OPINION

How to achieve better flood-risk governance in the United States

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Recent flood disasters (Fig. 1) have exposed issues with how flood risk is governed in the United States, raising questions about who owns responsibility for managing and paying for losses. In February 2017, 190,000 residents were evacuated as the primary and emergency spillways at Oroville Dam in California failed, a scenario that had been raised to and dismissed by Federal Energy Regulatory Commission engineers in 2005. To date, more than $1 billion in claims has been filed with the State of California associated with recovery from this failing infrastructure. More recently, the nation watched as Hurricanes Harvey and Irma flooded cities across the South, threatening to considerably deepen the National Flood Insurance Program's (NFIP's) $25 billion debt.

Furthermore, the 2017 hurricane season highlighted some of the key failures in the nation's leadership regarding flood response. Much of Houston, TX, failed to evacuate during Hurricane Harvey after mixed messages from political leaders and a catastrophic evacuation in 2005, and only 20% of homeowners in the area have flood insurance. More than 3,400 water evacuations

Fig. 1. Recent flooding has decimated infrastructure and left thousands homeless. In October 2015, Hurricane Joaquin caused widespread flooding in South Carolina and destroyed Cary Lake dam in Columbia (*Upper Left*). Heavy rain and flooding caused the Oroville Dam spillway in northern California to fail in February 2017 (*Upper Right*). And in August 2017, massive rains from Hurricane Harvey spurred extensive flooding across much of Houston (*Bottom Left and Right*). Images courtesy of Hermann Fritz (Georgia Institute of Technology, Atlanta) (*Upper Left*), The California Department of Water Resources (*Upper Right*), Shutterstock/DIIMSA Researcher (*Lower Left*), and Shutterstock/michelmond (*Lower Right*).

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were conducted within the 4 days after the hurricane made landfall (Fig. 1, *Bottom Right*), and the uninsured losses are expected to soar. Hurricanes Irma and Maria both exposed the important roles that politics play in governing recovery efforts, with Maria publicly exposing how the federal response in Puerto Rico was constrained by both national and local politics.

These events highlight why flood-risk governance in the United States needs a major overhaul, but they also suggest why the necessary refocus on shared responsibility will not be easy. A sustainable flood-risk governance will need to overcome the politicization of flood management, the lack of engagement of the public, and research limitations at the intersections of engineering, law, and social sciences. However, the return on investment for overcoming these obstacles in the near future will pay back governments and the public for generations to come.

Flood Governance

Flood losses can include loss of life, damage to infrastructure and agriculture, interruptions to business and education, and impacts on human health and welfare. It has long been known that such losses are primarily the result of human decisions. Nearly 75 years ago, Gilbert White, considered to be the father of floodplain management, argued that "Floods are acts of God, but flood losses are largely acts of man" (1). White spent his career investigating why people insist on living in flood-prone areas, and his work demonstrated how flood-protection measures contribute to floodplain occupants' underestimation of their flood risk. Despite this longstanding knowledge, history and politics in the United States have established a flood-risk governance structure that provides the perverse incentives for occupation of flood-prone areas along with a widespread lack of awareness of the associated risks.

A flood-governance structure describes the collection of regulations and cultural norms that establish the distribution of authority, responsibility, and resources for flood management (2). In the United States, flood-risk governance is defined by a largely uncoordinated set of laws, regulations, and infrastructure that resulted in part as responses to major flood hazards. Because flood mitigation, water law, and land-use regulation are not explicitly delegated to the federal government under the US Constitution, the authority and responsibilities for these activities mostly fall to the states. In the case of land-use regulation, most states have delegated authority to county and city governments.

However, there have been two important federal laws enacted that drive nationwide efforts with respect to flood-risk reduction. The first was the Flood Control Act (FCA) of 1936 and subsequent FCA legislation, in part a response to the catastrophic flooding of the Mississippi River in 1927 and of the Columbia River in 1948. The original FCA authorized federal engagement in flood-risk reduction, which has predominantly occurred through development of large infrastructure. The second law driving federal efforts was the National Flood Insurance Act of 1968 and associated amendments, which established the NFIP. The NFIP identified areas within the 100-year floodplain, meaning they have a 1% chance of being flooded every year, as high-risk areas. It also established a flood insurance program to provide incentives for communities that adopted land-use regulations and prohibited future construction below the 100-year flood elevation. But although NFIP discourages floodplain development, local governments ultimately have authority for land-use regulations. Thus, the historical lack of an articulated and coordinated flood-governance structure has led to a complicated blending of hierarchical, monocentric governance (2) at the federal level with more distributed polycentric governance at the regional and local levels.

This uncoordinated blending of flood-risk governance has produced significant conflicts across different levels of authority. A key example: The lawsuits challenging that the Federal Emergency Management Agency's (FEMA's) NFIP does not comply with the Endangered Species Act (ESA). As a federal agency, FEMA must comply with ESA by not producing adverse impacts on threatened and endangered species. FEMA has been sued in multiple states for the NFIP's role in enabling degradation of habitat for such species. As a result, FEMA has injected itself into the role of supervising and restricting activities within the floodplain in some locations where habitats for threatened and endangered animals have been affected (e.g., salmon in the Puget Sound, WA; Key Deer in the Florida Keys). Opposing lawsuits have been filed on behalf of local land-use authorities, such as those currently underway in Oregon, to challenge the new NFIP requirements and FEMA authority for being overly restrictive.

Levees represent another example of governance challenges and conflicts, with debate centered on the responsibility for maintaining the 30,000 to 100,000 miles of the nation's levees. Key actors include the (*i*) US Army Corps of Engineers, who originally constructed many of the nation's levees before handing them over to local entities and who regularly conducts levee inspections; (*ii*) FEMA, who certifies levees for the NFIP; and (*iii*) primarily nonfederal levee owners, who often do not have the resources to maintain the levees or effectively communicate the flood risk to the public living and working behind them.

The US approach to flood-risk governance also appears to have restricted the types of flood-management activities that occur, potentially reducing the effectiveness that flood-management actions could have in lowering flood risk. Experts (3) have called for reducing reliance on the centralized, structural approaches (e.g., dams, levees), which emphasize modifying flood characteristics (e.g., depth, extent, duration) and represent the foundation of flood-risk management in the current governance in the United States.

In some cases, structural approaches to flood risk reduction have actually increased residents' exposure. For example, by fostering floodplain development, levees lead to increased losses when levees fail or floods reach elevations higher than levee-crown elevations (4). Furthermore, structural measures tend to be inflexible to changing conditions. For example, reservoir operations are primarily driven by congressionally authorized water-control diagrams that are difficult to modify, and raising the height of levees to increase protection for an exposed community is problematic because it results in raising flood elevations in another location.

Thus, with the aging (5) and failure (Fig. 1, *Upper Left and Right*) of the nation's flood infrastructure and the rising operational costs and constraints as infrastructure budgets steadily decrease (6), some flood managers increasingly argue that the nation's flood-risk management should increase reliance on nonstructural measures and on sharing responsibility for flood risk among the federal government, regional and local communities, and the public (3, 7). Nonstructural measures tend to be local-scale actions that emphasize reducing exposure of the public to floods via behavioral adaptations (e.g., floodplain development restrictions, building codes, early warning systems, relocation) and localized stormwater management, rather than modifying the flood characteristics. Although nonstructural practices are being utilized in some locations across the United States, their effectiveness and widespread application have been limited by population growth, socioeconomics, and governance (8), as illustrated by the litigation related to the NFIP.

Furthermore, distributing some flood-risk responsibility to the public will require reshaping of public perceptions and motivations. The historical "flood control" paradigm in the United States has led the public to believe that federal flood managers can prevent all catastrophic flooding (7) and obtain very limited information about our flood risk (9) and the reliability of the flood infrastructure that protects us. This lack of awareness and action around flood responsibility has been shown to increase an individual's exposure and vulnerability to floods (10). However, the burden of communicating and socializing risk regarding flood infrastructure to increase awareness is a challenging and humbling task, particularly because it commonly falls to the engineers who design and operate flood infrastructure (11).

A New Kind of Flood Governance

There are major barriers to making the transition toward more sustainable and effective flood management, none of which are problems that engineers alone can solve.

First, the politicization of flood-risk governance has crippled the ability of the United States to protect the public from floods. As effectively argued by Wilke (12), the debate on less versus more government distracts decisionmakers from the critical task of making governance more efficient and effective. The more meaningful question is how to distribute authority and resources for planning, mitigating, and recovering from floods among individuals and institutions. Furthermore, revoking sound and cost-effective policies, including those that require stricter building standards when rebuilding publicly funded structures in flood zones (for example, Executive Order 13690, revoked August 2017), is not going to protect the people or economy of the United States over the long term.

Second, managers and politicians will have to overcome the public's perception that floods are "controlled" by federal flood managers and, thus, that we have no responsibility for reducing our own flood risk. The shaping of perceptions and institutions by existing infrastructure, such as the overconfidence of floodplain residents behind aging and uncertified levees, has been exceptionally effective. The essential task of reshaping those perceptions and institutions will be extremely difficult. The most effective flood-management solutions (i.e., land-use regulations) require political leadership and public outreach.

For example, in heavily leveed rivers, it can be more cost effective for managers to reduce the flood stage by reconnecting and expanding the floodplain rather than raising levees and constructing additional dams. Restoring the connectivity of floodplains may also allow upstream reservoirs to remain at a higher elevation during the flood season, thus increasing the available water supply and hedging against water scarcity during the dry season. However, reconnecting floodplains requires making the politically and economically difficult task of relocating residents who currently live in flood-prone areas. The high rate of repetitive loss claims in the NFIP demonstrates the lack of political willpower to even discourage rebuilding in areas known to flood, let alone the resettling of exposed populations. And oftentimes the public is unwilling to acknowledge its own role in reducing their flood risk.

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Third, engineers and social scientists need to work together to expand the research agenda on the sociological, economic, and geopolitical elements of floods and flood-risk management. For example, studies are needed to investigate and overcome the social and political barriers that hamper wider adoption of nonstructural flood management. In addition, collaborations between engineers and lawyers could contribute to identifying where flexibilities (e.g., operational changes in rule curves) exist in the institutions and infrastructure controlling flood management (13) and how and when those flexibilities can and should be exploited for adaptation under changing conditions. Another area ripe for integrative research is in the design of policies that advance public risk perception. Researchers have demonstrated that the public fails to appropriately understand risk, commonly rounding low probabilities (e.g., 1% flood exceedance of the 100-year flood) down to zero (14).

This assumption produces significant loss of life and property for two key reasons. First, confusion about the concept has encouraged development in areas subject to the 1% flood. Homeowners in such areas may be surprised to learn that the likelihood of their house flooding over the 30-year lifetime of their mortgage is in fact 26%. Second, landscape changes (e.g., urbanization, sedimentation of rivers, climate change) regularly result in changing flood exceedances. One promising alternative to the 1% exceedance is to represent flood risk as a continuum, similar to how life insurance is issued. Rather than applying a binary flood boundary, which is subject to large uncertainties, penalties (e.g. insurance premiums, development regulations) would be higher for properties with a higher likelihood and consequence of flooding. As the life and auto insurance industries have demonstrated, the public is capable of understanding more nuanced conceptualization of risk and of taking responsibility for actions (e.g., smoking cessation) to reduce risk and costs. The timing is ripe for such a transition. The hurricanes, heat waves, and floods of 2017 have raised the public's awareness of natural hazards and provide an important opportunity to understand and inform the public's perception of, and engagement in, flood-risk management.

However, making the transition will be difficult. The engineering design standards (e.g., 1% flood exceedance), which serve as the basis of both our flood infrastructure and our perception of tolerable risk, are fundamentally flawed when flood characteristics are changing. An effective flood-risk governance framework will need to acknowledge the concepts of complexity, uncertainty, and resilience (12) in balancing safety and cost for flood-risk reduction, but integrating these concepts will require new design, operational, political, and cultural norms.

The literature and engineering practice already offer some guidance on how flood management can be more effective as hydrology and populations change and as infrastructure age. Such guidance includes choosing design standards (e.g., land-use regulations, outlet elevations) to promote human and infrastructure systems that are robust and responsive to changes in hydrology and infrastructure, implementing real-time operations of reservoirs and early-warning systems based on modern data networks and forecasts, and targeting resources to support flood-safe behavior among the most vulnerable populations prior to floods. Initial steps in this transition are the execution and communication of bold and strategic experiments (e.g., resettling communities with repetitive losses, implementing aggressive land-use policies, community-based flood insurance, redevelopment of stormwater storage and conveyance systems), as well as initiatives that engender political and public support for adaptation. The most important resources in such a transition will be leadership across all levels of government, technical expertise, and financial capital.

If we are to manage floods in ways that are effective, sustainable, and equitable, major modifications to national flood-risk governance policy in the United States are deeply needed. The new policy needs to include and go beyond simply raising awareness of flood risk. In addition to clearly articulating the authorities and allocating appropriate resources for distributing flood risk, flood governance will need to emphasize engaging the public in behavioral adaptation aimed at reducing exposure and vulnerability to floods. A fundamental example of such a change is revision of the water- and land-use laws across the nation, which will require enormous political willpower, the likes of which is currently underway in the state of California (15). In addition, a new policy should integrate more recent analytical approaches for the evaluation of risks and benefits associated with a broader range of flood-mitigation practices (16). Finally, all adaptations need to acknowledge that exposure and vulnerability to flooding have a social-justice dimension, whereby mobility, native language, and economic and educational status, among other factors, have an impact on the ability of the public to manage our individual flood risk.

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1 White GF (1945) *Human Adjustment to Floods: Department of Geography Research Paper No. 29* (University of Chicago, Chicago).
2 Rogers P, Hall A (2003) Effective Water Governance: TEC Background Paper No. 7 (Global Water Partnership, Stockholm).
3 Gleick PH (2003) Global freshwater resources: Soft-path solutions for the 21st century. *Science* 302:1524–1528.
4 Larson L, Plasencia D (2001) No adverse impact: New direction in floodplain management policy. *Nat Hazards Rev* 2:167–181.
5 American Society of Civil Engineers (2017) Infrastructure report card. Available at www.infrastructurereportcard.org/. Accessed December 27, 2017.
6 McGinnis BP (2014) The long slog: What lies ahead for the financing of our nation's inland waterways infrastructure. *Water Resour Impact* 16:19–20.
7 Riley DT (2014) Can we keep the public safe from floods? *Water Resour Impacts* 16:15–16.
8 Dawson RJ, et al. (2011) Assessing the effectiveness of non-structural flood management measures in the Thames Estuary under conditions of socio-economic and environmental change. *Glob Environ Change* 21:628–646.
9 Galloway GE (2014) The Ostrich Syndrome: What we don't know likely will hurt us. *Water Resour Impact* 16:17–18.
10 Kreibich H, Thieken AH, Petrow T, Muller M, Merz B (2005) Flood loss reduction of private households due to building precautionary measures: Lessons learned from the Elbe flood in August 2002. *Nat Hazards Earth Syst Sci* 5:117–126.
11 Escuder-Bueno I, Halpin E (2016) Overcoming failure in infrastructure risk governance implementation: Large dams journey. *J Risk Res* 1–18.
12 Wilke H (2007) *Smart Governance: Governing the Global Knowledge Society* (University of Chicago, Chicago).
13 DiFrancesco K, Tullos D (2014) Assessment of flood management systems' flexibility with application to the Sacramento River basin, California, USA. *Int J River Basin Manage* 13:271–284.
14 Kousky C, Shabman L (2015) Understanding flood risk decision-making: Implications for flood risk communication program design. Available at www.rff.org/files/sharepoint/WorkImages/Download/RFF-DP-15-01.pdf. Accessed December 27, 2017.
15 Tullos D, et al. (2016) Review of challenges of and practices for sustainable management of mountain flood hazards. *Nat Hazards* 83:1763–1797.
16 Juarez Lucas AM, Kibler KM (2016) Integrated flood management in developing countries: Balancing flood risk, sustainable livelihoods, and ecosystem services. *Int J River Basin Manage* 14:19–31.