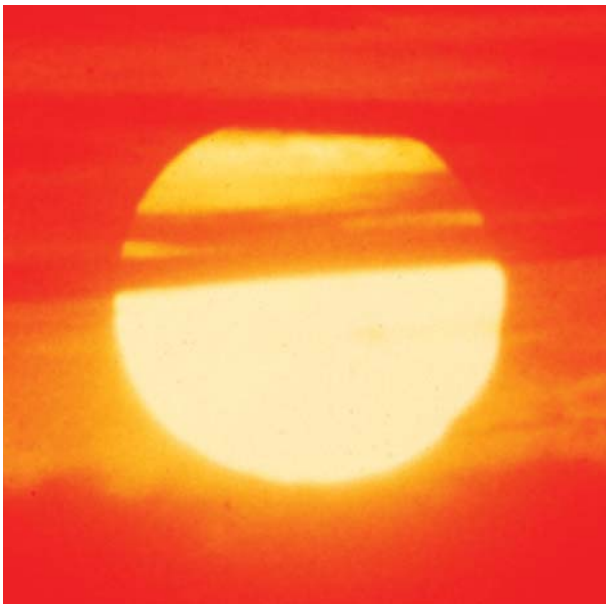
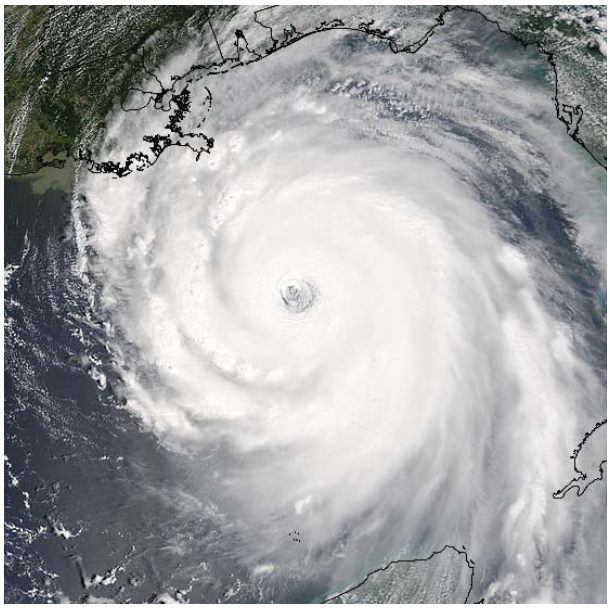
America's Flood Risk is Heating Up





AS TEMPERATURES RISE, THE ARMY CORPS OF ENGINEERS MUST IMPROVE THE NATION'S FLOOD-CONTROL SYSTEM

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ENVIRONMENTAL DEFENSE

finding the ways that work

NATIONAL WILDLIFE FEDERATION®

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Cover photos: Sun (Photo: U.S. Department of Agriculture); Satellite photo of Hurricane Katrina as it approached the Louisiana coast on August 29, 2005 (Photo: NASA).

Our missions

Environmental Defense is dedicated to protecting the environmental rights of all people, including the right to clean air, clean water, healthy food and flourishing ecosystems. Guided by science, we work to create practical solutions that win lasting political, economic and social support because they are nonpartisan, cost-effective and fair.

The mission of the **National Wildlife Federation** is to educate, inspire and assist individuals and organizations of diverse cultures to conserve wildlife and other natural resources and to protect the earth's environment in order to achieve a peaceful, equitable and sustainable future.

Contents

Executive Summary

Flood damages have increased three-fold in real dollars since Congress first immersed the federal government in the national effort to build flood-control projects in the 1920s. And that was before Hurricane Katrina.

Global warming now promises to increase the risk of flooding in several ways. Rising ocean temperatures have already increased the intensity of hurricanes and resulting storm surges like those experienced in New Orleans. This not only increases the risk of more severe storms in the Gulf of Mexico and the southern Atlantic coast, which have historically borne the brunt of hurricanes, but also increases the likelihood that major storms will reach further north.

Rising sea levels also raise storm surges. Sea levels along the New York coastline are projected to rise by 10 to nearly 45 inches by 2080, increasing the risk of a 100-year storm to as frequent as once every four years, under one scenario. Sea level has already risen by seven inches since 1900 in California and is projected to increase by an additional 22 to 35 inches by 2100, if emissions continue unabated.

The impacts of climate change can be seen inland as well. Nationwide, changing climates are increasing the amount of heavy rainfall and causing more snow to fall as rain. When snow occurs, it melts earlier in the season. In California, these effects could reduce snowpack by as much as 70 to 90% and increase spring stream-flow by up to 30% by the year 2100 if emissions continue unabated.

Flawed flood-control programs

Our federal flood-control programs are not prepared to respond to these increased pressures. Ironically, existing flood-control programs can increase flood damages by inadvertently inducing people to build in flood-prone areas. Federal flood-control projects often consist of a so-called 100-year levee. This does not mean the levee will only be overtopped once in 100 years. Rather, such a project has a 1% chance of being overtopped each year—or a 26% chance of overtopping in the life of a 30-year mortgage. Moreover, this risk often increases over time due to lax maintenance or subsidence of the levee itself, causing the structure to provide even less protection. Those who build behind a 100-year levee are not required to elevate their structures, ensure that the structure is able to withstand a flood, or even purchase flood insurance. For these reasons, construction of a 100-year levee often prompts construction of dense suburban development. As we saw in New Orleans, these projects ultimately put people in harm's way. At the same time, flood-control projects have contributed heavily to the loss of coastal wetlands, which would otherwise provide a natural buffer against storms.

Flood-control projects are undoubtedly needed to bolster hurricane protection, particularly in existing urban areas. These areas, like New Orleans and Sacramento, require bigger or stronger levees. But the system for authorizing and designing projects is overwhelmingly driven by politics. Corps officials, under pressure, repeatedly justify unworthy projects, which displace limited funds needed by more critical projects elsewhere. In the five years preceding Hurricane Katrina, for example, Louisiana received $1.9 billion in federal water project funds, far more than any other state, but devoted only a pittance to bolstering New Orleans' levees.

Flawed federal insurance program

The federal flood insurance program itself may encourage new development in flood-prone areas. Virtually everyone who is required to purchase insurance pays the same rate, regardless of degree of risk or flooding history, with variation depending exclusively on building elevation. Flood insurance maps are outdated and inaccurate. Moreover, the mere existence of flood insurance generates a false sense of reliance—and therefore entitlement—among those who are not required to buy flood insurance because they live behind levees or outside the floodplain depicted in an out-dated map. When these properties are flooded, a compassionate nation tends to provide substantial aid. In effect, federal taxpayers have assumed the risk of construction in flood-prone areas.

Recommendations for reform

Hurricane Katrina provided a hint of more to come. The federal government needs to enact major reforms. It needs to change the criteria for flood-control projects to stop encouraging development in areas that are vulnerable to floods and encourage the use of more non-structural flood-damage reduction projects in less developed areas. It needs to establish a system to direct limited funding to the greatest needs. It needs to bolster environmental criteria to stop eroding wetlands. It needs to incorporate the lessons of modern climate science to ensure that development is appropriate and that proper consideration is given to the environment and the ecosystems on which we depend. And it needs to de-politicize the process of designing and evaluating flood-control projects by adopting a system of independent expert review. In addition, the government needs to reform the flood insurance program, making it more actuarially sound by charging rates that reflect actual flood risk, and requiring those located behind levees to purchase insurance if they still face a serious residual risk of flooding.

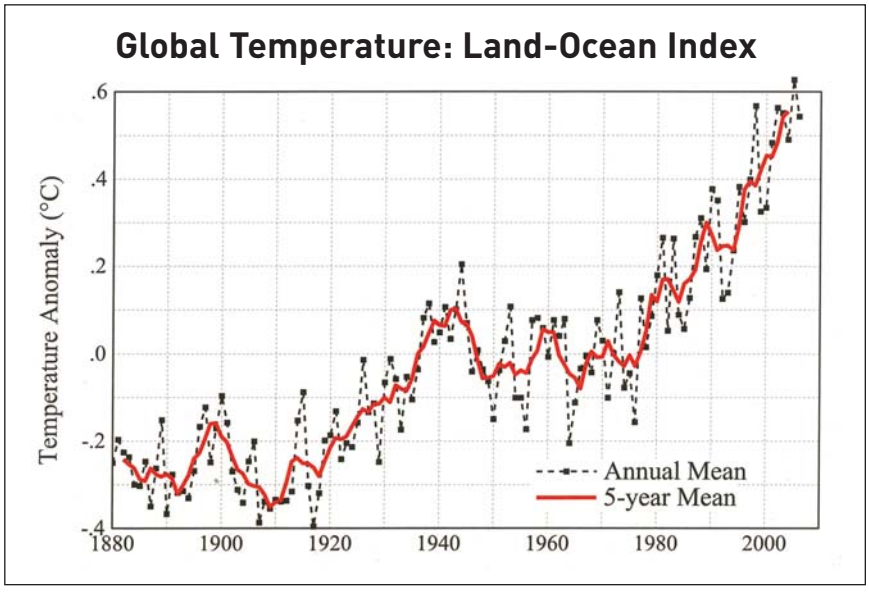
Introduction

The U.S. Geological Survey reports that floods caused more property damage and fatalities than any other natural disaster in the United States in the twentieth century.[1] Floodwaters can destroy buildings and erode soils underlying critical infrastructure. These damages will only increase as development continues in vulnerable areas and climate change increases the frequency of intense storms.

The Intergovernmental Panel on Climate Change (IPCC) released its Fourth Assessment Report in February. The report, which was produced by some 600 authors from 40 countries and reviewed by more than 620 experts, confirms that the evidence for global warming is "unequivocal," that there is a greater than 90% chance that it is due to human activities and that warming will continue for decades. The evidence is glaring: 11 of the past 12 years were among the 12 warmest years in recorded history; global average sea levels have been rising at a rate of 3.1 mm (0.12 inches) per year from 1993 to 2003; and we are already witnessing global temperature increases of about 0.4 degrees Fahrenheit (0.2 C) per decade.[2] These trends will affect flooding and storm events. They require us to reexamine our flood-control and water-resource infrastructure to ensure that it is equipped to handle the real and undeniable consequences of climate change.

Flood-control projects are constructed and maintained by the Army Corps of Engineers (the Corps). To this end, the Corps has constructed 11,000 miles of navigation channels, built 8,500 miles of levees and floodwalls, raised 500 dams, and deepened more than 140 ports and harbors since its creation in 1775. No other federal agency has had as large an impact on the nation's rivers, floodplains, wetlands and estuaries.

Climate change will impose a tremendous burden on the nation's flood-control infrastructure. Rising sea levels and increased frequency of intense storms means that existing structures will have to withstand larger impacts. The failure of the New Orleans levees during Hurricane Katrina has demonstrated that these structures do not provide sufficient protection against existing risks. As climate change raises the stakes, Congress and the Corps must make difficult decisions to upgrade and prioritize flood-control projects.



NASA

Figure 1
Global temperatures have already risen by about 0.2 degrees Celsius (nearly 0.4 F) per decade and are expected to continue to increase at this rate if existing emissions remain unchanged.

This report identifies several impacts of climate change that must be factored into domestic water-resource policy. It explains why existing policies often increase flood risks and fail to prioritize limited funding to address the nation's most important flood-control issues. To address these problems, Congress must enact major reforms to avoid inadvertently encouraging flood damages and to prioritize funds at the country's most important needs.

Climate Change Will Increase the Country's Flood Damages

NASA

Climate change has increased the threat of severe tropical storms like Hurricane Katrina, which ravaged the Gulf Coast on August 28, 2005, causing over $100 billion in damages and killing 1,400.

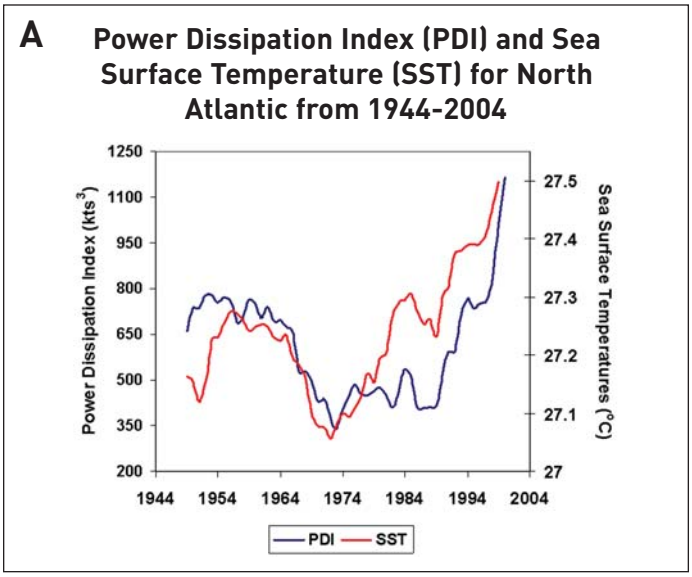
Increasing storm intensity

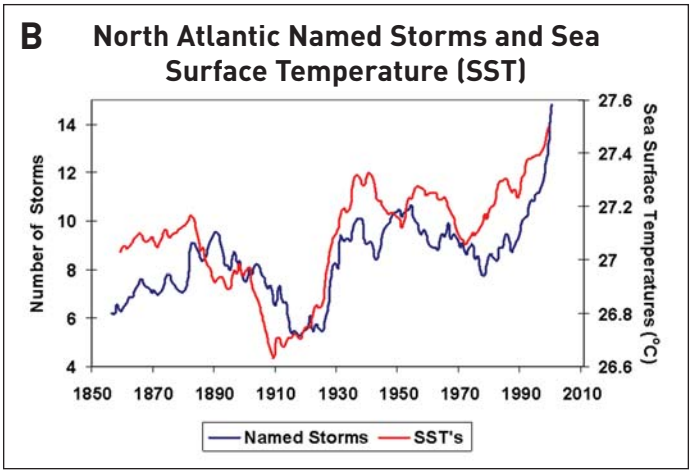
To form a hurricane, sea-surface water temperature must be at least 80 degrees Fahrenheit (26.5 C). It is now likely that rising sea-surface temperatures will cause tropical storms to become more intense, with larger peak wind speeds and more heavy precipitation.[3] A recent study published in the Proceedings of the National Academy of Sciences explains that "human-caused changes in greenhouse gases are the main driver of the 20th-century [sea-surface temperature] increases" and that there is a "direct link" between such temperature changes and hurricane intensity.[4] There is growing evidence of this link.

Hurricanes have caused extraordinary damage in recent years—and the stakes are rising. In 1992, Hurricane Andrew was the most costly U.S. hurricane then on record, causing $25 billion in damage in Florida. In 2004, Florida suffered its worst hurricane season in 118 years, with nine hurricanes, five of which were classified as major. This trend continued in 2005, the worst hurricane season in recorded history. It had the most named storms (27), the most hurricanes (15), and the most intense hurricane ever recorded (Wilma, a Category 5 that ravaged Mexico's Yucatan Peninsula). The hurricanes that hit the United States, including Hurricane Katrina, caused an estimated $100 billion in damages, with a death toll exceeding 1,400.[5]

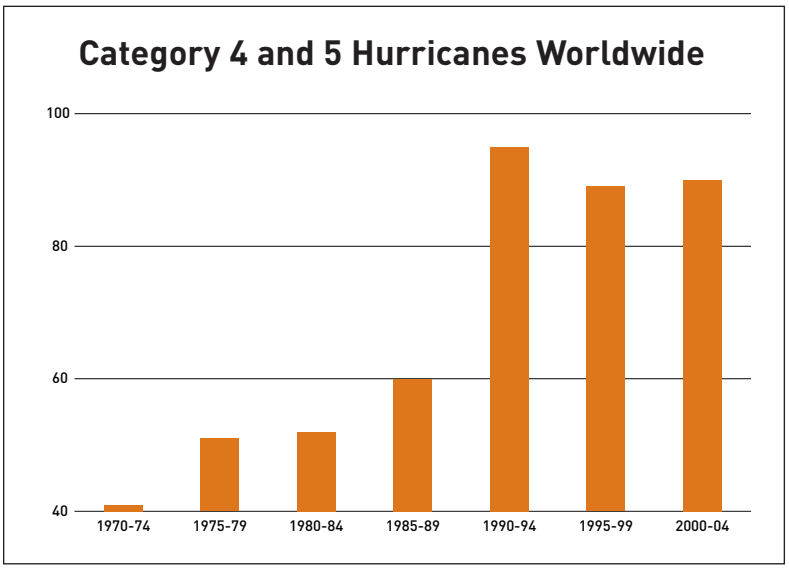
Although the total number of hurricanes per year has not changed, the number of Category 4 and 5 hurricanes occurring annually has almost doubled in the last 30 years.[6] Only weeks before Hurricane Katrina made landfall, Professor Kerry Emanuel of MIT found that hurricanes today are nearly twice as strong as those 30 years ago. Emanuel used a measure called the "power-dissipation index," which assesses hurricane intensity over the life of the storm. His data, published in the journal *Nature*, showed that this index has

Figure 2
There is a strong correlation between hurricane intensity (Fig. 2A), frequency (Fig. 2B) and sea surface temperature in the North Atlantic.





Courtesy Peter Webster



Georgia Institute of Technology

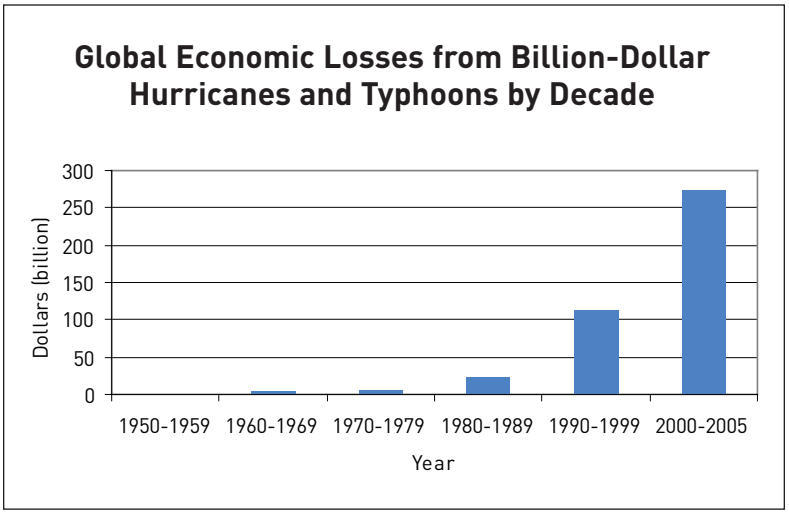
Figure 3
The number of Category 4 and 5 hurricanes per five-year period has increased dramatically since 1970. Worldwide, there are more than twice as many of these destructive storms today than there were 35 years ago.

increased steadily since the mid-1970s, indicating longer and stronger storms. Emanuel found that hurricane intensity is strongly influenced by sea-surface temperature—the warmer the water, the stronger the storm. Since 1975, sea-surface temperatures have been on the rise, and hurricane intensity has followed suit.[7]

The rise in hurricane intensity has serious implications. Hurricane damage potentially increases exponentially with storm intensity. Thus, with other conditions held constant, a Category 3 hurricane can result in 50 times the amount of damage as a Category 1 storm and a Category 4 storm can produce 250 times the damage. A Category 5 hurricane can produce 500 times as much damage as a Category 1 storm.[8] This increase can be attributed largely to the heightened storm surge associated with larger storms. While a Category 1 storm has wind speeds of 74 to 95 miles per hour and can result in a four-foot storm surge, a Category 5 storm has double the wind speed but can trigger an 18-foot storm surge.[9] Storm surges cause 90% of hurricane-related fatalities in the United States, and caused most of the levee failures in New Orleans, which were, in turn, responsible for most of the damage associated with Hurricane Katrina.[10]

The synergy of increasing storm intensity and coastal development have caused hurricane-related damages to skyrocket in the last 50 years. During the 1960s, worldwide damage from windstorms with economic losses of $1 billion or more totaled just $4 billion. By the 1990s, hurricane losses had increased to $113 billion. In the years 2000 to 2005 alone, hurricanes were responsible for $273 billion in damages. The insurance industry estimates that a single Category 5 storm hitting Metropolitan New York would cause $96 billion in insurable losses. A comparable storm in Miami would cost $155 billion. These trends have led insurance companies to decline coverage for homeowners in high-risk coastal areas.[11] Because rising sea-surface temperatures increase storm intensity, Yale University economics professor William Nordhaus estimates that climate change will cause annual damages in the United States alone to increase by $8 billion at 2005 incomes (.06% of GDP).[12]

Figure 4
Economic damages have increased dramatically since 1950, as coastal development has increased and hurricanes have increased in intensity.



Munich Re NatCatSERVICE

Looking beyond the Gulf

In the United States, we tend to think of truly devastating hurricanes as problems for states along the Gulf

of Mexico and the southern Atlantic, but increasing ocean temperatures also increase the likelihood of Category 3 and even Category 4 storms in the Northeast, including New York.[13]

National Hurricane Center

Hurricanes have the capacity to destroy critical infrastructure. Depicted here, Hurricane Hugo obliterated Ben Sawyer Bridge to Sullivans Island, SC.

A Category 3 storm in Metropolitan New York would cause enormous damage. The metropolitan region is surrounded by nearly 1,500 miles of coastline and four of its five boroughs are islands. This increases the risk of harm from storm surge and rising sea levels. Dense development throughout the region raises the stakes when storms hit, and a complex transportation network makes it virtually impossible to evacuate during extreme flood events.[14] Many of the region's transit entry points are less than ten feet above current sea levels, providing almost no buffer against major floods. For these reasons, despite the city's distance from the tropics, Applied Insurance Research Worldwide Corp. (AIR), has identified Metropolitan New York as the American city at second highest risk for potential total economic loss from a catastrophic storm.[15]

In 1821, a hurricane produced a 13-foot storm surge in the area that is now Battery Park City. In 1938, a Category 3 storm dubbed "The Long Island Express" created a wall of water 25 to 35 feet high, killing 700 people and injuring thousands more, mostly in southern New England. In September 1999, extra-tropical storm Floyd delivered 10 to 15 inches of rain in a single day, causing flash flooding in Manhattan and nearly shutting down the metropolitan transit system. Today, a Category 3 hurricane on a worst-case track and arriving at high tide could create a surge of up to 25 feet at JFK airport, 21 feet at the Lincoln Tunnel entrance, and 15 feet at LaGuardia Airport.[16]

Waves thrashing a seawall along the New England coast in a 1938 storm. Future storm damages could be far greater, given sea-level rise, increases in population density and the geographic vulnerability of New York City.

NOAA

Rising sea levels

Ocean warming is not the only factor causing increased storm damage. Global warming is also causing

sea levels to rise, which increases flood risks by drowning wetlands, expanding floodplains, overtopping levees and enhancing storm surges.

The ocean naturally absorbs more than 80% of the heat added to the atmosphere. Rising temperatures cause the ocean to warm and expand, which in turn causes sea-level rise. Meanwhile mountain glaciers, small ice caps and portions of the Greenland and Antarctic ice sheets are melting. Global sea levels rose 0.17 meters (6.7 inches) during the 20th century—ten times more than the average rate of increase over the preceding 3,000 years. The IPCC estimates that, as global warming continues, sea level will rise a minimum of 7 to 23 inches in the next century.[17] The range reflects uncertainty about global temperature projections, but the IPCC cautions that "[l]arger values cannot be excluded" because there could be sudden changes in ice sheet melting rates.[18] Rapid melting of Greenland or Antarctic ice sheets could lead to even more sea-level rise. Sea-level rise will also vary from region to region; for example, along the New York coast it will tend to be higher because the eastern continental margin is tilting downward.

Rising sea levels also increase flood risk because they destroy wetlands and erode beaches. In ideal circumstances, new wetlands would form further inland to replace those inundated by rising waters; however, in developed areas, bulkheads, dikes and other structures generally prevent wetland formation. EPA reports that a 1.6-foot (50 centimeter) rise in sea level would likely inundate roughly 10,000 square miles of land (including existing wetlands and newly inundated dry land), destroying 17 to 43% of the nation's wetlands in the process. This destruction increases the vulnerability of coastal areas to tropical storms because it removes beaches, dunes and wetlands that would otherwise provide a buffer from storm waves. Because so much of the coastline is developed, particularly in the United States where over half the population lives near the coast, this increases other damages—such as destruction of buildings and coastal infrastructure, including ports, ship channels and bridges.[19]

Rising sea levels pose a particular threat in the Gulf Coast, where so much of the natural wetlands hurricane buffer has already been destroyed. Coastal Louisiana is largely wetland, created by the sediments flowing down the Mississippi River and built up by freshwater wetland plants. Corps flood-control and navigation projects have stopped this natural process by straight-jacketing the Mississippi River with levees, starving the surrounding wetlands of the fresh water and sediment they need to grow while poisoning them with intruding saltwater. More than 1.3 million acres of Gulf coastal wetlands—an area larger than the state of Delaware—have been converted to open water since the 1930s. This represents 80% of the coastal wetland loss in the continental United States. These statistics are even more dramatic after Hurricane Katrina: The U.S. Geological Survey reports that the storm single-handedly destroyed 217 square miles of coastal wetlands.[20]

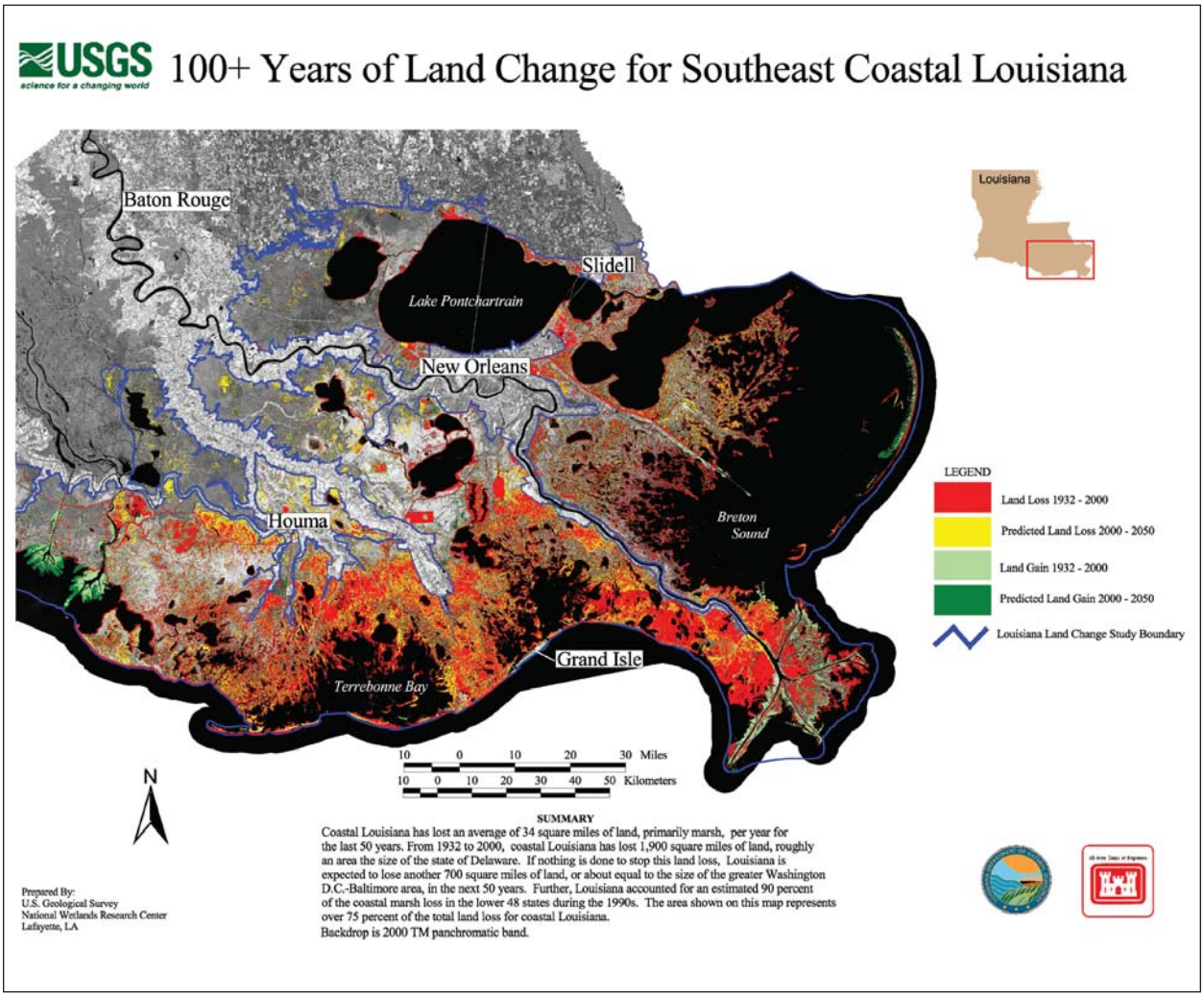
Global sea level has already risen about 6.7 inches (0.17 meters) over the last century.[21] If the wetlands of the Gulf Coast were healthy, they would keep up with the current pace of sea-level rise, but as the Corps has severely damaged the wetlands' land-building abilities, rising seawaters are contributing to the disappearance of the land. This loss will have a significant impact on storm damages. Scientists assume every two-and-a-half miles of wetlands reduces storm surge by one foot.[22] Moreover, all of the levees that were exposed to open water collapsed

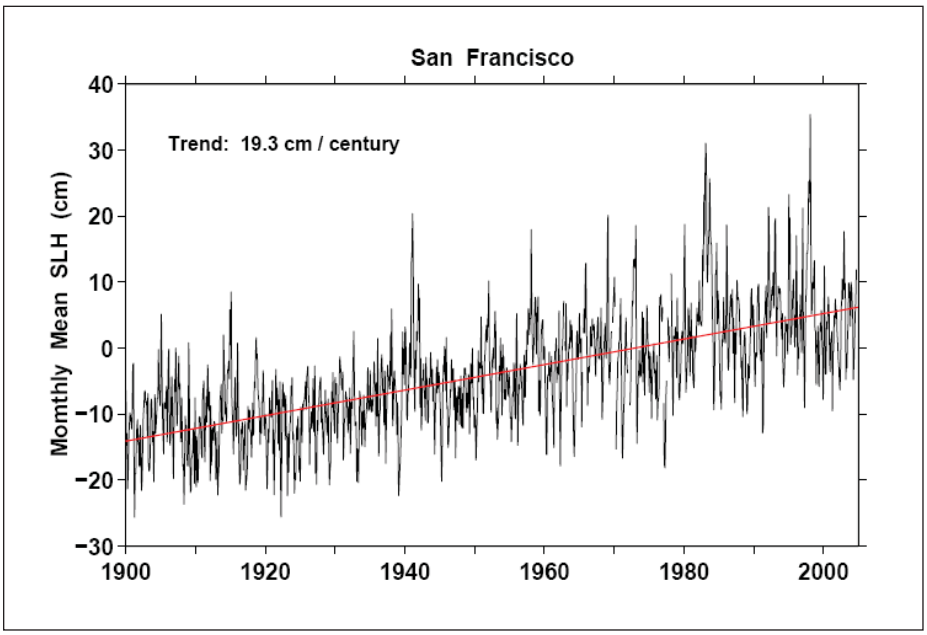
during the Katrina disaster; whereas those buffered by wetlands survived the storm.[23] Because climate change will amplify both direct wetland loss and the frequency of intense tropical storms, coastal Louisiana will become increasingly vulnerable in coming years—with devastating consequences.

Rising sea levels—and associated impacts—are not restricted to the Gulf Coast. For instance, sea level has already risen by seven inches since 1900 in California and is projected to increase by an additional 22 to 35 inches by 2100, if emissions continue unabated.[24] The state estimates that it would cost as much as $100 million annually to protect low-lying areas in the state from associated damages.[25]

Rising sea levels could have disastrous consequences in California. For instance, according to the California Climate Change Center, the entire city of Santa Cruz lies in the 100-year floodplain, only 20 feet above sea level. The city is currently protected by a "100-year levee," which theoretically shelters it from storm events that have a 1% chance of occurring in any given year. Even a one-foot increase in sea levels along the coastline would increase the frequency of 100-year storm events to once every 10 years.[26] Improving flood-control structures in the region must therefore be a high priority.

Figure 5
Land change in Southeast Coastal Louisiana. Red indicates the land loss from 1932-2000. Yellow indicates predicted land loss from 2000-2050. Light green represents land gain from 1932-2000. Dark green indicates predicted land gain from 2000-2050.





California Climate Change Center

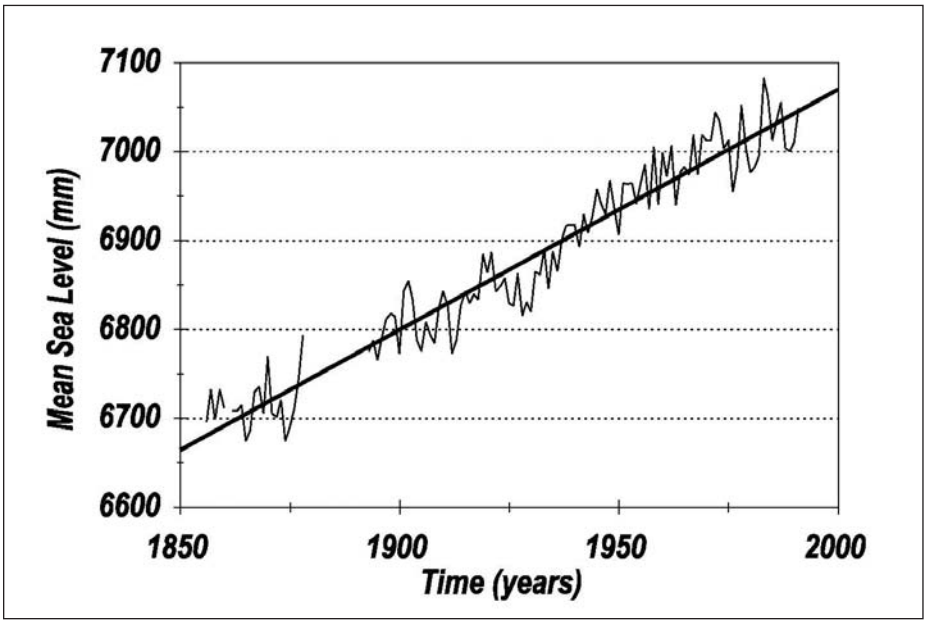
Figure 6
Sea level in California has already risen by seven inches since 1900 and is likely to increase by an additional 22 to 35 inches by 2100, if emissions continue unabated.

Rising sea levels also threaten the integrity of the Sacramento-San Joaquin Delta, which provides water for two-thirds of Californians. The Delta is surrounded by a complex system of more than 1,700 kilometers of levees. Some of these levees are built atop "substandard" foundations, face a substantial "risk of failure," and fail to provide 100-year flood protection under existing conditions. Increased storm intensity and rising sea levels would further compromise the struggling flood-control system by increasing pressure on the levees.[27]

Sea levels along the New York coastline are projected to increase by 10 to nearly 45 inches by 2080.[28] This will expand the 100-year floodplain to include thousands of currently uninsured properties, including portions of Queens and Brooklyn.[29] The dense development and high property values in this area will raise the stakes when flooding occurs.

Rising sea levels along the Atlantic Coast also increase the likelihood that future major storms (either a hurricane or nor'easter) would lead to more flooding in New York. Vivien Gornitz, of the Columbia University Center for Climate Systems Research, reports that the current 100-year flood could have a probability of occurring once in 43 to 80 years by the 2020s. By the 2050s, the chance could be once in 19 to 68 years. And by the 2080s, the chance could be once in 4 to 60 years, with actual frequency dependent upon the emissions scenario. Figure 8 depicts the changes that could occur to the 100-year storm zone.[30]

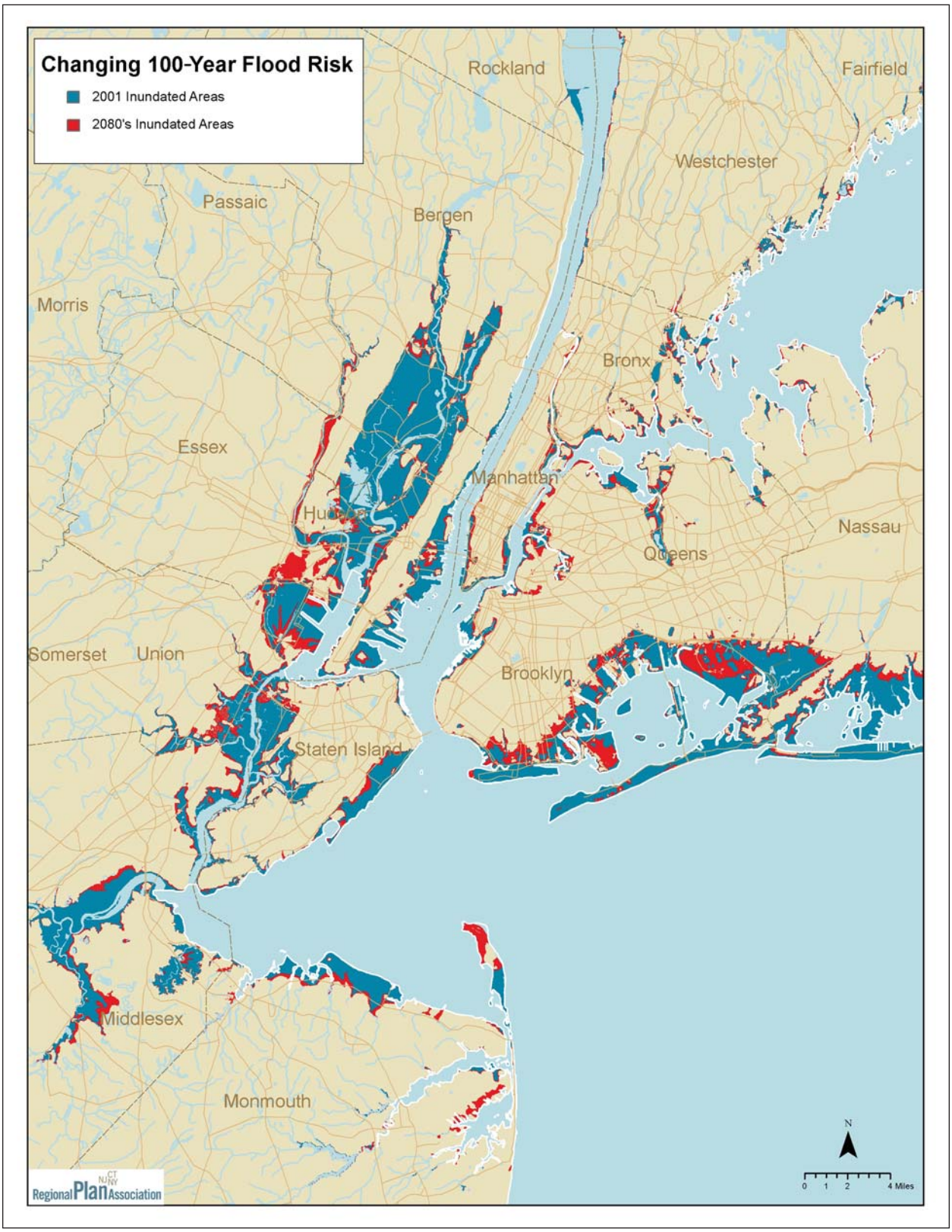
Figure 7
Measured Relative Sea Level at New York City (1850-2000).



Nicholls and Leatherman 1996/Pew Center on Global Climate Change

Altered precipitation patterns

The flood risk associated with climate change extends beyond the nation's coastline. Cli-

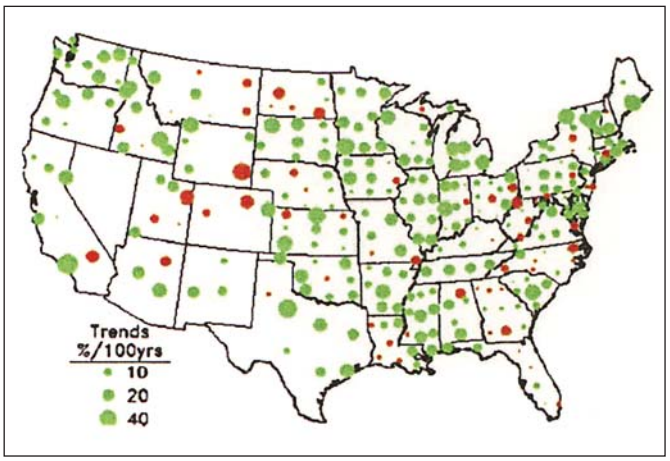


Jennifer Cox, Senior Planner—Regional Plan Association, 2007

Figure 8. Rising sea levels will dramatically increase the 100-year flood risk in New York, impacting more than one-million residents and causing the floodplain to extend to many areas that are already highly developed. Depicted here is the changing floodplain under a worst-case emissions scenario.

mate change is expected to increase the frequency of heavy rainfalls. It also causes more precipitation to fall as rain, rather than snow, which increases the risk of flooding.

There has been an "increase of precipitation, especially heavy and very heavy precipitation" in the last few decades. This increase is "significant" and growing. The number of large rainstorms is increasing. Likewise, the number of days with more than two inches of rainfall has increased by 20% in the last century.[31] These changes will put increasing pressure on the nation's existing flood-control infrastructure.



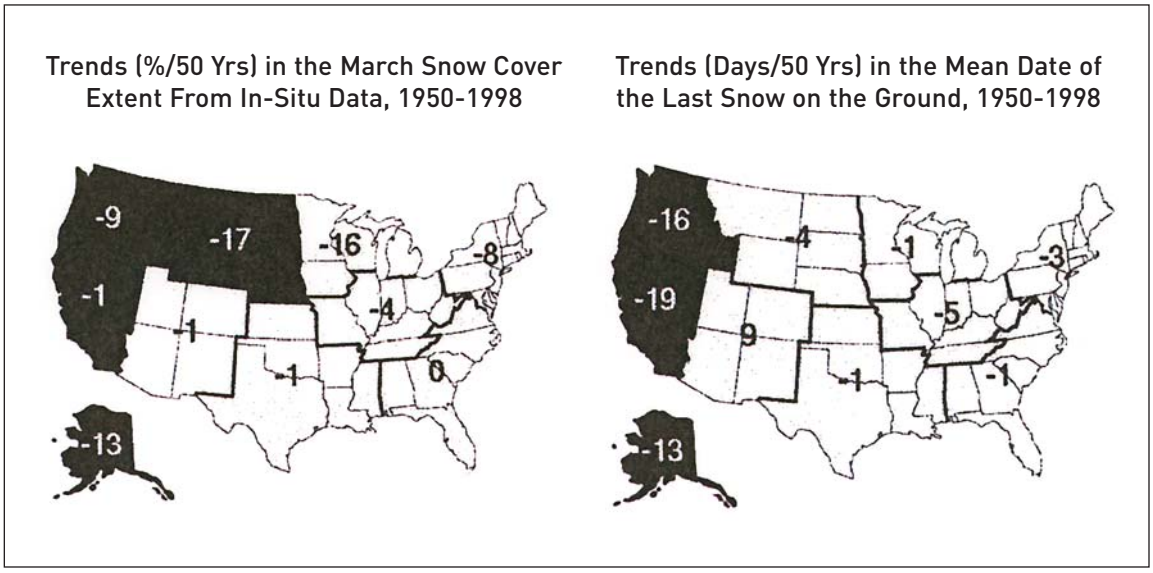
Pavel & Karl, 2001

Figure 9. Scientists have identified a clear pattern of increasing annual precipitation in the United States over the last century (1900-98). Green dots indicate increasing trends and brown dots show decreasing trends.

NOAA

In September 1998, Hurricane Georges swept over Puerto Rico, dumping an island-wide average of nearly one foot (0.3 meters) of rain—more than two months' worth of precipitation in only days. The deluge triggered landslides, flooding and severe erosion.

Climate change has also led to a loss of spring snow cover throughout the western United States during the last few decades. In fact, scientists have documented an earlier spring onset by two to three weeks during the past 50 years throughout the region.[32]



Pavel & Karl, 2001

Figure 10. There has been a significant retreat in spring snow cover throughout the western United States in recent decades.

California has begun to examine what such changes might mean for its water supply and flood-control systems. A recent analysis by the California Energy Commission estimates that, if unabated, climate change trends could reduce snowpack in the state by as much as 70 to 90% by the year 2100 and increase spring stream-flow by up to 30%.[33]

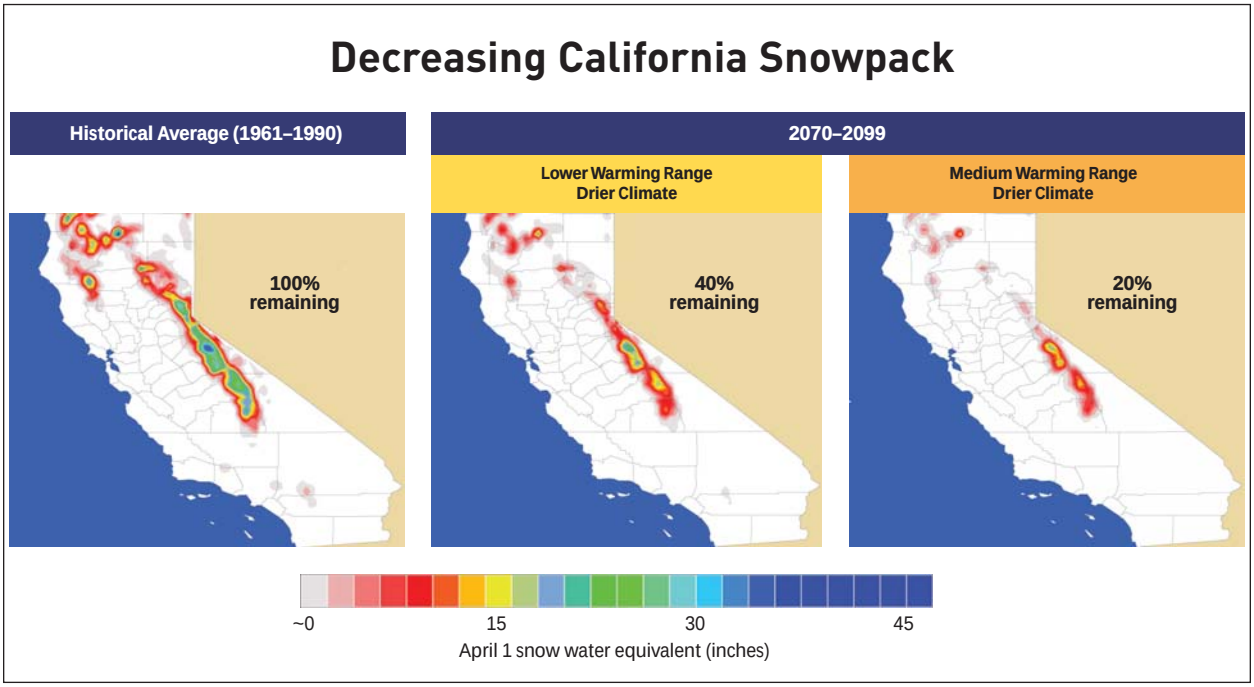


Figure 11
Scientists predict that the Sierra Nevada snowpack will decrease by 70-90% from 1990 levels by the end of the century if current trends are unabated.

Federal Flood-Control Programs Are Broken

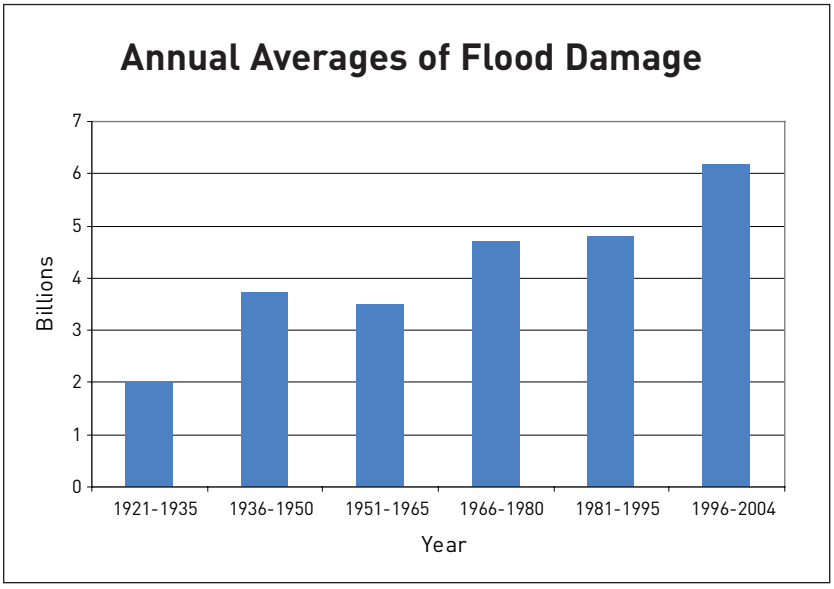
Because climate change will increase the frequency of major floods, the government's response to flooding will also become increasingly important. Unfortunately, federal flood-control programs are not working.

The federal government has a number of programs designed to help the nation reduce the risk of flood damages. Chief among them is the program by the Corps to construct and rebuild flood-control projects across the country, and the federal flood insurance program, administered by the Federal Emergency Management Agency (FEMA). Few would argue that these programs have been successful. Congress first directed the Corps to enter the flood-control business after the flood of 1927. By 2002, the Corps reported that it had spent $123 billion on flood-control projects since the 1920s. But average yearly flood damages had more than tripled *in real dollars* during this same period—even *before* Katrina struck.[34] Meanwhile, there are reasons for concern that the federal flood insurance program, in part through its interaction with Corps projects, is encouraging development in flood-prone areas. For a variety of reasons, neither program is presently capable of responding to the growing flood challenges associated with global warming.

Flood-control projects encourage development in areas that remain vulnerable to large floods

Floodplain managers recognize that while floods are natural events, flood damages arise because of human activity. Floods naturally occur in known locations, such as the floodplains of rivers and areas near the coast. Flood damages, however, only exist when people build or locate economic enterprises in those areas. Federal flood-control programs can increase flood damages by encouraging development in flood-prone areas.

Figure 12
Although the Corps has spent $123 billion on flood-control projects since the 1920s, average annual flood damages had more than tripled in real dollars during this same period, even before Katrina.



NOAA

The Corps' flood-control projects

Even before the federal government constructed large-scale, flood-control projects, most flood damages occurred when people built in areas protected by levees that gave them a false sense of security. There were three great flood disasters in the 1920s. The first two occurred in Florida when huge storms destroyed a dike around the southern perimeter of Lake Okeechobee, killing thousands of people who had settled on farmland below the lake. The third occurred in 1927 after a massive flood on the lower Mississippi River breached locally constructed levees protecting communities and farms. The federal government was not responsible for constructing any of the levees at issue in these floods (although the government indirectly encouraged settlement of these

areas through a series of Swamp Land Acts that gave wetlands away to those who drained them).

The Corps' flood-control program has resulted in bigger, more secure levees that have so far stopped catastrophic flooding from occurring in some of these trouble spots, like southern Florida and most of the lower Mississippi River floodplain. But the proliferation of flood-control projects has also encouraged people to build in areas that rely on levees and other structural systems to protect them from disaster. To most, the concept of flood control implies protecting those who are already in harm's way. But Congress has explicitly defined the term to include virtually any wetlands drainage project to promote economic growth.[35] As a result, many flood projects have increased the number of people at risk of truly large floods. This problem was evident in New Orleans. After Hurricane Betsy in 1965, the Corps was authorized to provide increased flood protection to the city. Instead of focusing only on improving the levees around the existing urban center, the Corps directed most of its resources into extending levees in the as-yet-undeveloped neighboring wetland areas to encourage new development in those areas. In fact, the Corps relied heavily on the improved property values from draining the wetlands to justify the project's costs (estimated in 1978 at $409 million).[36] Eventually, extremely dense development covered the area now known as New Orleans East, which was almost completely destroyed by Hurricane Katrina.

The interaction between flood-control projects and flood insurance magnifies this problem. The federal flood insurance program is principally focused on areas within the so-called 100-year floodplain. That does not mean that a flood will not occur for 100 years. Rather, it means that there is a 1% chance of flooding in any given year. The flood insurance program requires that residential buildings in these areas purchase flood insurance. And for communities to participate in the flood insurance program, they must enact rules requiring that buildings in the 100-year floodplain have protection against the 100-year flood, typically by elevating the structure above that flood line.

The flood insurance requirement now drives much of the Corps' flood-control programs. Landowners and communities wishing to spur development seek to construct levees or other projects that will be capable of withstanding a 100-year flood in order to be excused from the requirements of the flood insurance program to elevate structures and purchase insurance.[37] Since the 1970s, the Corps has no longer counted new development as a benefit, but it continues to justify projects even in sparsely populated areas by crediting agricultural "intensification benefits" and by the damages these projects prevent to existing buildings. Unfortunately, as in New Orleans East, the construction of a 100-year levee prompts new construction.

But a 1% risk of flooding each year remains substantial. In fact, over the course of a typical 30-year mortgage, this risk translates into a 26% chance that a flood that is big enough to overtop (and likely destroy) such a levee will occur. Moreover, as we learned in New Orleans, neither levees nor the science of predicting the 100-year flood is foolproof. As in New Orleans East, when a bigger flood arrives, devastating damages occur.

The Corps of Engineers defends its flood-control program, claiming that its projects prevented more than $208 billion in flood damages from 1991 to 2000.[38] But this statistic is meaningless. To generate it, the Corps assumes that all buildings behind its levees would have been constructed and would have remained there

regardless of whether the Corps had built the project in the first place. When a Corps' project prevents a flood from occurring, it assumes that the project prevented damages to all of the buildings located behind the levee. Because this calculus occurs after each flood, the Corps claims to save the same buildings over and over again. In reality, many of those buildings would not have been constructed in the floodplain if the levee did not exist.

At the same time, the Corps disregards damage to buildings that occur when one of its levees or dams fails or is overtopped, assuming the damaged buildings would have been constructed regardless of the existence of the levee and that it would have flooded in any event. This "heads I win, tails you lose" accounting allows the Corps to find that even the most flawed flood-control project generates benefits—even if the levee induces massive development that is eventually destroyed by a large flood, as occurred in New Orleans East.

Obviously, the Corps' projects prevent a great many floods, and some buildings would have been constructed in the floodplain even absent the existence of a levee. In addition, the Corps' projects, such as its comprehensive efforts in South Florida, have provided great benefits, such as facilitating development of previously uninhabitable areas. But many Corps' projects have also increased the risk of flood damages by stimulating development in flood-prone areas.

The alternatives to levees and dams are called "non-structural approaches." Non-structural approaches include any effort designed to limit the damage associated with flooding without building structures to alter the watercourse. This can include removal of buildings—even whole towns—from the floodplain, but it can also include elevating structures or using building materials that prevent water from penetrating the lower floor. Non-structural approaches may include retrofitting infrastructure, such as utility lines, to survive flooding. In an independent report prepared for Congress, the National Institute of Building Sciences found that a single dollar spent on nonstructural mitigation saves society an average of $4.[39] Accordingly, various government and professional reports have repeatedly encouraged greater reliance on non-structural measures.[40]

Non-structural approaches, such as elevating existing structures in flood-prone areas, can dramatically reduce flood damages at low cost. Each dollar spent on such mitigation measures saves society an average of $4 in avoided flood damages.

Kathy Hicks/iStockphoto.com

Despite these findings, the Corps typically dismisses non-structural approaches as impractical. Part of the problem is that powerful local interests often seek approval of a Corps' project in order to encourage development in the floodplain. These interests do not want non-structural solutions; they want a levee that will permit new development. Biases in the Corps' analyses emphasize this problem. First, the Corps overestimates the benefit of structural projects by disregarding the development its projects induce, thereby ignoring the additional damages that will occur when floods overwhelm its structural defenses. Yet these

Length of U.S. Coastline by State (in statute miles)

State	General Coastline	Tidal Shoreline
ATLANTIC COAST		
Maine	228	3,478
New Hampshire	13	131
Massachusetts	192	1,519
Rhode Island	40	384
Connecticut	—	618
New York	127	1,850
New Jersey	130	1,792
Pennsylvania	—	89
Delaware	28	381
Maryland	31	3,190
Virginia	112	3,315
North Carolina	301	3,375
South Carolina	187	2,876
Georgia	100	2,344
Florida (Atlantic)	580	3,331
Total Atlantic Coast	**2,069**	**28,673**
GULF COAST		
Florida (Gulf)	770	5,095
Alabama	53	607
Mississippi	44	359
Louisiana	397	7,721
Texas	367	3,359
Total Gulf Coast	**1,631**	**17,141**
PACIFIC COAST		
California	840	3,427
Oregon	296	1,410
Washington	157	3,026
Hawaii	750	1,052
Alaska (Pacific)	5,580	31,383
Total Pacific Coast	**7,623**	**40,298**
ARCTIC COAST		
Alaska (Arctic)	1,060	2,521
Total Arctic Coast	**1,060**	**2,521**
States Total	**12,383**	**88,633**

Table: Sea-level rise threatens the U.S. coastline. A one-meter rise in sea levels could inundate 35,000 square kilometers (21,749 square miles) of land. In addition, the 100-year coastal floodplain could increase by 38%, or at least 18,000 square kilometers (11,185 square miles). (Source: Pew Charitable Trust, Feb. 2000, "Sea-Level Rise and Global Climate Change," at 1 & 5). Because 8,700 new single-family homes are constructed along the U.S. coast each week, such a change could have disastrous effects.

Department of Commerce, NOAA, National Ocean Service

damages are significant costs of structural flood-control approaches, and in places like New Orleans East, these are the primary costs. In addition, for reasons discussed below, the Corps also tends to greatly underestimate environmental costs and the costs of mitigation associated with its structural projects, while over-stating the costs of non-structural approaches.

Under sound floodplain policy, non-intensive land uses, such as parks, would be located in the floodplain. In fact, there are a variety of federal programs to help restore wetlands and forests on flood-prone cropland. If non-structural approaches simply redirect money into the floodplain that would have been spent to support these land uses elsewhere, the only real cost of the non-structural approach is the added cost of locating the amenity in the floodplain. But the Corps typically calculates the entire cost as the non-structural cost.

For all of these reasons, federal flood-control projects often encourage development in areas that will remain at high risk of flooding from major storms.

Flood insurance and disaster relief

Federal flood programs are not the sole reason that Americans are increasingly putting themselves in harm's way. FEMA reports that there are already 8 to 12 mil-

lion homes in the floodplain.[41] And the stakes are growing, particularly along the coasts. Between 1980 and 2002, population growth in coastal communities was 4.5 times greater than it was elsewhere in the nation. Census data indicates that more than half of the nation's population lives in 673 coastal counties, which comprise only 17% of the nation's land area.[42] Each week about 8,700 new single-family homes are constructed along the U.S. coast.[43] At the same time, coastal residents have grown wealthier. As developers construct larger, more expensive homes, there is more at risk when the inevitable storm strikes.

Unfortunately, the National Flood Insurance Program may be encouraging development in the most flood-prone areas by, in effect, subsidizing that development. In January 2006, David Maurstad, acting director and federal insurance administrator to FEMA testified that the program insures more than $800 billion in assets on 4.8 million policies. It collects roughly $2 billion in annual premiums and fees. These fees do not provide adequate revenue to cover FEMA's expenses. Hurricane Katrina has greatly exacerbated these problems. In the wake of the 2005 hurricane season alone, the program was forced to borrow in excess of a mind-boggling $20 billion from the U.S. Treasury.[44] The disparity between revenue and expenses exists because insurance premiums do not reflect actual flood risks. To start, nearly one-quarter of the policyholders insured by the NFIP are paying less than half (40%) of what they would pay with a private, risk-based premium because Congress explicitly grandfathers in lower rates for these buildings.[45] The remaining properties pay a flat insurance rate, which varies only based on building elevation, but mostly regardless of the level of other flood risks. Thus, a house built in the 10-year floodplain pays the same premium as a property built in the 100-year floodplain. Because many oceanfront properties belong to the wealthy, Paul Gessing of the National Taxpayers Union has bemoaned the "taxpayer-subsidized building boom," which allows "increasing numbers of wealthy people [to] build their 'castles' on the sand."[46]

Another problem is that flood insurance premiums are based on outdated analyses. Flood maps are old and often inaccurate. They do not reflect changes in urban or suburban development or agricultural practices, even though these activities increase flooding by augmenting downstream flows.[47] Nor do they reflect the rising flood risks associated with climate change. Instead, taxpayers—who are the ultimate underwriters of the flood insurance program—are shouldering these increased risks.

Ironically, the availability of flood insurance has created an expectation that the government will compensate losses when buildings are flooded outside the mapped 100-year floodplain. Property owners feel justified in seeking assistance precisely because they believe the government misled them by not requiring them to purchase flood insurance. The government's outmoded flood maps compound this problem. Americans also tend to respond generously to those who suffer from natural disasters. After Katrina, the federal government ultimately provided the funds to affected states to pay up to $150,000 for each uninsured house that experienced flood damage.[48] Rising sea levels will further aggravate the problem by expanding the size of the floodplain, making even more properties vulnerable to catastrophic flooding. In short, the flood insurance program is one more example in which the market has failed to send the proper signal about the risk of building in certain areas.

In 2003, FEMA began a massive and expensive effort to update and modernize outdated floodplain maps. This initiative will ultimately improve the public's awareness of flooding risks. A number of communities are now beginning to receive updated, digitized floodplain maps that may be considerably easier to work with than the current paper versions. Yet, even this program to date is failing to include much of the information being amassed regarding evolving climate science, sea-level rise and other related risks of global warming.

Congress and the Corps have failed to prioritize flood-control needs

In 1936, Congress enshrined in law the explicit policy that the federal government will build any flood-control project if the benefits "to whomsoever they may accrue" exceed the costs.[49] Along with language defining flood control as drainage, this language put the government in the water-management business to provide economic benefits to anyone, at taxpayer expense, regardless of other public justification for government involvement. In addition, a project may be built if benefits exceed costs by as little as one penny. This is a low threshold—and political pressure often helps lever projects over it. In nearly all circumstances, Congress will authorize a project—in other words make it eligible for federal funding—if the Corps finds that it meets this low economic hurdle.

But "authorization" does not mean a project will be funded in the near term. Today, the Corps has a $58 billion backlog of authorized projects, but receives approximately $2 billion annually in construction funding.[50] Thus, even absent any additional authorizations, it would take around 30 years to clear the backlog. In the next year, Congress appears likely to pass a new authorizing bill that will add at least $15 billion in additional projects. While some of these projects are worthy and important, most of these projects are unlikely to receive much funding in the near future. In fact, the Energy and Water Development Appropriations Act of 2006 explicitly prohibits the "reprogramming" of any funds that "create[ ] or initiate[ ] a new program, project, or activity."[51] Representative David Hobson (R-OH), former Chairman of the Energy and Water Development Appropriations Subcommittee, well aware of the tremendous disparity between authorized projects and available funding, explains that this prohibition was intended to help reduce the Corps' enormous maintenance backlog.[52]

In recent years, the Office of Management Budget has tried somewhat to prioritize funding for projects already under construction in its budget recommendations to Congress. It does so by relying primarily on the ratio of remaining project benefits to remaining project costs. In other words, projects that the Corps estimated would produce a great deal of economic benefits receive top priority. But the Appropriations Committee in Congress—despite being led by Congressman David Hobson who has explicitly called for prioritization—have rejected this approach in part because its members are skeptical about the Corps' reliance on this single factor (a legitimate concern, as discussed below). Unfortunately, the alternative is an almost completely politics-driven system under which virtually every dollar of the Corps' budget is assigned to a particular project—an earmark—at the request of a member of Congress.

Katrina revealed the consequences of this almost complete failure to prioritize funds. In the five years prior to Katrina, Louisiana received $1.9 billion for water projects—far more than any other state, but only around 1% of these funds were

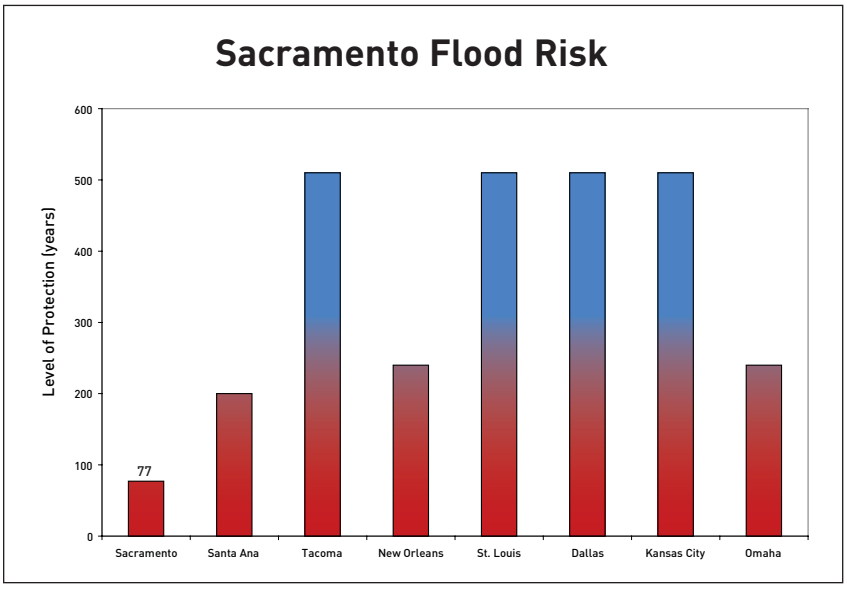
allocated for New Orleans' levees.[53] Even after Katrina, hurricane protection is not being properly prioritized. In fact, the new water projects bill that appears likely to pass the current Congress includes a $205 million project to deepen a channel for the Port of Iberia, even though the Corps recognizes that its chief economic benefits consist of stealing existing business from ports in Texas.[54]

These misplaced priorities are abundantly evident in the projects the Corps advocates nationwide. The Corps continues to spend money on "flood-control" projects designed to drain wetlands and other ecologically important floodplain habitats to increase production of basic crops for the benefit of a handful of farmers. For instance, the Corps continues to push the St. Johns Bayou Basin and New Madrid Floodway Project, a $108 million project that would drain approximately 75,000 acres of frequently flooded land in southeastern Missouri. The proposed project would wall off the last remaining link between the Mississippi River and its adjacent wetlands in the state of Missouri, draining an area larger than the District of Columbia and preventing fish and other wildlife from breeding. Ninety percent of the stated benefits of the project are in the form of increased soybean, corn and cotton production, yet the federal government spends billions of dollars annually to remove comparable land from production.[55]

The Corps originally promoted the St. Johns Bayou Basin and New Madrid Floodway Project by claiming that it would eliminate flooding in an economically distressed town. However, it has since conceded that the project would allow the town to continue to flood once every ten years as it does today and produce no economic development benefits. Despite this concession, local politicians continue to support the project, and it accordingly remains one of the Corps' top flood-control priorities.

In Mississippi, the Corps is pursuing the Yazoo Pumps, a $207 million alleged flood-control project. This project would drain over 200,000 acres of wetlands to increase agricultural production on the most sparsely populated land in the state. Strikingly, the Corps has not identified a single home that would be relieved of flooding once the project is built.[56]

In part as a result of this backlog of less critical projects, the Corps is losing its capacity to be a significant contributor to solving important flood problems. The San Joaquin-Sacramento flood-control system needs a major overhaul. It provides flood protection for 500,000 people, 2 million acres of farmland and property worth $47 billion, but it provides substandard protection for highly populated areas, faces an array of structural problems in places, and is subject to high erosion rates as a result of its design and construction.[57] While the cooperation of the U.S. Bureau of Reclamation and



Sacramento Area Flood Control Agency (SAFCA)

Figure 13
The Corps has prioritized agricultural drainage projects over actual flood control. As a result, Sacramento faces a higher risk of flooding than any other major city in the United States.

local interests have made it possible for improvements to move forward on the American River to protect Sacramento itself, Sacramento continues to need major improvements on the Sacramento River that local interests are now planning to undertake in the absence of Corps capacity. More broadly, the California Department of Water Resources has increased its estimated cost for overhauling the entire system at $16 to $18 billion, which some experts believe should involve a combination of levee improvements, relocation of levees to set them back from the River, use of floodplain overflow areas, improved management of reservoirs and better floodplain management.[58] In February 2006, Governor Schwarzenegger appealed to the federal government:

> "Increasingly severe weather systems each season have accelerated the deterioration of the state's levee system to the point where they are now in danger of failing during the next major rainfall or earthquake. This worsening situation creates conditions of extreme peril to the public and property protected by the levees, to the environment, and to the very foundation of California's economy."[59]

But the reality is that the Corps is not in a position to make a significant contribution, reporting that it "lacks the funding to carry out even the most critical repairs" to the existing system.[60] Recognizing the Corps' limited capacities, officials with the California Department of Water Resources have told state legislators that the state will have to assume principal responsibility for this overhaul.[61] Overall, that is probably beneficial. But if the federal government is to rely on the Corps to contribute to flood management, it should at least be able to make meaningful contributions to its own projects. The failure of the federal government to prioritize its efforts makes that doubtful.

Congressman Hobson expressed the need for a prioritization system after the Corps failed to respond to his request to produce a priority list of projects:

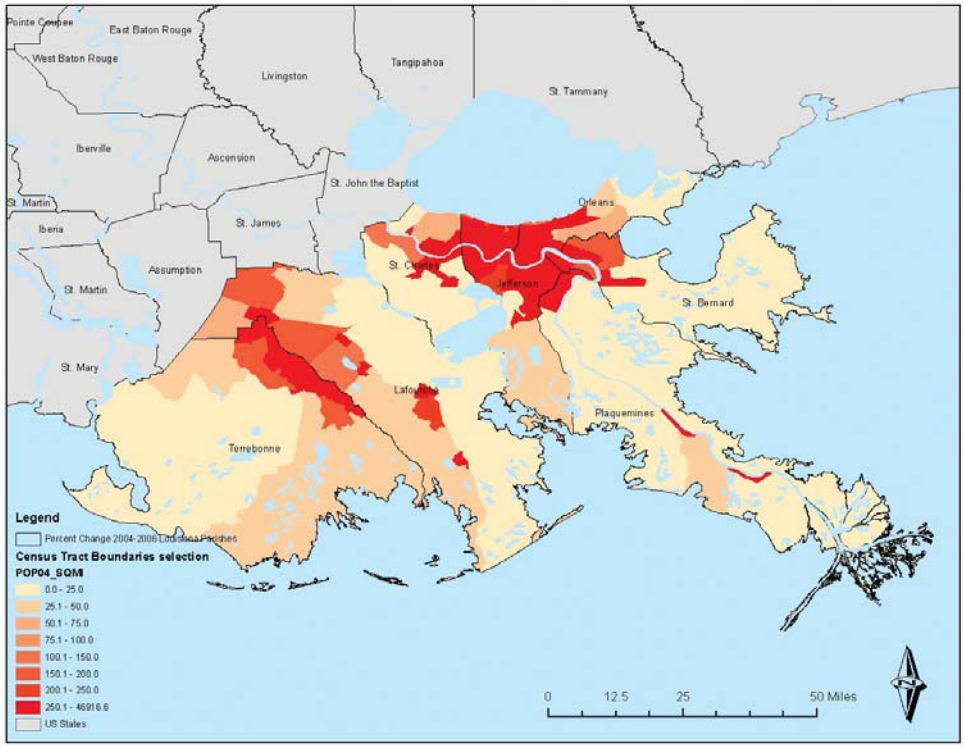
> "The devastating consequences of the hurricanes that hit the [G]ulf [C]oast last year demonstrate what happens when we make the wrong investments in critical water resources infrastructure.
>
> The [G]ulf hurricanes served as a wake-up call for many other parts of the country, such as Sacramento, that have inadequate flood protection.
>
> Last fall, we asked the [C]orps to provide Congress with a 'top 10' list of the flood control and navigation infrastructure needs in the country. The [C]orps was surprisingly unable or not allowed to respond to this simple request, and that tells me the [C]orps has lost sight of its national mission … what is still lacking is a long-term vision of what the nation's water resources infrastructure should look like in the future. 'More of the same' is not a thoughtful answer, nor is it a responsible answer in times of constrained budgets."[62]

Representative Hobson reiterated his concern that the Corps had still not produced such a list at a February 27, 2007 House appropriations hearing.

The response to Hurricane Katrina reaffirms the prioritization problem. Congress directed the Corps to analyze a system to protect the entire state of Louisiana, not merely the highly populated areas, from the largest possible (Category 5) hurricane. As Figure 14 depicts, the Corps initially responded by proposing a massive system of levees, which would extend across most of the Louisiana coast at the cost of tens of billions of dollars. Such a system would present enormous technical challenges, including the serious risk of accelerating wetlands loss.[63]

Figure 14
(A) Even before Hurricane Katrina, development was concentrated in several population centers throughout Louisiana. (B) Nonetheless, the initial post-Katrina hurricane protection plan incorporated a coast-wide levee proposal, which would harm the remaining wetlands buffer and needlessly encourage additional coastal development.

A



Source: Prepared by Peter Black, GIS Specialist—Environmental Defense, from data provided by the U.S. Census Bureau.

B

Source: U.S. Army Corps of Engineers, Louisiana Coastal Protection and Restoration Preliminary Technical Report.

Scientists likewise criticized the state Coastal Protection and Restoration Authority's first draft of a state master plan as following the Corp's initial overemphasis on levees.[64] The Corps and the state now appear to recognize the importance of prioritizing wetland restoration and protection of major urban areas, and are currently making serious integration-based revisions to the original plans. Ideally, the final protection plan will restore the wetlands buffer and direct levee funds to the most populated areas.

Flood-control projects cause environmental harm that may contribute to further flooding

Wetlands provide critical protection to coastal communities. They serve as a natural buffer against hurricanes by absorbing the storm's initial impact. Many Corps' flood-control projects have eliminated this benefit by creating a physical barrier between the sea and the adjacent floodplain. Properties built behind the levee further drain the wetlands, making the land even more vulnerable to storms.

These environmental impacts generate enormous costs. In Florida, the Corps has embarked on the largest environmental restoration effort in the world in its attempt to restore natural water flows in the Everglades. The Corps estimates that the restoration project will take more than 30 years to complete and will cost nearly $8 billion. Among other things, the effort involves removing more than 240 miles of canals and levees to restore natural flows through area wetlands. In other words, this multi-billion dollar project was necessitated because of the Corps' prior "flood-control" activities in the region.[65]

The Corps' flood-control projects have also led to large-scale environmental harm and subsequent restoration efforts in coastal Louisiana. Periodic overflows from the Mississippi River historically re-nourished the area's wetlands. Today, a complex network of levees have separated the nourishing silt and freshwater of the Mississippi River from their adjacent wetlands. Levees have essentially eliminated this overflow, killing the vegetation and preventing sediment from accumulating and rebuilding the floodplain.

Without this wetland buffer, Hurricane Katrina had unfettered access to the vulnerable Louisiana coast. Since the 1930s alone, Louisiana has lost an area the size of Delaware to the sea. While New Orleans was once protected from coastal storm surge by miles of wetlands, it now faces the sea head-on in some locations. It will cost billions of dollars to construct diversion projects that will reconnect the Mississippi River to its wetlands.[66] Congress has yet to provide significant funds toward this effort.

A little-used navigation canal, the Mississippi River Gulf Outlet (MRGO, known locally as Mr. Go), demonstrates the direct environmental consequences of the Corps' activities. This 76-mile channel provided an open path for Katrina's storm surge, increasing the intensity of the storm by 20% and raising the height of the wall of water by approximately three feet.[67] The canal itself was created by destroying 20,000 acres of wetlands. Without this natural hurricane buffer, MRGO exacerbated storm-related wave and flooding intensity and duration, becoming a "superhighway for storm surge."[68]

Despite this high cost, the channel brings few economic benefits; traffic has fallen by more than 50% since 1985 (Fig. 15). Today, less than one ocean-going ship travels on the canal in each direction per day. With maintenance costs

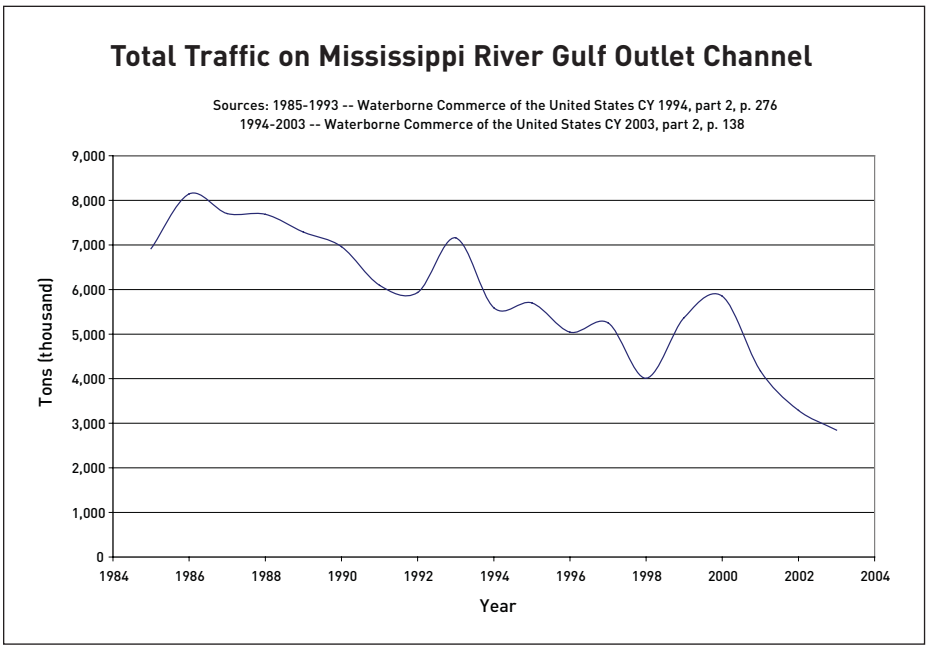


Figure 15
Katrina's damage was dramatically increased because of the Mississippi River Gulf Outlet, a little-used navigation channel. Congress has continued to allocate taxpayer dollars to maintaining the channel, even though traffic has declined by more than 50% since 1985.

approaching $12 million each year, it costs American taxpayers more than $22,000 each time a foreign vessel travels up or down the canal.[69] Fortunately, Congress has directed the Corps to develop a plan to close the channel, the Corps has called for doing so, and Congress seems likely to direct that closure.[70] But securing the funds to restore some of the wetlands the channel destroyed remains a major challenge.

The Corps' projects suffer from underlying design flaws that may increase flood damages

In theory, the Corps prevents Congress from authorizing unworthy flood-control projects by conducting an internal economic analysis before Congress may consider them. Congress, in turn, will generally only authorize a project if the Corps has found that its benefits exceed its costs. Unfortunately (as discussed above), this is an extremely low standard. In addition, the Corps' analysis is frequently influenced by political pressure, leading to the eventual authorization and construction of damaging or unnecessary flood-control projects. Local Congresspeople are powerful advocates, and those from other jurisdictions are unlikely to challenge individual projects, since this may prevent future authorization of their personal priorities.

The Army Inspector General (IG) highlighted this problem in 2000. The investigation revealed that powerful agency officials had ordered Corps employees to manipulate data to justify an expensive project expanding barging on the Upper Mississippi River. The IG concluded that this incident appeared to reflect an agency-wide bias for large-scale and expensive projects and that many Corps' employees questioned the integrity of the agency's planning process.[71] Outside studies have repeatedly found major errors in the Corps' analysis. In March 2006, the Government Accountability Office concluded that the four Corps' projects it had examined were "fraught with errors, mistakes and miscalculations" that could only be addressed through a "comprehensive revamping" of the system.[72]

New Orleans revealed the potential consequences of these defects. Shortly after Katrina, a joint investigation by an independent team of professional engineers found that much of the damage in New Orleans could be attributed to basic engineering design flaws.[73] The underlying soil was simply too weak to support the levees.[74] A May 2, 2006, report from the American Society of Civil Engineers confirmed that the Corps had failed to "account for design shear strengths in the clay beneath the slope and beyond the toe of the levee lower than those recommended

beneath the centerline, did not account for the fact that the strength of the clay increased markedly with depth, and did not account for a water-filled gap on the flood side of the sheet-pile wall."[75]

This study found that the Corps was long aware of deficiencies. In fact, before the hurricane protection project was constructed, the Corps knew that the floodwalls were vulnerable to failure; extremely unstable soils under sections of the floodwalls demanded a much stronger design; the floodwall design did not meet the Corps' own guidelines; and the levees needed to be higher than planned.[76] The Corps had apparently been given data in 1972 indicating these problems but failed to incorporate this data into its project design—even though critical elements of the system were not designed until the late 1980s and early 1990s.[77] Katrina highlights the need to institute quality controls that can increase the integrity of the Corps' analyses and counter-balance the external pressures on the Corps to produce particular results.

Conclusion

Congress has long embraced a system that directs limited dollars to the projects with the greatest political support, rather than to those with the greatest practical need. This system has led to a vast backlog of water-resource projects and a failure to prioritize funds. Meanwhile, flaws in the flood insurance program, coupled with abundant disaster relief, have effectively subsidized and indirectly encouraged Americans to build in flood-prone areas. As global warming makes the nation increasingly vulnerable to flooding, Congress needs to modernize the flood-control system.

Recommendations

The growing flood problems elaborated in this report provide one of many reasons the country needs to take decisive action to reduce global warming pollution. Key reforms to the Corps' system for flood-control projects should include the following:

- Changes to the criteria for evaluating the Corps' projects, in order to stop subsidizing and encouraging new development in harm's way and to favor non-structural approaches in areas that are not already densely developed;
- A process for establishing priorities that encourage Congress to direct taxpayer dollars where they are needed most;
- Improved environmental standards;
- Independent peer review of costly, controversial or critical projects; and
- A mandate that the Corps of Engineers incorporate modern climate science principles in planning, construction, and operation of water-resource projects.

Congress also needs to reform the flood insurance program. It should become more actuarial and risk-based and incorporate modern climate science. Rates should be increased to build a reserve, and properties located behind levees should still be required to purchase flood insurance.

Throughout history, major environmental disasters have sometimes inspired major environmental advancements. The Clean Water Act was written as fire erupted on the waters of the Cuyahoga River. The Oil Pollution Act was enacted in 1990 after the Exxon Valdez spilled 11 million gallons of oil into the Prince William Sound in Alaska. Hurricane Katrina was one of the nation's largest natural disasters and, as Yale economics professor Dr. William Nordhaus has found, the "costliest hurricane in U.S. history."[78] Congress and the Corps should learn from this tragedy by enacting legislation that will help reduce storm impacts in the future.

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