Natural Defenses from Hurricanes and Floods

Protecting America's Communities and Ecosystems in an Era of Extreme Weather

NATIONAL WILDLIFE FEDERATION

ALLIED WORLD

EARTH ECONOMICS

Natural Defenses from Hurricanes and Floods: Protecting America's Communities and Ecosystems in an Era of Extreme Weather

Lead Authors: Patty Glick and John Kostyack (National Wildlife Federation) and James Pittman, Tania Briceno, and Nora Wahlund (Earth Economics)

Acknowledgements: This report is the culmination of the efforts of numerous individuals at the National Wildlife Federation, including Linda Argueta, Jan Goldman-Carter, Sara Gonzalez-Rothi, Malia Hale, Aislinn Maestas, Susan Kaderka, Adam Kolton, David Muth, Kara Reeve, Joshua Saks, and Melissa Samet. Special thanks to Scott Carmilani and Wes Dupont (Allied World Assurance Company), Carolyn Kousky (Resources for the Future), and Josh Reyneveld (Earth Economics), and Matt Zieper (Trust for Public Land) for providing invaluable input and guidance throughout this project. Funding was provided through a generous grant from Allied World Assurance Company.

Cover photo: iStockphoto

Designed by: Maja Smith, MajaDesign, Inc.

National Wildlife Federation
901 E Street, Suite 400
Washington, DC 20004
202.797.6000
www.nwf.org

Natural Defenses from Hurricanes and Floods

Protecting America's Communities and Ecosystems in an Era of Extreme Weather

Lead Authors: Patty Glick and John Kostyack (National Wildlife Federation) and James Pittman, Tania Briceno, and Nora Wahlund (Earth Economics)

iStockphoto

Contents

Executive Summary

This report represents a collaborative effort of the National Wildlife Federation, Allied World Assurance Company, and Earth Economics to address the mounting risks of flooding and hurricanes to U.S. communities. Specifically, this report focuses on the U.S. coasts and coastal waters of the Atlantic and Pacific Oceans and the Gulf of Mexico and the nation's extensive network of rivers and streams –places where millions of Americans live and work. It asks whether federal, state, and local officials are paying enough attention to the growing threats of floods and hurricanes across the country and whether they are using the policy tools at their disposal to protect people and property endangered by these potentially-catastrophic natural hazards.

Unfortunately, the answer to these questions is no. Far too many people who live along America's coasts and rivers are at considerable risk of personal harm from floods and hurricanes, and their properties and economic livelihoods are highly vulnerable as well. Efforts by policy makers to grapple with and respond to these problems have been inadequate.

Yet solutions are at hand. Policy makers can make coastal and riverine communities safer and more resilient to floods and hurricanes by focusing on natural and nature-based approaches for risk reduction. These approaches protect and restore natural infrastructure such as wetlands, dunes, riparian zones, living shorelines, and natural open space. They are cost-effective and produce a host of benefits to residents in addition to flood protection, including clean water, habitat for fish and wildlife, and increased opportunities for recreation and tourism. They also produce savings for taxpayers nationwide.

This collaboration of the National Wildlife Federation, Allied World Assurance Company, and Earth Economics is driven by our organizations' converging goals around these policy solutions. National Wildlife Federation's interests in conserving wildlife and wildlife habitat, Allied World's interests in ensuring sound investments in insurance and other risk reduction strategies, and Earth Economics' interests in promoting economic methodologies that further sustainability converge around advancing the following broadly-accepted principles of resilience:

USFWS

- **Better understanding of actual risk may lead to more risk reduction.** Adequately informing communities in areas prone to floods and hurricanes about the risks they face both now and in the future, such as through risk-based pricing of insurance and updated, science-based mapping of hazard-prone areas, is fundamental to building resilience in the face of growing threats. Once risks are better understood, there is likely to be greater interest in mitigating them.

This report asks whether federal, state, and local officials are paying enough attention to the growing threats of floods and hurricanes across the country and whether they are using the policy tools at their disposal to protect people and property endangered by these potentially-catastrophic natural hazards.

iStockphoto

• **Investing in risk reduction now can produce large savings in the long term.** Investing in risk reduction measures well in advance of floods and hurricanes provides better outcomes for communities than rebuilding after these events. It is estimated that for every $1 spent on risk reduction activities, America saves $4 in disaster costs,[1] producing large savings for taxpayers and insurance policy holders over the long term.

• **Investments in natural infrastructure maximize resilience to floods and hurricanes.** Natural and nature-based approaches (i.e., protecting and restoring natural infrastructure) should be prioritized for hazard mitigation, and should be used either in combination with or as an alternative to gray infrastructure such as seawalls and levees. They often are the most-effective and least-costly option for reducing risks to communities from floods and hurricanes, and they provide an array of other critical benefits to society.

• **Actuarially-sound insurance provides an important way to encourage risk reduction.** In the face of growing risks from floods and hurricanes, insurance provides a way to spread risks and cover losses after they occur. When priced to reflect the risks it is intended to cover, insurance also provides an incentive for policy holders to adopt risk-reduction measures.

• **Consideration of social equity is a necessary component of natural catastrophe policy.** Given that risks from floods and hurricanes are unevenly distributed across society, social justice and equity are important considerations in the development and implementation of natural catastrophe policy.

With these principles serving as its foundation, this report identifies seven areas of federal and state law in need of improvement:

1. The National Flood Insurance Program is in need of critical reforms. Much work is necessary to reform the National Flood Insurance Program (NFIP) in both the executive and legislative branches of the federal government. In particular, the Administration can act now to increase the standards local communities must meet to participate in the program. The minimum standards for participation should include appropriate consideration of the role natural infrastructure plays in safeguarding people and property. Also, Congress can act now to transform NFIP's hazard mitigation program by making cost-effective investments in natural infrastructure to safeguard coastal and riverine communities. These investments must be at a "Marshall Plan" scale to truly address the gravity of the threat that floods and hurricanes pose to these communities.

2. Funding through the Stafford Act must prioritize proactive hazard mitigation. Congress and the Administration must place greater emphasis on disaster mitigation through programs funded under the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford Act), with priority emphasis on efforts that protect and restore natural infrastructure and that grapple with the realities of climate change.

3. Strengthening the Coastal Barrier Resources Act will greatly improve coastal resilience to floods and hurricanes. Congress and the Administration can make great strides in protecting coastal communities from the effects of sea-level rise and hurricanes while enhancing critical ecological systems by strengthening and expanding the Coastal Barrier Resources Act (CBRA).

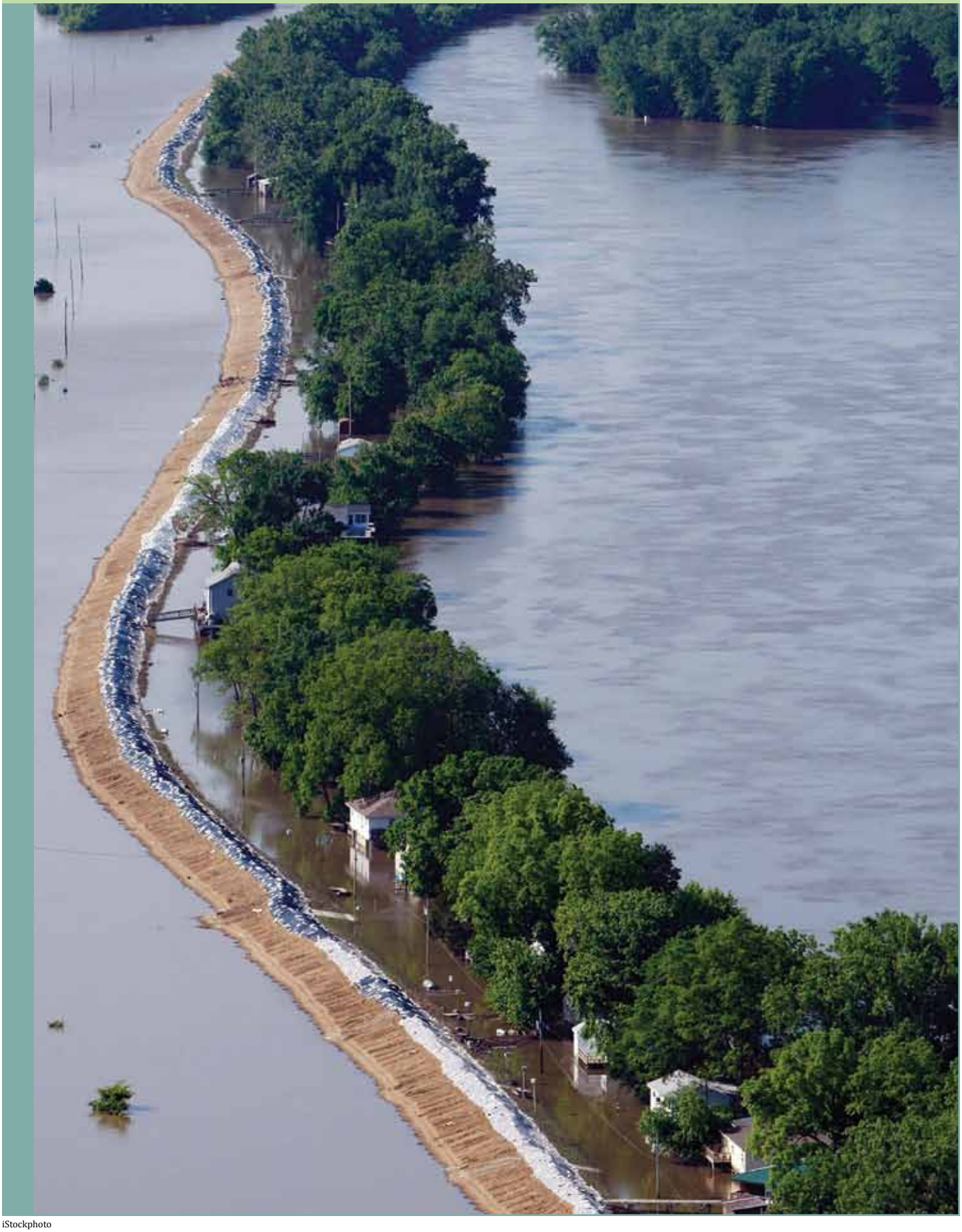
4. The Clean Water Act must protect the nation's diverse wetlands and streams. The Administration should finalize its proposed rule clarifying which waters are protected by the Clean Water Act. By restoring important protections for wetlands and streams, this rule will help protect America's communities from flooding and provide critical habitat for fish and wildlife.

5. The U.S. Army Corps of Engineers navigation and flood control policy must prioritize natural infrastructure. The Administration should prioritize the use of natural infrastructure and protect ecosystem services when planning and implementing U.S. Army Corps of Engineers (USACE) navigation and flood control projects. The Administration and Congress should also ensure that USACE projects are planned and managed to address current and projected climate conditions.

6. State insurance programs must be actuarially sound while addressing the needs of socially-vulnerable communities. States should reform their natural catastrophe insurance programs to ensure thorough accounting for flood and hurricane risks, to encourage greater investment in natural infrastructure and other risk mitigation, to more effectively spread risks through instruments such as reinsurance and alternative financing mechanisms, and to accommodate the needs of socially-vulnerable communities.

7. The United States must minimize risks by reducing carbon pollution. Congress, the Administration, and the States must confront one of the chief causes of the growth in flood and hurricane risk: climate change. Taking policy action to reduce carbon pollution is a critical step toward safeguarding wildlife and people from climate change impacts.

iStockphoto



iStockphoto

Chapter 1. The Need for Natural Catastrophe Policy Reform

The increasingly devastating and costly destruction caused by floods and hurricanes is a wake-up call policy makers cannot ignore. Improving the resilience of communities to these natural hazards must become a paramount tenet of public policy, recognizing that the risks will increase as the climate changes and that many more people will move into or find themselves in hazard-prone areas in the future.

Safeguarding Americans from the mounting risks from floods and hurricanes requires being proactive – implementing strategies to reduce exposure and vulnerability to such events before they happen, not just responding to them afterwards. Resilience also requires working with nature, rather than against it. There is growing recognition that emphasizing natural and nature-based approaches for reducing risks from floods and hurricanes can offer tremendous benefits to society, not just today, but for many years to come.[2] In this context, *natural approaches* are those that rely on existing or restored natural systems (e.g., wetlands, mangrove forests, beaches, dunes, barrier islands, and riparian zones) for their risk reduction and other associated benefits. *Nature-based approaches* are designed to mimic the risk reduction functions of natural systems but are constructed by humans (e.g., living shorelines, engineered oyster reefs, engineered dunes) (see Figure 1).[3] In this report, both natural and nature-based approaches are referred to as *protecting and restoring natural infrastructure.*

Investing in natural infrastructure can offer equal or better flood- and hurricane-protection benefits compared to gray infrastructure while avoiding the negative impacts of the latter, saving on maintenance and capital costs, and providing many additional ecosystem services. For example:

Figure 1. Natural and nature-based features at a glance. Adapted from: USACE. 2013. *Coastal Risk Reduction and Resilience*. CWTS 2013-3. U.S. Army Corps of Engineers, Washington, D.C.

• Research suggests that restoration of 13 million acres of wetlands in the upper portion of the Mississippi-Missouri watershed, an amount that represents half of the wetland acreage in the region drained since the late 18th century, would provide enough floodwater storage to accommodate excess flow in the region from an event comparable to the Great Flood of 1993.[4]

• In the Chesapeake Bay, studies have found that for every dollar spent to construct vegetative shoreline stabilization, as much as $1.75 is returned to the economy in the form of improvements to ecological resources, including submerged aquatic vegetation, fish, benthic organisms, shellfish, waterfowl, and wetland habitat.[5,6]

• New Jersey's freshwater wetlands have been estimated to save the state $3 billion per year in avoided losses from floods, storm surges, and other disturbances.[7]

• A $150 million investment in oyster reef restoration in the Gulf of Mexico is estimated to increase revenue and sales of fisheries by $6.87 million annually and save property owners up to $150 million on the construction of bulkheads.[8]

• A benefit-cost analysis of storm surge protection measures in San Francisco Bay compared marsh restoration to traditional structural methods. It found that a levee alone would cost $12 million in maintenance over its 50-year lifetime, but with a

Kara E. Reeve

marsh just 25 feet wide on the bayside, this cost would be reduced to around $6 million.[9]

• Globally, coral reefs have been found to reduce wave energy by as much as 97 percent, and do so more cheaply than structures such as breakwaters.[10] In the United States, coral reefs are estimated to reduce coastal hazard risks for as many as 7 million people who live in areas below 30 feet in elevation and within about 30 miles from the coastline.

Unfortunately, the current system for managing the risks from natural hazards frequently fails to capitalize on opportunities to protect and restore natural infrastructure. Instead, public policies and programs to address natural hazards continue to encourage development in particularly vulnerable coastal areas and riverine floodplains. Policy makers and planners frequently underestimate and undervalue the risks of such development. The NFIP, for instance, has subsidized premiums for more than one million policyholders and covered properties subject to severe repetitive losses, thus disguising the risks to property owners living and working in flood zones. Losses resulting from recent catastrophic events such as Hurricane Katrina and Hurricane Sandy underscore concerns that the program, now $24 billion in the red, represents an unsustainable drain on the U.S. economy.[11]

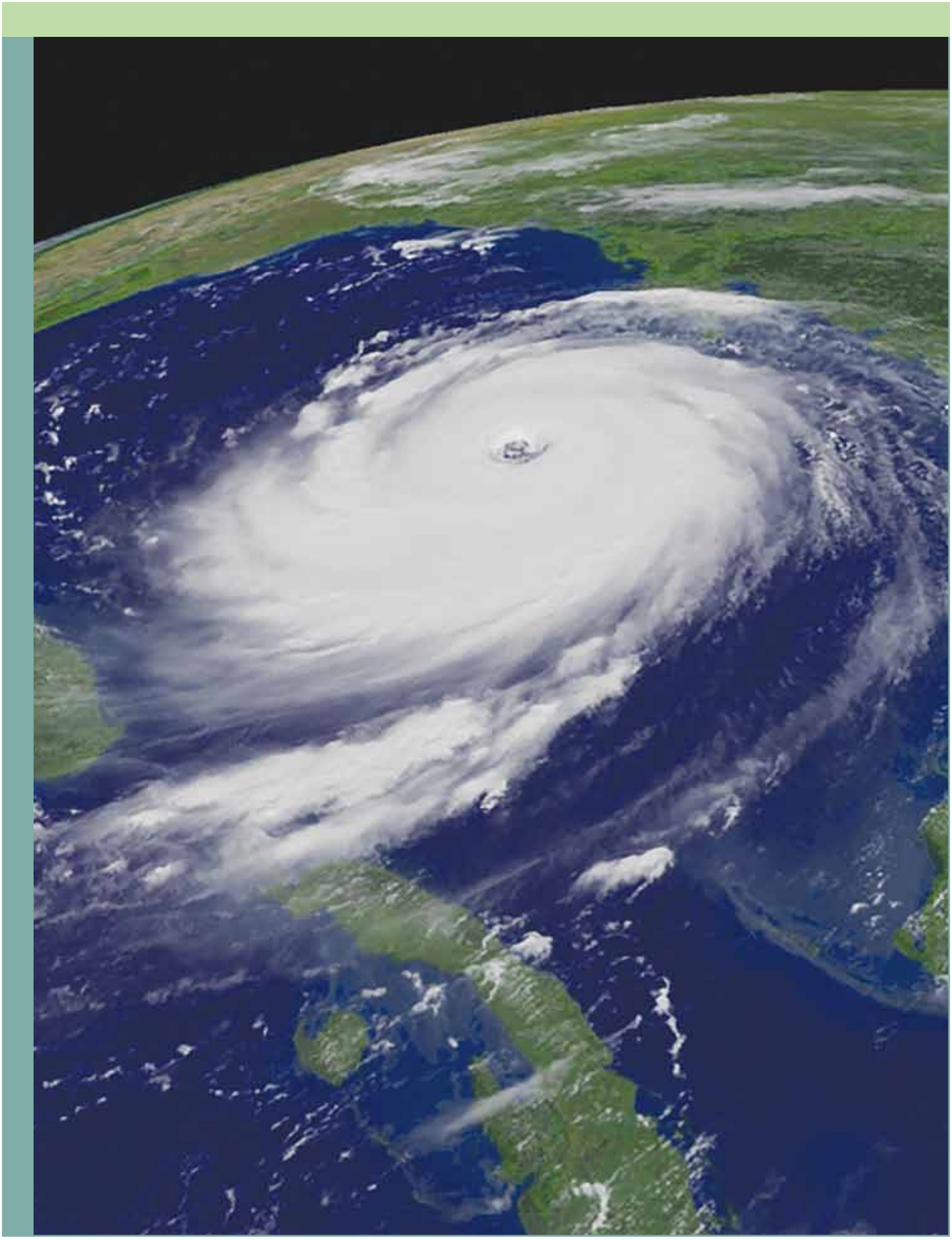
At the same time, local, state, and federal governments routinely underinvest in mitigating risks before floods and hurricanes occur due to factors such as budget constraints, lack of knowledge about risks and costs, and shortsightedness, despite the fact that investing in risk reduction measures can provide considerable economic benefits and cost-savings in the long run.[12] Especially slighted are efforts that focus on protecting and enhancing natural systems that play a role in flood mitigation. The multiple benefits of natural systems are often undervalued or overlooked altogether in the benefit-cost analyses often required to justify mitigation investments.[13]

Policy makers have relied heavily on structural protections such as seawalls, levees, jetties, and dikes, which incentivize development in hazard-prone areas. This imprudent development together with climate change actually increases flood and hurricane risk for many communities.

Creative Commons/Eric Mstr

The current approach has resulted in the degradation of the very natural systems that have attracted riverine and coastal development in the first place. In just the six-year period from 2004 through 2009, coastal watersheds of the conterminous United States lost wetlands at a rate of 80,000 acres per year, which equates to nearly seven football fields every hour.[14] An estimated 66 percent of all natural riparian areas in the United States have been destroyed or severely modified due to human activities, with the greatest losses occurring in the Mississippi River Delta, the agricultural Midwest, the arid Southwest, and California.[15,16] In addition, the area of the nation's natural oyster grounds have declined by 64 percent over the past century.[17] The loss of these and other natural systems has reduced the many important ecosystem services they provide, including attenuation of floodwaters and storm surges, waste removal functions, improved water quality, energy generation, and fisheries production, among others.[18]

Federal, state, and local policy makers must implement critical reforms to reduce the growing risks associated with floods and hurricanes and conserve natural functions in the process. This report highlights five key principles, described in Chapter 3, to help guide a better approach to dealing with the risks, particularly as the nation looks toward building resilience in an era of climate change. Building on those principles, the report identifies seven important areas for critical policy reform. Together, these principles and policies will help the nation work with nature to protect human communities, as well as conserve the fish, wildlife, and ecological systems that sustain us.



NOAA

Chapter 2. The Benefits and Risks of Living Alongside America's Rivers and Coasts

2.1. The Allure of America's Rivers and Coasts

People have long been drawn to the beauty and bounty of America's waterways and coasts, which support a vast diversity of fish and wildlife species and are a linchpin for the nation's economy, culture, and quality of life.[19]

- Rivers provide a lifeline of freshwater resources for people, agriculture, industry, and wildlife. In the continental United States, headwaters and intermittently flowing streams alone provide public drinking water supplies for approximately 117 million people – more than one-third of the nation's total population.[20]

- Riverine and coastal systems offer incredible opportunities for tourism and recreation. Spending on activities such as fishing, paddling, and hiking along America's river systems generate more than $20 billion per year in state and federal tax revenues.[21] In addition, coastal tourism and recreation accounted for more than 1.9 million jobs and $89 billion in economic output in 2010.[22]

- Coastal ecosystems comprise less than 10 percent of America's land area but support far greater proportions of fish and wildlife resources,[23] including 40 percent of the nation's National Wildlife Refuges, 40 percent of the federally-listed endangered species, 50 percent of the U.S. Fish and Wildlife Services' (FWS) fisheries activities, 25 percent of the nation's wetlands, and at least 30 percent of North American wintering waterfowl.[24]

- Ports and harbors in estuaries and bays support major interstate and international transportation and commerce. U.S. seaports support nearly 80 percent of America's imported and exported goods by volume.[25] In 2007 alone, seaports and seaport-related businesses generated 8.4 million jobs, and added $2 trillion to the national economy.[26]

- The oceans also provide a wealth of natural resources, from energy and minerals to abundant fisheries. Commercial fishing in the United States supported more than one million jobs and generated $32 billion in income in 2009.[27]

It is not surprising, therefore, that much of the land along rivers and coasts has been developed. Many of America's most iconic and vibrant urban centers are associated with major rivers and ocean shores, from the celebrated beaches of the Atlantic Ocean in Miami to the storied Potomac in the nation's capital; from the bountiful bayous of Louisiana to the Gateway to the West along the Mississippi River in St. Louis; and from the lush farmland fed by the South Platte River in Colorado to the seafood-loving communities on San Francisco Bay. For the people who live in these communities, riverine and coastal systems support more than just jobs – they are "home."

2.2. Along with the Benefits Come Growing Risks From Natural Hazards

Unfortunately, along with the numerous benefits of living along rivers and coasts come significant risks from natural hazards, especially floods and

hurricanes. Since flooding and hurricanes are natural events, coastal and riverine systems have evolved not only to accommodate but often to thrive with them. Riverine flooding creates pools, side channels, and islands that are home to fish, birds, and other wildlife. Floods can facilitate migration of plants and animals to new areas downstream. They also clear away old vegetation and debris, allowing understory plants to grow. Similarly, tropical storms and hurricanes can help build barrier beaches and coastal wetlands by moving sediments and provide important sources of rainwater to inland areas during droughts.[28] However, these natural events become *natural hazards* when they have the potential to cause damage or harm to the things people value – lives, personal property, businesses and jobs.

2.2.1. Rapidly-increasing development puts more people, property, and economies at risk

With America's population projected to grow by another 125 million to 160 million people within the next several decades, development in floodplains will continue and, with it, the nation will see a significant increase in the risks from floods and hurricanes.[29] The annual population growth rate along waterways and coasts is roughly double that of the United States as a whole.[30] Currently, floodplains account for 7 percent of America's overall land area, but they include 15 percent of the nation's major urban areas, including nearly 10 million households.[31] In 2010, 123.3 million people (or 39 percent of the U.S. population) lived in coastal shoreline counties, while those areas constitute only 10 percent of the total land area (excluding Alaska).[32] Among them, 3.7 million people currently live within one meter of high tide,[33] and 22.9 million people live within six meters of high tide. By 2020, the number of people in coastal shoreline counties is projected to grow by another 10 million people, or 8 percent. By 2100, the portion of the U.S. population living in coastal counties on a whole is expected to increase by as much as 144 percent.[34]

As population growth in floodplains continues, so does the loss of natural lands, increasing even more the risks from extreme-weather events. According to data compiled by the National Oceanic and Atmospheric Administration (NOAA), more than 40,000 acres of natural and agricultural lands in designated floodplains (including 11,000 acres in Florida alone) were lost to development from 2001 through 2006.[35]

New development in coastal and riverine floodplains can create greater risks for already settled communities, including those that may be outside of the original floodplain area. Urbanization, in particular, can considerably alter flood hydrology.[36] An increase in roads, parking lots, and other impervious surfaces contributes to greater runoff into rivers and streams, which may lead to flooding during heavy rainfall events. In addition, construction of levees or deposition of fill in one part of the floodplain can lead to increased flooding in other areas.[37] Drainage systems within leveed areas increase soil subsidence, which results in communities suddenly finding themselves below sea level and at risk of catastrophic flooding when protection levees and floodwalls fail. Similarly, the existence of seawalls to protect coastal property from storm surges and erosion can exacerbate the impacts of such events on adjacent unarmored areas. Despite these risks, local governments continue to allow for imprudent development (see Case Study 1).

2.2.2. Rapidly-changing climate means more-extreme, more-dangerous events

Human-induced climate change places properties in floodplains at even greater risk due to rising sea levels, more-intense coastal storms, and an increase in the number and intensity of heavy

Case Study 1: Promoting "non-significant" development along Clover Creek in Parkland, Washington

Along Clover Creek in suburban Parkland, Washington, lies three acres of undeveloped property. Clover Creek cuts through this empty lot diagonally, flowing from the southeast corner to the northwest. Surrounded by highly developed residential and commercial properties, the lot lies almost entirely within the 100-year floodplain, the Deep and Fast Flowing Floodway, and in an open space and fish and wildlife corridor. Flooding has plagued the surrounding neighborhood for years.

Pierce County, Washington

In 2007, Pierce County granted a Determination of Nonsignificance (DNS) for a proposal to build seven homes on lots on the east bank of the creek. In 2008, the applicant received a wetland variance to negate the shoreline, floodplain, and critical areas regulations that pertained to this property. Both the DNS approval and the variance indicated no environmental impact statement would be required.

Under the terms of the variance, the west bank of Clover Creek would remain undeveloped, with no alteration; the east bank, on the other hand, would be almost entirely taken up by the new structures and restoration activities would be required on the severely-reduced 35-foot buffer next to the creek. In order to keep the newly constructed homes out of the floodplain, the developer proposed to "mound" the foundations of the houses and create compensatory flood storage between them. According to the Pierce County Surface Water Management testimony at the variance hearing, the houses would become islands in the event of 100-year flooding. At best, the net impact of the new development on the surrounding community would be neutral; at worst, it would increase flooding.

A property appraisal was done to establish the best use and highest value of the property. The appraisal assumes that the property would be developed in compliance with existing environmental regulations and laws, even though the existing laws would seem to prohibit development at this site. The appraisal also fails to account for the costs of achieving compliance. Unsurprisingly, the conclusion of the appraisal was that the property would be best used as a commercial development. No consideration was given to a non-development option. What the appraisal failed to take into account is that flooding at this site is inevitable. Even if the Base Flood Elevation (i.e., the elevation to which floodwater is anticipated to rise during a 100-year base flood) does not reach the floor of the homes now, climate change increases the risk that it will in the future.

rainfall events. Evidence of a changing climate is extensive. As highlighted in the *Third National Climate Assessment:*[38]

• Heavy downpours are increasing nationally, especially over the past 3 to 5 decades, with the largest increases occurring in Midwest and Northeast.[39] In data ranging back to 1895, 9 of the 10 years for the most extreme precipitation events have occurred since 1990.[40] This has corresponded with a significant increase in annual flood magnitude from the 1920s through 2008.[41]

An increase in both the frequency and intensity of extreme precipitation events are projected across the United States in the decades to come.

• Since the 1950s, there has been an increase in the intensity, frequency, and duration of North Atlantic hurricanes, as well as in the frequency of the strongest (i.e., category 4 and 5) storms. According to the Accumulated Cyclone Energy index, which reflects the activity and destructive potential of tropical hurricanes as well as hurricane seasons, 6 of the 10 highest-rated years have occurred after

1995.[42] This increase is linked at least in part to an increase in sea surface temperatures. From 1880 to 1980, average sea surface temperatures rose 0.5° Fahrenheit, and in a much shorter period from 1980 to 2013, they rose another 0.5° Fahrenheit. This trend is projected to increase as global warming continues.

- Global average sea levels have risen about 8 inches since the late 1800s, and the rate of sea-level rise during this century is expected to accelerate. Since the early 1990s, the rate of sea-level rise has been about twice the rate observed over the past century.[43] Global average sea levels are projected to increase by another 1 to 4 feet by the end of this century.[44] Recent evidence of ice shelf loss in Antarctica suggests we are likely to experience the higher end of the range without significant action to reduce greenhouse gas emissions.[45]

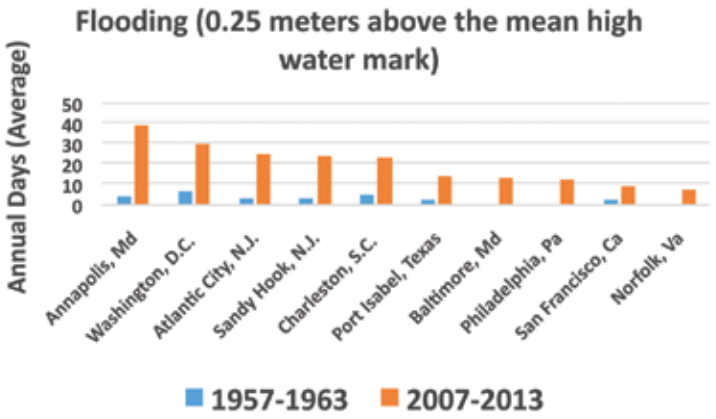


Figure 2. Top-ten cities experiencing an increase in average annual number of coastal flooding days associated with high tides. Adapted from: Sweet, W., J. Park, J. Marra, C. Zervas, and S. Gill. 2014. *Sea Level Rise and Nuisance Flood Frequency Changes around the United States*. NOAA Technical Report NOS CO-OPS 073. National Oceanic and Atmospheric Administration, Silver Spring, MD.

These and other changes are already having a significant impact on communities across the United States. For example, sea-level rise has rendered Miami more susceptible to flooding during high tides as its aging flood control system, low-lying topography, and porous limestone soils enable sea water to encroach inland.[46] In Louisiana, human-induced land subsidence and erosion, combined with global sea-level rise, have led to considerable loss of coastal marshes during the past century.[47] As a result, places like New Orleans – where more than half of the population currently lives below sea level – face greater exposure to storm surges, and small bayou communities flood even during routine sustained south winds accompanying a frontal passage.[48] According to a recent study by NOAA, an increase in relative sea levels has significantly exacerbated coastal flooding events (i.e., the number of hours and days when flood levels are more than 0.25 meters above the mean high water mark) experienced during high tides in many U.S. coastal regions.[49] Some areas, including Annapolis and Baltimore, Maryland, have experienced as much as a nine-fold increase in the average annual number of flood days since the middle of the last century (see Figure 2).

As sea levels continue to rise, the frequency and extent of coastal flooding events are expected to grow. In some areas of the Pacific Northwest, southern California, and the Southeast, for example, research suggests that sea-level rise could turn today's 100-year storm surge into an annual event. In addition, a study comparing storm surge risk for the southern shores of Long Island, New York found that even a relatively modest sea-level rise of 0.5 meters by 2080 would increase the number of people affected by 47 percent and the amount of property loss compared to the present day storm surge impacts by 73 percent.[50] Many communities under threat have never faced these types of extreme events, increasing the probability of damage and general hazard. On the Mid-Atlantic coast, sea-level rise has increased the probability of catastrophic storm-surge events comparable to the devastation caused by Hurricane Sandy in 2012.[51]

Don Becker/USGS

What would have been considered a once-in-a-century storm surge event in the region in 1950 can now be expected to recur every couple of decades.

2.2.3. The impacts and costs of natural hazards will continue to escalate

Natural hazards can take an enormous toll on society. Floods and hurricanes, in particular, are among the most common, costly, and deadly natural hazards in the United States.[52, 53,54,55] Yet no agency, non-governmental organization, or local government has effectively calculated the full cost of losses from a single flood or hurricane event. The information systems required to capture such data are not in place in most communities. Flood- and hurricane-loss estimates are generally based on infrastructure losses, reported costs to rebuild private homes (calculated based on grant applications to state and federal agencies), and general estimates of lost economic output. Even with all of this data, a considerable amount of information is not captured. For example, most communities do not keep track of operations and maintenance costs tied to flood and hurricane events.

Despite the absence of a comprehensive system of accounting for flood and hurricane losses, the available data show they are quite substantial. Total direct monetary losses from flooding and hurricanes (based on data from the Spatial Hazard

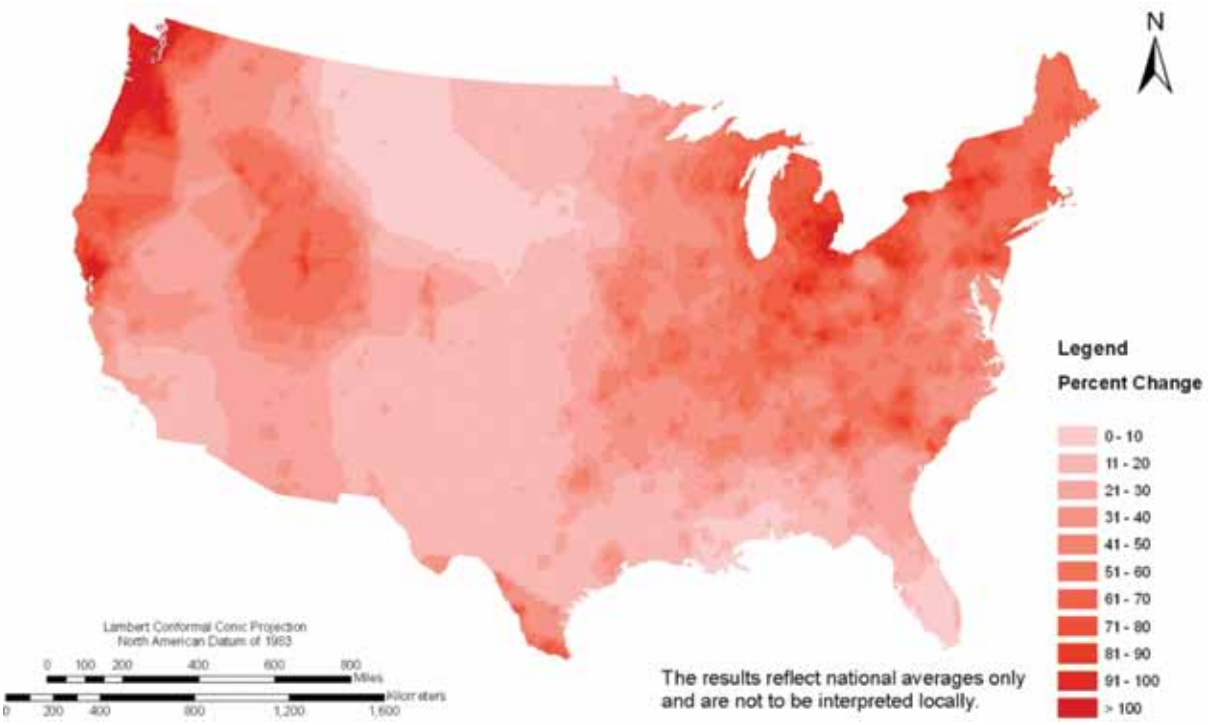


Figure 3. Median projected percent change in Special Flood Hazard Area for 2100 over current conditions.
Source: AECOM and FEMA. 2013. *The Impact of Climate Change and Population Growth on the National Flood Insurance Program through 2100.* AECOM and the Federal Emergency Management Agency, Washington, D.C.

Events and Losses Database for the United States, or SHELDUS) from 1960 to 2009 were estimated to be nearly $326 billion (in 2013 dollars), amounting to more than half of the total losses due to all types of natural hazards.[56] The 2005 and 2012 hurricane seasons, which included the infamous Hurricanes Katrina and Sandy, together cost taxpayers nearly $150 billion.[57] Hurricane Katrina alone destroyed 350,000 homes, 12-times more than the number destroyed by any previous disaster in U.S. history.[58] Research suggests that exposure to such extreme events can have a considerable adverse impact on long-term national economic growth.[59]

Floods have accounted for nearly two-thirds of all federal disaster declarations.[60] In Boulder County, Colorado, deadly flooding brought on by more than 20 inches of rain over a 5-day period in 2013, as much rain as the area normally gets in a year, damaged nearly 4,000 homes and caused more than $1 billion in damages.[61] In the Midwest, many of the communities ravaged by the Great Flood of 1993 have since experienced additional catastrophic floods. In 2008, more than 1,100 daily precipitation records were exceeded in the region, mostly in Iowa, Illinois, Wisconsin, and Missouri.[62] As a result, the Cedar, Illinois, Missouri, and Mississippi Rivers all topped their banks and levees, leaving hundreds of thousands of people displaced and contributing to more than $15 billion in agricultural and property losses. In 2011, unprecedented rainfall combined with spring snowmelt created a massive flooding event that lasted for weeks and affected states from Illinois and Kentucky to Louisiana and Mississippi. In response, the U.S. Army Corps of Engineers (USACE) was forced to open numerous spillway gates and activate floodways to prevent flooding in both upstream and downstream communities. Though the flood-protection system held on the lower Mississippi, the USACE requested $2 billion from Congress to repair flood damage to the levees.

Of course, economic data cannot convey the value of precious lives lost to floods and hurricanes. Nor is it easy to calculate the tremendous psychological impact that personal loss can have on communities affected by extreme events. Two years after Hurricane Katrina struck the coast of Louisiana, Post-Traumatic Stress Disorder and other mental health issues were still prevalent among residents who lived through the disaster.[63] Financial strain, displacement, and the loss of loved ones all contribute to a collective sense of loss not easily quantified by traditional estimates due to uncertainty, ethical questionability, and potential for social inequity inherent in the economic methods for dollar-based valuation of human life.[64] Standard loss estimates also fail to capture the long-term impacts of environmental damage wreaked during extreme events. For example, Colorado's current cycle of fire and flood has led to major erosion and sediment loading into streams, which has become a serious threat to drinking water.[65]

Together, a continuing influx of people and property in hazard-prone areas and an increase in the frequency and intensity of extreme events due to climate change mean America is likely to experience a dramatic increase in the costs of natural hazards in the coming decades. Without significant investments in better flood-protection measures, it is estimated that flood losses due to both changing socioeconomic and climate conditions in 136 of the world's major coastal cities could reach $60 trillion over the next 40 years. In the United States, New Orleans, New York City, and Miami alone could account for nearly a third of all global losses.[66]

Placing residential or commercial development in areas exposed to flooding every 100 years (i.e., a 1-percent chance of floods occurring there in any given year) means taking on significant risk. In the 30-year timespan of the typical mortgage, a house in the 100-year floodplain has more than a 25-percent chance of experiencing flooding.[67] Federal law requires that buildings in the 100-year floodplain participate in the NFIP as a condition of obtaining a federally-backed mortgage. Thus, the fact that exposure to 100-year flood events has more than doubled in some areas and will continue to increase across the United States[68,69] it is now of great significance to those concerned about the future of the nation's primary program for insuring flood losses.

The Federal Emergency Management Agency (FEMA) projects a 45-percent increase in the area of lands designated as Special Flood Hazard Areas (SFHA) (i.e., those subject to a 100-year flood event) across the United States by the end of this century (see Figure 3).[70] For coastal areas, the study projects a 55-percent increase in SFHA by 2100. This projection likely underestimates the geographic extent of coastal areas at risk since it assumes, in the face of much evidence to the contrary (see section 3.1.1), that coastal communities will be able to stabilize their shorelines with beach nourishment or a seawall. FEMA attributes about 30 percent of the increase in areas at risk to population growth, while 70 percent is due to sea-level rise and storms associated with climate change. Given these changes, the number of properties insured under the NFIP is projected to double, with the cost of payouts under the program increasing by 90 percent. As a result, the costs to taxpayers for providing flood insurance through this program, and the costs to policy holders for obtaining such coverage, will grow substantially. The demand for economically-viable and environmentally-sustainable solutions to this challenge will likewise grow.

iStockphoto

USACE

Chapter 3. Principles for Increasing Resilience to Floods and Hurricanes in an Era of Growing Risks

Given the increased risks from floods and hurricanes to people living and working in hazard-prone areas, America must put forward a new paradigm for natural catastrophe policy. This will require more efficient and effective policies and programs that safeguard communities before disasters occur. Priority attention must be given to those actions that provide the greatest economic, ecological, and social benefits for both individual communities and the nation as a whole.

Certainly, lessons gleaned from historical responses to major floods and hurricanes can help guide future risk-reduction decisions. Experience has shown that underestimating the risks and failing to adequately prepare for catastrophic events can have a tremendous cost on society. As highlighted above, not only do major floods and hurricanes lead to considerable economic losses for communities, but they can destroy the very ecological fabric that makes such communities thrive. The nuclear contamination of the coastal waters of Fukushima after the massive earthquake and tsunami off the coast of Japan in 2011 is just one example of how failure to prepare for natural hazards can wreak enormous havoc on public health and the natural environment.

Catastrophic events can galvanize public concern about the risks from natural hazards.[71, 72,73] At a minimum, such events move considerations of risk from the abstract to the real, at least for a while.[74] But this fleeting tendency also raises the question: How many more disasters will it take to ensure the investment necessary to create a society that is truly resilient to their impacts? Helping people better understand the human dimensions of natural hazards is key to motivating behavior. As geographer Gilbert F. White wrote in his seminal dissertation *Human Adjustment to Floods* in 1945, "Floods are 'acts of God,' but flood losses are largely acts of man."[75]

iStockphoto

Fortunately, federal, state, and local leaders have the opportunity to make communities safer and achieve a plethora of additional benefits by focusing on natural catastrophe policy reform. What it will take, however, is the foresight and leadership to fundamentally transform every aspect of policy, from assessment, communication, and ultimately management of flood and hurricane risks.

Toward this vision, the following five principles must guide the development of public policy to ensure that we can safeguard people and conserve nature now and in the future:

1. Better evaluation and articulation of risk may lead to more risk reduction.

2. Proactively investing in certain risk reduction measures can produce large savings over the long term.

3. Investments in natural infrastructure, including existing natural systems, maximize resilience to floods and hurricanes.

4. Actuarially-sound insurance provides an important way to incentivize risk reduction.

5. Consideration of social equity is a necessary component of natural catastrophe policy.

3.1. Better Understanding of Actual Risk Can Lead to More Risk Reduction

One of the fundamental principles of effective natural hazard management is to understand the risks as fully as possible.[76] In this context, risk refers to the probability and consequences of being harmed by a natural hazard. If the damages and losses associated with a natural hazard event have particularly severe consequences, it may be deemed a disaster or catastrophe.

Risk management seeks to predict and reduce (i.e., "mitigate") risk factors associated with those hazards. In the case of risks from floods and hurricanes, such management may involve structural and non-structural approaches. Structural approaches generally utilize man-made infrastructure such as levees, storm surge barrier gates, seawalls, and breakwaters to impede associated impacts. Structural measures can also utilize natural features to enhance their level of protection, like living shorelines or engineered log jams. Non-structural approaches include actions such as flood-proofing or elevation of infrastructure, hazard-preparedness planning, land-use regulation, relocation of infrastructure, protection of undeveloped open space, and restoration or enhancement of natural systems such as wetlands, mangroves, riparian forests, and reefs.[77]

An essential element of risk management is *risk analysis,* which involves assessing the probability that a natural hazard will occur and the magnitude of the impacts and their consequences. In some cases, both the probability of and potential consequences associated with a natural hazard are relatively clear. In areas that are flooded on a regular basis, for instance, property owners may stockpile sandbags or have contingency plans at the ready. When there are considerable uncertainties involved, however, making risk-management decisions can be more challenging.

Ideally, the amount invested in risk reduction will be proportional to the likelihood and magnitude of the risk and the cost-effectiveness with which that risk may be reduced.[78] Failure to adequately account for the full socioeconomic costs of risks leads to poor decisions and, consequently, higher risks than may be acceptable to those facing them.

3.1.1. Risk perception guides decisions

Perception of risk can play an important role in guiding decisions about whether and how to address it.[79,80] In some cases, people decide to engage in risky behavior, such as building homes and businesses in hazard-prone areas, even when the risk is fully understood.[81] In such cases, the accurate perception of risk can influence behavior. For example, property owners may elect to incur the high costs of mitigation activities, such as installation of a bulkhead or elevation of buildings, to protect their assets.

An essential element of risk management is risk analysis, which involves assessing the probability that a natural hazard will occur and the magnitude of the impacts and their consequences.

In other cases, a poor perception of risk is the key driver of behavior. In fact, throughout the 20th century, the risks of flooding and hurricanes were often not well known or not fully accounted for in key decisions by policy makers and property owners. In many land-use decisions, the risks at one site might have been well understood, but the

aggregate impact of a rapidly-developing watershed or coastline was not considered. As discussed further in section 3.3, armoring shorelines and riparian corridors has been shown to actually increase the intensity of flooding and erosion in many areas. As a result of the poor understanding of flood risk behind armoring, national policies have been skewed toward more development in areas at risk of floods and hurricanes and less investment in measures to reduce those risks.

There are several reasons why land-use decision makers frequently underestimate the risks from natural hazards. One important factor is that several key federal policies and programs intended to deter living in hazard-prone areas may instead have lowered the perceived risks of doing so. For example, until recently, the subsidized premium rates charged for flood insurance under the NFIP for structures built before their community's flood insurance rate map (FIRM) was created have buffered those purchasing insurance from the true risk and cost of the damage associated with property flooding, allowing a perception that such risk is lower than it actually is. Other properties are subsidized through a practice known as "grandfathering," whereby the risk has increased but FEMA continues to charge the rate associated with the original and lower risk zone.[82] Policies that fail to deter floodplain development do not just lower the perception of risk – they also impose externalities (i.e., social or environmental costs not included in economic or market prices) when subsidized rates come at the expense of all taxpayers who pay for associated flood defenses.[83]

There is also a tendency for people living behind structures such as seawalls, dikes, and levees, to overestimate the protection benefits provided. Especially as climate change contributes to more extreme floods and hurricanes, these structures often lure people into a false sense of security. Under the NFIP, for example, homeowners and businesses located in floodplain areas that have been protected by structures are often not required to purchase flood insurance if the structure is certified to provide protection from flood events with a probability of occurring once in every 100 years.[84] But if a flood with a lower probability but higher impact (e.g., 150-year flood) occurs, the structural protection could fail and the properties "protected" behind it could actually suffer worse damage than would have occurred in the absence of the structure. Until such a flood strikes, however, the false security creates an increased incentive for development in these areas, and a lower propensity to invest in hazard mitigation. Typically, such structures are designed to withstand historical floods and hurricanes, without consideration of the added risks from climate change. Consequently, communities may unwittingly invest in highly-vulnerable developments that are superficially protected by man-made structures (see Case Study 2).

NOAA

Recent catastrophic storms have shown that levees and other structures can, and often do, fail either because they are hit by high-magnitude storms that they were not designed to withstand or because of flaws in their design or construction.[85,86] For example, some of the greatest destruction and loss of life from Hurricane Katrina occurred when levees and other structures believed to be capable of withstanding a 100-year storm event catastrophically failed due to a combination of factors that contributed to overtopping, undermining, and structural failure.[87] The storm surge that reached some portions of the Greater New Orleans levee system during Hurricane Katrina was estimated by some to be equivalent to a 150-year event.[88] The speed and volume of

Case Study 2. A change of course after levee failures: protecting and restoring natural infrastructure in Yuba County, California

TRLIA and River Partners, Inc.

California has had a long history of building and maintaining levees for flood control along its rivers and streams to reduce damages to its expansive cropland and growing communities. In Yuba County, three major rivers, the Yuba, Bear, and Feather, have brought critical water resources – and devastating floods – to the region, dating back to the early 1800s.

Since then, the area has become a patchwork of levees surrounding farms and towns. But the aging infrastructure has not prevented major flood events. In 1986, a levee break on the Yuba River led to floods that damaged or destroyed nearly 4,000 homes and caused $22 million in losses.[91] In the wake of this disaster, the USACE spent millions of dollars to improve levees throughout the region, yet the flood risks remained. In 1997, levee failures along the Bear and Feather Rivers flooded 1,000 acres of residential, 15,500 acres of agricultural, and 1,700 of industrial land, causing damages estimated at more than $300 million.

These events have led several communities to rethink how they manage floods. While considerable investments continue to be made in shoring up levee infrastructure, there have been several notable projects to develop setback levees, which allow "room for the river" by incorporating natural floodplain lands and habitat restoration into the project design. Not only do such projects take advantage of the natural functioning of the floodplain, but the levees themselves often can be built and maintained at lower cost because they do not have to accommodate as much flood velocity as if they were directly along the river.

In one such project that was built by Three Rivers Levee Improvement Authority (TRLIA) and coordinated with the USACE, 9,600 feet of levees were set back along the confluence of the Bear and Feather Rivers, reconnecting 600 acres of flood-prone agricultural land to the floodplain.[92] This land has since been restored into riparian and grassland habitat that supports numerous species of fish and wildlife, provides a variety of recreational opportunities, and helps buffer the release of pollutants from nearby agricultural operations into the rivers. The new setback levee and restoration area are excellent examples of blending flood control with ecological habitat while maintaining all the necessary flood flow requirements. Although isolated cases of progress on levee setbacks exist, more specific information is needed about how these projects came about and which factors made them successful to facilitate the wide-spread use of this practice. A promising start, the Engineering with Nature initiative within the USACE has begun to identify opportunities for levee setbacks and document case studies of successful levee setback projects to advance the understanding of such projects and move forward with their implementation.[93]

the storm surge that hit parts of the city were greatly amplified by a federal navigation channel, the Mississippi River Gulf Outlet, which acted like a conveyor belt that funneled the surge into the city's Lower Ninth Ward. In other areas, portions of the hurricane protection system that failed (e.g., along the Industrial, London, and Seventeenth Street canals), experienced far lower surges that should not have caused failure. Upon post-failure inspection and analysis, it was determined that the failed levees and floodwalls did not meet the original 100-year standards and that the original standards were inadequate. While the design standards now used by the USACE have improved, and though the USACE has since spent $14.5 billion to rebuild the system with levees and floodwalls designed for a 100-year storm, New Orleans still lacks protection for a storm surge like the one experienced during Katrina.[89]

Levees and other protection measures, like building on fill to increase building height, can also result in unintended negative consequences for neighboring property owners and communities. By restricting space for floodwaters, the flood-protection structures and filled areas can deflect floodwaters to other areas, increasing the total threat and financial cost. For instance, modelling for Louisiana's proposed Morganza to the Gulf hurricane protection project, which includes construction of a 98-mile earthen levee, navigable floodgates, and other structures, suggests that if it is built, neighboring communities will have to raise their levees to deal with deflected floodwaters from hurricane storm surge.[90]

In some already-developed areas that were at one time considered safe, the risks from flooding and hurricanes have increased due to a range of both natural and anthropogenic factors such as land subsidence, coastal erosion, land use practices, and climate change. Yet, many FIRMs that FEMA uses to determine what areas and properties are subject to NFIP requirements do not reflect the future flood risk resulting from inadequately-designed structures, land-use practices, and climate change.

As the flood maps are used to set premium rates for the NFIP, these mapping flaws mean that in many places around the country, premiums may not reflect an accurate projection of flood losses. As discussed further in section 4.1, recent reforms to the NFIP, including the Biggert-Waters Flood Insurance Reform Act of 2012 (Biggert-Waters) and the subsequent Homeowners Flood Insurance Affordability Act of 2014 (Waters-Grimm) require important revisions to the national Flood Hazard Mapping Program to better reflect the risks of flooding to communities under both current and future conditions. For example, Waters-Grimm requires FEMA to use information on topography, coastal-erosion rates, sea-level rise, changing lake levels, and hurricane intensity. In addition, there are numerous mapping tools and other approaches that communities can use to help illuminate their vulnerability and exposure to floods from extreme rainfall events, storm surges, and sea-level rise, several of which are highlighted in Appendix 1.

3.2. Investing in Certain Risk Reduction Now Can Produce Large Savings over the Long-term

For properties at risk from floods and hurricanes, it is often more cost-effective to invest in strategies to prevent or avoid damage than to fund damage repair following a flood or storm, particularly where natural infrastructure can provide risk mitigation services. For example, King County, Washington, analyzed the cost of moving levees, reconnecting floodplains, and acquiring properties for restoration and found they were significantly lower than the cost of repairing damage to public and private property (see Case Study 3). If an area is at risk of repeated flood events, the cost-effectiveness of pre-disaster mitigation efforts can be even greater, as a one-time strategy for damage prevention can serve as a means to reduce risks from multiple storm events.

Case Study 3. Valuing flood mitigation efforts in King County, Washington

King County, surrounding the city of Seattle on the shores of Puget Sound, is at the forefront of pre-disaster mitigation efforts to reduce flood risk. The geographic extent of the county includes eight river drainage systems, most of which include residential and commercial properties located in high-risk areas within floodplains that are vulnerable to flooding. A system of over 500 levees and revetments was constructed over 45 years ago to provide flood protection for residential homes, commercial businesses, public infrastructure and roads. In many locations these structures are no longer sufficient to prevent flooding, due to disrepair and increasing flood severity. In addition, during some storm events water-flow constriction from levees simply transfers flood risk to other locations upstream.

Pacific Northwest National Laboratory

The 2006 King County Flood Hazard Management Plan, adopted in January 2007, advances several projects to strategically mitigate flood risk: levee setbacks, floodplain reconnection, and residential-home acquisition for floodplain restoration. The plan relies on economic analysis showing the avoided cost of reduced damage to residential structure as well as the value of ecosystem services from protected and restored floodplains, wetlands, and other natural infrastructure.

The analysis demonstrates that most of the mitigation strategies were cost-effective, with an estimated annual economic value of $700,000 to $3.5 million from avoided costs and improved ecosystem services. The mean net present value of proposed projects was estimated to exceed $18 million (based on a 3.5-percent discount rate). An updated 2013 plan and progress report has recently been approved, with revisions that include focused application of FEMA's Community Rating System (CRS).

In addition to providing valuable flood control benefits, King County's investments in protecting and restoring natural infrastructure are an important element of a collaborative, watershed-scale effort to protect critical habitat for the region's threatened Chinook salmon and bull trout.[102] While implementation of priority projects in the plan is estimated to cost from $272-$389 million, the ecosystem-service value the natural infrastructure enhanced by the projects is estimated to be at least $1.7 billion.

In addition to helping protect public safety, reducing risks from natural hazards through a combination of structural, non-structural, and restoration approaches can provide considerable economic benefits.[94, 95, 96, 97,98] A study by the Multihazard Mitigation Council of the National Institute of Building Sciences has found that, for every $1 spent on risk-reduction activities, America saves $4 in disaster costs.[99] The Congressional Budget Office (CBO) estimates that if federal funding for post-disaster assistance associated with floods and hurricanes declines in proportion to the decrease in property damage expected by investments made under FEMA's Pre Disaster Mitigation program, it could reduce federal spending by as much as $20 million per year over the next 50 years.[100] FEMA's natural hazard mitigation grants have been shown to be enormously cost-effective, with flood-damage-reduction benefits outweighing costs by 5 to 1.[101]

3.2.1. The need to properly account for the long-term benefits of risk reduction

Despite the potential for considerable net benefits to society, policy makers continue to underinvest in mitigation efforts in the United States.[103] As highlighted above, underinvestment in natural hazard mitigation is often related to underestimation of risk. If the economic consequences of a natural hazard are considered to be relatively low, then spending money up front to reduce the potential risk will be less attractive.

Many programs that support hazard risk mitigation activities require formal benefit-cost analysis to determine whether the monetary benefits of making upfront investments for elevating structures, flood-proofing homes, or other mitigation measures will offset the costs.[104] Typically, those benefits are measured as damages or losses avoided by mitigation. For example, while the construction of a diversion channel might reduce flooding, it likely will not do so by 100 percent. Overall benefit can be calculated by subtracting the avoided damages without the mitigation action from avoided damages with the measure.[105]

Poor methodologies for calculating the economic costs of floods and hurricanes can make it difficult to efficiently reduce the associated risks.[106,107] For example, flood and hurricane damage estimates can vary considerably based on the data available and methods used for valuing the costs.[108] Some measures focus specifically on insured losses, even though actual losses likely accrue to uninsured assets as well. Others are based on federal expenditures for disaster assistance, which may not adequately reflect actual losses to communities, especially over a longer timeframe than immediately after the event occurs.[109] In the case of hurricanes, damages from wind and erosion are often captured in inconsistent ways as factors such as types of insurance coverage come into play.

Metropolitan Transportation Authority

Furthermore, because total direct damages (both tangible and intangible) are often insufficiently accounted for, let alone indirect and "non-market" damages associated with natural hazards, the full socioeconomic costs of natural hazards are generally underestimated.[110, 111, 112] Direct tangible costs include things like loss of property, infrastructure, and lost business.[113] Direct intangible costs can include effects on human health, loss of life, loss of environmental goods and services (many of which, such as loss of species, require non-market valuation). Indirect costs are the specific consequences of the direct losses (e.g., lost economic activity, increased costs of production, and other welfare losses).[114] Also, there are likely to be important distributional impacts that aggregate figures may fail to disclose. For example, persons with less financial means often bear a disproportionately high share of the costs of natural hazards.[115]

Mitigation efforts also generally require upfront expenditures, while the direct benefits of those investments may not be realized until a flood or hurricane occurs. Without adequate consideration of probability in risk analysis, the lack of realized damage costs prior to a flood or hurricane event can be misconstrued as an absence of risk. The question becomes more complicated when there are potential tradeoffs between costs and benefits of mitigation today, versus costs and benefits in the future – especially when those future conditions are uncertain.

When making decisions about whether and how much to invest in mitigation efforts, the value of those costs and benefits must be measured in present terms. Accordingly, economists rely on a tool called "discounting." For projects that require a formal benefit-cost analysis, the rate at which future values are discounted can have a significant impact on the results. At a higher discount rate, future costs and benefits are valued lower than those in the near term. As a result, some investments that might provide considerable future benefits may not be considered worthwhile. Similarly, under lower discount rates, investments may be made for some projects that actually accrue high economic or societal costs over the long term (e.g., some structural flood control projects).[116]

Without adequate consideration of probability in risk analysis, the lack of realized damage costs prior to a flood or hurricane event can be misconstrued as an absence of risk.

Even where economic valuation is not involved, discounting can occur qualitatively, as people often tend to disregard events farther out from the present that they are likely to occur. Yet as climate change continues to worsen, future generations are committed to a legacy of irreversible impacts, with enormous economic and environmental consequences. In order to ensure that assessments of natural hazard mitigation and climate change adaptation actions that are likely to have considerable long-term benefits are not biased against future generations, some scientists and economists believe that analysts, when possible, should use a lower discount rate (a social rate of about 0.5 to 3 percent) to evaluate the present value of future impacts.[117, 118, 119]

Another factor that can create disincentives for state and local governments to invest in mitigation activities is the provision of federal disaster assistance. While several programs under the Stafford Act support state and local mitigation, FEMA assistance generally covers 75 percent of the cost for rebuilding public infrastructure in the event of a Presidentially-declared natural disaster. As discussed in section 4.2, unless this assistance is directly tied to meaningful actions on the part of communities to implement natural hazard mitigation plans, those communities may forego the upfront investments required to proactively reduce their risks.

NOAA

3.3. Investments in Natural Infrastructure Maximize Resilience to Floods and Hurricanes

Historically, the United States has relied on structural approaches for hazard mitigation. Hard armoring is undeniably necessary in some areas, such as major urban centers and places with heavy industry or hazardous activities. As noted previously, however, excessive use of this strategy is highly problematic. Many structures are susceptible to failure because they are exposed to more extreme events than those for which they were engineered, and their mere presence gives a false sense of protection to the communities dependent on them. In addition, hard armoring disrupts natural systems that would otherwise provide a wealth of benefits, including buffering communities from storm surge. Numerous studies have also found that hard armoring with seawalls, bulkheads, dikes, and other structures is typically detrimental to fish and wildlife habitats. For example, seawalls can disturb sea turtle nesting habitat, prevent coastal wetlands from migrating inland, limit natural sediment buildup, and cause further erosion in unarmored areas.[120, 121,122]

3.3.1. Investments in natural infrastructure produce a host of benefits in addition to reducing flood and hurricane risk

Natural infrastructure can offer equal or better flood and hurricane protection benefits compared to gray infrastructure while avoiding the negative impacts of the latter, saving on maintenance and capital costs, and providing many additional ecosystem services. In other words, investments in strategies to protect and restore natural infrastructure can provide a win-win-win solution

Case Study 4. Restoration of wetlands in Jamaica Bay, New York, through the beneficial use of dredged materials

FEMA

Within 10 miles of the hustle and bustle of Manhattan lies the beautiful, ecologically-rich Jamaica Bay, which is operated by the National Park Service as part of the Gateway National Recreation Area. The proximity of Jamaica Bay to highly-populated urban areas has made it a true natural sanctuary for millions of people who live in or visit the area each year, along with 325 species of waterfowl and shorebirds, 35 species of butterflies, more than 80 species of fish, and many other wildlife.[141]

Yet this proximity has also brought considerable stressors to the system. Today, just a fraction of the area's salt marsh islands remain after decades of damage from nitrogen loading and contaminants, dredging operations, boat traffic, and other factors; and the rate of wetland loss appears to be accelerating as a result of rising sea levels.[142] Without a concerted effort to restore the region's wetland habitats, they could disappear entirely within just a couple of decades.[143]

In what some might consider a paradox, a major effort is currently underway to restore more than 150 acres of salt marsh in Jamaica Bay using material from dredging operations associated with the New York and New Jersey Harbor Deepening Project. The restoration effort is a broad partnership between USACE, National Park Service, New York State Department of Environmental Conservation, New York City Department of Environmental Protection, The Port Authority of New York and New Jersey, the Natural Resources Conservation Service, and the New York-New Jersey Harbor Estuary Program, along with a number of non-profit organizations.

To date, more than 150 wetland acres have been restored using hundreds of thousands of cubic feet of dredged material and more than a million native marsh plants.[144] In the wake of Hurricane Sandy, these wetlands have proved to be resilient. Not only did the restored marshes avoid any significant losses during the storm, they also helped mitigate wave action.[145,146]

to reducing America's risks from floods and hurricanes. Even though gray infrastructure may be necessary in some cases, communities should prioritize the use of natural infrastructure and assess the extent to which it can be used instead of or in combination with gray infrastructure to reduce the vulnerability of people, built infrastructure, and natural systems.

Indeed, natural floodplains are among the most valuable ecosystems on earth. They provide a wealth of ecological services, including improving water quality and helping recharge groundwater, supporting vital habitat for a multitude of fish and wildlife species, and providing aesthetic and recreational opportunities, to name a few. For example, beaches and dunes drive much of the U.S. tourism industry valued at $322 billion per year, more than 25 times the total contribution of the National Park Service system to U.S. economy.[123] Globally, the estimated value of ecosystem services provided by natural systems as a whole ranges from $125 trillion per year to $145 trillion per year.[124]

Among many other benefits, natural systems such as wetlands, dunes, and riparian forests provide valuable protection to nearby communities from the impacts of floods and hurricanes by capturing and absorbing stormwater and buffering shorelines from waves and erosion.[125, 126, 127, 128, 129] For example, a single acre of wetland can store as much as 1.5 million gallons of floodwater.[130] Often, such natural infrastructure is less expensive and easier to maintain than hard armoring. Coastal wetlands,

for instance, have been estimated to provide as much as $23.2 billion worth of storm protection services in the United States each year.[131] These cost savings alone makes marsh restoration appealing even before taking into account additional benefits such as fish and wildlife habitat and associated recreational activities.

The dynamic nature of floodplain ecosystems also makes them especially resilient to natural disturbances.[132, 133] Healthy ecosystems, in particular, have considerable capacity to recover and regenerate over time following floods and hurricanes.[134] For example, the natural deposition of sediments from upstream or upland sources can provide sufficient levels of soil for marshes in deltas and estuaries to rebuild after storms and keep pace with rising sea levels through a process called accretion.[135] Beaches and other coastal habitats can migrate both landwards and seawards in response to disturbances and gradual changes over time, particularly in the absence of anthropogenic or natural barriers such as seawalls or bluffs.[136] And in natural riverine systems, many riparian plant species have adapted to accommodate a range of hydrologic conditions, including periodic flooding.[137] In contrast, engineered structures do not have the same adaptive or self-renewal capacities.

When riverine and coastal floodplains are damaged or destroyed by human activities, however, their ability to accommodate extreme events can be greatly diminished, along with the many ecosystem services that they provide.

When riverine and coastal floodplains are damaged or destroyed by human activities, however, their ability to accommodate extreme events can be greatly diminished, along with the many ecosystem services that they provide. In coastal Louisiana, for example, construction of levees and navigation channels, oil and gas operations, and other activities have destroyed vast areas of swamps and marshes that had once buffered coastal communities from storm surge. And from the Midwest to California, destruction of riparian vegetation through dam operations, damaging grazing, forestry, and agricultural practices, and development has greatly reduced the natural flood storage benefits they provide.[138, 139] In addition, human-induced climate change is likely to push these and other natural systems to their limits as sea levels rise and weather events become more frequent and severe. Ultimately, this results in a vicious cycle that threatens the health of human and natural communities alike.

To reverse this trend, floodplain management efforts should support the restoration and protection of the natural processes and functions of coastal and riverine floodplain systems under both current and projected future climate conditions. In some areas, for example, wetlands can be restored or enhanced through the use of clean and compatible sources of sediments from dredge operations or other carefully-identified sources (see Case Study 4). Similarly, a number of coastal communities along the Atlantic and Gulf coasts have constructed artificial dunes by placing discarded Christmas trees and other material along the shoreline to capture sand and planting grasses and other vegetation to reduce erosion.[140] While projects such as these must be based on sound ecological principles, they can be an important tool for enhancing natural infrastructure to reduce risks from floods and hurricanes.

3.3.2. Enhancing natural infrastructure for risk reduction is catching on

Recent catastrophic events such as Hurricane Sandy have galvanized interest in using nature-based natural infrastructure approaches, in combination with gray infrastructure, to reduce risks from floods and hurricanes – especially in light of the growing threats from climate change.

Case Study 5. Enhancing multiple lines of defense in Louisiana: lessons from Hurricane Katrina

Although there have long been "multiple lines of defense" against hurricanes in Louisiana, from the region's barrier islands and wetlands to the extensive system of dikes and levees, the heavy reliance on built infrastructure and the loss of coastal wetlands due largely to anthropogenic factors have significantly decreased the resilience of the coastline to extreme events.

The value of natural wetlands for storm and flood protection services is quite evident in the Mississippi River Delta region, particularly in the wake of Hurricane Katrina in 2005, which was one of the most costly and deadly storms in U.S. history. Historic losses of more than 1.2 million acres of coastal lands over the last 80 years have greatly increased storm and flood vulnerability in the region.[153] The trend of ecosystem deterioration in the Mississippi River Delta is amplified over time due to a positive feedback effect. Increases in storm and flood damage resulting from the loss of natural ecosystems accelerate the damage to land in the area. Losses from hurricanes in 2005 alone represent 42 percent of land loss that had previously been predicted over a 50-year period.[154,155]

NOAA

Economic analysis of future storm and flood risk reveals that without a change in course, continuation of the current trend of wetland loss in the area will result in more than $41 billion in economic losses.[156] This estimate includes only direct economic loss, without consideration of further losses from damage to natural infrastructure providing a range of ecosystem services. Given this, the USACE adopted a strategy to "hold the line" by taking measures to avoid further wetlands loss in the 2008 Louisiana Coastal Protection Technical Report (LACPTR). While this would be better than no action, it would not secure significantly greater natural hurricane buffering or even achieve the level of buffering available before Hurricane Katrina hit. The more effective option would be to work with the dynamic nature of the Delta and work to achieve sustainable restoration of wetlands through large-scale, controlled diversions of water and sediment from the Mississippi River to the Delta. In addition to avoiding the $41 billion in losses, it would add an estimated $21 billion in economic benefits.[157]

In the years since Hurricane Katrina, the USACE has invested heavily in a new flood protection system for New Orleans. One project, a new 1.4-mile long seawall in New Orleans cost $1.1 billion. It is the largest design-build project in the history of the USACE. While the seawall is designed to withstand a 100-year flood event, the continuing decline in wetlands and rising sea levels mean that the seawall and other armoring will face a greater brunt from storm surges. Accordingly, the region has been exploring the use of wetland restoration to reduce the risk to coastal communities. In 2012, Louisiana released its Coastal Master Plan (CMP), which identifies 109 projects that will deliver measurable benefits to coastal ecosystems and communities.[158] If fully implemented, restoration projects in the CMP would cost up to $25 billion and non-structural flood control efforts would cost an additional $12 billion. Compare that to the $108 billion in damages caused by Hurricane Katrina alone, and the long term value of investment in healthy coastal forests and marshes that reduce storm surge and protect communities through hurricane after hurricane is clear.

For years, the U.S. Environmental Protection Agency (EPA) has curated a toolkit on best practices for natural infrastructure projects. More recently, the USACE began looking at natural infrastructure as part of its portfolio of protection measures (e.g., its Engineering with Nature and Systems Approach to Geomorphic Engineering[149] initiatives). Similarly, the State of Maryland has issued new siting and design guidelines for state construction in response to a 2012 *Climate Change and "Coast Smart" Construction* executive order issued by Governor O'Malley.[150] Coast Smart practices include the identification, protection, and maintenance of ecological features that may serve to buffer a project from the impacts of future sea-level rise, coastal flooding, or storm surge, or that support general climate adaptation practices. In addition, EPA and the State of Vermont have developed guidance for communities developing flood management plans to improve flood resilience through a range of policy and regulatory tools.[151] The guidance includes a Flood Resilience Checklist that includes a range of options for consideration, from measures to promote land conservation and discourage development in river corridors, to the use of natural approaches to stormwater management at the watershed scale.

One of the most attractive things about natural infrastructure is that it appeals to a *multiple lines of defense* strategy. Mixing natural and gray infrastructure can enhance the effectiveness of a community's hazard-mitigation plan over gray infrastructure alone and thereby can improve the resilience of that community to natural hazards (see Case Study 5). Furthermore, many ecological features associated with coastal ecosystems are found in sequence, from reefs and seagrasses in the nearshore environment, to salt marshes and mangroves along the shore.[152] Often, these systems play cumulative role in wave attenuation.

3.3.3. Keeping people out of harm's way: the importance of protecting open space

One of the best opportunities to reduce risks to communities from flooding and hurricanes is to keep people out of harm's way by preventing new development and protecting natural open space in hazard-prone areas.[159] There are a number of lands in both current and projected future high-risk areas that could be protected from further development before disaster strikes.[160, 161, 162, 163] For example, a 2009 study of "intermediate lands" not already protected by conservation or already developed (e.g., agricultural lands) found that conservation easements, land acquisitions, zoning regulations, and non-structural measures could effectively limit development and reduce risk along the Atlantic Coast for areas below 1 meter in elevation.[164]

Several federal policies have encouraged open-space protection to a certain degree. Both FEMA's CRS (see section 4.1) and CBRA (section 4.3), for instance, help protect undeveloped areas on the coast and within riverine floodplains by reducing incentives for development and instead providing incentives for protecting open space as part of community hazard mitigation efforts. However, much more could be done. Resistance to open space planning is often focused on lost economic development or tax revenue, but the reality is that this practice is more focused on strategic development rather than no development.[165] Enormous tax savings can be achieved from avoided costs of repair to infrastructure, roads, utilities, and emergency services, not to mention decreased injury and mortality due to floods and hurricanes.[166]

By better accounting for the full costs and benefits of protecting open space, communities would likely find such investments more than worthwhile. Studies of floodplain conservation in St. Louis County, Missouri,[167] and the East River Watershed in Wisconsin[168] found that investments in land

iStockphoto

preservation to protect open space through land acquisitions or easements can help the community avoid considerable damage losses from flooding, particularly when such investments are targeted toward lower-cost parcels in areas most vulnerable to flooding. The economic benefits of protecting open space are even greater relative to foregone development after accounting for the value of ecosystem services provided by the natural floodplains. The challenge is to target the "right" places in order to maximize the flood protection benefits and minimize the cost of protecting lands from development.[169] This requires understanding where habitats are most likely to reduce exposure to flooding, erosion, storm surge, and sea-level rise and protect vulnerable people and property.[170] Vulnerability assessment tools highlighted in Appendix 1 can help managers identify the most optimal strategies.

3.3.4. Guidance on valuing natural infrastructure

As noted previously, despite the many benefits that natural systems provide, the majority of these often go unaccounted for in project or impact evaluations. Traditional benefit-cost analysis generally focuses on marketed goods and services to estimate the value of impacts. Given that many of the so-called "ecosystem services" provided by natural infrastructure are public in nature or provided outside a market setting, however, they are often taken for granted and not incorporated into the analyses. Accordingly, there is a need for a consistent approach for valuing the benefits of natural infrastructure and to develop tools, data, and best practices to advance the integration of such conservation into hazard-mitigation planning.

There has been important progress at the federal level to promote greater consideration of the broader non-market benefits of flood-mitigation investments. For example, FEMA policy directive FP-108-024-01 provides guidance and support for expanding benefit-cost analysis of acquisition activities by encouraging project managers to account for broader environmental benefits of mitigation investments.[171] The policy and supporting toolkit provide methods for including monetized valuation of environmental benefits in project appraisals based on avoided future costs from direct damage, reconstruction, or displacement. While the directive only applies to acquisitions for the purpose of open space and subsequent relocations or demolitions, it sets a new federal precedent for recognizing and correcting underestimation of the benefits of upfront investments in natural infrastructure for pre-disaster flood mitigation. By making the directive mandatory and broadening it to the full range of mitigation activities supported by the Pre-Disaster Mitigation and Flood Mitigation Assistance Programs, FEMA could go a long way in promoting the restoration and preservation of natural functions as a priority solution to reduce flood risks (see section 4.1).

Another important development is the release of the 2013 *Principles and Requirements for Federal Investments in Water Resources* (P&R) by the Council on Environmental Quality (CEQ).[172] The P&R now requires federal agencies to use an ecosystem-services approach to evaluate all potential federal water resources investments in order to appropriately capture the economic, environmental, and social costs of such projects. Assessments are to include monetary and non-monetary, quantified and unquantified effects. This is an important change from traditional assessment processes, which have evaluated federal investments in water resources using a relatively narrow benefit-cost analysis. The P&R also require agencies to address the risks and uncertainties associated with climate change and future land use. In addition, the P&R revision stresses a greater focus on nonstructural approaches, defined as actions that "alter the use of existing infrastructure or human activities to generally avoid or minimize adverse changes to existing hydrologic, geomorphic, and ecological processes….include modifications to public policy, regulatory policy, and pricing policy, and management practices, including green infrastructure."

Recently, a number of communities have been working with federal agencies to better account for the economic benefits of natural infrastructure (see Case Study 6, p. 32).

Appendix 2 highlights alternative methods and tools to help local and state planners, non-governmental organizations, and others to assess the non-market values of natural infrastructure. Each of these methods has strengths and limitations, and there are a number of guides available that can help users determine which approach is most suitable in a given situation.

3.4. Insurance Can Improve the Effectiveness of Natural Hazard Policies

Insurance is intended to help minimize financial losses from events such as illness, injury, or property damage by paying a third party (e.g., insurance companies) to assume that risk and spread potential losses across a broad pool of covered individual or entities. The economics of insurance works when companies are able to effectively evaluate potential risks and charge

There has been important progress at the federal level to promote greater consideration of the broader non-market benefits of flood-mitigation investments.

Case Study 6. Economic assessment of natural infrastructure for climate adaptation in Duluth, Minnesota

The city of Duluth, Minnesota, worked with NOAA to conduct an economic benefit-cost study of natural infrastructure projects to reduce flood risks.[173] The report and analysis was very timely. In 2012 alone, Duluth estimated that flooding resulting from torrential rains (see Figure 4) caused more than $55 million in damages. The analysis entailed hydrologic and hydraulic modeling to evaluate the effectiveness of a variety of natural infrastructure strategies at attenuating flood flows. NOAA then measured the effect that a 20-percent increase in flood storage as a result of natural infrastructure implementation would have on flood damages. Because Duluth so highly values the availability of open space for recreation, recreation benefits were also calculated for the avoidance of park closures that have been common in the wake of floods in recent years.

Interestingly, the key determinant in whether or not the natural infrastructure would be cost-effective was the timescale on which the decision was based. If the timeframe of the benefits had been extended over just 20 years, as is often common with gray infrastructure projects, the benefits only would have amounted to $1.63 million, providing an unfavorable 0.25 benefit-cost ratio. However, as discussed elsewhere, a short timespan favors shortsighted projects. When the time horizon was extended to 50 years instead of 20, the benefits rose to $4.68 million, proving a benefit-cost ratio exceeding the minimum threshold of 1.

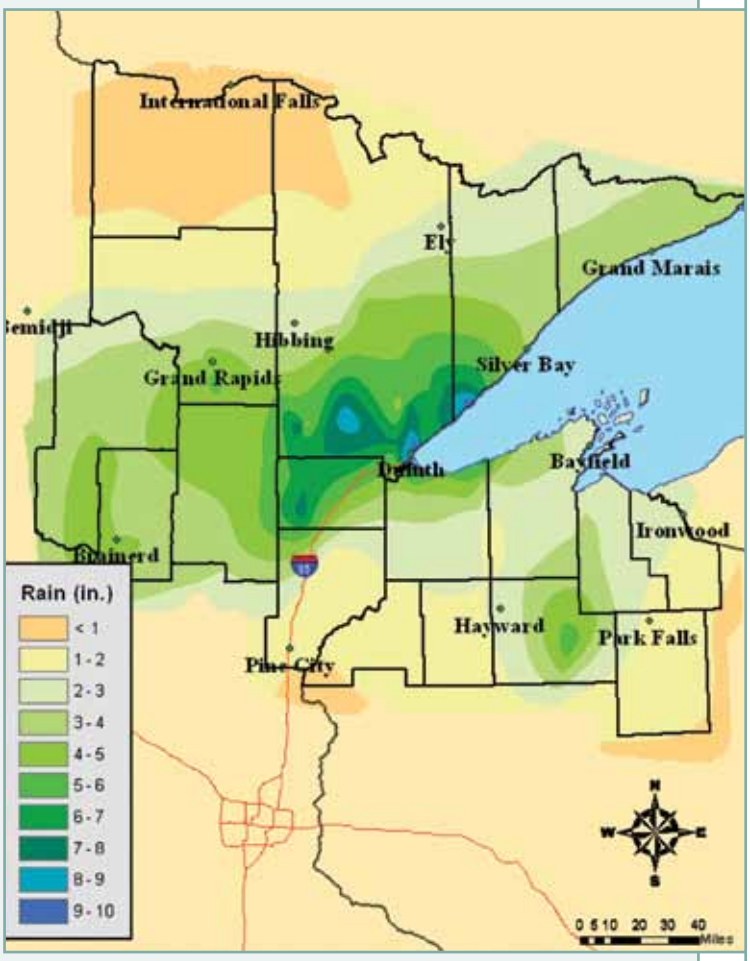


Figure 4. Flooding rains in the Upper Midwest June 19-20, 2012. Source: NOAA National Weather Service Forecast Office, Duluth, MN.

Knowing that the benefit-cost ratio for natural infrastructure was high, Duluth applied for and received the first Great Lakes Shoreline Cities Green Infrastructure Grant from EPA. This grant provides the city with $250,000 to install natural infrastructure projects designed to retain an estimated 200,000 gallons of stormwater.[174, 175]

premiums to insurance holders at levels that enable the company to build up enough reserves to cover losses when events occur (i.e., premiums that are actuarially sound), as well as make a reasonable profit. In turn, the price of acquiring insurance helps purchasers understand the true cost of risk and may encourage them to reduce risks in order to minimize cost. Similarly, insurance companies have an interest in investing in mitigation to keep their own financial responsibilities down. Policies to reduce risks from natural hazards are strengthened when they employ insurance and insurance principles.

3.4.1. The difficulty of insuring risks from catastrophic floods and hurricanes

In the case of natural hazard insurance, providing insurance is complicated due to the relatively high uncertainty on the location and extent of extreme and costly floods and hurricanes occurring.[176] In the wake of recent catastrophic events, private insurance companies have faced significant liability. Many have sought to reduce their financial exposure through measures such as purchasing reinsurance, and in some areas they have abandoned the market altogether, leaving the burden of losses on individuals, communities, and state and federal governments. Given the realities of climate change, these challenges will likely grow over time.[177]

3.4.2. Providing insurance with the National Flood Insurance Program

The especially high cost of flooding associated with major hurricanes was the impetus for the development of the NFIP, after the federal government was burdened with covering enormous losses through disaster assistance. The program was intended to help cover costs and reduce vulnerabilities to flooding by identifying flood hazards, encouraging and requiring floodplain management to mitigate flood risks, and providing flood insurance at reasonable rates within communities that choose to participate in the program. Although the intention was to reduce flood risk over time, there have been some unintended results.

To encourage participation in the program, the NFIP, from its inception, was not actuarially sound. Unlike private insurance programs regulated by state governments, Congress allowed the NFIP to operate without reserves or surplus to absorb risk from extreme events. Rather than charge premiums that adequately reflect the flood risks to property owners, the program was only required to cover administrative costs and historical average annual losses. The consequences of this practice came to light after the series of major hurricanes and associated losses over the past decade, during a period of economic turmoil and fiscal belt-tightening in Congress. The program is now more than $24 billion in the red.

In addition to inadequately reflecting flood risks by charging subsidized premiums and frequently relying on outdated maps (as discussed in section 4.1), the take-up rate for insurance under the NFIP (i.e., the percentage of people eligible for the program who actually participate) has been low. This low participation rate has occurred despite the fact that federal law requires owners of at-risk properties in communities participating in the program as a condition for getting federally-insured mortgages. Even with subsidized premiums, an estimated half of single family residences in SFHA floodplains do not have flood insurance.[178] Some households may initially buy the insurance as a condition for getting a federally-insured mortgage, but then allow it to lapse if they don't get a "return" on their investment (e.g., payout after an event).[179] Several studies also suggest that there is a lack of enforcement on the mandatory purchase requirement by some financial institutions.[180, 181, 182] In addition, some people in the flood risk areas do not need a mortgage.

The low participation rate in the NFIP means that flood risks are not spread as widely as necessary for the program to be economically efficient, which significantly increases the federal government's – and taxpayers' – exposure to uninsured property losses from flooding.[183] In addition, the program's arbitrary reliance on the 100-year flood plain as the sole measure of flood risk vastly underestimates the true risk from flooding. In many places around the country, federal descriptions of the 100-year flood zone are badly outdated. This means that many properties in areas of significant flood risk are currently uninsured.

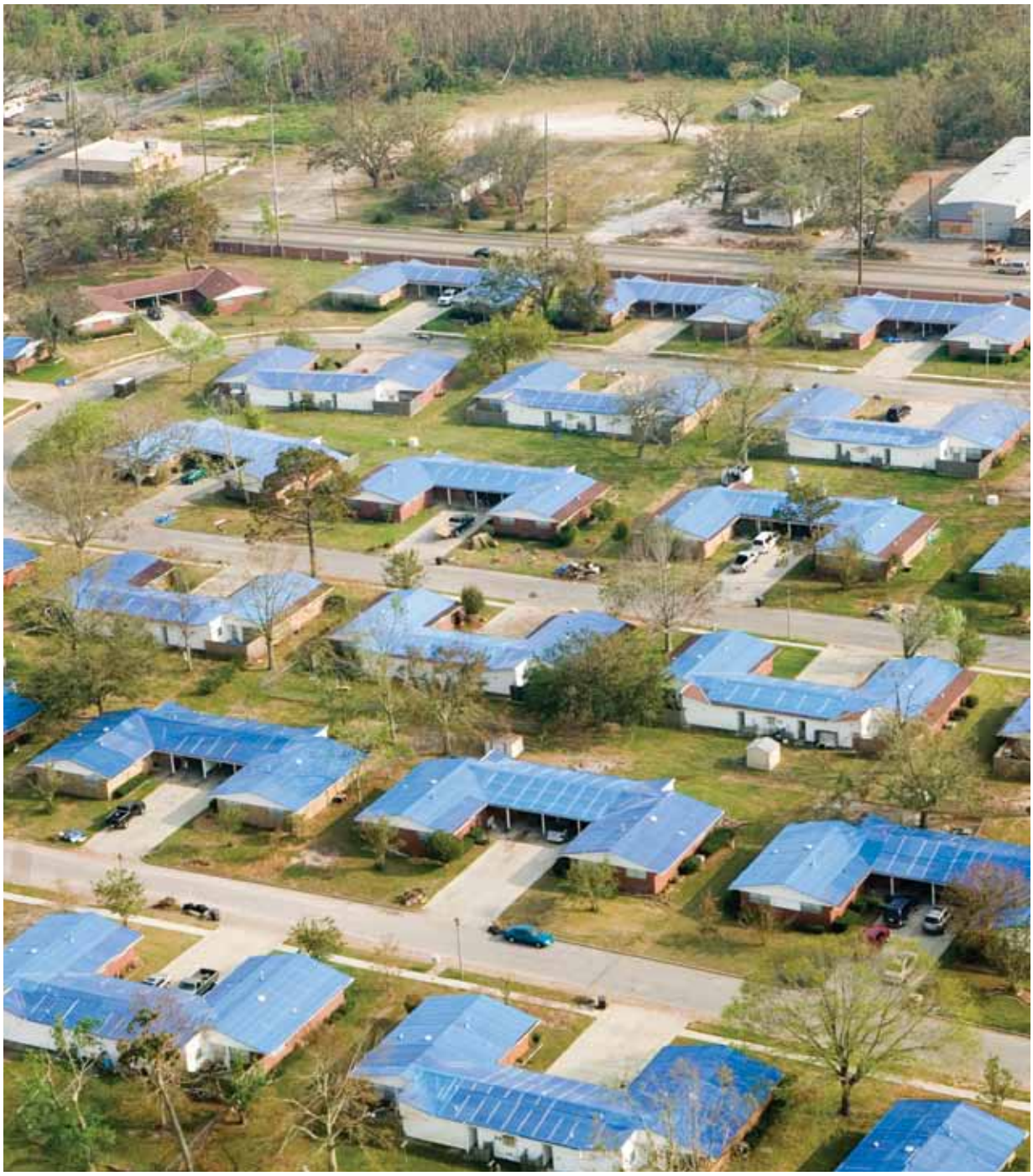
Another problem with the NFIP is that claims for second homes and "repetitive loss" properties (those that have received at least two flood-claims payments of over $1,000 in each of any 10-year period) are disproportionately represented.[184] Roughly 71,000 covered properties are in the repetitive loss category.[185] Over the period between 1978 and 2008, these properties represented just 1.2 percent of the NFIP portfolio but accounted for 16 percent of total payments.[186] About 1 in 10 of these properties has received cumulative flood insurance reimbursements that exceeded the value of the home.[187] In other words, rather than effectively spreading risk, in practice, the NFIP has mostly insured the highest-risk properties. The NFIP has had the unintended effect of actually encouraging development in hazard-prone areas. Disappointingly, more than 2.3 million buildings have been constructed in 100-year floodplains in communities after they had joined the NFIP. [188]

The low participation rate in the NFIP means that flood risks are not spread as widely as necessary for the program to be economically efficient, which significantly increases the federal government's – and taxpayers' – exposure to uninsured property losses from flooding.

3.4.3. Providing insurance for hurricane risks beyond flooding

The risks from natural hazards include more than just floods. In particular, one of the other major risks from hurricanes is damage from winds and erosion, which could be considerable. One study found, for example, that the economic damages from hurricanes that made landfall in the United States during the past century increased exponentially whenever the wind speed increased. [189] Specifically, if a storm with wind speeds of 50 miles per hour were to cause $10 billion in damages, one with twice the wind speed would cause more than 250 times that amount, or $2.5 trillion.[190, 191]

Both private insurance and reinsurance industries have had to factor in increasing losses associated with wind damage from hurricanes by charging higher premiums.[192] In some cases, firms have pulled out of areas where the risks are considered "uninsurable."[193] As a result, programs providing "residual" insurance (e.g., state-sponsored insurance for wind and other hazards not covered under the NFIP or readily available by private insurers) have grown substantially. A number of states and the District of Columbia have Fair Access to Insurance Requirements (FAIR) plans to provide coverage to some private property owners who cannot secure private insurance for certain hazards, including coverage for wind damage from hurricanes in some areas.[194] In addition, several states have created Beach and Windstorm Insurance plans that provide coverage in coastal communities. Between 1990 and 2005, the value of property insured by FAIR plans and Beach and Windstorm plans increased from $40.2 billion



FEMA

Creative Commons

to $387.8 billion. Between 1990 and 2011, the number of residual policies in the United States more than tripled.[195] With the added risks from climate change, the liability will grow even higher. Some areas of the country are especially vulnerable. For example, in the coastal counties and parishes of Alabama, Mississippi, Louisiana, and Texas, losses associated with hurricane winds, land subsidence, and sea-level rise could more than double (from $14 billion in annual losses today to $23 billion) by 2030.[196]

Like federal flood insurance, however, states often offer residual insurance at subsidized premium rates. As discussed in section 4.6, state-sponsored hazard insurance is not always the "insurer of last resort," as it is intended. In 2002, a public insurance program called Florida's Citizens Property Insurance Corporation (Citizens) was created to help provide affordable multi-peril and wind-only insurance for high-risk buyers. Over the past 10 years, the organization's total exposure to risk has grown from $155 billion to $500 billion.[197] And yet, the state has faced political pressure to keep premium rates low enough in the interest of accessibility and affordability that they essentially have driven comparable private insurance out of the market. These subsidies have served to incentivize continued development in hazard-prone areas. That said, there have been some important reforms to Citizens. Florida now prohibits Citizens coverage for newly-constructed structures seaward of the state's "coastal construction control line," which was established to preserve and protect Florida's beach and dune system from imprudent development, as well as those lands designated as units under the CBRA. Other states should be considering similar reforms (see section 4.6).

3.4.4. Incorporating insurance principles into disaster relief

When floods and hurricanes cause damage to property that is not insured, the economic burden of these disasters falls initially on those directly affected. Over time, federal taxpayers pick up a share of this burden by providing post-disaster funding assistance, primarily through the Stafford Act (see section 4.2). Recent estimates suggest that Hurricane Sandy cost at least $189 billion in economic damages, with less than half ($77 billion) insured.[198] Unlike with insurance, policy makers have taken few steps to ensure that disaster funds are used for mitigation efforts. There is little incentive to communities under Stafford Act disaster-response programs to reduce risks in advance of storms or to develop rebuilding plans that emphasize resiliency to growing flood and hurricane risks.

3.5. Consideration of Social Equity is a Necessary Component of Natural Catastrophe Policy

In the United States and around the world, communities most vulnerable to flood and storm impacts and damages are in many instances the same communities that have limited mobility and lack resources or options to relocate or retreat from high-hazard areas. Historically, America's low-income and minority communities have been disproportionately affected by extreme events such as hurricanes and floods.[199, 200, 201] Many live in mobile homes and other structures that are especially susceptible to damage from storms, particularly in the Southeast and Gulf Coast.[202, 203] The impacts from Hurricane Katrina in New Orleans illustrate the high vulnerability of low-income communities and the challenges that they can face in the wake of disasters.[204, 205] For instance, many citizens living in the highest-risk areas did not have access to automobiles or other effective transportation for evacuation.

Lower-income communities may also be disproportionately affected by the various solutions that constitute reforms in the area of natural catastrophe policy. They are the most in need of affordable insurance protection options and the least able to absorb a switch to risk-based insurance rates. They also are less likely to be able to independently make investments for mitigation actions, such as storm-proofing or elevating their homes. Nor can they easily accommodate a relocation or "managed retreat" (see Section 3.5.2). Natural catastrophe policy must recognize that both disasters and resilience activities can disproportionately affect the socially vulnerable – those who may be driven to live in high-risk areas for affordability.[206]

In addition to socioeconomic considerations in reforming disaster policy, there is also a reasonable basis for distinguishing between long-time property owners and new development. With the advent of new risk calculation and communication technology, strong disincentives to new development in high-risk areas are appropriate. On the other hand, it is unwise and unfair to punish existing homeowners for responding as would be expected to policies that allowed and even promoted the development of communities in hazard-prone areas.

As noted in section 3.1, some people have chosen to live in hazard-prone areas understanding the risks, as they consider the benefits of living there as outweighing the potential consequences. In other cases, however, people either did not know the risks from floods or hurricanes in the places where they live and work or they underestimated those risks, through no fault of their own. Furthermore, climate change, inadequate flood-risk management activities, poorly planned and maintained navigation projects, and industrial activities have significantly increased risk in communities that were historically well-protected by natural wetlands and barrier islands. In coastal Louisiana, for example, subsidence, decades of shortsighted water resource management by the USACE, oil and gas extraction, and other contributing factors have led to massive die-off and disappearance of these natural flood risk-reduction features. Over the course of just a few decades, New Orleans became increasingly vulnerable to floods and hurricanes. The same is true for many commercial fishing communities along the Louisiana coast. Communities like those in St. Bernard Parish were once protected by many miles of wetlands but are now exposed to tremendously greater risk due to government-sponsored navigation projects.

Historically, America's low-income and minority communities have been disproportionately affected by extreme events such as hurricanes and floods.

As such, a holistic and progressive natural catastrophe policy will make appropriate and equitable accommodations to limit the risk of existing homes and businesses. Section 4 provides policy recommendations that seek to balance market forces and public assistance and to create more-resilient communities with appropriate consideration given to both socioeconomic vulnerability and the residual impact of historic policies.

3.5.1. Addressing affordability without undermining public safety

Issues of both affordability and accessibility have long been important when considering the costs of insurance. However, charging premium rates below actuarially-sound levels reduces the effectiveness of insurance in covering losses, adequately reflecting risk, and incentivizing risk-reduction measures. This presented a considerable dilemma for policy makers in recent efforts to reform the NFIP. Striking an appropriate balance between public safety and affordability of insurance will likely become a major consideration as the NFIP and other natural catastrophe policies are debated in the future.

The recent reforms to the NFIP known as the Biggert-Waters law made important strides to ensure that premium rates under the program better reflect risk. However, associated rate increases would have left many property owners unable to afford the insurance. Although Biggert-Waters authorized studies by FEMA and the National Academy of Sciences (NAS) to address affordability issues, implementation of the reforms to premium rates began before those studies have been completed. Due in large part to the concerns about affordability of risk-based premiums, Congress enacted Waters-Grimm in February 2014.[207] While Waters-Grimm maintains some of the important reforms established under Biggert-Waters, one concern with the new legislation is that it does not address how Congress will achieve a reasonable amount of safety for the American people from flood and hurricane risk. Although the new law makes small improvements on affordability, it lacks any measures to limit affordability offerings to those policyholders that truly need them.[208] In particular, it eliminates the requirement that risk-based rates be imposed on any and all primary residences already participating in the NFIP. Thus, a substantial sacrifice was made to NFIP's risk-reduction goals without making serious progress in addressing affordability concerns. Many state-sponsored residual insurance policies have been designed with affordability as a stated goal as well, but they also lack targeting to low-income households.[209]

Of course, social concerns should be more than a matter of being able to afford insurance premiums.[210, 211] There is a critical need to provide more assistance to those households to mitigate risks and respond to disasters (e.g., through long-term mitigation loans and grant programs). Sections 4.1 and 4.6 provide suggested changes that can help bring state and federal government-based natural catastrophe policy more in line with the needs of the diverse communities they are intended to serve.

3.5.2. The case for managed retreat

In places where current and projected risks from floods and hurricanes are especially large, there is a case to be made for moving people out of harm's way through so-called "managed retreat." This may entail placing restrictions on coastal armoring and development through easements, zoning regulations, and other policies, and acquiring properties in hazard-prone areas, which ultimately may be converted to natural floodplain space.[212]

Both major and recurring disasters have provided impetus for some communities and the federal government to implement voluntary buyout programs or provide relocation assistance for property owners in a number of areas, especially places where there are numerous severe repetitive loss properties.[213, 214, 215, 216] From 1993 to 2011,

FEMA spent more than $2 billion to buy properties in flood-prone areas.[217] In addition, a growing number of communities across the country have already been engaged in a certain degree of managed retreat. For example:

• The city of Pacifica State Beach in San Mateo County, California, has been partnering with local land trusts and other non-governmental organizations to develop a combination of natural infrastructure investments such as marsh restoration and the purchase and removal of vulnerable structures to address long-term erosion and flooding problems along the community's beach.[218] Although the project required considerable upfront investment to implement, it had widespread support from local government leaders and the public. The project will ultimately save the community additional money in avoided losses.

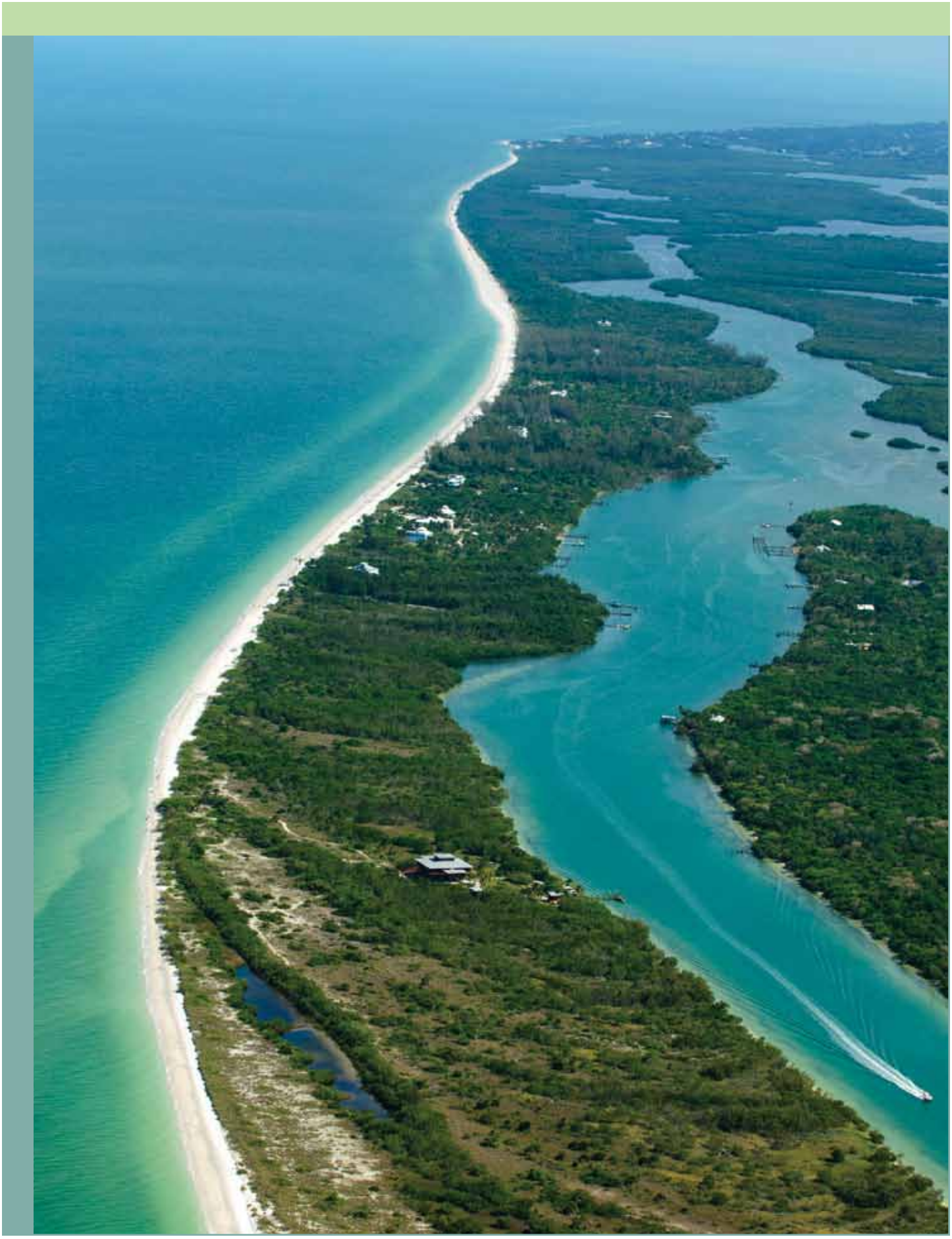
• After Hurricane Sandy, New York Governor Andrew Cuomo created a $400 million voluntary buyback program for flooded communities in the state funded by FEMA. The program is intended to take high-risk properties off the market and return them to a more natural state, providing wildlife habitat while reducing damage to properties and the state's future storm liability.[219]

• In St. Charles County, Missouri, a buyout program using state and federal funds established after the major 1993 flood event is estimated to have prevented losses of nearly $97 million from flooding events that occurred between 1999 and 2008. This represented a 212-percent rate of return on the $44 million dollars Missouri and FEMA had spent on the properties.[220]

Of course, buyouts and managed retreat efforts must be founded on sound principles. First, the community as a whole must be truly engaged in decisions.[221] Without full community participation, not only would the benefits of such buyouts for flood risk reduction over a larger scale be minimized, but there could be animosity among remaining property owners toward participating households if such buyouts are perceived to lower property values. Second, there must be sensitivity to the needs of the socially vulnerable, including efforts to help ensure that there are affordable places and jobs in areas where people may be relocated. As noted previously, many people moved to hazard-prone areas not fully cognizant of the risks, incentivized by the very governments now wanting some communities to move. In addition, some previously safe and well-established communities have become high risk due to factors outside of their control. Some – like commercial fishing communities – would be hard pressed to move because their livelihood depends on ready access to coastal natural resources. Moreover, for a number of households, living in higher risk areas may be the most affordable option given that housing costs in many of these areas tend to be lower.

Finally, *keeping* people out of harm's way is a proven strategy that is likely to be far easier to implement than moving people out of harm's way.[222] This is an opportunity that will decline as trends in population growth and climate change continue.

USGS



iStockphoto

Chapter 4. Seven Critical Policies Must be Reformed to Truly Address Growing Risks From Floods and Hurricanes

Although a wide array of policies will need to be updated at every level of government to make communities safe and resilient in the face of growing flood and hurricane risks, seven federal and state policies in particular deserve the urgent attention of policy makers.

4.1. The National Flood Insurance Program Needs Critical Reforms

There is a crucial need to reform the NFIP. The focus of this reform must be two-fold: 1) protecting and restoring natural infrastructure in communities facing significant flood and hurricane risk and utilizing these areas to protect people and property; and 2) helping the existing residents in coastal and floodplain areas make wise decisions to ensure their safety and a sustainable economy. By putting in place the following NFIP reforms, Congress and the Administration can help Americans prepare for the intensified floods and hurricanes that climate change is bringing and help ensure safer and more-prosperous communities.

4.1.1. Make a "Marshall Plan"-scale investment in conservation of natural infrastructure

Perhaps the most important choice that Congress can make to improve natural catastrophe policy is to significantly increase investments in hazard mitigation grant programs and other programs focused on protecting and restoring natural infrastructure. The current level of spending on hazard mitigation grants is $25 million annually, and only a small percentage of this is used for protecting or restoring natural infrastructure. Total spending on conservation of land, water, oceans, and fish and wildlife amounted to just 1.02 percent of the federal budget in 2013.[223] This means that in the vast percentage of communities around the country, Congress is investing little to nothing to in conserve natural infrastructure for flood protection. It is time for Congress to recognize the gravity of the flood and hurricane threat facing America's riverine and coastal communities and to make a "Marshall Plan"-scale investment in natural infrastructure by protecting and restoring the coastal wetlands, mangroves, oyster reefs, dunes, riparian forests, and other natural systems that buffer communities from the worst impacts of floods and hurricanes. With the right set of accountability rules, the money could be distributed to local governments and other local entities that are in the best position to determine land-use needs and priorities.

FEMA

The choice for Congress is straightforward: make a large-scale investment now in natural infrastructure for the benefit of communities at risk from floods and hurricanes, or continue with the status quo approach of no investment. We recommend that the initial investment should be no less than $50 billion allocated among local, state,

tribal, and federal agencies with a demonstrated risk of significant losses to floods and hurricanes. That figure amounts to less than a third of the estimated economic damages from Hurricane Sandy alone.[224] Strategies to protect and restore natural infrastructure would be eligible for funding only after a careful consideration of alternatives with benefit-cost analysis.

The only conceivable argument against making such an investment would be that the U.S. taxpayer cannot afford it. However, failure to make such an investment would not produce savings for the U.S. taxpayer. It would simply mean that spending would be postponed to another day in the near future, in the form of disaster relief and recovery payments. Such after-the-fact spending would far exceed the cost of upfront investments, with arguably fewer benefits because the funds would likely be spent in a hurried fashion with inadequate attention to long-term investment opportunities.

The reasons for investing $50 billion now go far beyond the savings to U.S. taxpayers. First and foremost, such an investment would help avoid massive human suffering and economic losses. Rather than having mostly homes, businesses, transportation, and communications infrastructure bear the brunt of storms, the United States would elect to have natural features absorb a much-greater share of the impact. Also, by investing now in natural infrastructure, the United States would not only be safer, it would have a far greater quality of life during the quiet days before the storms, enjoying restored wildlife and habitat and the numerous other co-benefits discussed above.

Those who live outside of coastal and floodplain communities may be asking why they should support the use of their taxpayer dollars to protect those communities. Apart from the need to show compassion for fellow Americans, there is a very pragmatic reason: the costs of natural catastrophes are borne by society as a whole by lowering long-term economic growth.[225]

4.1.2. Use market-based rates to incentivize wise development and mitigation choices while treating policy holders fairly

The first step in modernizing the NFIP must be for FEMA to use its existing authorities to reduce subsidies (i.e., shift to market-based rates) for coastal and floodplain development. The Biggert-Waters Act, as modified by Waters-Grimm, outlines the first necessary steps toward risk-based rates. In particular, it calls for annual premium increases of 25 percent for commercial properties, vacation homes, and severe repetitive loss properties. The Administration must give top priority to implementing these key provisions.

In addition, Congress must give FEMA authority to further reduce subsidies. Waters-Grimm halted further subsidy reduction in effort to address affordability concerns. Some of the concerns raised in the debate over this bill were quite legitimate: for example, there are middle- and low-income communities in coastal Louisiana and elsewhere that could face dramatic rate increases that would not only be unaffordable for existing home owners, but would in some areas render a home virtually unsellable. Some of these communities are at extraordinary flood risk not because of their choices but in large part because of governmental actions that changed the management of the lower Mississippi River, built a vast network of federal navigation channels, and permitted and incentivized thousands of miles of oil and gas canals, all leading to the highest marsh loss rate in the nation. The loss of millions of acres of marsh that formerly buffered those communities is a leading cause of their increasing vulnerability.

However, Waters-Grimm went too far. It continues subsidies even for the wealthiest of property owners, who would have been able to afford to pay the costs of living in high-hazard areas rather than continuing to shift them to

Infrogmation of New Orleans

taxpayers. The law also fails to take critical steps to protect and restore natural infrastructure; an authorization for large-scale investment in natural infrastructure, as discussed in 4.1.1 above, was warranted. Furthermore, Waters-Grimm limits in unprecedented ways FEMA's ability to send market signals and increase rates. It reduced the average increase allowed across a risk class compared to Biggert-Waters, exempts secondary structures from insurance requirements, sets for the first time a cap on individual premium increases, and pressures FEMA to keep rates low by requiring them to report to Congress on all policies that charge a premium greater than 1 percent of the coverage amount.

When Congress reauthorizes the NFIP in 2017, it must find a way to bring all NFIP policy rates, including those for primary residences, closer to the risk-based rates while balancing affordability concerns with the need to reduce the exposure of people and property to growing flood and hurricane risk. Fortunately, it will have the benefit of the insights of the affordability study being carried out at Congress's request by a panel of experts convened by the NAS. Congress must also work with FEMA to ensure that all levees and flood-control structures are properly credited and that property owners behind such structures still understand their risk and pay commensurate premiums.

It is likely that the NAS panel will reaffirm the widely-held principle that market-based rates are needed to educate policy holders and community leaders about flood risks and to incentivize them to mitigate that risk. Congress should find ways to address affordability concerns that do not undermine the shift toward market-based rates.[226] It can do so by:

- Targeting state and federal mitigation funds to low-income, high-risk areas to offset premium costs and better protect those communities.

- Tapping all revenue streams for mitigation dollars, including RESTORE Act funds, HUD Community Development Block Grants, and others.

• Capping the total premium for remapped primary residences at a level tied to income, the value of the home, or both.

• Extending the phase-in period for rate increases.

• Providing means-tested vouchers for low-income policy-holders.

• Ensuring that FEMA provides adequate credit for existing flood-control structures that currently are not impacting flood maps and associated rates.

• Enhancing mapping to ensure that natural features are shown and credited on flood maps and associated rates.

Until Congress acts to reauthorize the NFIP and address some of these concerns, FEMA must work to administratively harmonize Waters-Grimm and Biggert-Waters. It must determine how to increase rates and market signals while respecting the limits on premiums and ensure that those rate increases not overturned by Waters-Grimm will not be impeded by pressure from Congress to keep rates low. It should also work to clarify that the secondary structure exemption from mandatory purchase should only apply to new construction.

Congress should also expand the flood insurance mandatory purchase requirement beyond the 100-year floodplain. Doing so would expand the reach of market signals to demonstrate risk and encourage mitigation. In addition, this expansion would lessen the blow to property owners who are mapped into the 100-year floodplain upon remapping caused by subsidence, sea-level rise, and changing hydrology.

4.1.3. Strengthen eligibility rules to address natural infrastructure

The National Flood Insurance Act requires FEMA to establish eligibility rules for community participation in the NFIP, and it contains a host of provisions making clear that FEMA should consider land use as it implements the program. Unfortunately, FEMA has given little attention to date on how communities should mitigate flood risk through land-use management and policy. FEMA should update eligibility criteria so that communities are allowed to participate in the program *only* if they include within their Flood Hazard Mitigation Plans an analysis of the flood risk mitigation potential of the natural infrastructure within their boundaries. Communities already participating in the program should be given a 5-year deadline to update their plans and complete this analysis.

At a minimum, an eligibility analysis should include a thorough examination of alternatives for protecting and restoring natural infrastructure ("Natural Capital Conservation Alternatives," or NCCAs). Among the NCCAs that should be examined:

• **Zoning, planning, and building codes**. Do these codes need to be revised to steer development away from dunes, wetlands, stream banks, and other natural features of the land that protect against floods?

• **Environmental considerations.** Do local codes governing dredging and filling of wetlands and other disturbances of environmentally sensitive lands and waters require strengthening? Should the local government prepare a habitat conservation plan to ensure that development is in compliance with the Endangered Species Act and other federal environmental laws?

• **Public Land and Water Management.** Should natural habitats be protected or restored in the community's publicly owned lands and waterways to improve their flood mitigation potential?

Finally, local communities must be required to compare these NCCAs with other potential mitigation strategies using benefit-cost analysis. As noted previously, the field of economic valuation of

natural infrastructure is now well-advanced. FEMA already requires that environmental assets be taken into account when carrying out benefit-cost analyses for grant-funded mitigation projects (see FEMA policy directive FP-108-024-01).[227] FEMA must now take the next logical step and ensure that environmental amenities be considered in benefit-cost analysis as communities update their flood mitigation plans.

FEMA should not prescribe what alternatives local communities ultimately select when developing and updating their flood hazard plans. What revisions are appropriate is a question that can be decided by locally elected officials who are accountable to local residents and most knowledgeable of local conditions. However, FEMA would greatly improve the chances that local communities will conserve natural infrastructure and otherwise minimize flood risk by requiring that they make the costs and benefits of the various alternatives known to the public and subject to scrutiny and debate.

What revisions are appropriate is a question that can be decided by locally elected officials who are accountable to local residents and most knowledgeable of local conditions.

4.1.4. Strengthen the Community Rating System to benefit people and wildlife

The CRS of the NFIP was developed to encourage communities participating in the program to invest in floodplain management activities that exceed the NFIP's minimum standards. Under the CRS, communities receive credits for implementing all or a subset of 18 different activities, ranging from outreach projects and higher regulatory standards to open space protection and land acquisition and relocation of flood-prone buildings. In return, policyholders in those communities receive discounted premiums on their flood insurance.

A study of open space protection efforts designated under the CRS for 450 communities across the country found that such measures effectively attenuated flooding and reduced flood damages in those communities over the 11-year study period (1999 to 2009).[228] Communities across the country that have incorporated protection of significant areas of open space as part of their floodplain management efforts could potentially save nearly $1 million per community per year in reduced flood losses.[229] Under the CRS, areas are considered open space if they are "free from buildings, filling, or other encroachment to flood flows"[230] Currently, the CRS provides up to 900 credit points for open space preservation (out of a total of 14,850). Up to 750 of these points are provided for maintaining vacant lands within the floodplain, and additional points can be earned by establishing or maintaining permanent protections from development and restoring or keeping the lands in a natural state.[231]

However, although the number of communities engaging in open space protection and other natural infrastructure measures under the CRS program has grown, they are vastly underutilized strategies. On average, communities participating in the CRS earn just 191 points for open space protection.[232] Similarly, of a total of 670 possible points for stormwater management, communities earn an average of just 98. FEMA has an important opportunity to expand such activities. In particular:

- FEMA should modify the CRS to increase the percentage of total credits that communities can earn through measures that enhance natural infrastructure.

• FEMA should create greater awareness among communities of the multiple benefits that natural infrastructure can provide to communities, including reduction in flood risk.

4.1.5. Strengthen flood hazard mapping

Americans are entitled to accurate, up-to-date information about the flood and hurricane risks. Without such information, they may fail to take mitigation measures in their homes, to pursue voluntary buyouts or other mitigation grant programs, or to demand necessary policy measures from their elected leaders.

One of the ways FEMA identifies flood hazard areas is through a series of flood maps. Accuracy of these maps requires calculation of the flood risk reduction potential of various features and their likelihood of change over time. Until recently, however, many of FEMA's maps were outdated, and because many were hand-drawn, they have been difficult to update. Accordingly, FEMA has been undertaking a Multi-Hazard Flood Map Modernization Program, which includes digitization of the maps as well as incorporation of updated information regarding floodplain locations, levels and extent of flood risk, the existence of both gray and natural infrastructure, and other factors.[233] Although FEMA is beginning to make these advances, the pace of this work must be accelerated to ensure the best available scientific information is available to decision makers.

Recognizing the need for higher quality, updated mapping, Biggert-Waters established a Technical Mapping Advisory Committee (T-MAC). While T-MAC is statutorily comprised of a multi-disciplinary expert panel tasked with providing recommendations for mapping, the mission and makeup of the committee is insufficient to capture the recent understanding of the synergistic benefits to both natural and structural flood-risk features. Congress should enact a legislative correction to broaden the expertise of T-MAC and ensure its recommendations incorporate the most cutting-edge flood-risk reduction research.

4.2. Funding Through the Stafford Act Must Prioritize Proactive Hazard Mitigation

The Stafford Act was designed to provide federal assistance to communities to prepare for and respond to Presidentially-declared natural disasters. Accordingly, it is an important tool to help communities to reduce their risks to extreme events such as major floods and hurricanes before they occur, not just recover from them afterwards. As discussed throughout this report, proactively investing in natural hazard risk reduction not only helps prevent losses from occurring, but it produces considerable savings over the long-term.

As amended by the Disaster Mitigation Act of 2000, the Stafford Act requires state, tribal, and local governments to develop a hazard mitigation plan as a condition for receiving certain types of non-emergency disaster assistance.[234] While all State Hazard Mitigation Plans (SHMPs) are required to incorporate information on the future probability of hazard events, there is currently no requirement or mention of climate change in FEMA rules that govern the review process for such plans.[235, 236] In addition, the Stafford Act requires that affected areas being rebuilt with disaster assistance funds are reconstructed to the standards in place before the disaster.[237] As a result, many bridges, roads, flood control measures, and other public infrastructure are funded to be rebuilt based on historical climate conditions, rather than designed to be resilient to future impacts.

Efforts to support more-proactive mitigation through disaster assistance, including actions that enhance natural features, can reduce risks from

Integration & Application Network

both current and projected flooding and storm events. This can be done through the following:

• Communities should be required to emphasize open space protection, habitat restoration, and other natural infrastructure approaches and incorporate climate change into their hazard mitigation plans in order to be eligible for disaster assistance.[238, 239, 240] Fortunately, FEMA will be developing new guidance for states on how to incorporate climate change into their SHMPs.[241] However, FEMA must clarify that it will approve only SHMPs that adequately address climate change and amend their regulations to confirm that climate change must be addressed in Hazard Mitigation Plans, pursuant to the Stafford Act and Disaster Mitigation Act of 2000.[242]

• Considerably more funding should be provided for individuals and communities that lack sufficient resources to otherwise invest in such activities. This should include developing supplemental funding sources, such as disaster savings accounts that provide tax-deductible funds for mitigation purposes.

• To provide greater incentives for improved building codes and land-use regulations, the Stafford Act should be amended to tie a percentage of federal disaster assistance to states adopting and

enforcing land-use regulations and building codes that meet certain risk-mitigation standards. States that have failed to do so should receive less than the maximum 75 percent federal contribution if a natural disaster is declared.[243, 244]

4.3. Strengthening the Coastal Barrier Resources Act will Greatly Improve Coastal Resilience to Floods and Hurricanes

The CBRA, established in 1982, provides a useful example of how removing pro-development subsidies reduce high-risk development. The CBRA does not prohibit development, but it denies federal subsidies such as flood insurance to development projects on undeveloped areas on barrier islands and other coastal lands prone to erosion and flood damage. Currently, there are 584 units in the John H. Chafee Coastal Barrier Resources System (CBRS) comprising 1.3 million acres of beaches, islands, dunes, wetlands, and associated aquatic habitat. In 1990, the CBRA was amended to include conservation or natural resource protection properties designated as "otherwise protected areas" (OPA) within a more narrow funding prohibition only on federal flood insurance. There are 272 OPA covering 1.9 million acres within the system. To date, the CBRA has proven to be effective in helping to conserve coastal habitats and protect people and property, while at the same time saves considerable taxpayer money.[245] As of 2003, the CBRA has saved the federal government nearly $1.3 billion since it was established.[246]

To date, the CBRA has proven to be effective in helping to conserve coastal habitats and protect people and property, while at the same time saves considerable taxpayer money.

Although CBRS units are generally ineligible for most forms of federal funding, FEMA is authorized to acquire properties within system units and OPAs using hazard mitigation grant funding. However, FEMA's hazardous mitigation grant programs have historically been underfunded and oversubscribed. Furthermore, the CBRA does not prohibit state and local governments from subsidizing development in CBRS or OPA units, which runs counter to the intent of the federal program to discourage development in ecologically sensitive, high-risk areas.[247] Another challenge with implementing the CBRA is that maps of lands within the CBRS and OPA are outdated, which has led to uncertainty among some property owners about whether or not their property is eligible for federal support.[248] The FWS, which administers the CBRA, has been frequently faced with claims from property owners contesting their inclusion in the system. Some of the zones also have been challenged by Congress. And while FEMA and the FWS have been working to update and digitize the CBRS maps, the process has been piecemeal and lacked sufficient funding.

Given the success of the CBRA in protecting communities from natural hazards and saving taxpayers' money, we must seize important opportunities to both strengthen and expand the act.[249, 250, 251] Actions should include the following:

- The federal government must commit sufficient funds and effort to update and modernize the CBRS maps.

- FEMA should invest in further protection of lands included within the system by placing greater emphasis on acquisition of high-risk coastal properties in its hazard mitigation grant programs. A minimum allocation of 1 percent for property acquisition in CBRS units should be provided in each eligible grant program, with the FWS, in consultation with FEMA, serving as the applicant.

- States that enact policies to limit spending in CBRS units by withdrawing subsidies, limiting residual insurance eligibility, assessing a risk fee, or

iStockphoto

building risk into the property tax code as certified by FEMA should receive priority for hazard mitigation grant programs.

- Over the longer term, Congress should authorize a study of areas that might be added to the CBRS to provide better protection for these important resources under changing climate conditions.

4.4. The Clean Water Act Must Protect the Nation's Diverse Wetlands and Streams

Congress passed the Clean Water Act in 1972 to protect "waters of the United States." Unfortunately, for more than a decade, 20 million wetland acres and two million stream miles have been at increased risk of pollution and destruction following two convoluted Supreme Court rulings and subsequent agency guidance.[252] This includes the headwaters and intermittent streams (those that flow only seasonally or after rain) that comprise 60 percent of America's stream miles (excluding Alaska), and upwards of 80 percent in the arid and semi-arid Southwest.[253] Not only are these waters a source of drinking water for one third of Americans, but they also play a vital role in functioning watersheds – including flood storage, ground and surface water recharge, and water filtration.

In March 2014, EPA and the USACE released a joint proposed rule clarifying which waters are protected by the Clean Water Act.[254] The rule proposes to restore protection to all of the tributaries that flow to traditionally navigable and interstate waters and all of the wetlands, lakes, or other waters within the floodplains of these tributaries. The rule also specifically excludes many man-made ditches, ponds, and irrigation systems and honors the law's current exemptions for normal farming, ranching, and forestry practices.

This proposal is one of the most important policy measures in recent history for protecting wetlands,

headwaters, and other natural infrastructure, which will in turn safeguard people and property from floods and hurricanes. However, it still leaves many important waters at risk. Waters such as the prairie potholes, Carolina bays, vernal pools, and playa lakes are important for the health of downstream rivers and bays, providing important flood storage, recharge, filtration, and wildlife habitat benefits. However, these connections are less obvious because they are located beyond the floodplains of streams and rivers. To restore longstanding protections for these waters, we must also make the scientific case for protecting them as "waters of the United States."

The "waters of the United States" rulemaking offers an historic opportunity to reinstate Clean Water Act safeguards for millions of wetland acres and stream miles and, in so doing, better protect downstream rivers, lakes, and estuaries. Actions should include the following:

- EPA and the USACE should issue a final "waters of the United States" rule that clearly restores Clean Water Act safeguards to all tributaries, all water bodies located within the floodplains of tributaries, and all other wetlands and water bodies important to the health of downstream rivers and bays.

- EPA, the USACE, and state agency partners should once again enforce Clean Water Act safeguards in these "waters of the United States" in order to maintain and restore the chemical, physical, and biological integrity of America's waters.

4.5. U.S. Army Corps of Engineers Navigation and Flood Control Policy Must Prioritize Natural Infrastructure

The primary missions of the USACE are to improve navigation of the nation's coastal and inland waters, reduce flood damages, and carry out ecosystem restoration. Regrettably, many navigation and flood protection activities carried out by the USACE have caused significant damage to the nation's

NPS

rivers, floodplains, coasts, and wetlands, and the important ecosystem services those systems provide, including vital flood and storm attenuation benefits. Some USACE activities have resulted in very significant increases in river flood heights, including the Mississippi and Missouri Rivers. In short, many of USACE's actions have had the perverse effect of significantly undermining the very flood protection services that agency has been charged with providing.[255] These same actions have also played a major role in harming America's fish and wildlife.

Many more USACE projects will lead to additional significant harm to natural systems as the USACE has a backlog of more than 1,000 projects (estimated to cost well over $60 billion) that were developed under the same type of planning rules that have already led to so much environmental harm. Many of these backlogged projects are ecologically-unsound and fail to address modern priorities and needs. USACE also continues to operate hundreds of reservoirs and navigation projects across the country under outdated operating plans that do not account for the new norm of extreme weather events or the need to restore damaged ecosystems.

In short, many of USACE's actions have had the perverse effect of significantly undermining the very flood protection services that agency has been charged with providing.

Congress enacted important legislation to address some of the problems with USACE planning in the Water Resources Development Act (WRDA) of 2007. WRDA is the legislative vehicle that authorizes new USACE activities and policies.[256] The 2007 WRDA established a new National Water Resources Planning Policy, which requires that all water resources projects protect the environment by protecting and restoring the functions of natural systems and mitigating any unavoidable damage, while also seeking to maximize sustainable economic development and avoid the unwise use of floodplain or flood-prone areas. The legislation also strengthened the mitigation requirements for USACE projects, established a standardized process for independent peer review of major USACE projects, and directed the Administration to update the rules that guide USACE project planning. These rules, the federal P&G, had not been updated since they were established in 1983.

As highlighted previously, the CEQ has finalized the update of the P&G. The new rules, now known as the P&R, direct the USACE and other relevant agencies to consider the value of ecosystem services, evaluate risk and uncertainty including extreme weather and sea-level rise, and evaluate environmental impacts when planning federal water investments. The P&R recognize the importance of restoring natural systems for protecting public safety and encourage a greater focus on nonstructural approaches to reducing flood damages and to addressing other water resources problems.

However, the new P&R are not currently being utilized and will not be utilized until interagency implementing guidelines are finalized (USACE will also not be able to use the new P&R until a Congressional prohibition on its use by the agency is lifted; this prohibition was established through an appropriations bill rider). To ensure effective implementation of the new P&R, the interagency guidelines should provide clear guidance and mandatory plan selection criteria to ensure that federal water resources planning prioritizes protection of natural systems and the use of natural infrastructure and fully accounts for ecosystem services.

Unfortunately, the most recent WRDA, enacted as the Water Resources Reform and Development Act (WRRDA) of 2014, fails to build on the policy improvements enacted in 2007. Instead, it undermines protection of natural systems by rolling back the protections provided by meaningful environmental review under the National Environmental Policy Act (NEPA). NEPA is

an essential tool for ensuring that projects do not adversely affect the ecological systems that sustain us. WRRDA 2014 also increases already significant federal subsidies to navigation projects regardless of their adverse impacts on vital natural systems.

While the new P&R are an important first step in improving USACE activities, much more still needs to be done to improve federal water projects. USACE should build on steps it is currently taking to identify the many opportunities that exist for modernizing its practices. USACE has the authority and, in many cases, the responsibility to implement changes to its current practices that ultimately could lead to the protection and restoration of substantial areas of habitat and landscape features that would both improve ecosystem functions and provide the natural infrastructure needed to protect people and property from natural hazards. To protect wetlands, rivers, floodplains, and coasts that provide critical protections to communities from extreme weather events, it is critical to:

iStockphoto

- Require the USACE to use natural infrastructure and restoration solutions whenever such measures can provide an appropriate level of protection and benefits (this can be accomplished through the rules implementing the new P&R).

- Establish a regular, standardized schedule for updating operating plans for USACE projects including flood control reservoirs.

- Improve protections for natural systems that provide vital fish and wildlife habitat and critical ecosystem services during USACE's project planning process.

- Establish a meaningful non-federal cost share for operating and maintaining the inland waterway navigation system to help ensure that natural systems are not damaged or destroyed by navigation activities that provide little or no value to the nation (all segments of the inland waterway system are now funded 100 percent by the federal taxpayers, not waterway uses, even for segments that see little use or serve only parochial interests).

- Establish a merit-based systems to prioritize USACE projects so that limited federal funds are spent on projects that both address national priorities and protect and restore vital natural systems and the ecosystem services they provide.

4.6. State Insurance Programs Must Be Actuarially Sound While Addressing the Needs of Socially-Vulnerable Communities

Although state-sponsored residual insurance pools such as FAIR, Beach and Windstorm plans, and natural catastrophe funds have been required to charge premium rates above the market rate so as not to compete with private insurance, those

rates are often determined by factors other than risk.[257] In a number of states, all insurance premium rates are regulated by state insurance commissioners, who have tended to limit increases in rates to enhance availability and affordability for consumers. In some cases, this has helped drive out private insurance companies, which are unable to charge rates sufficient to cover operating costs and losses, placing the burden of coverage onto the government. In addition, premium rates under the state-based programs may be set through legislative action, which can be subject to political motivations.

For example, Citizens has been operating with underpriced premiums under reforms established in 2007, which required the organization to charge rates below the private market and froze premiums at 2006 levels. While subsequent legislation allows for Citizens to raise its rates over time, the increase is limited to no more than 10 percent per year until actuarially-sound rates are achieved.[258] Furthermore, Citizens receives reinsurance coverage from the Florida Hurricane Catastrophe Fund (Cat Fund), which has the authority to spread losses from catastrophic events through debt financing. By spreading the tax burden to future generations, the Cat Fund has been able to charge premium rates well below those of private reinsurance.[259]

State insurance programs also are not required to hold reserve funds to cover their obligations. As a result, several state programs have incurred considerable financial deficits in the wake of recent catastrophes. Following Hurricanes Katrina and Rita in 2005, the Texas Windstorm Insurance Association (Texas Windpool) faced program losses and expenses of $100 million; the Mississippi Windstorm Underwriting Association (Mississippi Windpool) incurred a net loss of $473 million; and the Louisiana Citizens Property Insurance Corporation (Louisiana Citizens) suffered losses of more than $1 billion.[260] To pay for these losses, the state programs have had to resort to postfunding from general revenues, bond issuance, and assessments on private insurance companies, the costs of which are passed through to taxpayers and private insurance policyholders in the state – some of whom may not live in hazard-prone areas.

Essentially, these subsidies encourage development in some of the nation's most hazard-prone areas, including properties within sensitive ecological areas such as lands within the CBRS. They also discourage developers and communities from investing in important mitigation efforts. And they limit the ability of private insurance companies to compete in the market.[261] In turn, they increase the exposure of residual markets to even greater losses. For the United States as a whole, the total residual market exposure to loss under the FAIR and Beach Windstorm Plans has skyrocketed from $54.7 billion in 1990 to $884 billion in 2011.[262] Florida and New York face the greatest potential for losses from catastrophic events due to high property values and exposure to windstorms, followed by Texas and Massachusetts.

States must do more to eliminate perverse subsidies and encourage private insurance coverage for property owners through the following actions:

- Premium rates for state residual insurance should be actuarially sound, with rate increases phased in over time to minimize adverse impacts on lower-income households.[263]

- Properties should be made ineligible for state-sponsored hazard insurance if private insurance is available at comparable cost. Recent reforms of Citizens, for instance, have made property ineligible for Citizens coverage if a private company offers a policy that is within 15 percent of the rates offered by the state-sponsored program for similar coverage.

• States should not provide insurance coverage for newly-constructed properties within the CBRS or other ecologically sensitive lands in high-risk areas.

4.7. The United States Must Minimize Risks From Extreme Weather by Reducing Carbon Pollution

All of the policy reforms discussed above can be placed under the heading of climate change adaptation, the steps needed to prepare for and cope with the intensification of storms and floods due to changing climate conditions. Although these reforms will significantly reduce the risk of intensified storms and floods to people and property, extreme weather events will pose a serious threat to public safety and economic well-being even if aggressive adaptation measures are enacted. In fact, unless the United States and other major emitters of carbon pollution drastically reduce their contributions to global warming, sea-level rise, storms, and floods will only become more extreme.[264] An essential action to address the growing risk of floods and hurricanes due to climate change is to carry out aggressive adaptation and carbon pollution reduction measures.

An essential action to address the growing risk of floods and hurricanes due to climate change is to carry out aggressive adaptation and carbon pollution reduction measures.

Many scientists have suggested that in order to maximize our chances of having a safe climate, we must strive to keep global warming below 2° Celsius (3.6° Fahrenheit) above pre-industrial levels.[265] This target was embraced by world leaders, including President Obama, at a U.N. climate change meeting in Copenhagen in 2009. Reaching this target will require deep reductions in carbon pollution from current levels by the middle of this century.[266] To have an 80-percent chance of avoiding the 2° Celsius threshold, world leaders must put their countries on a strict "carbon budget" and cumulatively emit just 652 gigatons of carbon pollution between 2006 and 2050. The world is currently on pace to burn this amount of carbon by 2024.[267] Stated differently, annual carbon emissions would need to be slashed to 11 gigatons from our current level of about 36 gigatons by 2050.[268]

Fortunately, we already know what to do to meet the challenge of reducing carbon pollution to safer levels. Economists have demonstrated that if society wants less of a certain economic activity, the easiest way to achieve that goal is to make that activity more expensive and to facilitate a shift to one or more substitutes.[269] In general, the price of carbon pollution can be increased one of two ways: through a carbon tax or through a market-based emissions trading system. The key will be for the United States to demonstrate leadership by establishing a meaningful price on carbon pollution in one of these two ways and then to secure similarly aggressive commitments by other industrialized countries.

A federal legislative price on carbon, either through a carbon tax or market-based emissions trading system, would send a strong signal to consumers about the true costs of goods and services that contribute to climate change.[270] It also would send similar signals to producers about which investments to make, and it would provide incentives for innovators to develop low-carbon technologies. It could be designed to have a neutral impact on the size of government (with all proceeds returned to consumers and the private sector), or the revenues from the tax or fee could address pressing social needs such as hazard mitigation and other climate change adaptation.[271, 272] According to an analysis by the CBO, a carbon tax started at $20 per ton (in 2012) and raised at a nominal rate of 5.8 percent per year would raise an estimated $1.25 trillion over a ten-year period.

iStockphoto

While a national legislative solution would be optimal, substantial carbon pollution reductions are also achievable through federal administrative action and through action by the states. EPA's proposed rule to limit power plant emissions under section 111(d) of the Clean Air Act is an excellent example of the major reductions that can be achieved using existing legislative authorities. This rule, if adopted, would cut the nation's carbon dioxide (CO_2) emissions from existing power plants by roughly 30 percent from 2005 levels by 2030. It would do so by allowing states to tailor approaches that would best fit their unique situations. The northeastern states participating in the Regional Greenhouse Gas Initiative, and California with its Global Warming Solutions Act, have already demonstrated that state action on power plant carbon pollution can be quite effective and can be easily integrated into the emerging federal Clean Air Act program.[273, 274]

Some will complain about the added burden to American households and businesses that could result from increasing fossil energy costs. Yet these costs can be greatly minimized through targeted investments to smooth the transition to a clean energy economy. Moreover, the transition to a clean energy economy has enormous positive economic effects, benefits that far outweigh the costs of transitioning away from polluting technologies. The costs of extreme weather and other already-present climate change impacts to the economy make it clear that failure to act on carbon pollution is not an option.[275]

Conclusion

This report proposes a set of policy actions that, if taken, would greatly improve the safety and resilience of communities threatened by the growing risks of floods and hurricanes. These policies would provide a host of benefits beyond flood and hurricane protection, ranging from wildlife and habitat conservation to taxpayer savings. It is hoped that this report opens up a new dialogue over how to achieve this "triple win" of public safety, environmental conservation, and fiscal and economic sustainability.

iStockphoto

Appendix 1. Tools and Approaches for Evaluating Risks from Hurricanes and Floods

InVEST: The Natural Capital project Integrated Valuation of Environmental Services and Tradeoffs (InVEST) software[276] is a robust set of assessment tools supporting qualitative and quantitative modeling of environmental, social, and economic dynamics. The software includes a number of individual modules for focused assessment, one of which is the coastal vulnerability model.[277] This model integrates Geographic Information Systems (GIS) spatial data for seven bio-geophysical variables: geomorphology, relief, natural habitats, sea level change, wind exposure, wave exposure, and surge potential. These factors are combined to generate an exposure index and ranking system for coastal vulnerability. Model outputs include maps of the areas of interest, as well as histograms of exposure and vulnerability. The InVEST software also includes economic valuation options to assess potential changes in ecosystem services provided by natural infrastructure, which makes it also relevant for the issues and approaches discussed in section 3.3 and Appendix 2.

Hazus-MH: Developed by FEMA, Hazus is a software program that has become the national standard when estimating loss from earthquakes, floods, and hurricanes.[278] For its most basic uses, it is fairly simple for those familiar with GIS. Hazus can be used to estimate physical damage to residential and commercial buildings, schools, critical facilities, and infrastructure; economic loss, including lost jobs, business interruptions, repair, and reconstruction costs; and social impacts, including estimates of shelter requirements, displaced households, and population exposed to scenario floods, earthquakes, and hurricanes.

Hydrology and Hydraulic Modeling: Hydrology and hydraulic modeling is the core of flood risk assessment, using precipitation patterns and geophysical attributes of a landscape to predict how individual events will affect watercourses and overbank flooding. In hydrological modeling, two types of models are used: stochastic models, those based on mathematical and statistical calculations to link inputs to outputs; and deterministic models, those that try to physically represent the processes that could be observed in the real world.

NOAA'S Risk and Vulnerability Assessment Tool: The Coastal Services Center at NOAA has developed a multi-faceted, online-based tool to assist communities in evaluating the vulnerability of people, property, and natural resources to natural hazard risks.[279] The tool allows for data analysis of risks under various scenarios of sea-level rise and storm surge through interactive mapping. It also allows for visualization of impacts via 3-D animations of projected inundation due to flooding from hurricanes and tropical storms. In addition, users can review the potential effectiveness of various activities for hazard mitigation under FEMA's CRS. NOAA also offers an online training and provides support for in-person workshops to help communities develop effective hazard preparedness and mitigation strategies.

Appendix 2. Methods and Tools for Valuing the Benefits of Natural Infrastructure

Alternative Valuation Methods for Non-Market Goods and Services[280]

Avoided Cost (AC): This method estimates the economic value of ecological services that allow society to avoid costs that would have been incurred in the absence of those services. For example, storm protection provided by barrier islands avoids property damages along the coast.

Replacement Cost (RC): This method allows for comparison between the costs of services provided by ecological systems with comparable services provided by cheapest alternative. For example, nutrient cycling by wetlands can provide a similar service to those of engineered water treatment systems.

Factor Income (FI): Services provided by natural infrastructure can enhance income beyond the direct activities that those services support. For example, improvement to water quality may also increase commercial fisheries catch and in turn, the incomes of fishermen and women.

Travel Cost (TC): The value of natural systems in some areas can be measured by the expenditures that people make to travel to those areas for certain activities. For example, recreation areas may attract visitors whose value placed on that area is at least what they were willing to pay to travel to it, including the imputed value of their time.

Contingent Valuation (CV): This method typically involves surveys that ask people's "willingness to pay" for services under hypothetical scenarios of alternatives. For instance, people generally state that they are willing to pay for increased preservation of beaches or endangered species protection.

Hedonic Pricing (HP): This method estimates the value of certain services based on the price people are willing to pay for them. It is often used to estimate property values associated with aesthetic qualities of natural systems. For example, housing prices along the coastline tend to exceed the prices of inland homes, reflecting the added value people place on the amenities offered by being near the coast.

Marginal Product Estimation (MP): The demand for ecological services can be estimated in a dynamic modeling environment using a production function (Cobb-Douglas) to estimate the change in the value of outputs in response to a change in material inputs.

Group Valuation (GV): This approach is based on principles of deliberative democracy and the assumption that public decision making should result, not from the aggregation of separately measured individual preferences, but from open public debate.

Ecosystem Service Valuation Tools

EVT: The Ecosystem Valuation Toolkit (EVT) is an online global resource that houses a comprehensive, spatially explicit, web-based repository of published and unpublished economic values for ecosystem services.[281] It provides tools for translating the values provided by, or reduced by damage to, natural systems through an elaborate benefit transfer methodology. It links the ecosystem understanding provided by the natural sciences to the information required by investors, markets, and economic decision-makers.

Endnotes

[1] Multihazard Mitigation Council. 2005. *Natural Hazard Mitigation Saves: An Independent Study to Assess the Future Savings from Mitigation Activities.* National Institute of Building Sciences, Washington, D.C.

[2] National Research Council. 2014. *Reducing Coastal Risk on the East and Gulf Coasts.* Committee on U.S. Army Corps of Engineers Water Resources Science, Engineering and Planning: Coastal Risk Reduction, Water Science and Technology Board, Ocean Studies Board, Division of Earth and Life Studies. The National Academies Press, Washington, D.C.

[3] USACE (U.S. Army Corps of Engineers). 2013. *Coastal Risk Reduction and Resilience.* CWTS 2013-3. Directorate of Civil Works, U.S. Army Corps of Engineers, Washington, D.C.

[4] Hey, D.L., and N.S. Philippi. 1995. Flood reduction through wetland restoration: the upper Mississippi River Basin as a case history. *Restoration Ecology* 3: 4-17.

[5] Erdle, S.Y., J.L.D. Davis, and K.G. Sellner. 2006. *Management, Policy, Science, and Engineering of Nonstructural Erosion Control in Chesapeake Bay: Proceedings of the 2006 Living Shoreline Summit.* Chesapeake Research Consortium Publication 08-164.

[6] USACE. 1990. *Chesapeake Bay Shoreline Erosion Study.* Department of the Army, U.S. Army Corps of Engineers, Baltimore, MD.

[7] Costanza, R., M.A. Wilson, A. Troy, A. Vioinov, and S. Liu. 2006. *The Value of New Jersey's Ecosystem Services and Natural Capital.* New Jersey Department of Environmental Protection, Woodbine, N.J.

[8] Kroeger, T., and J. Haner. 2014. *The Economics of Oyster Reef Restoration in the Gulf of Mexico: A Case Study in Mobile Bay, Alabama.* The Nature Conservancy, Arlington, VA. URL: http://www.habitat.noaa.gov/pdf/tnc_oyster_economics_factsheet.pdf (accessed July 14, 2014).

[9] Lowe, J., B. Battalio, M. Brennan, M. Holmes, E. Niemi, and C. Toms. 2013. *Analysis of the Costs and Benefits of Using Tidal Marsh Restoration as a sea-level rise Adaptation Strategy in San Francisco Bay.* Prepared for The Bay Institute by ESA PWA, San Francisco, CA.

[10] Ferrario, F., M.W. Beck, C.D. Storlazzi, F. Micheli, C.C. Shepard, and L. Airoldi. 2014. The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. *Nature Communications* 5: doi: 10.1038/ncomms4794.

[11] Kunreuther, H.C., and E.O. Michel-Kerjan. 2013. *Implementing the National Flood Insurance Reform Act in a New Era of Catastrophes.* Public Policy Initiative Volume 1, Number 9. Penn Wharton Public Policy Initiative, The Wharton School, University of Pennsylvania, Philadelphia, PA.

[12] Michel-Kerjan, E.O., and C. Kousky. 2010. Come rain or shine: evidence on flood insurance purchases in Florida. *Journal of Risk and Insurance* 77: 369-397.

[13] Vorhies, F. 2012. *The Economics of Investing in Disaster Risk Reduction.* Working paper commissioned by the Secretariat to the U.N. International Strategy for Disaster Reduction (UNISDR), Geneva, Switzerland.

[14] Dahl, T.E., and S.M. Stedman. 2013. *Status and Trends of Wetlands in the Coastal Watersheds of the Conterminous United States 2004 to 2009.* U.S. Department of the Interior, Fish and Wildlife Service and National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

[15] NAS (National Academy of Sciences). 2002. *Riparian Areas: Functions and Strategies for Management.* The National Academies Press, Washington, D.C.

[16] Swift, B.L. 1984. Status of riparian ecosystems in the United States. *Water Resources Bulletin* 20: 223-228.

[17] Ermgassen, P.S.E.Z., M.D. Spalding, B. Blake, L.D. Coen, B. Dumbauld, S. Geiger, J.H. Grabowski, R. Grizzle, M. Luckenbach, K. McGraw, W. Rodney, J.L. Ruesink, S.P. Powers, and R. Brumbaugh. 2012. Historical ecology with real numbers: past and present extent and biomass of an imperiled estuarine habitat. *Proceedings of the Royal Society B*: doi: 10.1098/rspb.2012.0313.

[18] Kousky, C., and R. Zeckhauser. 2006. JARing actions that fuel the floods. In: R.J. Daniels, D.F. Kettle, and H. Kunreuther (Eds.). *On Risk and Disaster: Lessons from Hurricane Katrina.* University of Pennsylvania Press, Philadelphia, PA: 59-73.

[19] Kildow, J.T., C.S. Colgan, J.D. Scorse, P. Johnston, and M. Nichols. 2014. *State of the U.S. Ocean and Coastal Economies 2014.* National Ocean Economics Program, Center for the Blue Economy, Monterey, CA.

[20] EPA (U.S. Environmental Protection Agency). 2009. *Geographic Information Systems Analysis of the Surface Drinking Water Provided by Intermittent, Ephemeral and Headwater Streams in the U.S.* U.S. Environmental Protection Agency,

Washington, D.C. URL: http://water.epa.gov/lawsregs/guidance/wetlands/surface_drinking_water_index.cfm (accessed May 20, 2014).
[21] American Rivers. 2014. *Economic Impacts of Rivers and Recreation.* URL: http://www.americanrivers.org/assets/pdfs/national-river-cleanup/economic-impact-of-rivers-and.pdf (accessed May 20, 2014).
[22] Kildow, J.T., C.S. Colgan, J.D. Scorse, P. Johnston, and M. Nichols. 2014. *State of the U.S. Ocean and Coastal Economies 2014.* National Ocean Economics Program, Center for the Blue Economy, Monterey, CA.
[23] FWS (U.S. Fish and Wildlife Service). 2014. Coastal Program: Habitat and Resources Conservation. URL: http://www.fws.gov/coastal/ (accessed July 2, 2014).
[24] Miner, D. 2007. U.S. Fish and Wildlife Service Coastal Program: geographic focus areas. *Proceedings of Coastal Zone 07,* Portland, Oregon, July 22 to 26, 2007. URL: http://www.csc.noaa.gov/cz/CZ07_Proceedings/PDFs/Tuesday_Abstracts/2781.Miner.pdf (accessed July 2, 2014).
[25] NOAA (National Oceanic and Atmospheric Administration). 2014. *NOAA Helps Keep Our Marine Transportation System Sailing Smoothly.* URL: http://www.noaa.gov/features/economic_0708/ (accessed May 20, 2014).
[26] NOAA. 2012. *NOAA's State of the Coast. Economy: Ports – Crucial Coastal Infrastructure.* U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Silver Spring, MD.
[27] NMFS (National Marine Fisheries Service). 2010. *Fisheries Economics of the United States, 2009.* U.S. Department of Commerce, NOAA Technical Memorandum NOAA NMFS-F/SPO-118. National Marine Fisheries Service, Silver Spring, MD.
[28] Battaglia, L.L., and R.R. Sharitz. 2005. Effects of natural disturbance on bottomland hardwood regeneration. In: Fredrickson, L.H., S.L. King, and R.M. Kaminski (Eds.), *Ecology and Management of Bottomland Hardwood Ecosystems: The State of our Understanding.* University of Missouri, Columbia: 121-136.
[29] ASFPM (Association of State Floodplain Managers) Foundation. 2007. *Floodplain Management 2050. A Report of the 2007 Assembly of the Gilbert F. White National Flood Policy Forum, Washington, D.C.*
[30] Wright, J.M. 2008. *Floodplain Management: Principles and Current Practices.* The University of Tennessee, Knoxville.
[31] Ibid.
[32] NOAA and the U.S. Census Bureau. 2013. *National Coastal Population Report: Population Trends from 1970-2020.* URL: http://stateofthecoast.noaa.gov/features/coastal-population-report.pdf (accessed May 9, 2014).
[33] Strauss, B.H., R. Ziemlinski, J.L. Weiss, and J.T. Overpeck. 2012. Tidally adjusted estimates of topographic vulnerability to sea-level rise and flooding for the contiguous United States. *Environmental Research Letters* 7: 014033.
[34] EPA. 2010. *Climate Change Vulnerability Assessments: A Review of Water Utility Practices.* EPA 800-R-10-001. U.S. Environmental Protection Agency, Washington, D.C.
[35] NOAA. 2014. *Coastal County Snapshots, Flood Exposure Snapshot.* URL: http://www.csc.noaa.gov/snapshots (accessed June 10, 2014).
[36] Ntelekos, A.A., M. Oppenheimer, J.A. Smith, and A.J. Miller. 2010. Urbanization, climate change and flood policy in the United States. *Climatic Change* 103: 597-616.
[37] Heine, R.A., and N. Pinter. 2011. Levee effects upon flood levels: an empirical assessment. *Hydrological Processes* 26: 3225-3240.
[38] Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville. 2014. Ch. 2: *Our Changing Climate. Climate Change Impacts in the United States: The Third National Climate Assessment,* J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds. U.S. Global Change Research Program, 19-67: doi: 10.7930/JOKW5CXT.
[39] Kunkel, K.E., T.R. Karl, H. Brooks, J. Kossin, J. Lawrimore, D. Arndt, L. Bosart, D. Changnon, S.L. Cutter, N. Doesken, K. Emanuel, P. Ya. Groisman, R.W. Katz, T. Knutson, J. O'Brien, C.J. Paciorek, T.C. Peterson, K. Redmond, D. Robinson, J. Trapp, R. Vose, S. Weaver, M. Wehner, K. Wolter, and D. Wuebbles. 2013. Monitoring and understanding trends in extreme storms: state of knowledge. *Bulletin of the American Meteorological Society* 94: doi: 10.1175/BAMS-D-11-00262.1.
[40] NOAA. 2014. *U.S. Climate Extremes Index.* URL: www.ncdc.noaa.gov/extremes/cei (accessed June 16, 2014).
[41] Peterson, T.C., R.R. Heim, R. Hirsch, D.P. Kaiser, H. Brooks, N.S. Diffenbaugh, R.M. Dole, J.P. Giovannettone, K. Guirguis, T.R. Karl, R.W. Katz, K. Kunkel, D. Lettenmaier, G.J. McCabe, C.J. Paciorek, K.R. Ryberg, S. Schubert, V.B.S. Silva, B.C. Stewart, A.V. Vecchia, G. Villarini, R.S. Vose, J. Walsh, M. Wehner, D. Wolock, K. Wolter, C.A. Woodhouse, and D. Wuebbles. 2013. Monitoring and understanding changes in heat waves, cold waves, floods and droughts in the United States: state of knowledge. *Bulletin of the American Meteorological Society* 94: 821-834.

[42] NOAA. 2014. *The Atlantic Hurricane Database Re-analysis Project.* URL: http://www.aoml.noaa.gov/hrd/hurdat/comparison_table.html (accessed June 16, 2014).
[43] Church, J.A., and N.J. White. 2011. Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics* 32: 585-602.
[44] Walsh et al., 2014.
[45] McMillan, M., A. Shepherd, A. Sundal, K .Briggs, A. Muir, A. Ridout, A. Hogg, and D. Wingham. 2014. Increased ice losses from Antarctica detected by CryoSat-2. *Geophysical Research Letters:* doi: 10.1002/2014GL060111.
[46] Davenport, C. May 7, 2014. Miami finds itself ankle-deep in climate change debate. *The New York Times.* URL: http://www.nytimes.com/2014/05/08/us/florida-finds-itself-in-the-eye-of-the-storm-on-climate-change.html?_r=0 (accessed August 12, 2014).
[47] Couvillion, B.R., J.A. Barras, G.D. Steyer, W. Sleavin, M. Fischer, H. Beck, N. Trahan, B. Griffin, and D. Heckman. 2011. *Land Area Change in Coastal Louisiana from 1932 to 2010.* U.S. Geological Survey Scientific Investigations Map 3164, scale 1:265,000, 1 sheet, 12 p. pamphlet.
[48] Campanella, R. 2010. *Delta Urbanism: New Orleans.* American Planning Association, Chicago, IL. 224 pp.
[49] Sweet, W., J. Park, J. Marra, C. Zervas, and S. Gill. 2014. *Sea Level rise and Nuisance Flood Frequency Changes around the United States.* NOAA Technical Report NOA CO-OPS 073. National Oceanic and Atmospheric Administration, Silver Spring, MD.
[50] Shepard, C.C., V.N. Agostini, B. Gilmer, T. Allen, J. Stone, W. Brooks, and M.W. Beck. 2012. Assessing future risk: quantifying the effects of sea-level rise on storm surge risk for the southern shores of Long Island, New York. *Natural Hazards* 60: 727-745.
[51] Sweet, W., C. Zervas, S. Gill, and J. Park. 2013. Hurricane Sandy inundation probabilities: today and tomorrow. In: Explaining Extreme Events of 2012 from a Climate Perspective. *Bulletin of the American Meteorological Society* 94: S17-S20.
[52] Perry, C.A. 2000. *Significant Floods in the United States During the 20th Century – USGS Measures of a Century of Floods.* USGS fact sheet 024-00. U.S. Geological Survey, Lawrence, KA.
[53] Michel-Kerjan, E., and H. Kunreuther. 2011. Redesigning flood insurance. *Science* 333: 408-409.
[54] Rocky Mountain Insurance Information Association. *Catastrophe Facts and Statistics.* URL: http://rmiia.org/Catastrophes_and_statistics.asp (accessed April 23, 2014).
[55] Mileti, D.S. 1999. *Disasters by Design: A Reassessment of Natural Hazards in the United States.* Joseph Henry Press, Washington, D.C.
[56] Gall, M., K.A. Borden, C.T. Emrich, and S.L. Cutter. 2011. The unsustainable trend of natural hazard losses in the United States. *Sustainability* 3: 2157-2181.
[57] Kunreuther and Michel-Kerjan, 2013.
[58] National Association of Home Builders. 2005. Rebuilding Katrina-destroyed homes at least a year away. *Nation's Building News.* URL: http://www.nbnnews.com/NBN/issues/2005-10-10/Front+Page/index.html (accessed May 20, 2014).
[59] Hsiang, S.M., and A.S. Jina. 2014. *The Causal Effect of Environmental Catastrophe on Long-Run Economic Growth: Evidence from 6,700 Cyclones.* NBER Working Paper No. 20352. The National Bureau of Economic Research, Cambridge, MA.
[60] Michel-Kerjan and Kunreuther, 2011.
[61] University Corporation for Atmospheric Research. 2013. *Inside the Colorado deluge: how much rain fell on the Front Range, and how historic was it?* URL: http://www2.ucar.edu/atmosnews/opinion/10250/inside-colorado-deluge (accessed May 13, 2014).
[62] NCDC (National Climatic Data Center). 2009. Billion Dollar U.S. Weather Disasters, 1980-2008. URL: http://www.ncdc.noaa.gov/oa/reports/billionz.html (accessed May 13, 2014).
[63] Chen, A.C., V.M. Keith, K.J. Leong, C. Airriess, W. Li, K. Chung, and C. Lee. 2007. Hurricane Katrina: prior trauma, poverty and health among Vietnamese-American survivors. *International Nursing Review* 54: 324-331.
[64] Chia-Chen, A., V.M. Keith, C. Airress, W. Li, and K.J. Leong. 2007. Economic vulnerability, discrimination, and Hurricane Katrina: health among Black Katrina survivors in eastern New Orleans. *Journal of the American Psychiatric Nurses Association* 13: 257-266.

[65] Writer, J.H., and S.F. Murphy. 2012. *Wildfire Effects on Source-water Quality: Lessons from Fourmile Canyon Fire, Colorado, and Implications for Drinking Water Treatment.* USGS Fact Sheet 2012-3095.
[66] Hallegatte, S., C. Green, R.J. Nicholls, and J. Corfee-Morlot. 2013. Future flood losses in major coastal cities. *Nature Climate Change* 3: 802-806.
[67] Opperman, J.J. 2014. *A Flood of Benefits: Using Green Infrastructure to Reduce Flood Risks.* The Nature Conservancy, Arlington, VA.
[68] Strauss, B., C. Tebaldi, and R. Ziemlinski. 2012. *Surging Seas: Sea-Level Rise, Storms, and Global Warming's Threat to the U.S. Coast.* A Climate Central Report.
[69] Tebaldi, C., B.H. Strauss, and C.E. Zervas. 2012. Modelling sea-level rise impacts on storm surges along U.S. coasts. *Environmental Research Letters* 7: 014032.
[70] AECOM and FEMA (Federal Emergency Management Agency). 2013. *The Impact of Climate Change and Population Growth on the National Flood Insurance Program through 2100.* AECOM and the Federal Emergency Management Agency, Washington, D.C.
[71] Berrang-Ford, L., J.D. Ford, and J. Paterson. 2011. Are we adapting to climate change? *Global Environmental Change* 21: 25-33.
[72] Vogel, C., S.C. Moser, R.E. Kasperson, and G.D. Dabelko. 2007. Linking vulnerability, adaptation, and resilience science to practice: pathways, players, and partnerships. *Global Environmental Change* 17: 349-364.
[73] Farley, J., D. Baker, D. Batker, C. Koliba, R. Matteson, R. Mills, and J. Pittman. 2007. Opening a policy window for ecological economic: Katrina as a focusing event. *Ecological Economics:* doi: 10.1016/j.ecolecon.2006.07.029.
[74] Pater, C.S., and M.K. Lindell. 2000. Politics of hazard mitigation. *Natural Hazards Review* 1: 73-82.
[75] White, G.F. 1945. *Human Adjustment to Floods*. University of Chicago Department of Geography Research Paper No. 29.
[76] Kunreuther, H. 1996. Mitigating disaster losses through insurance. *Journal of Risk and Uncertainty* 12: 171-187.
[77] USACE. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures.* Directorate of Civil Works, U.S. Army Corps of Engineers, Washington, D.C.
[78] Merz, B., J. Hall, M. Disse, and A. Schumann. 2010. Fluvial flood risk management in a changing world. *Natural Hazards and Earth System Sciences* 10: 509-527.
[79] Kunreuther, H., and E.U. Weber. 2012. *Facilitating and Aiding Human Decisions to Adapt to or Mitigate the Impacts of Climate Change.* Risk Management and Decision Processes Center, The Wharton School, University of Pennsylvania, Philadelphia, PA.
[80] Kunreuther, 1996.
[81] Kousky, C. 2013. Informing climate adaptation: a review of the economic costs of natural disasters. *Energy Economics:* http://dx.doi.org/10.1016/j.eneco.2013.09.029 (accessed May 9, 2014).
[82] Filatova, T. 2013. Market-based instruments for flood risk management: a review of theory, practice and perspectives for climate adaptation policy. *Environmental Science & Policy:* URL: http://dx.doi.org/10.1016/j.envsci.2013.09.005 (accessed June 19, 2014).
[83] Filatova, T. 2013. Market-based instruments for flood risk management: A review of theory, practice, and perspectives for climate adaptation policy. *Environmental Science and Policy:* http://dx.doi.org/10.1016/j.envsci.2013.09.005 (accessed June 19, 2014).
[84] Ludy, J., and G.M. Kondolf. 2011. Flood risk perception in lands "protected" by 100-year levees. *Natural Hazards:* doi: 10.1007/x11069-011-0072-6.
[85] Kates, R.W., C.E. Colten, S. Laska, and S.P. Leatherman. 2006. Reconstruction of New Orleans after Hurricane Katrina: a research perspective. *Proceedings of the National Academy of Sciences* 103: 14653-14660.
[86] Tobin, G.A. 1995. The levee love affair: a storm relationship. *Water Resources Bulletin* 31: 359-367.
[87] Interagency Performance Evaluation Task Force (IPET). 2008. *Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System: Final Report of the Interagency Performance Evaluation Task Force.* U.S. Army Corps of Engineers, Washington, D.C.
[88] Swenson, D. August 16, 2013. Hurricane Katrina flooding compared to a 500-year storm today: graphic. *The Times-Picayune.* URL: http://www.nola.com/hurricane/index.ssf/2013/08/hurricane_katrina_floodwater_d.html (accessed July 11, 2014).
[89] National Academy of Engineering and Natural Research Council. 2009. *The New Orleans Hurricane Protection System: Assessing Pre-Katrina Vulnerability and Improving Mitigation and Preparedness.* The National Academies Press, Washington, D.C.

[90] USACE, Louisiana Coastal Protection and Restoration Authority Board, and Terrebonne Levee and Conservation District. 2013. *Final Post Authorization Change Report and Revised Programmatic Environmental Impact Statement: Morganza to the Gulf of Mexico, Louisiana.* U.S. Army Corps of Engineers, Louisiana Coastal Protection and Restoration Authority Board, and Terrebonne Levee and Conservation District, New Orleans, LA.
[91] Be Prepared Yuba. 2014. *History of Flooding and Flood Control*. URL: http://www.bepreparedyuba.org/pages/prepare/history.aspx (accessed June 26, 2014).
[92] River Partners. 2014. Bear River Restoration: A Framework for Multi-Benefit Projects and Flood Management. URL: http://riverpartners.org/news-and-events/newsletters/201303_BearRiverRestoration.html (accessed June 26, 2014).
[93] USACE. 2014. *Engineering with Nature.* URL: http://el.erdc.usace.army.mil/ewn/ (accessed July 14, 2014).
[94] CBO (Congressional Budget Office). 2007. *Potential Cost Savings from the Pre-Disaster Mitigation Program.* Congressional Budget Office, Washington, D.C.
[95] Czajkowski, J., H. Kunreuther, and E. Michel-Kerjan. 2012. *A Methodological Approach for Pricing Flood Insurance and Evaluating Loss Reduction Measures: Application to Texas.* Center for Risk Management and Decision Processes, The Wharton School, University of Pennsylvania, Philadelphia, PA.
[96] The Multihazard Mitigation Council. 2005. *Natural Hazard Mitigation Saves: An Independent Study to Assess the Future Savings from Mitigation Activities.* Volume 1 – Findings, Conclusions, and Recommendations. National Institute of Building Sciences, Washington, D.C.
[97] Sweeden, P., and J. Pittman. 2007. *An Ecological Economic Assessment of King County's Flood Hazard Management Plan.* Earth Economics, Tacoma, WA.
[98] Earth Economics. 2013. *Return on Investment Analysis of Pierce County Flood Risk Management Solutions.* Earth Economics, Tacoma, WA.
[99] Multihazard Mitigation Council. 2005. *Natural Hazard Mitigation Saves: An Independent Study to Assess the Future Savings from Mitigation Activities.* National Institute of Building Sciences, Washington, D.C.
[100] CBO. 2007. *Potential Cost Savings from the Pre-Disaster Mitigation Program.* Congressional Budget Office, Washington, D.C.
[101] Rose, A., K. Porter, N. Dash, J. Bouabid, C. Huyck, J.C. Whitehead, D. Shaw, R. Eguchi, C. Taylor, T. McLane, L.T. Tobin, P.T. Ganderton, D. Godschalk, A.S. Kiremidjian, K Tierney, and C.T. West. 2007. Benefit-cost analysis of FEMA hazard mitigation grants. *Natural Hazards Review* 8: 97-111.
[102] Green/Duwamish and Central Puget Sound Watershed Water Resource Inventory Area 9 (WRIA 9) Steering Committee. 2005. *Salmon Habitat Plan: Making our Watershed Fit for a King. Prepared for the WRIA 9 Forum.* URL: http://www.govlink.org/watersheds/9/plan-implementation/HabitatPlan.aspx#download (accessed June 27, 2014).
[103] Israel, N.D. 2012. *Inaction on Climate Change: The Cost to Taxpayers.* Ceres, Boston, MA.
[104] Vorhies, 2012.
[105] Hawley, K., M. Moench, and L. Sabbag. 2012. *Understanding the Economics of Flood Risk Reduction: A Preliminary Analysis. Institute for Social and Environmental Transition* – International, Boulder, CO.
[106] Meyer, V., N. Becker, V. Markantonis, R. Schwarze, J.C.J.M. van den Bergh, L.M. Bouwer, P. Bubeck, P. Ciavola, E. Genovese, C. Green, S. Hallegatte, H. Kreibich, Q. Lequeux, I. Logar, E. Papyrakis, C. Pfurtscheller, J. Poussin, V. Przyluski, A.H. Thieken, and C. Viavattene. 2013. Review article: assessing the costs of natural hazards – state of the art and knowledge gaps. *Natural Hazards and Earth System Sciences* 13: 1351-1373.
[107] Cutter, S.L., and C. Emrich. 2005. Are natural hazards and disaster losses in the U.S. increasing? *Eos* 86: 381-396.
[108] Gall, M., K.A. Borden, and S.L. Cutter. 2009. When do losses count? Six fallacies of natural hazards loss data. *Bulletin of the American Meteorological Society* 90: 799-809.
[109] Kousky, 2013.
[110] Ibid.
[111] Ibid.
[112] Meyer, V., N. Becker, V. Markantonis, R. Schwarze, J.C.J.M. van den Bergh, L.M. Bouwer, P. Bubeck, P. Ciavola, E. Genovese, C. Green, S. Hallegatte, H. Kreibich, Q. Lequeux, I. Logar, E. Papyrakis, C. Pfurtscheller, J. Poussin, V. Przyluski, A.H. Thieken, and C. Viavattene. 2013. Review article: assessing the costs of natural hazards – state of the art and knowledge gaps. *Natural Hazards and Earth System Sciences* 13: 1351-1373.
[113] Ibid.
[114] Kousky, 2013.
[115] Vorhies, 2012.

[116] Powers, K. 2003. *Benefit-Cost Analysis and the Discount Rate for the Corps of Engineers; Water Resources Projects: Theory and Practice.* Congressional Research Service, Washington, D.C.
[117] Arrow, K., P. Dasgupta, L. Goulder, G. Daily, P. Ehrlich, G. Heal, S. Levin, K.-G. Maler, S. Schneider, D. Starrett, and B. Walker. 2004. Are we consuming too much? *The Journal of Economic Perspectives* 18: 147-172.
[118] Weitzman, M.L. 1998. Why the far-distant future should be discounted at its lowest possible rate. *Journal of Environmental Economics and Management* 36: 201-208.
[119] Fisher, A.C., and P.V. Le. 2014. Climate policy: science, economics, and extremes. *Review of Environmental Economics and Policy:* doi: 10.1093/reep/reu009.
[120] Reeve, K.E., and R. Kingston. 2014. *Green Works for Climate Resilience: A Guide to Community Planning for Climate Change.* National Wildlife Federation, Washington, D.C.
[121] Galbraith, H., R. Jones, R. Park, J. Clough, S. Herrod-Julius, B. Harrington, and G. Page. 2002. Global climate change and sea-level rise: potential losses of intertidal habitat for shorebirds. *Waterbirds* 25: 173-183.
[122] Mosier, A.E., and B.E. Witherington. 2002. *Documented Effects of Coastal Armoring Structure on Sea Turtle Nesting Behavior.* Florida Fish and Wildlife Conservation Commission, Tallahassee, FL.
[123] Houston, J.R. 2008. The economic value of beaches: a 2008 update. *Shore & Beach* 76: 22-26.
[124] Costanza, R., R. de Groot, P. Sutton, S. van der Ploeg, S.J. Anderson, I. Kubiszewski, S. Farber, and R.K. Turner. 2014. Changes in the global value of ecosystem services. *Global Environmental Change* 26: 152-158.
[125] Arkema, K.K., G. Guannel, G. Verutes, S.A. Wood, A. Guerry, M. Ruckelshaus, P. Kareiva, M. Lacayo, and J.M. Silver. 2013. Coastal habitats shield people and property from sea-level rise and storms. *Nature Climate Change* 3: doiI:10.1038/NCLIMATE1944.
[126] Guerry, A.D., M.H. Ruckelshaus, K.K. Arkema, J.R. Bernhardt, G. Guannel, C.-K. Kim, M. Marsik, M. Papenfus, J.E. Toft, G. Verutes, S.A. Wood, M. Beck, F. Chan, K.M.A. Chan, G. Gelfenbaum, B.D. Gold, B.S. Halpern, W.B. Labiosa, S.E. Lester, P.S., Levin, M. McField, M.L. Pinsky, M. Plummer, S. Polasky, P. Ruggiero, D.A. Sutherland, H. Tallis, A. Day, and J. Spencer. 2012. Modeling benefits from nature: using ecosystem services to inform coastal and marine spatial planning. *International Journal of Biodiversity Science:* doi: 10.1080/21513732.2011.647835.
[127] Jones, H.P., D.G. Hole, and E.S. Zavaleta. 2012. Harnessing nature to help people adapt to climate change. *Nature Climate Change* 2: doi: 10.1038/NCLIMATE1463.
[128] Nelson, E.J., P. Kareiva, M. Ruckelshaus, K. Arkema, G. Geller, E. Girvetz, D. Goodrich, V. Matzek, M. Pinsky, W. Reid, M. Saunders, D. Semmens, and H. Tallis. 2013. Climate change's impact on key ecosystem services and the human well-being they support in the U.S. *Frontiers in Ecology and the Environment* 11: 483-493.
[129] Spalding, M.D., A.L. McIvor, M.W. Beck, E.W. Koch, I. Möller, D.J. Reed, P. Rubinoff, T. Spencer, T.J. Tolhurst, T.V. Wamsley, B.K. van Wesenbeeck, E. Wolanski, and C.D. Woodroffe.2013. Coastal ecosystems: a critical element of risk reduction. *Conservation Letters* 00: 109.
[130] EPA. 2001. *Functions and Values of Wetlands.* URL: http://water.epa.gov/type/wetlands/upload/2006_08_11_wetlands_fun_val.pdf (accessed July 2, 2014).
[131] Costanza, R., O. Pe'rez-Maqueo, M.L. Martinez, P. Sutton, S.J. Anderson, and K. Mulder. 2008. The value of coastal wetlands for hurricane protection. *Ambio* 37: 241-248.
[132] Spalding, M.D., A.L. McIvor, M.W. Beck, E.W. Koch, I. Möller, D.J. Reed, P. Rubinoff, T. Spencer, T.J. Tolhurst, T.V. Wamsley, B.K. van Wesenbeeck, E. Wolanski, and C.D. Woodroffe. 2013. Coastal ecosystems: a critical element of risk reduction. *Conservation Letters* 00: 1-9.
[133] Feagin, R.A., W.K. Smith, N.P. Psuty, D.R. Young, M. Luisa Martínez, G.A. Carter, K.L. Lucas, J.C. Gibeaut, J.N. Gemma, and R.E. Koske. 2010. Barrier islands: coupling anthropogenic stability with ecological sustainability. *Journal of Coastal Research:* doi: 10.2112/09-1185.1.
[134] Spalding, M.D., A.L. McIvor, M.W. Beck, E.W. Koch, I. Möller, D.J. Reed, P. Rubinoff, T. Spencer, T.J. Tolhurst, T.V. Wamsley, B.K. van Wesenbeeck, E. Wolanski, and C.D. Woodroffe. 2013. Coastal ecosystems: a critical element of risk reduction. *Conservation Letters* 00: 1-9.
[135] Batker, D., I. de la Torre, R. Costanza, P. Swedeen, J. Day, R. Boumans, and K. Bagstad. 2010. *Gaining Ground: Wetlands, Hurricanes and the Economy: The Value of Restoring the Mississippi River Delta.* Earth Economics, Tacoma, WA.
[136] Spalding, et al., 2013.
[137] Blom, C.W.P.M., and L.A.C.J. Voesenek. 1996. Flooding: the survival strategies of plants. *Trends in Ecology and Evolution* 11: 290-295.

[138] Nisson, C., and K. Berggren. 2000. Alterations of riparian ecosystems caused by river regulation. *BioScience* 50: 783-792.
[139] Stromberg, J.C., K.E. McCluney, M.D. Dixon, and T. Meixner. 2012. Dryland riparian ecosystems in the American Southwest: sensitivity and resilience to climate extremes. *Ecosystems*: doi: 10.1007/s10021-012-9606-3.
[140] Feagin, R.A. 2005. Artificial dunes created to protect property on Galveston Island, Texas: the lessons learned. *Ecological Restoration* 23: 89-94.
[141] New York City Audubon. 2014. *Jamaica Bay Project.* URL: http://www.nycaudubon.org/jamaica-bay-project (accessed July 18, 2014).
[142] Hartig, E.K., V. Gornitz, A. Kolker, F. Muschacke, and D. Fallon. 2002. Anthropogenic and climate-change impacts on salt marshes of Jamaica Bay, New York City. *Wetlands* 22: 71-89.
[143] Gateway National Recreation Area, National Park Service, U.S. Department of the Interior, and Jamaica Bay Watershed Protection Plan Advisory Committee. 2007. *An Update on the Disappearing Salt Marshes of Jamaica Bay, New York.* URL: http://www.nytimes.com/packages/pdf/nyregion/city_room/20070802_FinalJamaicaBayReport.pdf (accessed July 18, 2014).
[144] USACE. 2014. *Jamaica Bay Marsh Islands.* URL: http://www.nan.usace.army.mil/Missions/CivilWorks/ProjectsinNewYork/EldersPointJamaicaBaySaltMarshIslands.aspx (accessed July 18, 2014).
[145] The American Littoral Society. 2012. *Assessing the Impacts of Hurricane Sandy on Coastal Habitats.* The National Fish and Wildlife Foundation, Washington, D.C.
[146] Elias, V. 2013. Jamaica Bay marsh islands withstand Sandy, helps mitigate impacts. *U.S. Army Corps of Engineers New York District Times.* January Edition 2013. URL: http://www.esf.edu/glrc/library/documents/NewYorkDistrictTimesHurricaneSandyEdition.pdf (accessed July 18, 2014).
[147] EPA. 2014. Water: *Green Infrastructure.* URL: http://water.epa.gov/infrastructure/greeninfrastructure/index.cfm (accessed August 19, 2014).
[148] USACE. 2014. *Engineering with Nature.* URL: http://el.erdc.usace.army.mil/ewn/ (accessed June 26, 2014).
[149] Virginia Institute of Marine Science. 2014. *Systems Approach to Geomorphic Engineering.* http://www.ccrm.vims.edu/sage/ (accessed June 26, 2014).
[150] The State of Maryland. 2012. *Climate Change and "Coast Smart" Construction.* Executive Order 01.01.2012.29. Executive Department, The State of Maryland, Annapolis, MD.
[151] EPA. 2014. *Planning for Flood Recovery and Long-Term Resilience in Vermont: Smart Growth Approaches for Disaster-Resilient Communities.* EPA-231-R-14-003. U.S. Environmental Protection Agency, Washington, D.C. URL: http://www.epa.gov/smartgrowth/pdf/vermont-sgia-final-report.pdf (accessed July 14, 2014).
[152] Koch, E.W., E. Barbier, B.R. Silliman, D.J. Reed, S.D. Hacker, E.F. Granek, J.H. Primavera, N. Muthiga, S. Polasky, B.S. Halpern, C.J. Kennedy, C.V. Kappel, and E. Wolanski. 2007. Non-linearity in ecosystem services: temporal and spatial variability in coastal protection. *Frontiers in Ecology and the Environment* 7: 29-37.
[153] Day, J.W., Jr., D.F. Boesch, E.J. Clairain, G.P. Kemp, S.B. Laska, W.J. Mitsch, K. Orth, H. Mashriqui, D.J. Reed, L. Shabman, C.A. Simenstad, B.J. Streever, R.R. Twilley, C.C. Watson, J.T. Wells, and D.F. Whigham. 2007. Restoration of the Mississippi Delta: Lessons from Hurricanes Katrina and Rita. *Science* 315: 1679-1684.
[154] U.S. Geological Survey. 2006. *Land Area Change in Coastal Louisiana after the 2005 Hurricanes – A Series of Three Maps.* Open-File Report 06-1274. U.S. Geological Survey, Washington, D.C.
[155] Barras, J.A., S. Beville, D. Britsch, S. Hartley, S. Hawes, J. Johnston, P. Kemp, Q. Kinler, A. Martucci, J. Porthouse, D. Reed, K. Roy, S. Sapkota, and J. Suhayda. 2003. *Historical and Projected Coastal Louisiana Land Changes: 1978-2050.* Open File Report 03-334. U.S. Geological Survey, Washington, D.C.
[156] Batker et al., 2010.
[157] Ibid.
[158] State of Louisiana Coastal Protection and Restoration Authority. 2012. *Louisiana's Comprehensive Master Plan for a Sustainable Coast.* Baton Rouge, LA. URL: http://www.coastalmasterplan.louisiana.gov/ (accessed June 18, 2014).
[159] Brody, S.D., and W.E. Highfield. 2013. Open space protection and flood mitigation: a national study. *Land Use Policy* 32: 89-95.
[160] Berke, P., W. Lyles, and G. Smith. 2014. Impacts of Federal and State hazard mitigation policies on local land use policy. *Journal of Planning Education and Research:* 0739456X13517004.

[161] Burby, R., T. Beatley, P. Berke, R. Deyle, S. French, D. Godschalk, E. Kaiser, J. Kartez, R. Patterson, and R. Platt. 1999. Unleashing the power of planning to create disaster-resistant communities. *Journal of the American Planning Association* 65: 247-258.

[162] Smith, G. 2009. Planning for sustainable and disaster resilient communities. In: *Natural Hazards Analysis: Reducing the Impact of Disasters.* J. Pine (Ed.). CRC Press, Boca Raton, FL.

[163] National Research Council. 2006. *Facing Hazards and Disasters: Understanding Human Dimensions.* The National Academies Press, Washington, D.C.

[164] Titus, J.G., D.E. Hudgens, D.L. Trescott, M. Craghan, W.H. Nuckols, C.H. Hershner, J.M. Kassakian, C.J. Linn, P.G. Merritt, T.M. McCue, J.F. O'Connell, J. Tanski, and J. Wang. 2009. State and local governments plan for development of most land vulnerable to rising sea level along the U.S. Atlantic Coast. *Environmental Research Letters* 4: 044008.

[165] National Research Council. 2006. *Facing Hazards and Disasters: Understanding Human Dimensions.* The National Academies Press, Washington, D.C.

[166] Jones, S.B. 2009/10. Hanging in the coastal balance. How do coastal communities choose between economic growth and protecting their citizens? *Sea Grant Law and Policy Journal* 2: 63-73.

[167] Kousky, C., and M. Walls. 2013. *Floodplain Conservation as a Flood Mitigation Strategy.* Resources for the Future, Washington, D.C.

[168] Kousky, C., S.M. Olmstead, M.A. Walls, and M. Macauley. 2013. Strategically placing green infrastructure: cost-effective land conservation in the floodplain. *Environmental Science and Technology:* dx.doi.org/10.1021/es303938c.

[169] Kousky, C. 2014. Managing shoreline retreat: a U.S. perspective. *Climatic Change:* doi: 10.1007/s10584-014-1106-3.

[170] Arkema, K.K., G. Guannel, G. Verutes, S.A. Wood, A. Guerry, M. Ruckelshaus, P. Kareiva, M. Lacayo, and J.M. Silver. 2013. Coastal habitats shield people and property from sea-level rise and storms. *Nature Climate Change* 3: doi: 10.1038/NCLIMATE1944.

[171] FEMA. 2013. FEMA Mitigation Policy – FP-108-024-01, *Consideration of Environmental Benefits in the Evaluation of Acquisition Projects under the Hazard Mitigation Assistance (HMA) Programs.* Federal Emergency Management Agency, Washington, D.C.

[172] CEQ (Council on Environmental Quality). 2013. *Principles and Requirements for Federal Investments in Water Resources.* Council on Environmental Quality, Washington, D.C.

[173] Eastern Research Group, Inc. 2014. *Economic Assessment of Green Infrastructure Strategies for Climate Change Adaptation: Pilot Studies in the Great Lakes Region.* NOAA Coastal Services Center. URL: http://www.csc.noaa.gov/digitalcoast/publications/climate-change-adaptation-pilot (accessed June 17, 2014).

[174] Cassell, P., and A. Rowan. February 20, 2014. Duluth Receives U.S. EPA's First Great Lakes Shoreline Cities Green Infrastructure Grant. URL: http://yosemite.epa.gov/opa/admpress.nsf/0/FAB16FB869F3D44D85257C8500679B91 (accessed June 27, 2014).

[175] EPA. 2014. Great Lakes Shoreline Cities Green Infrastructure Grants. URL: http://www.epa.gov/grlakes/fund/shoreline/ (accessed June 25, 2014).

[176] Nguyen, T. 2013. *Insurability of Catastrophe Risks and Government Participation in Insurance Solutions.* Background Paper Prepared for the Global Assessment Report on Disaster Risk Reduction 2013. The United Nations Office for Disaster Risk Reduction, Geneva, Switzerland.

[177] Moser, S.C., M.A. Davidson, P. Kirshen, P. Mulvaney, J.F. Murley, J.E. Neumann, L. Petes, and D. Reed. 2014. Ch. 25: *Coastal Zone Development and Ecosystems. Climate Change Impacts in the United States: The Third National Climate Assessment,* J.M. Melillo, T.C. Richmond, and G.W. Yohe (Eds.). U.S. Global Change Research Program: 579-618.

[178] Dixon, L., N. Clancy, S.A. Seabury, and A. Overton. 2006. *The National Flood Insurance Program's Market Penetration Rate: Estimates and Policy Implications.* Rand Corporation, Santa Monica, CA.

[179] Kunreuther and Michel-Kerjan, 2013.

[180] Michel-Kerjan, E.O. 2010. Catastrophe economics: the National Flood Insurance Program. *Journal of Economic Perspectives* 24: 399-422.

[181] Landry, C.E., and M.R. Jahan-Parvar. 2008. Flood insurance coverage in the coastal zone. *The Journal of Risk and Insurance* 78: 361-388. URL: http://ideas.repec.org/p/pra/mprapa/15498.html (accessed May 27, 2014).

[182] Kousky, C. 2011. Understanding the demand for flood insurance. *Natural Hazards Review* 12: 96-110.

[183] King, R.O. 2013. *The National Flood Insurance Program: Status and Remaining Issues for Congress.* Congressional Research Service, Washington, D.C.

[184] CBO. 2007. *Value of Properties in the National Flood Insurance Program.* Congressional Budget Office, Washington, D.C.
[185] CBO. 2009. *The National Flood Insurance Program: Factors Affecting Actuarial Soundness.* Congressional Budget Office, Washington, D.C.
[186] Ibid.
[187] King. R.O. 2009. *National Flood Insurance Program: Background, Challenges, and Financial Status.* Congressional Research Service, Washington, D.C.
[188] Burby, R.J. 2001. Flood insurance and floodplain management: the U.S. experience. *Environmental Hazards* 3: 111-122.
[189] Nordhaus, W. 2006. *The Economics of Hurricanes in the United States.* The National Bureau of Economic Research, Cambridge, MA.
[190] Repetto, R., and R. Easton. 2009. *Climate Change and Damage from Extreme Weather Events.* Political Economy Research Institute, Amherst, MA.
[191] Nordhaus, 2006.
[192] UCS (Union of Concerned Scientists). 2013. *Overwhelming Risk: Rethinking Flood Insurance in a World of Rising Seas.* Union of Concerned Scientists, Washington, D.C.
[193] Michel-Kerjan, 2010.
[194] Hartwig, R.P., and C. Wilkinson. 2012. *Residual Market Property Plans: From markets of Last Resort to Markets of First Choice.* Insurance Information Institute, New York.
[195] UCS, 2013.
[196] America's Wetland Foundation, America's Energy Coast, and Entergy. 2010. *Building a Resilient Energy Gulf Coast: Executive Report.* America's Wetland Foundation, America's Energy Coast, and Entergy, New Orleans, LA.
[197] Hartwig, R.P., and C. Wilkinson. 2012. *Residual Market Property Plans: From markets of Last Resort to Markets of First Choice.* Insurance Information Institute, New York.
[198] SwissRe. 2013. *SwissRe's Sigma on Natural Catastrophes and Man-Made Disasters in 2012. Reports USD 77 Billion in Insured Losses and Economic Losses of USD 189 Billion.* URL: http://swissre.com/media/news_releases/nr_20130327_sigma_natcat_2012.html.
[199] Cutter, S.L., and C.T. Emrich. 2006. Moral hazard, social catastrophe: the changing face of vulnerability along the hurricane coasts. *The ANNALS of the American Academy of Political and Social Science* 604: 102-112.
[200] Lee, D., and J. Jung. 2014. The growth of low-income population in floodplains: a case study of Austin, TX. *Korean Society of Civil Engineers Journal of Civil Engineering* 18: 683-693.
[201] Godschalk, D.R., T. Beatley, P. Berke, D.J. Brower, and E.J. Kaiser. 1999. *Natural Hazard Mitigation: Recasting Disaster Policy and Planning.* Island Press, Washington, D.C.
[202] De Sauza, R.-M. 2004. *In Harm's Way: Hurricanes, Population Trends, and Environmental Change.* Population Reference Bureau, Washington, D.C.
[203] Tierney, K. 2006. Social inequality: humans and disasters. In: R.J. Daniels, D.F. Keitl, and H. Kunreuther (Eds.). *On Risk and Disaster: Lessons from Hurricane Katrina.* University of Pennsylvania Press, Philadelphia, PA.
[204] Pastor, M., R. Bullard, J. Boyce, A. Fothergill, R. Morello-Frosh, and B. Wright. 2006. *In the Wake of the Storm: Environment, Disaster and Race after Katrina.* Russell Sage Foundation, New York, N.Y.
[205] Elliott, J.R., and J. Pais. 2006. Race, class, and Hurricane Katrina: social differences in human responses to disaster. *Social Science Research* 35: 295-321.
[206] Pidot, J.R. 2007. *Coastal Disaster Insurance in the Era of Global Warming: The Case for Relying on the Private Market.* Georgetown Environmental Law & Policy Institute, Georgetown University Law Center, Washington, D.C.
[207] ASFPM. 2014. *ASFPM Analysis of the Homeowners Flood Insurance Affordability Act.* URL: http://www.floods.org/ace-files/documentlibrary/2012_NFIP_Reform/HFIAA_Analysis_ASFPM_4-17-14_Final.pdf. (accessed April 24, 2014).
[208] ASFPM. 2014. ASFPM's analysis of HFIAA finds BW-12 core still there, and narrowly focused improvement to affordability. *The Insider.* Association of State Floodplain Managers, Madison, WI.
[209] Kousky, C. 2010. *Managing the Risks of Natural Catastrophes: The Role and Functioning of State Insurance Programs.* Resources for the Future, Washington, D.C.
[210] Martinich, J., J. Neumann, L. Ludwig, and L. Jantarasami. 2011. Risks of sea-level rise to disadvantaged communities in the United States. *Mitigation and Adaptation Strategies for Global Change:* doi: 10.1007/s11027-011-9356-0.
[211] Cutter and Emrich, 2006.

[212] Siders, A. 2013. *Managed Coastal Retreat: A Legal Handbook on Shifting Development Away from Vulnerable Areas.* Columbia Law School, Center for Climate Change Law, New York, N.Y.
[213] Conrad, D.R., B. McNItt, and M. Stout. 1998. *Higher Ground: A Report on Voluntary Property Buyouts in the Nation's Floodplains, A Common Ground Solution Serving People at Risk, Taxpayers and the Environment.* National Wildlife Federation, Washington, D.C.
[214] Kousky, 2014.
[215] Polefka, S. 2013. *Moving Out of Harm's Way.* Center for American Progress, Washington, D.C.
[216] Verchick, R.R.M., and L.R. Johnson. 2014 (Forthcoming). When retreat is the best option: flood insurance after Biggert-Waters and other climate change puzzles. *John Marshall Law Review* 47. Loyola University New Orleans College of Law Legal Studies Research Paper Series. URL: http://dx.doi.org/10.2139/ssm.2418089 (accessed June 27, 2014).
[217] Lieb, D.A., and J. Salter. 2011. FEMA flood buyouts top $2 billion since 1993. *APNewsbreak,* July 13, 2011. URL: http://cnsnews.com/news/article/apnewsbreak-fema-flood-buyouts-top-2b-1993 (accessed July 18, 2014).
[218] NOAA. 2014. *Managed Retreat Strategies.* URL: http://coastalmanagement.noaa.gov/initiatives/shoreline_ppr_retreat.html (accessed August 15, 2013).
[219] Reeve and Kingston, 2014.
[220] FEMA. 2009. *Loss Avoidance Study: Eastern Missouri, Building Acquisition, Part One: General Overview.* Federal Emergency Management Agency, Washington, D.C. URL: http://www.fema.gov/media-library-data/20130726-1728-25045-1085/loss_avoidance_study_eastern_missouri__building_acquisition_part_1.pdf (accessed June 18, 2014).
[221] Verchick and Johnson, 2014 (Forthcoming).
[222] Berke, P., W. Lyles, and G. Smith. 2014. Impacts of federal and state hazard mitigation policies on local land use policy. *Journal of Planning Education and Research:* 0739456X13517004.
[223] The Nature Conservancy. 2014. Green Investments: The Impacts of Budget Cuts to Protecting Natural Resources and the Environment, and the Need for Reinvestment in FY15. URL: https://soe.salsalabs.com/o/1/images/FY15%20Green%20Investments.pdf (accessed July 14, 2014).
[224] *SwissRe. 2013. SwissRe's Sigma on Natural Catastrophes and Man-Made Disasters in 2012. Reports USD 77 Billion in Insured Losses and Economic Losses of USD 189 Billion.* URL: http://swissre.com/media/news_releases/nr_20130327_sigma_natcat_2012.html.
[225] Hsiang and Jina, 2014.
[226] Kousky, C., and H. Kunreuther. 2014. Addressing affordability in the National Flood Insurance Program. *Journal of Extreme Events:* doi: 10.1142/S2345737614500018.
[227] FEMA, 2013.
[228] Brody and Highfield, 2013.
[229] Ibid.
[230] FEMA. 2007. *National Flood Insurance Program Community Rating System Coordinator's Manual.* Federal Emergency Management Agency, Washington, D.C.
[231] Brody and Highfield, 2013.
[232] FEMA. 2013. *National Flood Insurance Program Community Rating System: A Local Official's Guide to Saving Lives, Preventing Property Damage, Reducing the Cost of Flood Insurance.* Federal Emergency Management Agency, Washington, D.C. URL: http://www.fema.gov/media-library-data/20130726-1708-25045-7720/99032_nfip_small_brochure.pdf (accessed June 27, 2014).
[233] U.S. Department of Homeland Security Office of Inspector General. 2005. *Challenges in FEMA's Flood Map Modernization Program.* OIG-05-44. U.S. Department of Homeland Security, Washington, D.C.
[234] FEMA. 2014. *Mitigation Planning Laws, Regulations, and Guidance.* URL: http://www.fema.gov/mitigation-planning-laws-regulations-guidance (accessed June 19, 2014).
[235] Babcock, M. 2013. *State Hazard Mitigation Plans & Climate Change: Rating the States.* Columbia Law School Center for Climate Change Law, New York, N.Y.
[236] FEMA. 2013. *Robert T. Stafford Disaster Relief and Emergency Assistance Act, as Amended.* Federal Emergency Management Agency, Washington, D.C.
[237] Moss, L.M., and C. Shelhamer. 2007. *The Stafford Act: Priorities for Reform.* New York University Center for Catastrophe Preparedness and Response, New York, N.Y.

[238] Godschalk, D.R., T. Beatley, P. Berke, D.J. Brower, and E.J. Kaiser. 1999. *Natural Hazard Mitigation: Recasting Disaster Policy and Planning.* Island Press, Washington, D.C.
[239] Tang, Z., Z. Dai, X. Fu, and X. Li. 2013. Content analysis for the U.S. coastal states' climate action plans in managing the risks of extreme climate events and disasters. *Ocean & Coastal Management* 80: 46-54.
[240] Natural Resources Defense Council and National Wildlife Federation. 2012. *Petition Requesting that the Federal Emergency Management Agency Comply with the Stafford Act and Disaster Mitigation Act of 2000 by Approving Only State Hazard Mitigation Plans That Adequately Address Climate Change; Amend it Regulations to Confirm that Climate Change Must be Addressed in Hazard Mitigation Plans; and Provide Agency Guidance to States Regarding How to Address Climate Change in Hazard Mitigation Plans.* Filed with: Rules Docket Clerk, Office of the General Council, Federal Emergency Management Agency, Washington, D.C. URL: http://switchboard.nrdc.org/blogs/rhammer/FEMA%20Petition%20-%20FINAL%20-%2010-2-12.pdf (accessed July 16, 2014).
[241] The White House. 2014. *Fact Sheet: Taking Action to Support State, Local, and Tribal Leaders as They Prepare Communities for the Impacts of Climate Change.* The White House Office of the Press Secretary, Washington, D.C. URL: http://www.whitehouse.gov/the-press-office/2014/07/16/fact-sheet-taking-action-support-state-local-and-tribal-leaders-they-pre (accessed July 16, 2014).
[242] FEMA. 2008. *Multi-Hazard Mitigation Planning Guidance Under the Disaster Mitigation Act of 2000.* Federal Emergency Management Agency, Washington, D.C.
[243] Israel, N.D. 2012. *Inaction on Climate Change: The Cost to Taxpayers.* Ceres, Boston, MA.
[244] Lindsay, B.R., and F.X. McCarthy. 2012. *Stafford Act Declarations 1953-2011: Trends and Analyses, and Implications for Congress.* Congressional Research Service, Washington, D.C.
[245] Milleman, B.A. 2010. *The Coastal Barrier Resources Act: Accomplishments, Challenges, and Future Opportunities.* A Report Commissioned by the Natural Resources Defense Council, Washington, D.C.
[246] FWS. 2002. *The Coastal Barrier Resources Act: Harnessing the Power of Market Forces to Conserve America's Coast and Save Taxpayers' Money.* U.S. Department of the Interior, Washington, D.C.
[247] Milleman, 2010.
[248] Sanders, L. 2013. *Opportunities for the Expansion of the Coastal Barrier Resources Act of 1982.* R Street Shorts No. 4. R Street, Washington, D.C.
[249] Millemann, 2010.
[250] GAO (U.S. Government Accountability Office). 2007. *Coastal Barrier Resources System: Status of Development that has Occurred and Financial Assistance Provided by Federal Agencies.* U.S. Government Accountability Office, Washington, D.C.
[251] Sanders, 2013.
[252] National Wildlife Federation. 2014. *What We Do.* URL: http://www.nwf.org/What-We-Do/Protect-Habitat/Waters/Clean-Water-Act.aspx (accessed June 3, 2014).
[253] Levick, L., J. Fonseca, D. Goodrich, M. Hernandez, D. Semmens, J. Stromberg, R. Leidy, M. Scianni, D. P. Guertin, M. Tluczek, and W. Kepner. 2008. *The Ecological and Hydrological Significance of Ephemeral and Intermittent Streams in the Arid and Semi-arid American Southwest.* U.S. Environmental Protection Agency and USDA/ARS Southwest Watershed Research Center, EPA/600/R-08/134, ARS/233046, 116 pp.
[254] Department of Defense, Department of the Army, Corps of Engineers and Environmental Protection Agency. 2014. Definition of "Waters of the United States" Under the Clean Water Act. Proposed Rule. *Federal Register* 79: 22188-22274.
[255] Bagsta, K.J., K. Stapleton, and J.R. D'agostino. 2007. Taxes, subsidies, and insurance as drivers of United States coastal development. *Ecological Economics* 63: 285-298.
[256] Samet, M. 2009. *A Citizen's Guide to the Corps of Engineers.* American Rivers and the National Wildlife Federation.
[257] GAO. 2007. *Natural Disasters: Public Policy Options for Changing the Federal Role in Natural Catastrophe Insurance.* U.S. Government Accountability Office, Washington, D.C.
[258] Cámara, C. 2013. *Coastal Preservation through Citizens Reform.* R Street Policy Study No. 8. R Street, Washington, D.C.
[259] King, R.O. 2013. *Financing Natural Catastrophe Exposure: Issues and Options for Improving Risk Transfer Markets.* Congressional Research Service, Washington, D.C.
[260] GAO. 2007. *Natural Disasters: Public Policy Options for Changing the Federal Role in Natural Catastrophe Insurance.* U.S. Government Accountability Office, Washington, D.C.
[261] Hartwig, R.P., and C. Wilkinson. 2011. *Residual Market Property Plans: From Markets of Last Resort to Markets of First Choice.* Insurance Information Institute, New York, N.Y.

[262] Ibid.
[263] Lehmann, R.J. 2013. Ten reforms to fix Florida's property insurance marketplace – without raising rates. *The James Madison Institute Backgrounder* 74. The James Madison Institute, Tallahassee, FL.
[264] National Research Council. 2011. *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia.* The National Academies Press, Washington, D.C.
[265] Peters, G.P., R.M. Andrew, T. Boden, J.G. Canadell, P. Ciais, C. Le Quéré, G. Marland, M.R. Raupach, and C. Wilson. 2012. The challenge to keep global warming below 2°C. *Nature Climate Change* 3: 4-6.
[266] National Research Council. 2011. *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia.* The National Academies Press, Washington, D.C.
[267] Bagley, K. 2013. The most influential climate science paper today remains unknown to most people. *InsideClimateNews.* URL: http://insideclimatenews.org/news/20140213/climate-change-science-carbon-budget-nature-global-warming-2-degrees-bill-mckibben-fossil-fuels-keystone-xl-oil?page=show (accessed July 15, 2014).
[268] Sustainable Development Solutions Network and Institute for Sustainable Development and International Relations. 2014. *Pathways to Deep Decarbonization. Interim 2014 Report.* Sustainable Development Solutions Network and Institute for Sustainable Development and International Relations, New York, N.Y.
[269] Nordhaus, W. 2007. *The Challenge of Global Warming: Economic Models and Environmental Policy.* Yale University, New Haven, CT.
[270] Ibid.
[271] Rausch, S., and J. Reilly. 2012. *Carbon Tax Revenue and the Budget Deficit: A Win-Win-Win Solution?* MIT Joint Program on the Science and Policy of Global Change. Massachusetts Institute of Technology, Cambridge, MA.
[272] Morris, A.C., and A. Mathur. 2014. *A Carbon Tax in Broader U.S. Fiscal Reform: Design and Distributional Issues.* Center for Climate and Energy Solutions, Arlington, VA.
[273] CBO. 2011. *Reducing the Deficit: Spending and Revenue Options.* Congressional Budget Office, Washington, D.C.
[274] Rausch and Reilly, 2012.
[275] Gordon, K. 2014. *Risky Business: The Economic Risks of Climate Change in the United States.* A Product of the Risky Business Project. URL: http://riskybusiness.org/ (accessed June 27, 2014).
[276] Natural Capital Project. 2014. *Integrated Valuation of Environmental Services and Tradeoffs* (InVEST). Stanford University. URL: http://www.naturalcapitalproject.org/InVEST.html (accessed May 30, 2014).
[277] Natural Capital Project. 2014. *InVEST Tip Documentation: Coastal Vulnerability Model.* Stanford University. URL: http://www.naturalcapitalproject.org/InVEST.html (accessed May 30, 2014).
[278] FEMA. 2014. *Hazus: The Federal Emergency Management Agency's (FEMA's) Methodology for Estimating Potential Losses from Disasters.* URL: http://www.fema.gov/hazus (accessed August 13, 2014).
[279] NOAA. 2014. *Roadmap for Adapting to Coastal Risk.* URL: http://csc.noaa.gov/digitalcoast/training/roadmap (accessed June 17, 2014).
[280] Batker et al., 2010.
[281] Earth Economics. 2014. *Ecosystem Evaluation Toolkit.* URL: http://esvaluation.org/ (accessed August 13, 2014).

National Wildlife Federation
901 E Street, Suite 400
Washington, DC 20004
202.797.6000
www.nwf.org