



Synthesis

A new framework for flood adaptation: introducing the Flood Adaptation Hierarchy

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ABSTRACT. Traditional flood risk paradigms and associated strategies are no longer sufficient to address global flood adaptation challenges due to climate change and continued development in floodplains. The current flood adaptation approach is failing to take advantage of the benefits provided by intact ecosystems and perpetuates social and economic inequities, leaving those who are most vulnerable at highest risk. Rooted in the experiences of the United States, we propose a new framework, the Flood Adaptation Hierarchy, which prioritizes outcomes into six tiers. Overall, the tiers distinguish between nature and nature-based solutions, with preference given to natural ecosystems. The most important outcome in our hierarchy is to avoid risk by protecting and restoring natural floodplains; next, eliminate risk by moving communities away from danger; and then to accommodate water with passive measures and active risk reduction measures. We include, but deprioritize, a defense of community assets using nature-based engineering and hardened engineering. Throughout the hierarchy, we provide guidance on the equity considerations of flood adaptation decision making and highlight “impacts,” “resources,” and “voices” as important equity dimensions. Implementing the framework through an iterative process, using justification criteria to manage movement among tiers, alongside equity considerations, will support adaptation to changing environmental and social conditions and contribute to risk reduction at scale. Though this approach is focused on U.S. flood management and adaptation, prioritizing risk reduction, elimination of risk, and accommodation of hazards over the defense against threats not only has global applicability to flood adaptation, but should also be evaluated for applicability to other climate-driven challenges.

Key Words: *climate adaptation; climate change; ecosystem-based solutions; equity; Flood Adaptation Hierarchy; flood management; flood mitigation; flood risk management; natural flood solutions; nature-based solutions*

INTRODUCTION

Incredible and destructive shifts in precipitation patterns are occurring globally, sea levels are rising, and storm surge records continue to be broken as the climate changes and becomes more volatile. Many communities need to prepare for a future with more water (Wing et al. 2018, Wobus et al. 2019), and for some, the “future” is already here (Mallakpour and Villarini 2015). Past attempts to constrain nature, particularly freshwater and marine systems, created a false sense of security for waterfront communities that increased their risk and vulnerability. Some groups, particularly lower income groups, indigenous groups, and communities of color, are experiencing negative consequences of flooding disproportionately (Shi et al. 2016, Marino 2018, Siders 2019a, 2019b). Using the United States (U.S.) experience with flood management and adaptation as an illustration, we present a framework for flood risk management that prioritizes creating more room for water. Simply put, this means enabling coastal and riverine systems to perform as naturally as possible with little restriction to their dynamism, allowing nature to provide the full suite of direct and indirect benefits to communities (e.g., flood protection, water filtration, sediment transport, carbon sequestration, recreation). Communities and decision makers will need the flexibility to systematically consider the application of a comprehensive spectrum of adaptation strategies in more deliberate ways; there is no single-best solution for all circumstances.

Climate risk is increasing for communities worldwide, and the United States is no exception. Development in riverine, estuarine, and coastal floodplains, coupled with increasing flood frequency

and magnitude, are expected to expose more people and important development to flood risk (Wing et al. 2018). This combination of land-use patterns and climate change has influenced risk profiles in the United States. For example, in a 100-year floodplain, the average homeowner has a 26% chance of being flooded at least once during the span of a 30-year mortgage (U.S. Geological Survey 2010). Because of climate change, flooding in a 100-year floodplain could become 2–5 times more frequent by the end of this century (Wobus et al. 2017). In the United States alone, from 2000 to 2015, flood damages cost \$8 billion annually and floods took more than 100 lives every year (Lam 2018, Johnson et al. 2020). The frequency and intensity of heavy precipitation is increasing in the Northern Great Plains, the Upper Midwest, and the Northeast regions of the United States (U.S. Global Change Research Program 2018). The challenges are not just related to riverine flooding; average global sea levels are expected to increase by 0.15–0.36 m by 2050 and 0.30–1.22 m by 2100, with greater increases possible (e.g., 2.44 m by 2100; U.S. Global Change Research Program 2018). In short, both coastal and inland areas that were not previously vulnerable to flooding in the past are now at risk, such as floodplains in the rural southern United States where low-income residents and racial minorities, including indigenous communities, are over-represented (Tate et al. 2021, Wing et al. 2022). At the same time, rapid development of flood-prone areas is on the rise and this trend is expected to continue, exacerbating challenges to managing flood risk (Winsemius et al. 2016, Bajaj et al. 2017, Cohen 2019). An emerging dimension of the challenge is that risks faced by floodplain communities are not experienced equally and are

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largely driven by both social and economic factors (e.g., median income, historic use, development pressures). These factors can include the socioeconomic and adaptability of a community (Ahern et al. 2005, Alderman et al. 2012), increases in impermeable surfaces (Konrad and Booth 2002), and previous interventions that have altered natural systems (Coleman et al. 1998, Hardy et al. 2018).

Challenges facing U.S. flood adaptation

In the United States, flood adaptation is largely executed through a complex set of tiered public and private-sector institutional interactions, from the federal government down to hyper-local entities and landowners. This multi-level institutional approach to flood management is not unique to the U.S. With many institutional players and interests involved, the result is disjointed flood adaptation responses that focus on engineered solutions, perpetuate socioeconomic inequalities, and cause extensive disruption of ecosystem dynamics. These institutional flood response policies and engineered solutions, along with their unintended consequences, are not socially, economically, or environmentally sustainable (Sutton-Grier et al. 2018, Haigh et al. 2020), and, in fact, are likely to make conditions worse (Munoz et al. 2018, Auerwald et al. 2019). To overcome these shortcomings and reduce the risk of negative consequences (intended or unintended), changes to institutional decision-making processes are needed. Only recently has government begun to reconsider outdated policies and to look for alternatives that support more proactive responses to increasing flood intensities and magnitudes (FEMA 2020). The decision-making processes must more appropriately account for the role of natural ecosystems and processes and expand the suite of engaged stakeholders to purposefully include all those likely to benefit from and be impacted by adaptation measures. New governance processes such as policy development, decision making, and implementation processes, should integrate a nature-first philosophy that is coupled with an intense focus on inclusive engagement and equitable outcomes where and when flood adaptation measures are considered.

There is no systematic decision-making process in which adaptation strategies concurrently consider physical, political, and socioeconomic contexts (Auerwald et al. 2019, Tate and Emrich 2021). In some cases, communities make choices without considering decision-making criteria and in a post-disaster setting, when urgency and politics favor rebuilding in place, constructing sea walls, and installing other hardened engineering options instead of considering broader, systemic implications (Thomsen et al. 2012, Gittman et al. 2015). In other cases, decision-making criteria are limited in scope or favor expedient outcomes and/or those that are perceived to be permanent. For example, some benefit-cost analyses (BCAs) frequently undervalue the protections and benefits provided by nature, are evaluated over short time horizons (e.g., the life of an engineered structure), and do not account for the full suite of environmental and social trade-offs (Shreve and Kelman 2014, Mechler 2016). Fortunately, the Federal Emergency Management Agency (FEMA) changed its BCA guidance to account for the multiple benefits provided by nature and nature-based solutions, making them more competitive and, therefore, more likely to be eligible for funding (FEMA 2020).

Policies at the federal, state, and local levels favor private benefit over public good, which results in development and redevelopment of flood-prone areas (often using federally subsidized flood insurance) and implementation of short-term flood abatement over options that allow communities to accommodate flooding over the long term (Gaul 2019, Siders 2019a). For example, many states have either general or emergency storm recovery permits to fast-track shoreline stabilization and structural repair activities (Bowling 2019, NYSDEC 2020), but do not consider the long-term impacts of these decisions surrounding flood vulnerability. It is time to invest in a more proactive, balanced approach to flood management that considers the risk of future flood exposure from climate change, values nature, reduces vulnerability and inequities, and supports the long-term needs of individuals, institutions, and communities so they can prosper now and in the future (Tyler et al. 2019).

The transition to flood adaptation

In 1990, the Coastal Zone Management Subgroup of the first Intergovernmental Panel on Climate Change (IPCC) released its climate change assessment report, which suggested that the effective adaptation paradigm to handle sea-level rise were to defend (the report used the term “protect”), “accommodate,” or “retreat” (Dronkers et al. 1990). For over 30 years, individuals, communities, and institutions across the globe have used these options to respond to all types of marine and freshwater flooding, in a particular sequence or “hierarchy”: first, to defend the status quo, typically using hardened engineering solutions like sea walls, then to accommodate periods of inundation by modifying structures, and finally, if all else fails, to retreat from flood-prone areas (Klein et al. 2001, Thomsen et al. 2012, Siders 2019a). This approach is failing on multiple fronts, including engineering (Munoz et al. 2018, American Society of Civil Engineers 2021), economic (Smith 2020, NCEI 2022), social (Ashley and Ashley 2008, Cigler 2017, Marino 2018, Siders 2019b, Emrich et al. 2020), and natural systems (Haeuber and Michner 1998, Howard et al. 2017).

Ecosystems, natural dynamics, and equity were seemingly overlooked elements in the initial phase of this adaptation paradigm. In 2009, the International Union for the Conservation of Nature introduced an alternative, the Ecosystem-based Adaptation paradigm (Colls et al. 2009), which drew attention to the capacity of natural and restored ecosystems to buffer against the effects of climate change and began to recognize the social implications, including inequity. In response to the emerging realities of climate change, another framework to clearly identify ecosystem-based solutions and integrate equity was released in 2017 (FEBA 2017). Although these qualification criteria were welcomed contributions, guidance remains a need particularly regarding how to: (1) select from a broad range of flood adaptation strategies; and (2) integrate equity evaluations. This is problematic because ecosystem-based solutions may not be viable in many situations, and flood risk management programs are under escalating scrutiny for their role in creating or perpetuating deep inequities (Siders 2019b, Wing et al. 2022).

The early failures of past adaptation paradigms have deepened social, economic, and environmental problems (Haigh et al. 2020, Wing et al. 2022). As floods increase in severity and response efforts intensify, existing social stresses and structural inequities

are compounded. Because of the perpetuation of historically racist and biased institutional decision-making systems, lower-income groups, communities of color, and indigenous communities often lack access to resources and have little to no opportunity to participate in decisions about flood management (Anguelovski et al. 2016, Koslov 2016, Shi et al. 2016, Marino 2018, Siders 2019b, Wing et al. 2022). The economic implications of flood recovery are escalating because of the rising costs of replacing newly vulnerable and repetitively impacted development and implementing new defenses. An increasing body of evidence demonstrates that floods have negative impacts to society via individual health implications, both physical (e.g., disease, injury, death) and mental (e.g., depression, anxiety, post-traumatic stress; Ahern et al. 2005, Alderman et al. 2012, Walker-Springett et al. 2017). Finally, the environmental toll of historic defense measures is significant and continues to mount, as these structures undermine the naturally occurring landscape features and processes that are known to reduce physical and economic damage during major storms (Coleman et al. 1998, Del Valle et al. 2019). As the number of major storm events, the amount of precipitation, and water levels rise because of climate change, traditional flood response efforts (e.g., hardening and accommodation) continue to have negative environmental, economic, and social consequences (Gittman et al. 2016a), some intended, others unintended. Although infrastructure such as sea walls and levees can be built relatively quickly, they are also known to fail, sometimes catastrophically, and to impede the natural functioning of ecosystems, adversely affecting the surrounding communities (Suckall et al. 2019).

THE CASE FOR A NEW FLOOD ADAPTATION FRAMEWORK

Paradigms, or theoretical models, are heuristic tools that simplify complex relationships. Decision-making tools, such as frameworks, are then developed to differentiate among or organize strategies, practices, outcomes, trade-offs, and other attributes. Meadows (1999) suggests that societal breakthroughs in response to large-scale challenges (e.g., flooding) occur through the “transcendence” of existing paradigms or adopting a new context (i.e., world view) beyond those used to develop existing philosophies.

At least two principal factors have emerged to create a transcending moment in flood management and adaptation. One factor is climate change, as evident within the dramatic and sustained increases of flood occurrence, intensity, and impacts to both natural and social systems. In response to changing flood conditions, a new set of response paradigms are evolving around ecosystems, nature and nature-based solutions (Haeuber and Michner 1998, Colls et al. 2009, Cohen-Shacham et al. 2016, FEBA 2017, Chapman et al. 2018). A second factor is the increasing realization that existing flood management and response paradigms are largely inequitable. Those most vulnerable and impacted carry the greatest burden and may be more susceptible to perturbations than prior to the flood event. Responses to the equity implications are just beginning to emerge but clear solutions have yet to be agreed upon (Finucane et al. 2020, Elias et al. 2021).

In the framework that follows, we do not promote or describe a new, transcending flood management paradigm; rather, we

introduce a new framework, which we view as a decision-making tool that differentiates among and prioritizes outcomes and that may guide flood management and adaptation. We advocate for a new approach that raises key considerations about social inequality and prioritizes the conservation and restoration of natural systems in a hierarchical framework. The first distinguishing element of our flood adaptation framework is that the protection and restoration of intact ecosystems is prioritized over all other adaptation strategies, including nature-based and grey infrastructure, which we argue greatly differs from natural ecosystems.

The second distinguishing feature of our framework is that it establishes a tight link between nature and people through an equity lens. Using a series of embedded questions related to impacts, resources, and voices, we identified the relationships between adaptation strategies and equity and provide guidance on how to consider the challenges and opportunities surrounding equity during application of the framework. These unique contributions are intended to support implementation of the flood adaptation paradigm and may outline a replicable pathway to desirable social-ecological outcomes.

Our proposed framework recognizes and leverages the inherent flood protection and other benefits provided by healthy, intact ecosystems, while also raising key questions surrounding social equity for each available option. What follows is further justification for why a nature-first perspective is necessary, key guidance on how to integrate equity, and descriptions of the six framework tiers. We close with U.S. examples of how the framework might be integrated into institutional decision making through (dis)incentive programming, identification of future research needs, and potential non-flooding applications.

Prioritizing nature

Natural areas can serve as important buffers between people and water, provide additional ecosystem services, and enable communities to naturally adapt to changing environmental conditions (Colls et al. 2009, Narayan et al. 2017, Tyler et al. 2019, Glick et al. 2020). Prioritizing nature is an obvious flood mitigation strategy from a conservation perspective, but the benefits of this approach move beyond environmental benefits, as nature and people are linked (Díaz et al. 2006). Healthy, functional floodplains provide many services and co-benefits to human and natural communities (Task Force on the Natural and Beneficial Functions of the Floodplain 2002, ASFPM 2008, Colls et al. 2009, Edwards et al. 2013, Glick et al. 2020). For example, natural floodplains and wetlands convey and store water (Barbier 2015), establish physical space between people and flooding, sequester carbon (Howard et al. 2017), allow groundwater recharge, enhance biodiversity (Scyphers et al. 2015, Hunt et al. 2018, Lawrence et al. 2018), dampen waves (Barbier et al. 2008), filter water to maintain water quality (Chen et al. 2019, Harvey et al. 2019), contain agricultural and forestry resources, and provide recreational opportunities and other co-benefits. These benefits can reduce the costs of water filtration and flood damage, generate revenue for outdoor recreation and tourism, and improve mental health and social cohesion (Sandifer et al. 2015, Sutton-Grier and Sandifer 2019).

An emphasis on nature does not marginalize or deprioritize people; rather, it is a more effective approach to mitigating risk

to people. Key considerations in flood management are the protective benefits that may accrue to individuals and communities who live in and around healthy floodplains. These benefits include the avoidance of potential impacts, such as property damage from storms (Arkema et al. 2013, Narayan et al. 2016a), negative health implications from flooding (e.g., anxiety, mold exposure), and social and economic disruption from floods. Co-benefits are explicitly tied to the additional benefits a community receives from natural infrastructure approaches, which often are not included in a traditional decision-making frame (such as a benefit-cost analysis). Co-benefits are wide ranging and include added recreational opportunities (e.g., fishing or birdwatching; O'Brien et al. 2017), water quality improvements (Chen et al. 2019), and more open space (Kim and Song 2019). An evolving body of research is exploring the additional co-benefits of green spaces, particularly those related to mental health and social cohesion (Díaz et al. 2006, Barbier et al. 2008, Grabowski et al. 2012, Sandifer et al. 2015, Scyphers et al. 2015, Sutton-Grier et al. 2018, Sutton-Grier and Sandifer 2019).

Natural systems can provide better habitat conditions between storms than built systems (Sebastian-Gonzalez and Green 2016, Chapman et al. 2018, Hunt et al. 2018, Lawrence et al. 2018), as well as outperforming built and engineered solutions during storms (Del Valle et al. 2019, Glick et al. 2020). For example, an assessment suggested that properties in coastal North Carolina that were protected by bulkheads incurred more damage and adjacent shorelines suffered more erosion during Hurricanes Irene and Matthew than properties protected by natural shorelines (Gittman et al. 2014, Smith and Scyphers 2019). Coastal wetlands in the northeast United States protected communities from a potential \$625 million in losses during Hurricane Sandy (Narayan et al. 2017). Arkema et al. (2013) suggest that if coastal habitats are left intact, risk to the property and people most vulnerable to flooding can be reduced by half. Though we need a greater understanding of the habitat and protection limits of constructed and natural solutions (Chapman et al. 2018), there is compelling evidence to support natural features and systems as effective risk-reduction measures (Watson et al. 2016, Narayan et al. 2017, Del Valle et al. 2019, Sutton-Grier and Sandifer 2019, Glick et al. 2020). On top of these considerations, there are both immediate and long-term costs of developing and maintaining infrastructure (Narayan et al. 2016a, 2016b), as well as the costs associated with both temporarily and permanently moving people out of harm's way as waters rise.

Integrating equity issues

Environmental equity is defined by the University of California at Los Angeles Luskin Center of Innovation as “protection from environmental hazards as well as access to environmental benefits for all, regardless of income, race, and other characteristics (2021).” There are no easy solutions to address systemic inequities within flood adaptation. The current flooding paradigms of “defend, accommodate, or retreat” and ecosystem-based adaptation do not fully integrate social equity with flood adaptation. In the framework that follows, we identify where equity issues may be integrated with the implementation of flood adaptation. To achieve this integration, we focus on three pathways through which equity functions in flood management: (1) who is impacted (impacts); (2) who receives resources before

and after a flooding event (resources); and (3) whose voices are included in decision making that influences land use, planning, and management (voices). Below, we use these pathways as a frame to contribute guiding questions for practitioners alongside each outcome category, or tier, of the proposed framework, in order to help integrate equity into decision pathways. Although this paper does not offer a comprehensive solution on how to integrate equity, the proposed equity pathways—impacts, resources, and voices—are posed as questions that may guide researchers and practitioners in fostering more equitable approaches and outcomes.

Three equity pathways

1. **Impacts:** Climate change is exacerbating flooding and extreme water events for all who live in floodplains. In the United States, there is a mix of wealth in floodplain communities, but those with socioeconomic vulnerability or less wealth experience more stress and lose a greater proportion of their wealth during and after a flooding event (Shonkoff et al. 2011, Muñoz and Tate 2016, Hardy et al. 2018, Emrich et al. 2020). Because floodplain communities tend to have repeat events, inequities can be compounded over time. For example, poorer communities of color received less protective infrastructure (fewer levees) for flood protection prior to Hurricane Katrina, and more affluent white communities received priority for (re)construction after the event, even when they experienced less flooding (Kates et al. 2006). Furthermore, low-income communities and communities of color may face discriminatory policies that exacerbate flood impacts. For example, the city of Cedar Rapids, Iowa, responded to flooding in 2008 by implementing new flood protections for the city's central business district on the east side of the Cedar River, but did not provide new protections for vulnerable populations and workforce housing on the west side (Cedar Rapids 2021, Tate and Emrich 2021). When considering flood adaptation strategies for equitable impacts, the overarching questions are the following: Who is benefiting or being harmed, and how are these benefits and harms comparatively experienced? What are the short and long-term impacts from flooding? Who is disproportionately impacted throughout the disaster and recovery?
2. **Resources:** Resources are not distributed evenly before or after flood events (Hardy et al. 2018). Around the world, the communities located in floodplains tend to be poorer (Pelling and Garschagen 2019). A recent nationwide analysis on buyouts and federal funding in the United States (Elliott et al. 2020) identified a disconnect between communities that experience flooding events and communities that receive federal buyout opportunities, highlighting racial inequality. How resources are allocated to run buyout programs and then from the buyout programs to communities in need varies greatly and impacts how the programs are realized in different communities. For example, federal funding sources, such as the Hazard Mitigation Grant Program run by FEMA in the United States, provides 75% of funding for projects but requires a local cost-share of 25%, which can be challenging for communities with a weaker tax base or smaller municipal budget. To examine the resources dimension of flood adaptation, the overarching questions

are these: What are specific community needs, and in what ways do some communities need more support than others? Which people and communities have pre-flood capacity or have the ability to acquire outside resources, and which ones do not? How do programs that administer adaptation efforts such as buyouts incorporate equity considerations into their process and funding allocations? In what ways can resource allocations, both financial and administrative, support just adaptation efforts for under-resourced communities in floodplains? What are specific community needs, and in what ways do some communities need more support than others?

3. **Voices:** People within historically excluded groups, such as low-income and indigenous communities and communities of color, have limited opportunity to influence the governance process writ large, including with regard to flooding (Hardy et al. 2018). A diversity of perspectives is necessary to find equitable flood adaptation solutions (Shi et al. 2016, Pelling and Garschagen 2019, Maldonado et al. 2020), and these perspectives must be meaningfully represented in the planning, decision making, and implementation phases for adaptation projects to succeed. For example, green infrastructure planning and siting often privilege known actors or communities over historically excluded communities of color (Hoover et al. 2021). To effectively consider the voices of people and communities within the flood adaptation process, the overarching questions are the following: Whose interests are being represented, and do people and communities have a genuine opportunity to be included in the decision-making processes? What are the mechanisms to incorporate local voices and concerns?

Overarching equity considerations must be integrated into any adaptation strategy. These questions can be used by municipalities, federal disaster response institutions, or any other community leaders. We propose general equity integration questions here and add more specifics in tandem with the framework tiers below. Although these questions do not provide an exhaustive list of considerations, we believe that if these types of questions are not considered, any solution will ultimately fail, particularly on the equity fronts.

A NEW FLOOD ADAPTATION FRAMEWORK

A multitude of paradigms and embedded strategies can be applied in flood adaptation scenarios, ranging from resistance (e.g., command and control) to transformative (e.g., allowing new realities or conditions to develop or occur; Cook et al. 2016, Peterson St-Laurent et al. 2021). It is unlikely that the application of any single paradigm or embedded strategy will overcome the array of social-ecological challenges facing flood adaptation. However, evaluations of flood management paradigms and strategies should broadly consider the following: (1) Does the approach keep people and property safe? (2) What are the immediate and long-term costs of developing, maintaining, or moving infrastructure? (3) Are there additional co-benefits of a particular approach? (4) What are the impacts on, or the benefits to, the surrounding ecological system? These unprioritized considerations are offered as a starting point from which a robust problem evaluation framework can emerge, shifting away from

ineffective approaches. Typical responses to flood risk and post-flood recovery efforts in the developed world do not adequately address these considerations, often keep people in harm's way, and miss opportunities to leverage nature to reduce risk and provide essential habitat (Grabowski et al. 2012, Narayan et al. 2016a, 2016b, 2017, Del Valle et al. 2019, Tyler et al. 2019). In recognition of these realities, the perspectives described below are largely aligned with the ecosystem-based adaptation paradigm (Colls et al. 2009, Scarano 2017) with strong connections to the “defend, accommodate, or retreat” paradigm and associated strategies (Dronkers et al. 1990).

A prioritized framework, such as a hierarchical framework, is a tool that can help decision makers evaluate multiple paradigms and embedded strategies within a large complex system or across a gradient of many systems (Roni et al. 2002, Dicks et al. 2014, Driscoll et al. 2018, Stigall 2019). We propose the following flood adaptation hierarchy as a decision framework that places the highest priority on natural ecosystems over engineered solutions. This framework acknowledges clear and viable roles for other strategies (e.g., altering existing infrastructure through natural or engineered measures) to accommodate or defend against periodic inundation (see Table 1). Assigning different values to outcomes can affect decisions that consider benefits and costs, longevity of a solution, characteristics of a particular location, and individual property versus community holdings.

For our proposed flood adaptation framework to be effective, it must include several concurrent and integrated concepts. The implementation of this hierarchy requires individual property owners, community decision makers, and response/recovery entities to consider the frequency, duration, and magnitude of risks, potential impacts, proposed solutions, socioeconomic factors and trade-offs, and the integration of iterative assessments (Glavovic 2008, Auerswald et al. 2019, Doberstein et al. 2019, Tyler et al. 2019). This means prioritizing solutions with a lifespan over 100 years that promote healthy, natural systems, eliminating criteria that favor expediency and/or short-term solutions, and accounting for future conditions (e.g., sea-level rise, groundwater flooding, storm surge, higher intensity and more frequent precipitation events). The framework must be able to work at different scales (e.g., parcel to watershed) and in diverse landscapes to accommodate the unique needs of individual communities (Poff 2002, Van der Nat et al. 2016, Gourevitch et al. 2020). Socioeconomic factors, such as equity considerations (Difflenbaugh and Burke 2019, Kreslake 2019, Finucane et al. 2020), should be included in the evaluation of different options, as well as the ecological and social trade-offs at play in each situation (Doberstein et al. 2019, Raikes et al. 2019, Alves et al. 2020). It is also critical to allow for iteration throughout the process to account for changing environmental and social conditions (Tyler et al. 2019) and to support successful implementation at scale (Poff 2002, ASFPM 2008, McClaymont et al. 2020, Zevenbergen et al. 2020).

The proposed flood adaptation hierarchy is flexible enough to accommodate different local social, economic, and environmental needs and challenges and can be applied through incentive, regulatory, planning, and funding contexts. The following explanation of each proposed tier includes benefits and trade-offs. It is worth noting that this hierarchy uses the term “nature”

Table 1. Characterization of flood adaptation hierarchy tiers with proposed equity pathways.

Description	Examples	Strengths	Weaknesses	Equity Considerations
Tier 1. Avoid Risk by Protecting and Restoring Natural Floodplains				
Measures that protect natural (i.e., undeveloped) floodplains from new development	Legal protection of natural floodplains (e.g., fee ownership or easement)	Allows ecosystems to move and adapt to climate change	Opportunity cost of not developing floodplains (e.g., municipal property tax revenue, private business opportunities)	Impacts: How will protection and restoration change access to and cultural relevance of the floodplain?
Time frame: Long-term (> 100 years)	Land-use regulations that prevent development in the floodplain	Prevents risk		Resources: What local capital and natural resources may make protection and restoration more successful in certain places?
	Restoration of existing, degraded floodplains	No chance of failure during extreme events		Voices: How are representative community stakeholders included in decision making around land protection and restoration?
		Co-benefits of natural areas (e.g., fish and wildlife habitat, recreational access, scenic value, public health) No/low maintenance costs		
Tier 2. Eliminate Risk by Moving Communities Away from Danger				
Measures that permanently move people and infrastructure out of floodplains to safe receiving areas and restore floodplain function	Managed retreat (e.g., voluntary home buyouts)	Allows ecosystems to move and adapt to climate change	Opportunity cost of not developing floodplains (e.g., municipal property tax revenue, private business opportunities)	Impacts: How does managed retreat influence destination communities (managed retreat of people) and receiving locations (of infrastructure)?
Time frame: Long-term (> 100 years)	Restoration of floodplains to natural areas or open space (e.g., parks) that can function as floodplains	Removes risk: no chance of failure during extreme events	Social cohesion and sense of place may be lost	Resources: How are managed retreat program resources administered in an effective, equitable and timely manner?
	Co-benefits of natural areas (e.g., fish and wildlife habitat, recreational access, scenic value, public health) No/low maintenance costs			Voices: What planning processes most effectively engage people (from retreating and receiving locations)?
Tier 3. Accommodate Water with Passive Risk-Reduction Measures				
Measures that design or upgrade infrastructure to withstand temporary periods of inundation	Elevated structures, utilities, and roads	May allow ecosystems to move and adapt to climate change	May fail during events beyond design standards	Impacts: How does variable performance of passive measures relate to social vulnerability?
Time frame: Medium-term (25–100 years)	Right-sized culverts and bridges	May provide some co-benefits of natural areas (e.g., fish and wildlife habitat)	Contributes to a false sense of security	Resources: Do underprivileged communities have the means and capacities to maintain risk reduction measures over time?
	Stormwater storage tanks	Additional tax revenue from coastal and riverine properties and businesses	Leaves people and infrastructure at risk	Voices: How is tension between buyouts and passive risk reduction resolved?
	Tidal backflow valves	Low maintenance costs Provides reliable performance within design standards		
Tier 4. Accommodate Water with Active Risk-Reduction Measures				
Measures that temporarily reduce flood risk by:	Deployable flood protection barriers (e.g., Tiger dams)	Tax revenue from coastal and riverine properties and	Most do not allow ecosystems to move and adapt to climate change	Impacts: What infrastructure is evacuated and what is left in place at times of emergency? How does protection prioritization vary across communities?
(1) deploying temporary barriers to keep water out	Mobile, seasonal recreational structures (e.g., docks, cabins)	businesses	May fail during events beyond design standards	Voices: How are evacuation plans developed and discussed with the public? How is public input incorporated within the preparation for and response to a flood emergency?
(2) temporarily moving people and/or infrastructure out of floodplains	Evacuation	Some provide reliable performance within design standards	Leaves people and infrastructure at risk	

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(3) temporarily modifying infrastructure to withstand inundation	Preemptive infrastructure shut-down (e.g., power plants)		Requires maintenance, training, and successful prediction and deployment prior to flood events	
Time frame: Short-term (< 50 years)				
Tier 5. Defend Community Assets Using Nature-Based Engineering Measures that alter the natural floodplain system to stabilize it by reducing or withstanding wave energy and/or erosion using primarily living and/or natural (e.g., sand, stone) materials to mimic natural systems Time frame: Short-term (< 50 years)	Submerged vegetation, oyster or marine mussel beds	Tax revenue from coastal and riverine properties and businesses	Does not allow ecosystems to move and adapt to climate change	Impacts: Who may experience infrastructure implementation as a loss or disruption, and who may not?
	Edging	May provide some co-benefits of natural areas (e.g., recreational access, scenic value)	May fail during events beyond design standards	
	Sills	Provides reliable performance within design standards	Leaves people and infrastructure at risk	
	Beach nourishment	Establishment of new or improved habitat	Contributes to a false sense of security	
	Vegetated dunes	Loss of physical connection to water	May impact adjacent areas (e.g., erosion, flooding)	
Tier 6. Defend Community Assets Using Hardened Engineering Measures that alter the natural floodplain system to stabilize it by reducing/withstanding wave energy and/or erosion, using primarily non-living and non-natural materials (e.g., concrete, metal) Time frame: Medium-term (25–100 years)	Root wads and boulders	Maintenance costs		Resources: How can resources be allocated to minimize transboundary risks? What additional resources are necessary to protect neighboring communities?
	Groins/jetties	Tax revenue from coastal and riverine properties and businesses	Does not allow ecosystems to move and adapt to climate change	
	Sea walls	Provides reliable performance within design standards	May fail during events beyond design standards	
	Bulkhead/retaining walls		Leaves people and infrastructure at risk	
	Revetments (e.g., riprap)		Contributes to a false sense of security	
Breakwater		May impact adjacent areas (e.g., erosion, flooding)		
In-water storm surge barriers		Potential loss of connection or access to water		

and associated natural processes rather than “nature-based” because the latter term has become shorthand for an extremely wide-ranging set of human-made manipulations that are not the same as nature. Instead, nature-based solutions are built or engineered solutions (U.S. Army Corps of Engineers 2013, Cohen-Shacham et al. 2016). Many of these built, nature-based solutions are designed to inhibit dynamism and natural processes (e.g., erosion and sediment transport) or focus on restoring one component of function rather than restoring a fully functioning system. These built options should not be considered automatic substitutes for nature. Therefore, “nature-based” approaches have been de-emphasized in the framework.

EXPLANATION OF HIERARCHY TIERS

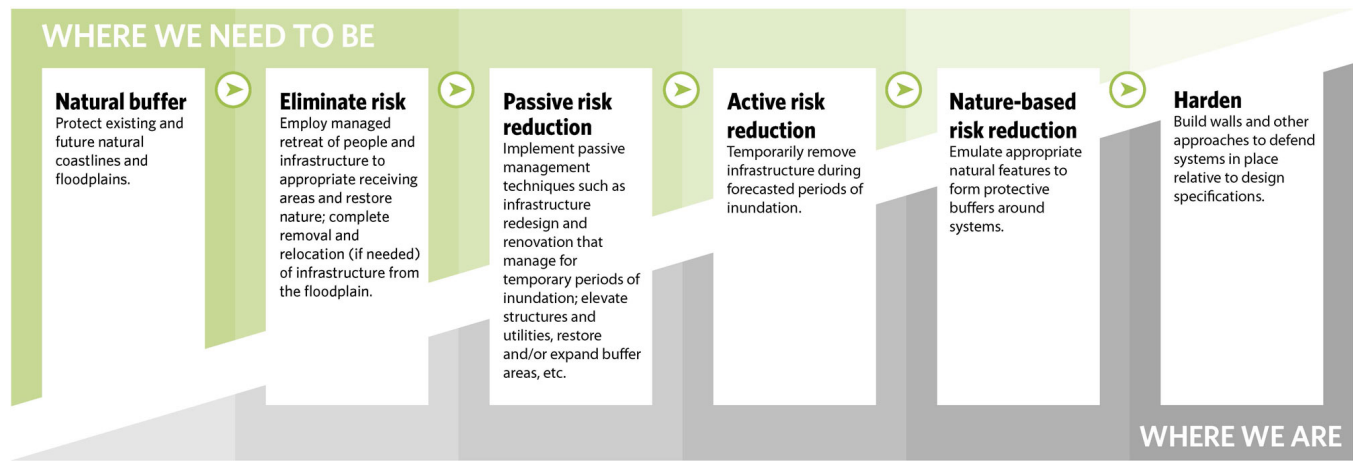
Achieving flood resilience over the short and long term will require the collective application of many practices (which can be associated with more than one tier) within a project footprint and/or across the landscape (Van der Nat et al. 2016, Tyler et al. 2019). The proposed hierarchy, however, advocates for a far greater focus on, and use of, natural systems to capitalize on the dynamism of natural systems and help achieve flood resilience, rather than relying on expeditious, anchored, constructed solutions (also called nature-based or grey infrastructure). Our hierarchy is the opposite of the current practice (Fig. 1). With regard to equity,

we offer no conclusive solution but rather questions that may guide equity considerations at each tier. Actions at any tier can be strengthened with these equity considerations in mind. The tiers, described in Table 1, are prioritized according to the purpose of the project and their capacity to protect and enhance both nature and people’s long-term welfare. Many techniques (e.g., wetland restoration, reef creation) within each tier could be deployed to achieve an array of outcomes (e.g., asset protection, stormwater management, habitat restoration) depending on the landscape context, social-ecological conditions, future scenarios, and other factors. Therefore, the tiers are distinguished by the desired purpose or outcome, not the specific techniques to be used.

Tier 1: avoid risk by protecting and restoring natural floodplains

This tier reduces flood risk by protecting natural (i.e., undeveloped) floodplains from new development. This principle can be followed by establishing legal protection (e.g., fee ownership, easement) for natural floodplains, enacting land-use regulations that prevent development in the floodplain and restoring existing floodplains that are degraded. Natural floodplains reduce flood risk because people and development do not occupy these floodplains and therefore remain out of harm’s way. Intact floodplains also provide a natural buffer between water and human communities and development. One

Fig. 1. This paper is focused on prioritizing approaches to flood risk management, not on practices or tactics. The proposed flood adaptation hierarchy (“Where We Need To Be,” on the top, moving left to right) is contrasted with the current practice (“Where We Are,” on the bottom, moving right to left). Clearly, all tiers will need to be deployed to achieve flood resilience at the landscape scale. However, a paradigm shift is needed to place a greater emphasis on protecting and/or restoring the dynamism of natural systems, as these features will yield more robust, long-term flood resilience than built or engineered solutions.



benefit-cost analysis case study conducted in the United States on nearly 55,000 km² of floodplains showed that every dollar spent protecting floodplains can yield five dollars of net economic benefits through avoided flood damages (Johnson et al. 2020). Equity considerations within floodplain restoration may include impacts on floodplain access for cultural or recreation purposes (Elias et al. 2021), how residents can voice their attitudes and concerns about protection and restoration (Wells et al. 2021), and how access to financial resources may improve floodplain conditions in one area or negatively impact under-resourced, downstream communities (Gourevitch et al. 2020).

Tier 2: eliminate risk by moving communities away from danger

This tier permanently relocates people and development out of floodplains to safe receiving areas and restores original floodplain habitat and function. This may be achieved through managed retreat (e.g., voluntary home buyouts) and restoration of floodplains to natural areas or open space (e.g., parks) that can function as floodplains. Moving communities away from danger reduces flood risk by removing people and development from the floodplain, so that when floods occur, neither are impacted. Relocation also allows the floodplain to naturally adapt and accommodate water as part of a dynamic system. A successful example of strategic retreat is a program in Austin, Texas, that used both buyouts and restoration to achieve adaptive social and ecological outcomes (Kodis et al. 2021). Dense, urban areas in coastal and floodplain areas may be initially difficult to consider returning to nature. However, when future conditions and likely implications are considered along with ever-increasing costs of managing engineered strategies, the cost of not retreating is likely to outpace the costs of relocation and restoration. Equity considerations should include all three pathways (impacts, resources, and voices), given the complexity of effects on society from relocating people and communities. We need further investigation to understand who will experience a benefit or bear a burden from these decisions, how the interests of non-property

owners are considered, and how program resources can be administered in a timely and equitable manner. The results of this investigation must be integral components of decision making. Additionally, the impacts on, and engagement with, destination communities—for both displaced people and development—should be considered (Marandi and Main 2021).

Tiers 1 and 2 of the flood adaptation hierarchy have many similarities. Both tiers are effective over long periods of time (> 100 years) and allow ecosystems to move and adapt to climate change. In addition to reducing flood risk, protecting and restoring natural areas provide numerous co-benefits to people and nature (e.g., fish and wildlife habitat, recreational access, scenic value, public health benefits; Sandifer et al. 2015, Sutton-Grier et al. 2015, 2018, Glick et al. 2020). Because people are protected from flooding, there are limited consequences if the system is overtopped, shifted, or destroyed. A key trade-off is the opportunity cost of not developing in the floodplain (e.g., loss of municipal property tax revenue, loss of private business opportunities). In addition, relocating communities away from flood danger requires moving people from their homes and businesses, which may result in unintended loss of community cohesion and sense of place (Binder et al. 2015, Siders 2019a, 2019b). This is a challenging and fraught proposition because moving people from their homes disrupts their social, emotional, and personal connections. It is politically, culturally, and economically challenging to do so in a manner that keeps communities intact and avoids unnecessary trauma. Furthermore, many buyout programs as currently funded and administered do not meet demand, perpetuate or exacerbate risk and vulnerability (disproportionately impacting disadvantaged groups), and result in decreased property values when bought-out land is left as unintended vacant lots (Binder and Greer 2016, Zavar and Hagelman III 2016, Siders 2019b, Binder et al. 2020). It is possible, however, to achieve successful relocation with careful planning, iterative management, and community involvement and buy-in

(McCann 2006). In addition, relocation may reduce the mental health burdens associated with repeated flooding and rebuilding (Koslov 2016). Tiers 1 and 2 do not consistently align because buyout programs often do not target areas where floodplains are preserved or functioning effectively, hence the need to remove people and structures from the flood-prone areas. There is a place for nature in managed retreat, with greater emphasis on floodplain restoration after buyouts and relocation occur (Kodis et al. 2021).

Tier 3: accommodate water with passive risk reduction measures

This tier aims to permanently upgrade infrastructure to withstand temporary periods of inundation. They are discrete actions that are generally undertaken only once and do not normally require management or maintenance. In developed floodplains where risk cannot be completely eliminated, passive risk reduction measures ensure that constructed features can withstand ephemeral flooding impacts. This can be achieved through structure modification (e.g., elevated buildings and utilities) or through improved design and engineering (e.g., right-sized culverts and bridges, tidal backwater valves). These solutions are particularly effective for temporary flood events, such as those caused by storms, but are less practical as a response to more permanent flooding, such as that caused by rising sea level.

There are several advantages to reducing flood risk through this approach. First, many passive risk reduction measures allow ecosystems to move and adapt as the climate changes, while also providing benefits for fish and wildlife. For example, right-sized culverts are specifically designed to mimic natural stream function and carry floodwaters that exceed levels for a 100-year storm (Gillespie et al. 2014). Second, in floodplains that are already developed, passive risk reduction measures at a minimum maintain the fiscal status quo (e.g., tax revenue) and community structure of local municipalities. Finally, these measures often last over half a century, and maintenance costs are typically low after an initial capital investment (Aerts 2018). However, passive risk reduction measures can contribute to a false sense of security, as they may still be susceptible to failure. Many of these measures are designed to function within a specified range of conditions. The more conditions exceed these design specifications, the more vulnerable the systems are to failure, yet even when conditions are within design standards, failure may occur. For example, right-sized culverts may still wash out during nominal flood events if a debris jam forms on or near the structure (Forest Service Stream Simulation Working Group, 2008). Passive risk reduction measures cannot be designed to accommodate all current and future conditions, so they remain vulnerable. Equity considerations may include additional investigation to understand how communities resolve the tension between managed retreat programs and passive risk reduction measures. Furthermore, practitioners and researchers should consider whether all communities, by means of their socioeconomic status, have the resources and capacities to implement and maintain risk reduction measures into the future.

Tier 4: accommodate water with active risk reduction measures

Activities in this tier reduce flood risk by temporarily enacting measures to withstand short-term inundation. Given sufficient lead time, actions in this tier require pre-event or during-event deployment, include post-event retrieval, and may involve

repetitive actions. Examples of active risk-reduction measures include deployable dams, mobile recreational structures (e.g., docks, cabins), evacuation during extreme weather events, and preemptive power plant shutdowns. To successfully reduce flood risk, these strategies necessitate rapid, sometimes complicated, intervention by trained individuals prior to or during flood events and also require residents to comply with evacuation orders. They depend on accurate and timely weather predictions and a swift, skilled, pre-planned, and coordinated response. Under certain conditions like low-level floods, active risk reduction measures provide reliable flood protection within design standards. However, they can fail for many reasons, including inappropriate use, poor timing, and water levels that exceed the design capacity of engineered structures (e.g., overtopping), leaving people at risk (de Graaf et al. 2013).

The key difference between passive and active risk reduction measures is that passive measures are longer term solutions that endure for a limited lifespan once they have been completed, whereas active measures are short-term actions taken in response to a prediction of imminent flooding. Passive risk reduction measures often allow floodplains to naturally function to some degree, whereas active risk reduction measures are designed to protect existing development without regard to floodplain function. Both tiers preserve development within floodplains, which maintains local tax revenue from properties and businesses, but also perpetuates flood risk to people and infrastructure. These risks are not distributed equally, as found in a study of Hurricane Irma evacuation patterns in Florida, where residents of low-income communities were less likely to evacuate to safe locations than residents of high-income locations (Yabe and Ukkusuri 2020). Finally, similar to passive measures, active risk-reduction measures can contribute to a false sense of security, as they are susceptible to failure because of random occurrences (e.g., an inflatable door dam can be punctured by debris) or situations that exceed design conditions. Equity considerations in this tier may include additional investigation on what aid and resources are available and to whom, whether communities have enough resources to engage this tier, and how accessible that aid is for short- and long-term recovery across the community.

Tier 5: defend community assets using nature-based engineering

Activities in this tier seek to stabilize and strengthen floodplains, stream channels, and coastlines to reduce or withstand wave energy and erosion that can lead to movement or habitat migration. Achievement of this outcome primarily relies on living (e.g., vegetation, oysters, mussels) and natural (e.g., sand, stone) materials to mimic natural systems. Typically, a combination of vegetation and rocks or some other hard structure is placed on a shoreline to prevent erosion and limit the dynamic movement of the shoreline or floodplain edge. In other words, it holds the existing feature in place. Other examples include sills to break wave energy, beach nourishment, and vegetated dunes. Nature-based engineering is also referred to as living shorelines (O'Donnell 2017). Like all the other elements in this hierarchy, nature-based engineering aims to avoid flood damage and improve safety, but this tier also provides some ecological and socioeconomic benefits. These may include enhancement of an area's scenic value, provision of fish and wildlife habitat, improved water quality, and support of other natural processes (Bilkovic et al. 2016, Gittman et al. 2016b). Equity considerations may include

the distribution of benefits and harms related to engineered solutions (Siders and Keenan 2020), and the involvement, or lack thereof, of local communities in the restoration site identification, as technical experts (not community members) are typically the most involved in siting and planning for nature-based engineering (Kochnowar et al. 2015). The inclusion of indigenous knowledge and voices in the planning, implementation, and harvest of oysters and other shellfish is particularly ripe for further research (Toone et al. 2021).

Tier 6: defend community assets using hardened engineering

Activities taken within this tier use non-living or non-natural materials to alter the floodplain system to reduce or withstand wave energy, erosion, they may also aim to keep flowing water in a dedicated channel. Examples of hardened engineering include jetties, sea walls, bulkheads or retaining walls, revetments (e.g., riprap), offshore breakwaters, and in-water storm surge barriers. An analysis of climate adaptation behaviors in coastal North Carolina, in the United States, found that shoreline hardening is correlated with high household income, high home value, high population density, and low racial diversity (Siders and Keenan 2020). When shorelines are hardened, the spillover effects harm ecological and structural integrity, development, and property values on adjacent areas (Dundas and Lewis 2020). Equity considerations may include the amount and duration of additional resources allocated to support areas that are adjacent to hardened shorelines.

Nature-based and hardened engineering have many similarities in desired outcome, strengths, and weaknesses. Distinctions between the two tiers can be blurry, particularly when a hybrid of the two approaches is used, as is often the case for hardening and beach replenishment (Siders and Keenan 2020). Although nature-based engineering is often viewed more favorably because of its ecological benefits, neither of these approaches makes way for additional water. Both tiers are based in a mindset that water can be kept separate from people and infrastructure, and both disrupt natural erosion and deposition processes. Neither allows ecosystems to move and adapt to climate change. For the most part, neither approach uses intact, functioning ecosystems to provide flood risk reduction, but in some cases, nature-based engineering may result in that outcome (e.g., vegetated dunes may be considered a naturally occurring habitat type and intact ecosystem). Compared with other tiers, nature-based and hardened engineering provide the shortest useful time frame—typically less than 50 years—and require maintenance over that period (Beavers et al. 2016, Sutton-Grier et al. 2018).

Both these tiers have negative unintended consequences. Both can decrease people's physical connections to the water, provide a false sense of security, and fail under the burden of progressively extreme events (Van Heerden 2007, Granja and Pinho 2012, Houston et al. 2019). Equity implications for both tiers require further investigation to understand who is most at risk for engineering failure and the unintended outcomes that could accumulate in adjacent areas. Both methods should be viewed only as temporary measures that may "buy more time" until long-term solutions (e.g., ecosystem protection or restoration, managed retreat, and community relocation) can be enacted (Seddon et al. 2020), particularly because these infrastructure measures may delay or complicate the necessary future adaption

measures. However, the urge to expand or incrementally add to nature-based or hardened protections after each storm of record should be avoided. The energy and resources needed to plan, implement, and manage these engineered solutions may take resources, urgency, and momentum away from that of far more beneficial and long-term, natural solutions. Implementation of engineered solutions may also further complicate or undermine the future application of the prioritized tiers.

Intended uses of this framework

As we have suggested throughout, it is critical to remember that most of the current flooding paradigms do not adequately address equity issues; thus, additional evaluation steps are necessary. We recommend that application of the framework take into consideration: (1) who is impacted; (2) who receives resources before/after an event; and (3) whose voices are included in decision making that influences or impacts future land use, planning, and management.

The proposed flood adaptation hierarchy is an ordered set of possible actions. Tiers 1, 2, and 3 are preferred applications of existing paradigms and embedded strategies, as the outcomes protect and restore natural areas and associated dynamics while allowing communities to leverage natural benefits provided by healthy ecosystems, even in the face of climate change and increased flood risk. Tiers 4, 5, and 6 may look appealing, given that benefit-cost ratios of projects are easy to calculate for these tiers, but they often favor short-term solutions, they do not include non-monetary benefits like intrinsic or aesthetic values, and no specialized ecological expertise is required to evaluate proposed projects. A known weakness of a hierarchical framework is the likelihood of rationalizing the selection of the most convenient or efficient solution while disregarding solutions that may be more complex, but likely to yield more durable or preferred results. To counter this weakness, mechanisms like justification criteria are used to manage the progression from tier to tier in a methodical way that does not undermine the intended prioritized structure of the framework (McKenney and Kiesecker 2010).

To retain the framework's prioritization structure, justification criteria are necessary to thwart selection of the most convenient or efficient adaptation outcome (i.e., tier). Circumstances surrounding each application will be highly variable, and we recognize that it is not viable to prescribe a fixed set of justification criteria. Rather, specific justification criteria need to be developed on a case-by-case basis. Regulatory examples of doing so are already in practice in the United States and have proven effective. The Compensatory Mitigation Hierarchy under the U.S. Clean Water Act restricts downward movement from the upper tiers by using disincentives (e.g., increasing project costs and project complexity) as projects move down the hierarchy (U.S. Department of Defense and U.S. Environmental Protection Agency 2008). This methodology could be similarly applied to the flood adaptation hierarchy via program or permitting processes that require decision makers to engage in a meaningful, ordered evaluation of prioritized outcomes. Urgency, whether demonstrated or political in nature, will likely promote the use of lower priority hierarchy tiers. Ways to limit movement to lower tiers, such as justification criteria, should be developed carefully to prioritize nature, consider socioeconomic factors that reduce existing inequities, weigh future conditions, base choices on other

Table 2. Example applications of the flood adaptation hierarchy framework.

Incentives	Regulations	Planning
Certifications	Federal	Hazard Mitigation Plans
Community Rating System	Additional mitigation credits (e.g., Endangered Species Act, Clean Water Act)	Resiliency Plans
Sector climate commitments (e.g., Second Nature)	Executive Orders [†] (e.g., EO 11988)	Coastal Zone Management Plans
Accountability standards (e.g., Sustainability Accounting Standards Board, disclosure standards)	Memoranda of Understanding between agencies [†]	Comprehensive/Master Plans
Public designations	State	Habitat Management Plans
State Programs (e.g., New York State's Climate Smart Communities)	Permitting requirement of mitigation of future condition	Siting: renewables, transportation, military
Grant Funding	Floodplain Development Permit	Estuary plans (e.g., Site Wind Right)
FEMA's Hazard Mitigation Assistance Programs or state authorized agency	Coastal Commission permits	Planning toolkits (e.g., U.S. Climate Resilience Toolkit)
HUD's Community Development Block Grants or state authorized agency	Consistency review by primary planning agency	
USDA Natural Resources Conservation Service and Farm Service Agency Conservation Programs	Building codes	
USDOI, National Park Service Land and Water Conservation Fund	Local	
State flood mitigation and planning funding	Intermunicipal agreements	
State environmental funding (e.g., New York State Environmental Protection Fund) or environmental bonds	Codes and ordinances	
	Site plan review checklists	

[†]State or Federal level.

reasons than expediency, and avoid or minimize negative consequences (Fisk and Kay 2010, FEBA 2017, Tylor et al. 2019). For example, the Association of State Floodplain Managers (2003) recommends a managing principle of “No Adverse Impact” to ensure that any actions by a community or property owner do not adversely affect the property or rights of others to address the existing shortcomings of floodplain management programs. Choosing the wrong set of justification criteria, or not developing them at all, could block the successful implementation of the hierarchy (McKenney and Kiesecker 2010).

EXAMPLES OF FRAMEWORK APPLICATION

As previously discussed, it is increasingly necessary to update flood adaptation paradigms and embedded strategies to more fully integrate ecosystem form and function and incorporate social equity. To change how flood adaptation strategies are selected, policy prescriptions should be instituted so that incentives and disincentives could encourage the application of the Tiers 1 and 2 proposed herein, as they represent the greatest possibility of risk reduction and benefit. Adoption and implementation of better flood adaptation strategies can be successfully developed and deployed through programming structures such as certifications, regulations, and planning and funding initiatives, as shown in Table 2. Though this is not an exhaustive list, these are common approaches used in the U.S. context, with global transferability, to drive desired framework adoption. The equity elements of the proposed framework will certainly render it useful in community-led or regional adaptation planning situations. The prioritized framework concept and guiding equity questions may also be considered at a broader scale for top-down implementation at state or country policy levels; however, it may become evident that local or regional initiatives will be able to adopt and apply this framework with greater ease and efficacy than higher levels of governance.

Certifications are one way to encourage programmatic adoption of the hierarchy to reduce flood risk. For example, the U.S. National Flood Insurance Program's Community Rating System (CRS) is a voluntary program that rewards communities that exceed minimum floodplain management standards by discounting their premium rates to reflect reduced flood risk. Following the flood adaptation hierarchy would meet two of the three CRS program goals: reduce flood damage to insurable property and encourage a comprehensive approach to floodplain management (FEMA 2021). The hierarchy could be incorporated into the program's guidance and creditable activities to garner municipalities extra points toward discounted insurance premiums for residents. As an example, CRS member communities could be encouraged to use the framework as an objective in local land-use planning or local laws. FEMA could incorporate the three equity pathways into the program to make it more equitable.

Regulations (e.g., rules, administrative codes) are intended to protect individuals or the environment. They are created, adopted, and enforced by all levels of government and can include penalties for violations. Regulations could mandate the use of the framework and levy disincentives such as fees, restrictions, or additional compensation (e.g., off-site protection or restoration) for projects that choose lower tier strategies. For example, building codes could require that developers who are working in a floodplain include setbacks to protect natural buffers from development, set limitations on the amount of hardened shoreline, or require offsetting protection or restoration elsewhere in the watershed or along the coastline. Regulations that are carefully crafted and implemented can account for and help to reconcile inequitable resource distribution.

Planning is another important tool that can be used to apply the framework. Planning serves many important purposes, including

providing a clear sense of direction and purpose, minimizing risks and uncertainty, and coordinating capacity. For example, municipal comprehensive plans could feature the framework and equity considerations, thus setting a long-term vision for a community that prioritizes protecting and restoring natural buffers (like floodplains), integrate strategic retreat and restoration in the riskiest areas, and enable road-stream crossings and other immovable infrastructure to accommodate flooding. It is critical to integrate diverse voices and perspectives throughout the planning process.

Public and private funding programs greatly influence behavior and decision making. Public-private partnership models are emerging that raise funds through user or beneficiary fees and apply those funds to protect critical natural or community assets (Bisaro and Hinkle 2018, Beck et al. 2020). Equity challenges warrant very thoughtful consideration in relation to funding arrangements, as they may perpetuate resource disparities across communities experiencing flood impacts. Public and private disaster preparedness grant programs could implement the flood adaptation hierarchy to drive the development of project proposals that target strategies associated with Tiers 1–3. Disaster relief and recovery programs could also apply the proposed framework to drive transformative outcomes rather than promoting repetitive in-kind repair and replacement. Implicit with all funding opportunities are equity issues associated with, but not limited to, who has the resources to secure the funding and who was initially engaged to develop the proposed initiative.

The proposed flood adaptation hierarchy has many potential applications, ranging in scale from improving local decisions on private property to prioritizing federal funding and regulatory programs. It offers guidance on where to begin to address systemic inequities that are perpetuated by current flood mitigation strategies and how to avoid creating new, unjust structures. We identify incentive and disincentive programs associated with certification, regulatory, planning, and funding programs as to encourage outcomes that are consistent with protecting and restoring ecosystems, getting people and infrastructure out of flood-prone areas, and accommodating a world with more water. We recognize that all six tiers of the framework may not be realistic options in every location, particularly in areas with substantial and fixed infrastructure investments in flood-prone areas (e.g., wastewater treatment plants, dense coastal urban communities); however, serious consideration of each tier could open decision makers to new possibilities for people and nature. If communities and institutions adopt and customize the framework, creative and effective pathways to more routinely integrate equity considerations into decision making are likely to emerge. Potential users of this framework should develop robust, customized justification criteria to control the movement among tiers or risk perpetuating the status quo, resulting in a patchwork of disconnected measures that, collectively, may undermine desired outcomes.

CONCLUSION

Flooding is a natural and restorative phenomenon in many ecosystems. However, flooding poses a significant and increasing risk to humans because of development in flood-prone areas and the increasing severity of floods. As described above, current solutions to manage flood impact are flawed. Though they are

not globally unique, existing U.S. policies and decision-making structures result in disjointed solutions that fail to effectively integrate the co-benefits of nature's dynamic properties and critically important equity considerations. A comprehensive suite of paradigms and embedded strategies are required to achieve systematic and comprehensive flood adaptation solutions because not all solutions are viable in every situation. In recognition of this reality, we do not call for the elimination of any paradigm, strategy, or practice. Rather, our proposed flood adaptation hierarchy prioritizes flood adaptation paradigms and embedded strategies that can be applied at many scales. We prioritize the protection and restoration of natural ecological systems, which offer more attractive long-term benefits to both built and natural communities than those of short-term, engineered solutions. We also raise essential considerations and offer guidance, through the lenses of impacts, resources, and voices, to integrate equity considerations more fully into decision making.

This framework has not yet been put into practice; therefore, case studies documenting future applications, research-based learning, and practitioner recommendations will be needed to assess overall effectiveness and guide necessary improvements. Studies that seek to identify, quantify, and ideally monetize the costs and benefits in a more comprehensive way, and attempt to better evaluate these across time would help to refine this framework. More effectively incorporating indigenous knowledge and cultural norms into the hierarchy tiers would expand the realm of possible application as well as enhance the equity elements already built into the framework. It is important to continue exploring and resolving known challenges associated with existing adaptation strategies, such as development of areas following buyouts, distribution of program resources in more timely and equitable ways, and effects of adaptation decisions on non-property owners. We must also continue exploring iterative revision cycles to incorporate new knowledge and new circumstances into the framework, to ensure that it remains a useful and relevant tool. Finally, while this particular hierarchy is focused on flooding, the concept of focusing on long-term, sustainable benefits to both people and nature and to following an order of operations could apply to other impacts of climate change-induced impacts (e.g., fire, drought). The sequence of preventing risk, eliminating risk, accommodating hazards, and defending against hazards may be applicable in many contexts and should be explored by other communities of practice.

We are in a global race to make room for more water. Attempts to control natural dynamics are failing on multiple fronts. Costs of these failures continue to mount in the form of loss of life, personal well-being, community cohesion, reconstruction costs, and ecosystem impacts. Evidence is mounting that communities are best served by allowing natural dynamics to dictate where and how water moves across a landscape. It is incumbent upon natural resource and flood management institutions to quickly adapt programming to this reality and upon practitioners and communities to advocate for improved solutions that yield fair, effective outcomes. We hope that our framework will serve as a useful tool to inform and influence the transition to a new flood risk-management paradigm that allows people and nature to thrive.

Responses to this article can be read online at:
<https://www.ecologyandsociety.org/issues/responses.php/13544>

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Data Availability:

Data/code sharing is not applicable to this article because no data/code were analyzed in this study.

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