Adaptation over Fatalism: Leveraging High-Impact Climate Disasters to Boost Societal Resilience

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The property damaged and the lives disrupted by recent hurricanes, floods, droughts, and water quality violations highlight the inadequacy of water infrastructure in the United States and around the world. Decisions about managing these infrastructure systems are strongly informed by societal perceptions of risk, which in turn are shaped through narratives of high-impact events in academic, governmental, commercial, and popular media.

In recent years, post hoc analyses of high-impact water and climate disasters have increasingly focused on the role of anthropogenic climate change (ACC). This is a welcome development that helps to build support for much-needed mitigation of global greenhouse gas emissions and pushes companies, governments, and aid agencies to prepare for a changing environment. Yet climate *impacts* require a confluence of physical hazards and societal vulnerabilities, and so narratives centered only on the role of ACC can neglect the aging infrastructure, increasing development with exposure to climate risks, and inadequate maintenance that set the stage for meteorological and hydrological events to become humanitarian disasters. The fatalistic narratives that emerge, which often imply that because an event was exacerbated by climate change its consequences could not have been averted, discourage adaptive planning.

How Climate Disasters Emerge

Climate risk is defined as the product of hazard, or the probability that a particular event occurs, and exposure, which encompasses vulnerability and resilience to describe the damage that will result if the event does occur. ACC causes dynamic and thermodynamic changes that have already altered the intensity, seasonality, frequency, and location of water-related climate extremes, thereby shifting climate hazard, and further changes are anticipated. Yet analysis of recent high-impact water and climate disasters reveals that avoidable planning decisions including poor land use policy, misaligned incentives for risk taking, and inadequate physical infrastructure dramatically amplify the impact of climate hazards. Systematic analysis of global changes in exposure to floods (Jongman et al. 2012) and hurricanes (Peduzzi et al. 2012) emphasize that changing exposure far outpaces changing hazard in the historical record.

For example, failure of the primary and auxiliary spillways at the Oroville Dam in 2017, which prompted an evacuation of the Feather River (California) basin, was widely attributed to ACC in popular and scientific (e.g., Huang et al. 2018) media, despite an absence of such claims by the state management agency. While ACC may have contributed to this event both directly, by increasing the moisture-holding capacity of the atmosphere, and indirectly, by possibly favoring the persistence of the wet regime, the flows over the two spillways at the time of their failures were only 18% and 3% of the design capacities, respectively (France et al. 2018, pp. 7–27). Further, continued development of highly vulnerable downstream communities increased the number of individuals and the total value of property exposed to potential flooding even though the structural deficiencies had been known and documented for several decades (France et al. 2018, pp. 53–56). Thus, while the rainy spring may have been exacerbated by ACC, the resulting flood *risk* was dominated by inadequate system planning and investment.

Recent hurricanes also illustrate the importance of local decisions in high-impact events. For example, while ACC made Hurricane Harvey's precipitation approximately 15% more intense (Emanuel 2017), unmanaged sprawl and the destruction of Bayou wetlands increased peak runoff volume and the total value of property exposed to flooding (Jacob et al. 2014). Even worse, forensic infrastructure inspection in New Orleans following Hurricane Katrina revealed that unrealistic design assumptions and inadequate maintenance caused several levees to fail before design levels were reached (Sills et al. 2008). Even though hurricane intensity is anticipated to increase under ACC (Knutson et al. 2010), the first lesson of New Orleans and Houston is that human error, inadequate infrastructure maintenance, and inadequate risk zoning for regional growth dominate observed changes in many climate risks.

These same factors have also turned unexceptional hydrological droughts into severe water shortages. For example, the 2015–2017 "Day Zero" drought in Cape Town, South Africa, was described as unprecedented and linked to ACC in the public narrative. While Cape Town's reservoirs were designed primarily to supply urban demand, the government approved withdrawals for irrigation following a long wet period. These agricultural releases were maintained through much of the drought, contributing to Day Zero. Although ACC is projected to increase the frequency of multiyear droughts (Otto et al. 2018), similar droughts were observed in the late 1930s and early 1970s and hydrologists had warned that they could occur again (Muller 2018). Recent water crises in Mexico City, São Paulo, Brazil, and Barcelona, Spain, also occurred during meteorological droughts that had close analogs within the historical record. In all these cases, predictable water shortages were exacerbated by unmanaged consumption, leakage losses (in the case of Mexico City as much as 130 L per person per day, or 40% of total supply; Tortajada 2006), poor water allocation, and new agricultural water consumption. Although it is tempting to use ACC as a scapegoat, responsible authorities must better communicate to the public the ways in which short-sighted planning dramatically increases long-term risk.

Toward Constructive Narratives

Despite clear risks from ACC, local resource and infrastructure systems management still drive societal resilience to water and climate risks. Improving these built and social systems requires developing consensus for large investments and management shifts, which may be easier if ACC is presented as one of many stress factors challenging our water infrastructure. In this section we offer some suggestions for ways in which researchers and practitioners working on water infrastructure systems can discuss ACC in ways that emphasize both the need for improved local resilience and the need for mitigation of global greenhouse emissions.

DO discuss specific ways in which the local environment has changed over the design life of existing infrastructure. Even where detailed attribution studies that assess the causal effect of specific forcings are not available, observational evidence can be linked to collective memory. For example, changes in snow frequency have already been observed in many parts of New England (Huntington et al. 2004), which has implications not only for snow management but also for stormwater design and reservoir operation. Communicating ACC by relating history and local memories to rigorous science can build credibility and help frame discussion of future changes.

DO describe how uncertainties including the extent of future greenhouse emissions, global climate dynamics, and local environment challenge long-term planning. Making costly investments for a specific, possibly worst-case, scenario that does not arrive (i.e., overpreparation) leads to significant opportunity costs relative to other activities that may require a more immediate response. For example, while rising sea levels threaten coastal communities, it is not possible to protect every community around the world through purely structural means. Instead, it is important to help communities develop flexible and adaptive policies that make use of climate and demographic forecasts at many timescales.

DO NOT conflate deep uncertainty as to the distant future with potentially predictable, uncertainty as to the near future. For example, there has been successful identification and prediction of climate on subseasonal to decadal timescales, and this can be used to inform the development of tools to alleviate the impact of weather and climate hazards. For example, skillful prediction of the North Atlantic Oscillation could inform hurricane risk and coastal adaptation decisions along the Susquehanna River (Toomey et al. 2019) or financial preparedness and disaster fund allocation for floods in Europe (Zanardo et al. 2019). In order to use these forecasts, however, planners must embrace uncertainty and develop decision frameworks that make use of probabilistic information at many timescales.

DO talk about how local changes in development, land use, and disaster readiness have changed the consequences of a given storm. For example, better early warnings and early action plans have dramatically reduced the number of lives lost to landfalling tropical cyclones even in very poor regions (Kumar et al. 2019). However, as development along waterfronts has grown, the value of property damaged by a given storm has risen dramatically. While ideas like risk, exposure, and vulnerability can seem abstract, contextualizing them within the local environment can bring them to life.

DO talk about the original design considerations of existing infrastructure relative to current needs. It is natural to pay water infrastructure little attention until something goes wrong. However, tens of thousands of dams in the United States that put life and property at risk are well beyond their original design age, and their maintenance status is generally poor or unknown (Ho et al. 2017). While recent dam failures have not had an impact as significant as the Johnstown, Pennsylvania, floods of 1889 and 1977, dam failure remains a risk for many communities. Further, as the case of Cape Town illustrates, past and future changes in demographics, regulations, funding, technology, and resource management often demand that our critical infrastructure perform tasks for which it was not originally designed.

DO NOT assume that construction is sufficient to solve infrastructure systems challenges. Well-recognized phenomena include the levee effect or safe development paradox, which describes the mechanism by which new flood protection infrastructure can lead to low perceived risk, increased development, and thus amplified impacts when extremes eventually occur. Analogs to this effect exist in water storage (increased water availability can lead to increased water demand), transportation (building highways can lower the marginal cost of driving and induce greater traffic), and many other applications. This does not imply that new structures are never needed, but rather emphasizes the need to couple them with strong governance. For example, the construction of flood protection infrastructure could be accompanied by zoning regulations that limit development in the floodplain it protects. This sort of comprehensive planning can impose order on the complex feedbacks between humans, the environment, and infrastructure systems that the safe development paradox describes.

DO consider how financial, regulatory, and technological advances can help water systems fail safely (Brown 2010) and support resilience. Strict zoning policies can limit future sprawl and ensure that new construction in high-risk areas like the New York City waterfront can withstand anticipated storms. Decentralized water reuse networks can provide clean drinking water without requiring costly public investments in water treatment facilities, conveyance, and source development. Parametric and forecast insurance can provide funds for rapid response and recovery (Clarke and Dercon 2016). The particular circumstances of each place are unique, but a public discourse that transparently evaluates a wide range of options should be promoted.

DO NOT fall back on fatalist narratives in the aftermath of natural disasters. Fatalist climate narratives divert attention from productive discussions about the use of adaptive planning and management strategies to decrease damages from similar events in the future. Promoting policies that curb excessive exposure and promote responsible upkeep of critical infrastructure may be particularly constructive.

Final Word

Deep uncertainty caused by ACC, the unpredictable performance of aging infrastructure, changing social and economic conditions, and a myriad of other factors have motivated the integration of structural and nonstructural adaptation strategies for managing water infrastructure systems. These instruments represent creative and resilient solutions for climate risk adaptation, transcending traditional infrastructure design and build approaches to more integrally consider land use and financial instruments as part of a strategy for response and recovery. By communicating the challenges of climate change adaptation through a systems lens, the public can more readily assess which strategies make sense in their specific context.

Of course, the execution of thoughtful local climate adaptation plans can by no means preclude the need for dramatic action to mitigate global greenhouse gas emissions.

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