted in the same direction. For example, in terms of institutional influences, the Environment Agency can employ NFM in its regular duties. There was also a clearly indicated set of 'consents' outside of that of the landowner that had to be sought out. This allowed a smooth legal transition and implementation, which allowed smoother social and financial influences furthering positive action. In these six case studies, the social interaction and financial resources cannot be fully separated. For example, there was the perception that the proposed NFM measures would have little direct impact on the business operations of the person providing the land, except for a relevant positive ecosystem service for a given business, for example, more populous fish species, reduced maintained costs or reduced soil erosion. A common theme was the presence of objectives overlapping with the flood risk manager's objective. Another positive opportunity was how objectives overlapped between actors and development of a common vision on how to move forwards and implement the measures. This creates a targeted activity to create win–win situations for all stakeholders to create suitable tipping points for implementation for their business, as well as engaging the social aspect of businesses involved. Thereby, embracing this aspect of NFM can create the social and financial tipping point for active implementation, especially when combined with the rather minor and externally funded expenditure required for the project. In this activity, therefore, the initial investment of financial resources was made by the local Environment Agency, but the social interaction helped to overcome hesitancy that the landowner or user had with regard to using the NFM measure on their land. Again, this respected the property rights of the owners rather than property rights becoming an inhibiting factor. This is because of a positive argument for the long-run enhancement of benefits the land users were getting from proactively engaging with the local Environment Agency. A tangible incentive was produced by employing an NFM measure where it would be most attractive, and minimally intrusive.

4.3 | Case study 3: NFM in Taraba State, Nigeria

We shall now turn to the case study presented in Ripiye (2016) concerning potential NFM in Taraba State (Nigeria). It is considered there that the multi-functional nature of NFM is applicable to the sustainable development agenda; however, comparing this to the previous positive examples, Ripiye (2016) notes that successful NFM in Nigeria struggles at a systematic level for a range of interconnected reasons, especially when compared to examples drawn from Scotland. This can be argued to indicate that the institutional and social settings in Taraba state were not directly supportive of NFM. Ripiye (2016) tentatively suggests that strategies should lean towards embracing the social dynamics required for NFM via collaborative environmental management. When exploring opportunities for success in the Ripiye (2016) case study, we would argue that the interplays of institutional setting and social interaction created the largest synergistic barriers to NFM in Nigeria. These two influences cannot be separated as the presence of several institutional weaknesses (e.g., weak institutions, poor coordination, top-down approaches, and focus only on post-flood actions) actively inhibits the development of suitable institutional influences, which prevents the building of sufficiently positive social stimuli with the local stakeholders and policymakers. Thereby, meaningful collaborative environmental management is prevented unless there is a much-expanded conceptualization of how to act among the institutional actors, which in turn requires the development of a new skill set across all stakeholders (Ripiye, 2016) and an alteration of power dynamics to create a suitably interlocking allocation of responsibilities. Ripiye (2016) compared this situation to Scotland, where in comparison, local risk managers were more accepting of such alterations. Unless these initial "cultural" barriers were overcome, a further analysis of the financial resources and physical conditions of the catchments was not needed due to the inherent difficulty of the project.

5 | CONCLUSION

NFM has recently become a more prominent strategy in countries all over the world (Sudmeier-Rieux et al., 2021; Worldbank, 2018). It offers multiple benefits and demands stronger consideration among current flood risk management strategies. Land use changes caused by NFM influence the current and future flood risk management strategies (Rust et al., 2014; te Wierik et al., 2020). There are several opportunities for success, which need to be analyzed in understanding the current conditions for each of the identified influence categories, which when combined contextualize, constrain, or enhance the needs which have to be addressed to implement NFM. Analysis of the successful implementation of NFM must identify stakeholders, impacts, the funds necessary, and decision-makers who have the power (Green, 2010b; Lukes, 1974) (Figure 1) to establish the business case for acting effectively in the catchment. These are the four essential opportunities within the negotiation process and the development of an agreement on the accepted changes. For each and between categories, it is also important to capture whether there is already opportunity and, if not, whether there is the possibility of creating such an opportunity. It may appear that such opportunity does not exist or does, but at a disproportionate cost. A consensus can be explored as to why costs are seen to be disproportionate and whether a more inclusive understanding of value can be useful in readdressing this perception and better reflect that society pursues more than just one objective at any given time. For this reason, one cannot view the different categories as wholly independent of one another. The various categories can be synergetic or antagonistic to each other on a case-by-case basis.

Overall, NFM measures require careful management and planning to play a vital role in current flood risk management systems (Cooper et al., 2021). Disadvantages of traditional technical mitigation measures include cost of the implementation and maintenance, strong influence on the aesthetic of the landscape, and strong negative environmental drawbacks, all of which NFM may be able to overcome. However, NFM needs space—often crossing competing areas with varying interests, such as the increased needs for renewable energy production, food production, tourism activities, and so on—and shows great uncertainty in its influence on flood peaks (Carrick et al., 2019; Cohen-Shacham et al., 2019; Cooper et al., 2021; Nicholson et al., 2020). Furthermore, climate change might reduce the future capacity of NFM. The NFM loses its capacity if rainfall events become more severe and the timeframe becomes longer. Such events might increase because of a warmer climate (Kay et al., 2019).

The examples shown above have demonstrated especially the importance of social capital, trust, norms, and institutional setting within the case studies and countries. For instance, NFM must often encompass privately owned or managed land, which then demands voluntary agreement by landowners in most countries; alternatives might be Eminent Domain in the United States of America or Expropriation in Canada, for example. Additionally, solidarity between the communities as well as trust in public administration might encourage implementation where the costs of an intervention are felt locally but the benefits externally. High social capital, including trust toward public administration, can therefore encourage the implementation of NFM, which is also highly influenced by the institutional setting. The institutional setting may or may not encourage NFM as a possible concept within flood risk management. This includes, for example, the legal use of private-owned land to be flooded or to compensate landowners. If the legal context forbids the use of NFM on privately owned land, NFM as a strategy will be impossible. Overall, the implementation of NFM might require a radical new perspective on dealing with flood hazards (Werritty, 2006). NFM may be effective, but it may also include clumsy solutions (Hartmann, 2011; Smith et al., 2014). This is particularly a threat in NFM because of the focus on a range of pluralistic and inclusive benefits, which means that a wider range of impacts and participants will be considered in the decision to invest in a particular measure. Whether or not this can be seen as clumsy depends on how the societal objective is constructed and understood and whether the expected outcome is desirable to all stakeholders.

AUTHOR CONTRIBUTIONS

Thomas Thaler: Conceptualization (equal); funding acquisition (lead); investigation (equal); project administration (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal). **Paul Hudson:** Conceptualization (equal); investigation (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal). **Christophe Viavattene:** Conceptualization (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal). **Colin Green:** Writing – original draft (equal); writing – review and editing (equal).

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CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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FURTHER READING

Coles, N. A., Wang, Y., Volk, M., & Wu, J. (2018). Ecoservices and multifunctional landscapes: Balancing the benefits of integrated ES-based water resources, agricultural and forestry production systems. *Ecohydrology & Hydrobiology*, *18*, 262–268. https://doi.org/10.1016/j.ecohyd.2017.10.006

REFERENCES

Ackers, J. C., & Bartlett, J. M. (2009). Flood storage works. Chapter 10 in fluvial design guide. Retrieved from http://evidence.environment-agency.gov.uk/FCERM/en/FluvialDesignGuide.aspx

Acreman, M., & Holden, J. (2013). How wetlands affect floods. *Wetlands*, *33*, 773–786. https://doi.org/10.1007/s13157-013-0473-2

Albert, C., Brillinger, M., Guerrero, P., Gottwald, S., Henze, J., Schmidt, S., Ott, E., & Schröter, B. (2021). Planning nature-based solutions: Principles, steps, and insights. *Ambio*, *50*, 1446–1461. https://doi.org/10.1007/s13280-020-01365-1

Albrecht, J., & Hartmann, T. (2021). Land for flood risk management—Instruments and strategies of land management for polders and dike relocations in Germany. *Environmental Science & Policy*, *118*, 36–44. https://doi.org/10.1016/j.envsci.2020.12.008

Bark, R. H., Martin-Ortega, J., & Waylen, K. A. (2021). Stakeholders' views on natural flood management: Implications for the nature-based solutions paradigm shift? *Environmental Science & Policy*, *115*, 91–98. https://doi.org/10.1016/j.envsci.2020.10.018

Barber, N. J., & Quinn, P. F. (2012). Catchment-scale management of farm runoff and the multiple benefits it can achieve. In *BHS Eleventh National Symposium, hydrology for a changing world, British Hydrological Society, Dundee*. British Hydrological Society.

Bateman, I. J., & Balmford, B. (2018). Public funding for public goods: A post-Brexit perspective on principles for agricultural policy. *Land Use Policy*, *79*, 293–300. https://doi.org/10.1016/j.landusepol.2018.08.022

Bell, S. J. (2020). Frameworks for urban water sustainability. *WIREs Water*, *7*, e1411. https://doi.org/10.1002/wat2.1411

Biesbroek, G. R., Klostermann, J. E. M., Termeer, C. J. A. M., & Kabat, P. (2013). On the nature of barriers to climate change adaptation. *Regional Environmental Change*, *13*, 1119–1129. https://doi.org/10.1007/s10113-013-0421-y

Black, A., Peskett, L., MacDonald, A., Young, A., Spray, C., Ball, T., Thomas, H., & Werritty, A. (2021). Natural flood management, lag time and catchment scale: Results from an empirical nested catchment study. *Journal of Flood Risk Management*, *14*, e12717. https://doi.org/10.1111/jfr3.12717

Blanc, J., Wright, G., & Arthur, S. (2012). Natural flood management (NFM) knowledge system: Part 2—The effect of NFM features on the desynchronising of flood peaks at a catchment scale. CREW Report. Retrieved from http://www.crew.ac.uk/projects/natural-flood-management

Brillinger, M., Dehnhardt, A., Schwarze, R., & Albert, C. (2020). Exploring the uptake of nature-based measures in flood risk management: Evidence from German federal states. *Environmental Science & Policy*, *110*, 14–23. https://doi.org/10.1016/j.envsci.2020.05.008

Brillinger, M., Henze, J., Albert, C., & Schwarze, R. (2021). Integrating nature-based solutions in flood risk management plans: A matter of individual beliefs? *Science of the Total Environment*, *795*, 148896. https://doi.org/10.1016/j.scitotenv.2021.148896

Burns, M. J., Schubert, J. E., Fletcher, T. D., & Sanders, B. F. (2015). Testing the impact of at-source stormwater management on urban flooding through a coupling of network and overland flow models. *WIREs Water*, *2*, 291–300. https://doi.org/10.1002/wat2.1078

Calder, I. R., & Aylward, B. (2006). Moving to an evidence-based approach to watershed and integrated flood management. *Water International*, *31*(1), 87–99. https://doi.org/10.1080/02508060608691918

Calliari, E., Staccione, A., & Mysiak, J. (2019). An assessment framework for climate-proof nature-based solutions. *Science of the Total Environment*, *656*, 691–700. https://doi.org/10.1016/j.scitotenv.2018.11.341

Cannon, T., & Müller-Mahn, D. (2010). Vulnerability, resilience and development discourses in context of climate change. *Natural Hazards*, *55*, 621–635. https://doi.org/10.1007/s11069-010-9499-4

Carina, E., & Keskitalo, H. (2020). What can an understanding of the changing small-scale forest owner contribute to rural studies? The Swedish case. *Small-Scale Forestry*, *19*, 129–143. https://doi.org/10.1007/s11842-019-09427-3

Carrick, J., Rahim, M. S. A. B. A., Adjei, C., Kalee, H. H. A., Banks, S. J., Bolam, F. C., Campos, L. I. M., Clark, B., Cowton, J., Domingos, I. F. N., Golicha, D. D., Gupta, G., Grainger, M., Hasanaliyeva, G., Hodgson, D. J., Lopez-Capel, E., Magistrali, A. J., Merrell, I. G., Oikeh, I., … Stewart, G. (2019). Is planting trees the solution to reducing flood risks? *Journal of Flood Risk Management*, *12*, e12484. https://doi.org/10.1111/jfr3.12484

Chang, C.-T. (2008). Introduction of a tradeable flood mitigation permit system. *Environmental Science & Policy*, *11*(4), 329–335. https://doi.org/10.1016/j.envsci.2007.11.002

CMS. (2017). *Natural flood management—Six case studies from the catchment of the Stroud River Frome*. CMS Retrieved from http://www.cmscoms.com/?p=9755

Cohen, A., & Davidson, S. (2011). The watershed approach: Challenges, antecedents, and the transition from technical tool to governance unit. *Water Alternatives*, *4*(1), 1–14.

Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., Maginnis, S., Maynard, S., Nelson, C. R., Renaud, F. G., Welling, R., & Walters, G. (2019). Core principles for successfully implementing and upscaling nature-based solutions. *Environmental Science & Policy*, *98*, 20–29. https://doi.org/10.1016/j.envsci.2019.04.014

Collentine, D., & Futter, M. N. (2018). Realising the potential of natural water retention measures in catchment flood management: Trade-offs and matching interests. *Journal of Flood Risk Management*, *11*, 76–84. https://doi.org/10.1111/jfr3.12269

Connelly, A., Snow, A., Carter, J., & Lauwerijssen, R. (2020). What approaches exist to evaluate the effectiveness of UK-relevant natural flood management measures? *A Systematic Map Protocol. Environmental Evidence*, *9*, 11–13. https://doi.org/10.1186/s13750-020-00192-x

Constanza, R. (2010). The value of a restored earth and its contribution to a sustainable and desirable future. In F. A. Comin (Ed.), *Ecological restoration: A global challenge* (pp. 78–90). Cambridge University Press.

Cooper, M. M. D., Patil, S. D., Nisbet, T. R., Thomas, H., Smith, A. R., & McDonald, M. A. (2021). Role of forested land for natural flood management in the UK: A review. *WIREs Water*, *8*, e1541. https://doi.org/10.1002/wat2.1541

Cuillo, A., Kwakkel, J. H., de Bruijn, K. M., Doorn, N., & Klijn, F. (2020). Efficient or fair? Operationalizing ethical principles in flood risk management: A case study on the Dutch-German Rhine. *Risk Analysis*, *40*, 1844–1862. https://doi.org/10.1111/risa.13527

Dadson, S. J., Hall, J., Murgatroyd, A., Acreman, M., Bates, P., Beven, K., Heathwaite, L., Holden, J., Holman, I. P., Lane, S. N., O'Connell, E., Penning-Rowsell, E., Reynard, N., Sear, D., Thorne, C., & Wilby, R. (2017). A restatement of the natural science evidence concerning catchment-based 'natural' flood management in the UK. *Proceedings of the Royal Society A – Mathematical, Physical and Engineering Sciences*, *473*, 1–19. https://doi.org/10.1098/rspa.2016.0706

Di Baldassarre, G., Viglione, A., Carr, G., Kuil, L., Yan, K., Brandimarte, L., & Blöschl, G. (2015). Debates—Perspectives on socio-hydrology: Capturing feedbacks between physical and social processes. *Water Resources Research*, *51*(6), 4770–4781. https://doi.org/10.1002/2014WR016416

Disse, M., Johnson, T. G., Leandro, J., & Hartmann, T. (2020). Exploring the relation between flood risk management and flood resilience. *Water Security*, *9*, 100059. https://doi.org/10.1016/j.wasec.2020.100059

Dixon, S. J., Sear, D. A., Odoni, N. A., Sykes, T., & Lane, S. N. (2016). The effects of river restoration on catchment scale flood risk and flood hydrology. *Earth Surface Processes and Landforms*, *41*, 997–1008. https://doi.org/10.1002/esp.3919

Dunham, J. B., Angermeier, P. L., Crausbay, S. D., Cravens, A. E., Gosnell, H., McEvoy, J., Moritz, M. A., Raheem, N., & Sanford, T. (2018). Rivers are social-ecological systems: Time to integrate human dimensions into riverscape ecology and management. *WIREs Water*, *5*, e1291. https://doi.org/10.1002/wat2.1291

EA. (2009). *Achieving more: Operational flood storage areas and biodiversity—Final report*. Environment Agency.

Eder, M., Löschner, L., Herrnegger, M., Hogl, K., Nordbeck, R., Scherhaufer, P., Schober, B., Seher, W., Wesemann, J., Zahnt, N., & Habersack, H. (2022). RegioFEM—Applying a floodplain evaluation method to support a future-oriented flood risk management (part II). *Journal of Flood Risk Management*, *15*(1), e12758. https://doi.org/10.1111/jfr3.12758

EU. (2014). *Policy document on natural water retention measures. Office for Official Publications of the European Communities*. European Commission.

EU. (2021). *Communication from the commission to the European Parliament, the council, the European economic and social committee and the committee of the regions: Forging a climate-resilient Europe – The new EU strategy on adaptation to climate change. COM/2021/82*. European Commission.

Frantzeskaki, N. (2019). Seven lessons for planning nature-based solutions in cities. *Environmental Science & Policy*, *93*, 101–111. https://doi.org/10.1016/j.envsci.2018.12.033

Frantzeskaki, N., & McPhearson, T. (2021). Mainstream nature-based solutions for urban climate resilience. *BioScience*, *72*, 113–115. https://doi.org/10.1093/biosci/biab105

Garvey, A., & Paavola, J. (2022). Community action on natural flood management and the governance of a catchment-based approach in the UK. *Environmental Policy and Governance*, *32*(1), 3–16. https://doi.org/10.1002/eet.1955

Green, C. (2010a). Towards sustainable flood risk management. *International Journal of Disaster Risk Science*, *1*(1), 33–43.

Green, C. (2010b). The practice of power: Governance and flood risk management. In G. Pender & H. Faulkner (Eds.), *Flood risk management and science* (pp. 357–385). Wiley.

Green, C. (2014). Competent authorities for the flood risk management plan—Reflections on flood and spatial planning in England. *Journal of Flood Risk Management*, *10*(2), 195–204. https://doi.org/10.1111/jfr3.12097

Green, C., & Anton, B. (2010). Why is Germany 30 years ahead of England? *International Journal of Water*, *6*(3), 195–212.

Green, D., O'Donnell, E., Johnson, M., Slater, L., Throne, C., Zheng, S., Stirling, R., Chan, F. K. S., Li, L., & Boothroyd, R. J. (2022). Green infrastructure: The future of urban flood risk management? *WIREs Water*, *8*, e1560.

Hartmann, T. (2011). *Clumsy floodplains: Responsive land policy for extreme floods*. Taylor & Francis.

Hartmann, T., Slavikova, L., & McCarthy, S. (Eds.). (2019). *Nature-based flood risk management on private land*. Springer.

Hartmann, T., Slavíková, L., & Wilkinson, M. (Eds.). (2022). *Spatial flood risk management: Implementing catchment-based retention and resilience on private land*. Eward Elgar Publishing.

Hewett, C. J. M., Wilkinson, M. E., Jonczyk, J., & Quinn, P. F. (2020). Catchment systems engineering: An holistic approach to catchment management. *WIREs Water*, *7*, e1417. https://doi.org/10.1002/wat2.1417

Hodgson, G. M. (2006). What are institutions? *Journal of Economic Issues*, *40*, 1–25.

Holstead, K. L., Kenyon, W., Rouillard, J. J., Hopkins, J., & Galán-Díaz, C. (2017). Natural flood management from the farmer's perspective: Criteria that affect uptake. *Journal of Flood Risk Management*, *10*, 205–218. https://doi.org/10.1111/jfr3.12129

House of Parliament. (2011). Natural flood management. *Postnote* 396. Retrieved from https://researchbriefings.files.parliament.uk/documents/POST-PN-396/POST-PN-396.pdf

Huang, Y., Tian, Z., Ke, Q., Liu, J., Irannezhad, M., Fan, D., Hou, M., & Sun, L. (2020). Nature-based solutions for urban pluvial flood risk management. *WIREs Water*, *7*, e1421. https://doi.org/10.1002/wat2.1421

Hudson, P., Pham, M., & Bubeck, P. (2019). An evaluation and monetary assessment of the impact of flooding on subjective well-being across genders in Vietnam. *Climate and Development*, *11*, 623–637. https://doi.org/10.1080/17565529.2019.1579698

Iacob, O., Brown, I., & Rowan, J. (2017). Natural flood management, land use and climate change trade-offs: The case of Tarland catchment, Scotland. *Hydrological Sciences Journal*, *62*, 1931–1948. https://doi.org/10.1080/02626667.2017.1366657

Iacob, O., Rowan, J. S., Brown, I., & Ellis, C. (2014). Evaluating wider benefits of natural flood management strategies: An ecosystem-based adaptation perspective. *Hydrology Research*, *45*, 774–787. https://doi.org/10.2166/nh.2014.184

Jakubinsky, J., Prokopová, M., Raška, P., Salvati, L., Bezak, N., Cudlín, O., Purkyt, J., Vezza, P., Comporeale, C., Danek, J., Pástor, M., & Lepeska, T. (2021). Managing floodplains using nature-based solutions to support multiple ecosystem functions and services. *WIREs Water*, *8*, e1545. https://doi.org/10.1002/wat2.1545

Kay, A. L., Old, G. H., Bell, V. A., Davies, H. N., & Trill, E. J. (2019). An assessment of the potential for natural flood management to offset climate change impacts. *Environmental Research Letters*, *14*, 044017. https://doi.org/10.1088/1748-9326/aafdbe

Kiss, B., Sekulova, F., Hörschelmann, K., Salk, C. F., Takahashi, W., & Wamsler, C. (2022). Citizen participation in the governance of nature-based solutions. *Environmental Policy and Governance*, *32*(3), 247–272. https://doi.org/10.1002/eet.1987

Kuhlicke, C., Seebauer, S., Hudson, P., Begg, C., Bubeck, P., Dittmer, C., Grothmann, T., Heidenreich, A., Kreibich, H., Lorenz, D. F., Masson, T., Reiter, J., Thaler, T., Thieken, A. H., & Bamberg, S. (2020). The behavioral turn in flood risk management, its assumptions and potential implications. *WIREs Water*, *7*, e1418. https://doi.org/10.1002/wat2.1418

Lane, S. (2017). Natural flood management. *WIREs Water*, *4*, e1211. https://doi.org/10.1002/wat2.1211

Löschner, L., Eder, M., Herrnegger, M., Hogl, K., Nordbeck, R., Scherhaufer, P., Schober, B., Seher, W., Wesemann, J., Zahnt, N., & Habersack, H. (2022). RegioFEM—Informing future-oriented flood risk management at the regional scale (part I). *Journal of Flood Risk Management*, *15*(1), e12754. https://doi.org/10.1111/jfr3.12754

Lukes, S. (1974). *Power: A radical view*. Macmillan.

Lundqvist, J., & Falkenmark, M. (2000). Focus on upstream-downstream conflicts of interests. *Water International*, *25*(2), 168–171. https://doi.org/10.1080/02508060008686814

Machac, J., Hartmann, T., & Jilkova, J. (2018). Negotiating land for flood risk management: Upstream-downstream in the light of economic game theory. *Journal of Flood Risk Management*, *11*(1), 66–75. https://doi.org/10.1111/jfr3.12317

Martin, J. G. C., Scolobig, A., Linnerooth-Bayer, J., Liu, W., & Balsiger, J. (2021). Catalyzing innovation: Governance enablers of nature-based solutions. *Sustainability*, *13*(4), 1971. https://doi.org/10.3390/su13041971

Matczak, P., & Hegger, D. (2021). Improving flood resilience through governance strategies: Gauging the state of the art. *WIREs Water*, *8*(4), e1532. https://doi.org/10.1002/wat2.1532

McCarthy, S., Viavattene, C., Sheehan, J., & Green, J. (2018). Compensatory approaches and engagement techniques to gain flood storage in England and Wales. *Journal of Flood Risk Management*, *11*, 85–94. https://doi.org/10.1111/jfr3.12336

Metcalfé, P., Beven, K., Hankin, B., & Lamb, R. (2017). A modelling framework for evaluation of the hydrological impacts of nature-based approaches to flood risk management, with application to in-channel interventions across a 29-km^2 scale catchment in the United Kingdom. *Hydrological Processes*, *31*, 1734–1748. https://doi.org/10.1002/hyp.11140

Milman, A., Warner, B. P., Chapman, D. A., & Short Gianotti, A. G. (2018). Identifying and quantifying landowner perspectives on integrated flood risk management. *Journal of Flood Risk Management*, *11*, 34–47. https://doi.org/10.1111/jfr3.12291

Morris, J., Beedell, J., & Hess, T. M. (2016). Mobilising flood risk management services from rural land: Principles and practice. *Journal of Flood Risk Management*, *9*, 50–68. https://doi.org/10.1111/jfr3.12110

Nicholson, A. R., O'Donnell, G. M., Wilkinson, M. E., & Quinn, P. F. (2020). The potential of runoff attenuation features as a natural flood management approach. *Journal of Flood Risk Management*, *13*, e12565. https://doi.org/10.1111/jfr3.12565

North, D. C. (1990). *Institutions, institutional change and economic performance*. Cambridge University Press.

Ostrom, E. (1986). An agenda for the study of institutions. *Public Choice*, *48*(1), 3–25.

Paavola, J., & Primmer, E. (2019). Governing the provision of insurance value from ecosystems. *Ecological Economics*, *164*, 106346. https://doi.org/10.1016/j.ecolecon.2019.06.001

Potočki, K., Hartmann, T., Slavíková, L., Collentine, D., Veidemane, K., Raška, P., Barstad, J., & Evans, R. (2022). Land policy for flood risk management—Towards a new working paradigm. Earth's. *Futures*, *10*(4), e2021EF002491. https://doi.org/10.1029/2021EF002491

Putnam, R. D. (2001). *Bowling alone. The collapse and revival of American community*. Simon & Schuster.

Quinn, C. H., Fraser, E. D. G., Hubacek, K., & Reed, M. S. (2010). Property rights in UK uplands and the implications for policy and management. *Ecological Economics*, *69*, 1355–1363. https://doi.org/10.1016/j.ecolecon.2010.02.006

Raška, P., Bezak, N., Ferreira, C. S. S., Kalantari, Z., Banasik, K., Bertola, M., Bourke, M., Cerdà, A., Davids, P., Madruga de Brito, M., Evans, R., Finger, D. C., Halbac-Cotoara-Zamfir, R., Housh, M., Hysa, A., Jakubínský, J., Solomun, M. K., Kaufman, M., Keestra, S., … Hartmann, T. (2022). Identifying barriers for nature-based solutions in flood risk management: An interdisciplinary overview using expert community approach. *Journal of Environmental Management*, *310*, 114725.

Raymond, C. M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Razvan Nita, M., Geneletti, D., & Calfapietra, C. (2017). A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environmental Science & Policy*, *77*, 15–24. https://doi.org/10.1016/j.envsci.2017.07.008

Reid, H. (2016). *Community-based adaptation: Mainstreaming into national and local planning*. Routledge.

Rijke, J., van Herk, S., Zevenbergen, C., & Ashley, R. (2012). Room for the river: Delivering integrated river basin management in The Netherlands. *International Journal of River Basin Management*, *10*, 369–382. https://doi.org/10.1080/15715124.2012.739173

Ripiye, N. (2016). Natural flood management applications (NFM): The role of local institutions. PhD Thesis at School of Science, Engineering and Technology Abertay University Dundee, United Kingdom.

Rouillard, J. J., Ball, T., Heal, K. V., & Reeves, A. D. (2015). Policy implementation of catchment-scale flood risk management: Learning from Scotland and England. *Environmental Science & Policy*, *50*, 155–165. https://doi.org/10.1016/j.envsci.2015.02.009

Rust, W., Corstanje, R., Holman, I. P., & Milne, A. E. (2014). Detecting land use and land management influences on catchment hydrology by modelling and wavelets. *Journal of Hydrology*, *517*, 378–389. https://doi.org/10.1016/j.jhydrol.2014.05.052

Satizabal, P., Cornes, I., de Lourdes Melo Zurita, M., & Cook, B. R. (2022). The power of connection: Navigating the constraints of community engagement for disaster risk reduction. *International Journal of Disaster Risk Reduction*, *68*, 102699. https://doi.org/10.1016/j.ijdrr.2021.102699

Schanze, J. (2017). Nature-based solutions in flood risk management—Buzzword or innovation? *Journal of Flood Risk Management*, *10*, 281–282. https://doi.org/10.1111/jfr3.12318

Scheidl, C., Heiser, M., Kamper, S., Thaler, T., Klebinder, K., Nagl, F., Lechner, V., Markart, G., Rammer, W., & Seidl, R. (2020). The influence of climate change and canopy disturbances on landslide susceptibility in headwater catchments. *Science of the Total Environment*, *742*, 140588. https://doi.org/10.1016/j.scitotenv.2020.140588

Sebald, J., Senf, C., Heiser, M., Scheidl, C., Pflugmacher, D., & Seidl, R. (2019). The effects of forest cover and disturbance on torrential hazards: Large-scale evidence from the eastern Alps. *Environmental Research Letters*, *14*, 114032. https://doi.org/10.1088/1748-9326/ab4937

Seddon, N., Chausson, A., Berry, P., Girardin, C. A. J., Smith, A., & Turner, B. (2020). Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society, B: Biological Sciences*, *375*(1794), 20190120. https://doi.org/10.1098/rstb.2019.0120

Seher, W., & Löschner, L. (2018). Balancing upstream–downstream interests in flood risk management: Experiences from a catchment-based approach in Austria. *Journal of Flood Risk Management*, *11*, 56–65. https://doi.org/10.1111/jfr3.12266

Smith, B., Clifford, N. J., & Mant, J. (2014). The changing nature of river restoration. *WIREs Water*, *1*, 249–261. https://doi.org/10.1002/wat2.1021

Snel, K. A. W., Priest, S. J., Hartmann, T., Witte, P. A., & Geertman, S. C. M. (2021). 'Do the resilient things.' Residents' perspectives on responsibilities for flood risk adaptation in England. *Journal of Flood Risk Management*, *14*(3), e12727. https://doi.org/10.1111/jfr3.12727

Sudmeier-Rieux, K., Arce-Mojica, T., Boehmer, H. J., Doswald, N., Emerton, L., Friess, D. A., Galvin, S., Hagenlocher, M., James, H., Laban, P., Lacambra, C., Lange, W., McAdoo, B. G., Moos, C., Mysiak, J., Narvaez, L., Nehren, U., Peduzzi, P., Renaud, F. G., … Walz, Y. (2021). Scientific evidence for ecosystem-based disaster risk reduction. *Nature Sustainability*, *4*, 803–810. https://doi.org/10.1038/s41893-021-00732-4

Taylor, A. C. (2009). Sustainable urban water management: Understanding and fostering champions of change. *Water Science and Technology*, *59*(3), 883–891. https://doi.org/10.2166/wst.2009.033

te Wierik, S. A., Gupta, J., Cammeraat, E. L. H., & Artzy-Randrup, Y. A. (2020). The need for green and atmospheric water governance. *WIREs Water*, *7*, e1406. https://doi.org/10.1002/wat2.1406

Thaler, T. (2014). Developing partnership approaches for flood risk management: Implementation of inter-local co-operations in Austria. *Water International*, *39*, 1018–1029. https://doi.org/10.1080/02508060.2014.992720

Thaler, T., Doorn, N., & Hartmann, T. (2020). Justice of compensation for spatial flood risk management—Comparing the flexible Austrian and the structured Dutch approach. *DIE ERDE – Journal of the Geographical Society of Berlin*, *151*(2–3), 104–115. https://doi.org/10.12854/erde-2020-467

Thaler, T., & Levin-Keitel, M. (2016). Multi-level stakeholder engagement in flood risk management—A question of roles and power: Lessons from England. *Environmental Science & Policy*, *55*, 292–301. https://doi.org/10.1016/j.envsci.2015.04.007

Thaler, T., Löschner, L., & Hartmann, T. (2017). The introduction of catchment-wide co-operations: Scalar reconstructions and transformation in Austria in flood risk management. *Land Use Policy*, *68*, 563–573. https://doi.org/10.1016/j.landusepol.2017.08.023

Thaler, T., Priest, S., & Fuchs, S. (2016). Evolving inter-regional co-operation in flood risk management: Distances and types of partnership approaches in Austria. *Regional Environmental Change*, *16*, 841–853. https://doi.org/10.1007/s10113-015-0796-z

Thorne, C. R., Lawson, E. C., Ozawa, C., Hamlin, S. L., & Smith, L. A. (2018). Overcoming uncertainty and barriers to adoption of blue-Green infrastructure for urban flood risk management. *Journal of Flood Risk Management*, *11*, S960–S972. https://doi.org/10.1111/jfr3.12218

Thorslund, J., Jarsjö, J., Jaramillo, F., Jawitz, J. W., Manzoni, S., Basu, N. B., Chalov, S. R., Cohen, M. J., Creed, I. F., Goldenberg, R., Hylin, A., Kalantari, Z., Koussis, A. D., Lyon, S. W., Mazi, K., Mard, J., Persson, K., Pietron, J., Prieto, C., … Destouni, G. (2017). Wetlands as large-scale nature-based solutions: Status and challengesfor research, engineering and management. *Ecological Engineering*, *108*, 489–497. https://doi.org/10.1016/j.ecoleng.2017.07.012

Uittenbroek, C. J., Janssen-Jansen, L. B., & Runhaar, H. A. C. (2013). Mainstreaming climate adaptation into urban planning: Overcoming barriers, seizing opportunities and evaluating the results in two Dutch case studies. *Regional Environmental Change*, *13*, 399–411. https://doi.org/10.1007/s10113-012-0348-8

van Berchum, E. C., Mobley, W., Jonkman, S. N., Timmermans, J. S., Kwakkel, J. H., & Brody, S. D. (2019). Evaluation of flood risk reduction strategies through combinations of interventions. *Journal of Flood Risk Management*, *12*, e12506. https://doi.org/10.1111/jfr3.12506

van Straalen, F., Hartmann, T., & Sheehan, J. (Eds.). (2018). *Property rights and climate change. Land use under changing environmental conditions*. Routledge.

Vitale, C., & Meijerink, S. (2021). Understanding inter-municipal conflict and cooperation on flood risk policies for the metropolitan city of Milan. *Water Alternatives*, *14*(2), 597–618.

Warner, J. F., Wester, P., & Hoogesteger, J. (2014). Struggling with scales: Revisiting the boundaries of river basin management. *WIREs Water*, *1*, 469–481.

Watson, N. (2004). Integrated river basin management: A case for collaboration. *International Journal of River Basin Management*, *2*, 243–257. https://doi.org/10.1080/15715124.2004.9635235

Watson, N. (2015). Factors influencing the frames and approaches of host organizations for collaborative catchment management in England. *Society & Natural Resources*, *28*, 360–376. https://doi.org/10.1080/08941920.2014.945059

Waylen, K. A., Holstead, K. L., Colley, K., & Hopkins, J. (2018). Challenges to enabling and implementing natural flood Management in Scotland. *Journal of Flood Risk Management*, *11*, S1078–S1089. https://doi.org/10.1111/jfr3.12301

Wells, J., Labadz, J. C., Smith, A., & Islam, M. M. (2020). Barriers to the uptake and implementation of natural flood management: A social-ecological analysis. *Journal of Flood Risk Management*, *13*, e125621. https://doi.org/10.1111/jfr3.12561

Werritty, A. (2006). Sustainable flood management: Oxymoron or new paradigm? *Area*, *38*, 16–23.

Wilkinson, M. E., Quinn, P. E., & Welton, P. (2010). Runoff management during the September 2008 foods in the Belford catchment, Northumberland. *Journal of Flood Risk Management*, *3*, 285–295. https://doi.org/10.1111/j.1753-318X.2010.01078.x

Wingfield, T., Macdonald, N., Peters, K., Spees, J., & Potter, K. (2019). Natural flood management: Beyond the evidence debate. *Area*, *51*, 743–751. https://doi.org/10.1111/area.12535

Wohlin, C. (2014). Guidelines for snowballing in systematic literature studies and a replication in software engineering. In *EASE'14*: *Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering*, Vol. 38, pp. 1–10. https://doi.org/10.1145/2601248.2601268

Wolf, S., Pham, M., Matthews, N., & Bubeck, P. (2021). Understanding the implementation gap: Policy-makers' perceptions of ecosystem-based adaptation in Central Vietnam. *Climate and Development*, *13*, 81–94. https://doi.org/10.1080/17565529.2020.1724068

Worldbank. (2018). *Nature-based solutions for disaster risk management*. Worldbank.

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