CLIMATE CHANGE AND YOUR HEALTH

After the Storm:
The Hidden Health Risks of Flooding in a Warming World




Union of Concerned Scientists
Citizens and Scientists for Environmental Solutions

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The Union of Concerned Scientists is a nonprofit partnership of scientists and citizens combining rigorous scientific analysis, innovative policy development, and effective citizen advocacy to achieve practical environmental solutions. Established in 1969, we seek to ensure that all people have clean air, energy, and transportation, as well as food that is produced in a safe and sustainable manner. We strive for a future that is free from the threats of global warming and nuclear war, and a planet that supports a rich diversity of life. Sound science guides our efforts to secure changes in government policy, corporate practices, and consumer choices that will protect and improve the health of our environment globally, nationally, and in communities throughout the United States. In short, UCS seeks a great change in humanity's stewardship of the earth.

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Introduction

OVER THE PAST 30 YEARS, FLOODS have tended to be one of the most deadly and expensive types of natural disasters in the United States (NOAA 2010). Like most other extreme weather events, the impact of a flood* is typically measured in terms of lives lost and the dollar value of property damaged or destroyed. But what these estimates typically don't take into account are the often-substantial public health costs that follow a flood—and the toll that such health impacts may take on families even long after the waters have receded.

Over half of all waterborne disease outbreaks in the United States occur in the aftermath of heavy rain, and floodwaters may contain over 100 types of disease-causing bacteria, viruses and parasites (Batterman et al. 2009; Domino et al. 2003; Rose et al. 2001). As rain-water falls, a river rises, or a storm surge rushes in from the sea, water, if not contaminated already, may become tainted by mixing with agricultural waste, chemical pollutants, raw sewage, or other environmental contaminants. The fouled waters may flow into homes, be dangerous on contact, render tap and well water unsafe for drinking, and taint recreational locations such as swimming holes and fishing spots. In addition, flooding can cause molds to proliferate and sewage to back up into people's homes. These health threats are not limited to the flood-afflicted areas; they may reach into neighboring communities as well.

Extreme rainfall events have become more common in the United States at the same time the climate has warmed, and the problem will likely grow worse as the climate continues to warm, leaving more and more of our growing population vulnerable to the immediate and lingering health impacts of these events. While the risks of flooding to our homes and communities are based on a variety of factors, including where we live and how our region has developed, the influence of climate change can no longer be ignored.

This report first discusses the health hazards posed by extreme precipitation and flooding and what can be done to protect families, particularly those who are at greatest risk. Next, it addresses other flooding risk factors, such as where and how we choose to develop. Finally, the report summarizes the evidence linking climate change to the increased risk of weather events that can lead to flooding.

© FEMA NewsPhoto/Bob McMillan

After a 2004 flash flood inundated this home in Bridgeville, PA, all of its baseboards and insulation were removed to prevent mold and mildew. Long after a flood's waters have receded, residents often continue to struggle with mold-induced respiratory illnesses, depression, and the stress of repairing or rebuilding an uninhabitable home.

* In this report we define a flood or flooding event as an occurrence of water in areas not normally covered or saturated by water, which can lead to negative public health and economic impacts. Floods can vary in extent, from inundation of large areas down to flooding in individual homes.

Public Health Dangers of Extreme Precipitation and Flooding

Dangers During the Week of the Flood

Drowning and Trauma

When precipitation from an intense rain storm or hurricane falls on land that is too saturated to absorb large volumes of water, rapidly rising water—known as flash floods—can occur. More than 20,000 cities and towns in the United States are at risk of flash flooding (Greenough et al. 2001; Malilay 1997). These dangerous events occur with little warning and involve substantial amounts of swiftly moving water—a combination that makes them the most deadly type of flood. Typically 60 to 100 American lives are lost each year in flash floods, largely as a result of drowning (NOAA 2010; NWS 2001; French et al. 1983).* Almost half of the total flood fatalities in 2010 involved individuals who drown while attempting to drive through floodwaters (NOAA 2010). Similarly, most hurricane fatalities are due to drowning associated with flooding (French 1989). Those with limited swimming abilities—such as infants, young children, and the elderly—are particularly vulnerable to drowning (Gilchrist, Sacks, and Branche 2000).


© U.S. Coast Guard

The U.S. Coast Guard rescued this woman from floodwaters in a Chicago suburb. The elderly and children are particularly at risk of drowning during floods; everyone, however, is endangered by the swiftly moving waters of flash floods and downed electrical wires.

Downed power lines and damage to a home's electrical system make electrocution and fire common risks during a flood. Unusually heavy rains, combined with poor land use planning, overbuilding, and deforestation, caused disastrous flooding in Thailand in the fall of 2011 that affected millions of people and left at least 600 dead (Associated Press 2011).While the majority of these deaths resulted from drowning, Thai officials estimate that electrocution—caused, for example, by contact with submerged power lines—accounted for about 50 deaths, or 8 percent of the total (Bangkok Post 2011). Within the United States, approximately 3 percent of flood-related deaths following inland flooding events result from electrocution (Jonkman and Vrijling 2008).

Drinking and Recreational Water Contamination

When heavy rains overwhelm a community's water-supply and sewer systems, contaminated water is sent into the local drinking water and waterways. The impacts affect not only the flood-afflicted community but the entire population served by the systems. Drinking water for a much larger area can become contaminated and dangerous to residents' health. Direct contact with contaminated floodwaters also can cause significant numbers of illness cases (Greenough et al. 2001; Malilay 1997). Direct contact occurs, for example, when people attempt to walk through floodwaters or swim in them. Extreme precipitation events and outbreaks of waterborne disease are strongly linked: very heavy rainfall events (defined as those in the top 7 percent)

* According to National Weather Service Data, an average of 71 people died every year in floods from 2001–2010. The 30-year (1981–2010) annual average for fatalities was 92 deaths.

more than double the probability of a waterborne disease outbreak (Thomas et al. 2006; Schuster et al. 2005; Curriero et al. 2001).

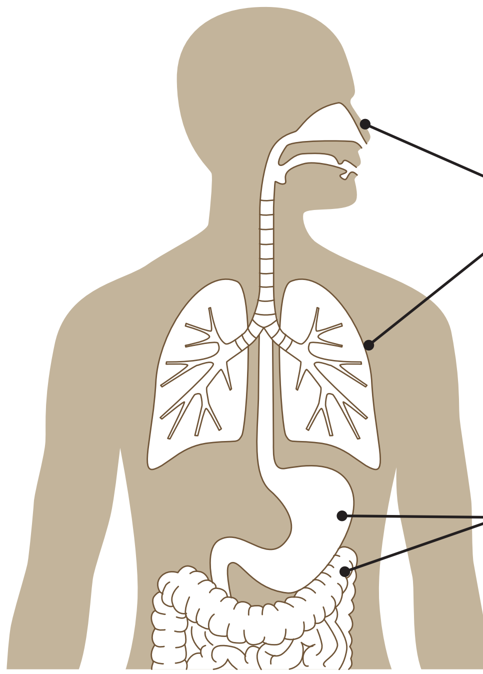
As a result of floodwater's mixing with agricultural runoff human and animal wastes (feces), chemical pollutants (for example, motor oil and antifreeze), and other environmental contaminants, the water we drink, clean with, and play and swim in can contain over 100 types of disease-causing agents, including pathogenic microorganisms, biotoxins, and chemical contaminants (Batterman et al. 2009; Domino et al. 2003; Rose et al. 2001). Pathogens include protozoa that cause cryptosporidiosis, bacteria that cause legionellosis, viruses that cause viral gastroenteritis, amoebas that cause amoebic meningoencephalitis, and algae that cause neurotoxicity (Portier et al. 2010, citing Batterman et al. 2009). Symptoms of these diseases range from mild to acute and include nausea, vomiting, and diarrhea (Batterman et al. 2009; Rose et al. 2001).

Waterborne pathogens are associated with high rates of (usually mild) gastrointestinal symptoms and a small but significant number of deaths (Portier et al. 2010, citing Craun and Calderon 2006; Rose et al. 2001). Children under the age of five, the elderly, and others with weak immune systems are particularly at risk from waterborne diseases; thus they experience a relatively high incidence of illness following heavy rainfalls (Teschke et al. 2010; Wade et al. 2004). For example, in the days immediately following an intense rainfall event in Wisconsin, one children's emergency room reported an 11 percent increase in visits for acute gastrointestinal illness (Drayna et al. 2010). From the Mississippi River basin to the coastal plains of Houston, people whose homes or yards have flooded are up to four times more likely to contract gastrointenstinal illnesses than those whose property was spared (Wade et al. 2004; Waring et al. 2002).

Waterborne diseases exact a toll not only on our health but also on our health care system. When significant flooding occurs—such as in the wake of Hurricane Floyd, which hit North Carolina in 1999—the number of people visiting emergency rooms and seeking hospital-based outpatient care increases substantially (Domino et al. 2003).

Over half of waterborne disease outbreaks in the United States are caused by heavy rainfall events (Curriero et al. 2001). While not flood-specific, the five most common waterborne diseases—giardiasis, cryptosporidiosis, legionnaires' disease, otitis externa and non-tuberculous mycobacterial infection—account for the majority of outbreaks, resulting in over 40,000 hospitalizations and costing $970 million per year (Collier et al. 2012).

FIGURE 1. How Contaminated Water (Drinking or Recreational) Affects the Human Body



Source: Based on Batterman et al. 2009; Domino et al. 2003; Rose et al. 2001.

© FEMA/Walter Jennings

Five weeks after this 2008 flood, homes in Spring Green, WI, remained uninhabitable as FEMA officers assessed the substantial health risk posed by sewage and infectious algae growth. Once the risk of waterborne disease subsided, residents of this housing development had to grapple with the health risk of molds.

The American Society of Civil Engineers recently estimated that about $9.4 billion more per year would be needed for water and sewer work between now and 2020 in order to stave off regular disruption of water service and a jump in contamination caused by sewage-borne bacteria (ASCE 2011). Earlier, in 2010, the U.S. Environmental Protection Agency (EPA) estimated the total cost of the capital investment that would be required to maintain and upgrade drinking-water and wastewater-treatment systems across the country: it came to $91 billion. With only $36 billion funded, however, a substantial gap in investment ($55 billion) remains-an investment that could ameliorate the risk of future incidents of water contamination and their associated health impacts (EPA 2010).

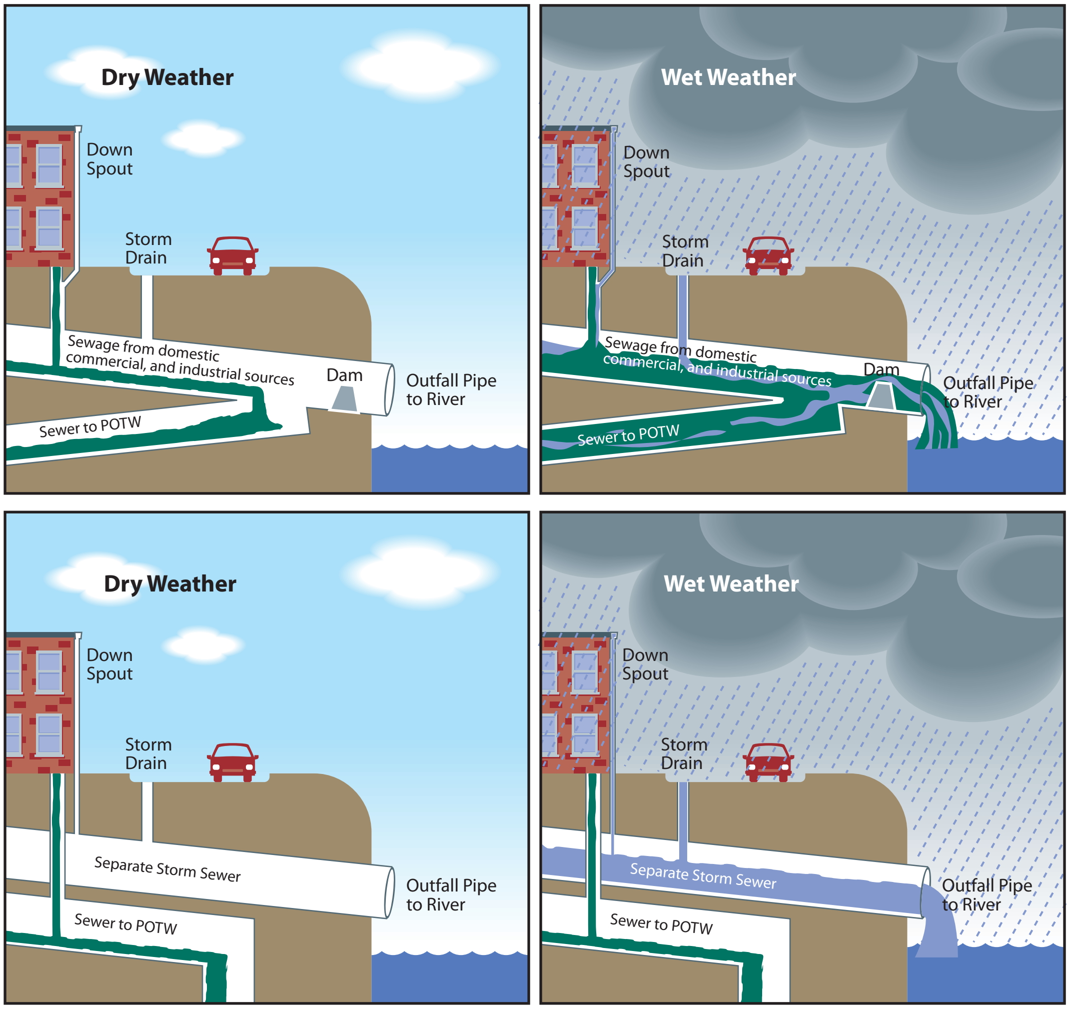
The cities most at risk from the threat of water contamination—more than 700 communities throughout the nation—are those with combined sewer overflow systems, which carry both raw sewage and stormwater to a wastewater treatment plant (EPA 2011). When these systems are faced with heavy flows, such as from excessive rainfall, during a short period, they can overflow and send a mixture of stormwater and untreated raw sewage directly into area waterways (Curriero et al. 2001). The likelihood of such uncontrolled release depends on the design and condition of the region's sewer system. For example, in the Chicago area, more than 2.5 inches of rainfall in one day will send sewage and stormwater into Lake Michigan, whereas in Indianapolis a mere quarter of an inch of rain can result in sewage discharge (Hayhoe and Wuebbles 2008). On a national basis, combined sewage overflows deliver more than 850 billion gallons (3.2 trillion liters), or over a million Olympic-size swimming pools, of raw sewage and stormwater to our waterways every year (EPA 2004), including to the many coastal beach areas and rivers where families swim.

Over half of all waterborne disease outbreaks in the United States occur in the aftermath of heavy rain.

© Rick Dove

When Hurricane Floyd hit North Carolina in September 1999, numerous livestock-waste lagoons—such as the one at the hog farm pictured above—were inundated or breached, resulting in the spewing of animal wastes and fertilizer into North Carolina's waterways and causing increased health risks from waterborne illnesses. In the first month after the hurricane, some 6,500 cases of gastrointestinal illness were reported, accounting for 11 percent of all emergency room visits. Many affected areas had a high proportion of low-income populations dependent on wells for drinking water.

FIGURE 2. The Peril of Dual Use: Combined Sewer Overflow Systems



Combined Sewer Overflow (CSO) System

Separate System

The top two boxes illustrate a combined sewer overflow (CSO) system, in which rainwater and raw sewage drain into the same pipes and, potentially, into a local waterway. The top-left corner image shows that indoor sewage normally (in dry weather) drains from a CSO to the treatment plant (POTW, for "publicly owned treatment works"). In times of extreme rainfall (top-right image), however, rainwater draining from streets enters the pipes that also are carrying raw sewage. If the sewage treatment plant cannot process the sudden and excess influx of fluids, the unhealthy mixture of rainwater and raw sewage will back up and eventually be dumped directly into a nearby lake, river, or ocean. The bottom two boxes demonstrate how a separate system avoids this problem.

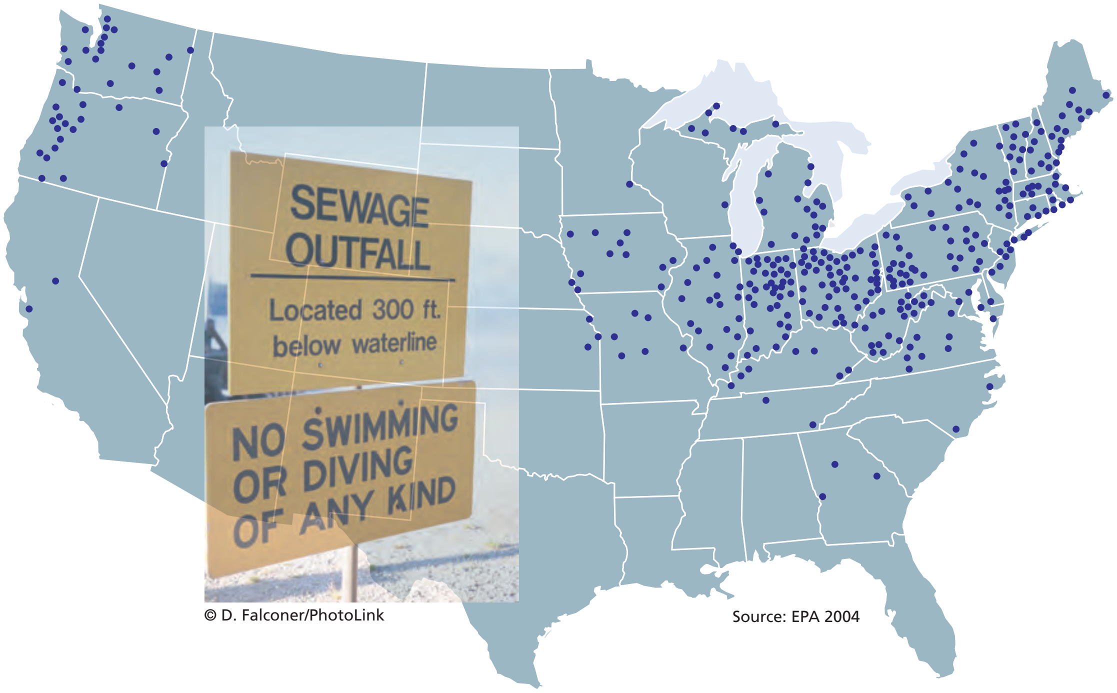
Source: Based on a graphic by the Kentucky Department of Environmental Protection (Kentucky DEP 2012)

More than 60 percent of drinking water contamination cases in urban watersheds occur during storm events (Fisher and Katz 1988). In recent years, cities with older combined sewer systems—throughout the Midwestern and Great Lakes regions, as well as the Northeast—have experienced outbreaks of waterborne disease when heavy rains sent sewage directly into local waterways. In 1993, after receiving its heaviest rainfall in more than 50 years, Milwaukee had a major outbreak of gastrointestinal infections from the *Cryptosporidium* parasite (MacKenzie et al. 1994; Dubey, Speer, and Fayer 1990).The infections, which caused severe diarrhea lasting from several days to a week, affected more than 400,000 people and caused over 100 deaths (MacKenzie et al. 1994; Dubey, Speer, and Fayer 1990).

Escherichia coli (*E. coli*), a type of bacterium that typically originates in the intestines of humans and can cause gastroenteritis, has been found in stormwater released to Lake Michigan after heavy rains and at concentrations 100 to 500 times higher than the maximums specified by water quality standards (McLellan et al. 2007). In Walkerton, Ontario, after five days of heavy rain in 2000, high levels of *E. coli* in the town's

FIGURE 3. Locations of Combined Sewer Overflow Systems

Combined sewer overflow systems are heavily concentrated in the Northeast and Midwest, as this map illustrates. These are the very regions of the United States that are already experiencing a greater increase in extreme precipitation events compared with the rest of the country, and this trend is projected to continue, or perhaps worsen, as temperatures rise.



© D. Falconer/PhotoLink

Source: EPA 2004

© Narragansett Bay Commission

water supply caused over 2,300 cases of illness and seven deaths (Auld, MacIver, and Klaassen 2004).

In such circumstances, some segments of the population are more at risk than others. Hospital and emergency room visits due to gastrointestinal infections and diarrhea have been shown to disproportionately affect children five to 18 years of age, especially during hot periods (Ostro et al. 2010; Green et al. 2009).

Depending on the amount of overall emissions in the years to come, climate models project that the frequency of extreme precipitation events in the Midwestern and Great Lakes regions will rise by 50 to 120 percent by the end of the century (Patz et al. 2008). These changes will heighten the risk of sewage discharge into the Great Lakes, an important source of drinking water and recreational opportunities (such as swimming) for, at present, some 40 million people. (Patz et al. 2008).

The Narragansett Bay Commission of Providence, RI, spent 15 years and more than $300 million to complete phase one of a storage project aimed at containing untreated sewage during rainstorms (Save the Bay 2012). The project (shown left) will reduce the approximately 2.2 million gallons of sewage that annually enters Narragansett Bay by 40 percent, but more than a million gallons of sewage will continue spewing into the bay until further construction is finished (Narragansett Bay Commission 2012). As rainstorms intensify in a warmer world, even the new infrastructure may be inadequate to prevent future overflows, forcing Rhode Island to close beaches and ban shellfishing after rain storms—and lose revenue from these economically important sources.

Dangers that Persist for Months After the Flood

WHILE SOME OF THE IMMEDIATE health hazards associated with flooding diminish as floodwaters subside, others linger or appear well after the primary event has ended. Waterborne pathogens can take time to affect a person's health, so the demand for medical assistance for gastrointestinal infections may rise in the weeks following the flood (Teschke et al. 2010). For instance, over a three-month period after the major Midwest floods of 1993, primary health care visits increased by more than 30 percent at an Iowa clinic in a community affected by flooding (Axelrod et al. 1994). In addition, long after floodwaters have receded, water-damaged buildings may harbor mold growth, drinking water may remain contaminated, and residual pools may provide breeding grounds for bacteria. Combined, the immediate and lingering hazards associated with flooding take a toll on the physical and mental health of our communities and carry a significant economic burden from health care costs.

Studies show that infants and children exposed to mold before one year of age are 2.8 to 4 times more likely to develop asthma than their peers.

Dangerous Indoor Air Quality: Mold and Degraded Building Materials

While many factors contribute to mold and bacterial growth in buildings, dampness—which can persist for weeks or months after even a minor flood—provides a nearly optimal breeding ground for these organisms (CDC 2005). And the amount of mold growth in a home correlates with the magnitude of its water damage; however temperature and humidity also play a role (Dillion et al. 1999). In the wake of Hurricanes Katrina and Rita of 2005, for example, heavy mold growth was identified in 70,000 water-damaged homes, and those with more than three feet of indoor flooding experienced greater mold damage than residences with little flooding. Areas that flooded during Katrina and Rita also had higher airborne mold counts than areas that did not flood, with indoor air mold counts being as much as seven times higher than those of outside air (Barbeau et al. 2010; Solomon et al. 2006).

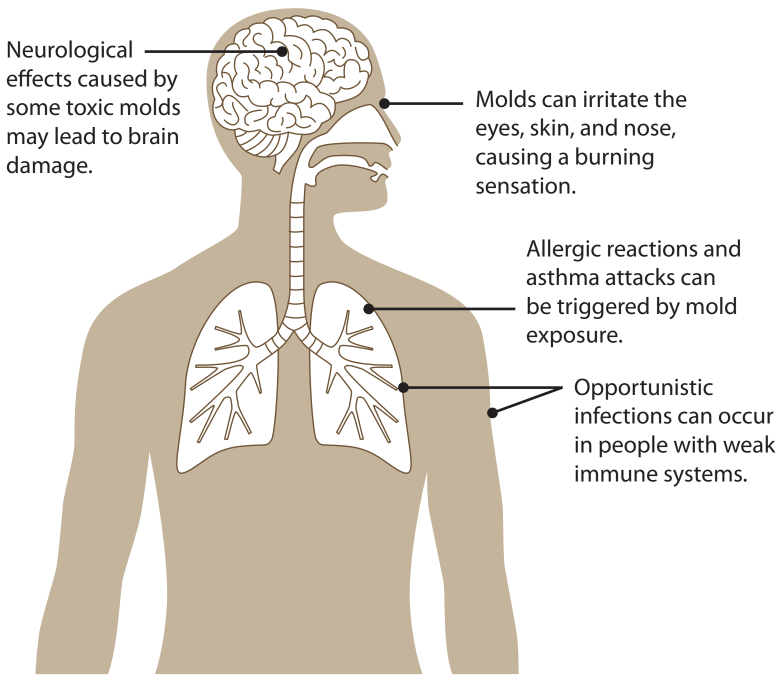
Molds and other fungi disperse airborne spores that, when inhaled, can trigger allergic reactions and other respiratory symptoms. Similarly, the inhalation of bacteria can cause respiratory inflammation (Solomon et al. 2006, citing Douwes et al. 2003).

A comprehensive review of nearly 150 epidemiological studies suggests that upper respiratory tract symptoms, such as coughing, wheezing, and the exacerbation of asthma, are associated with indoor dampness and poor indoor air quality (Mendell et al. 2011).

The association between dampness, mold, and the exacerbation of asthma has long been recognized. However, it is only in the past few years that scientists have been able to confirm a causal link between dampness or mold and the *development* of asthma. For example, studies show that infants and children, particularly those of lower socioeconomic status, who are exposed to mold before one year of age are 2.8 to 4 times more likely to develop asthma than their unexposed peers (Mendell et al. 2011, citing Pekkanen et al. 2007; Reponen et al. 2011). Removing visible mold and sources of dampness from homes dramatically reduces asthmatic symptoms in children and decreases their acute-care

A couple stands in despair in the mold-infested bedroom of their first home, which they had finished remodeling shortly before it was flooded by Hurricanes Katrina and Rita. In the aftermath of the storms, an estimated 46 percent of homes in New Orleans and surrounding parishes had some mold contamination and 17 percent had heavy mold contamination (Barbeau et al. 2010). Inhaling the spores from mold can trigger allergic reactions and exacerbate asthma.

FIGURE 4. How Mold Affects the Human Body



Source: Based on Barbeau et al. 2010; Solomon et al. 2006

visits by 90 percent in the 6 to 12 months following improvement of environmental conditions (Mendell et al. 2011, citing Kercsmar et al. 2006).

Asthma cases associated with dampness and mold are costly not only to our health but also to our economy. In the United States some 25 million people live with asthma, and 12 to 29 percent of those cases are attributable to dampness and mold exposures in the home (CDC 2009). On a national basis, these cases incur expenses of $2.1 billion to $4.8 billion annually, including direct medical costs (such as from medications, hospital charges, and physician visits) and indirect costs such as lost work days (Mudarri 2007).

Beyond the growth of mold and bacteria, dampness in buildings may corrode materials and allow the release of potentially harmful chemicals such as formaldehyde from composite wood products and chemicals from the plasticizers in vinyl flooring. Like mold and bacteria, these chemicals can worsen asthmatic symptoms (Mendell et al. 2011, citing McGwin, Lienert, and Kennedy 2010; Mendell 2007; Norback et al. 2000; Matthews et al. 1986).

Global climate change exacerbates these problems. Because the conditions favorable to mold and bacterial growth become more likely in many parts of the United States—due to an increased risk of flooding—indoor air quality could worsen and related health problems could become more widespread and severe (IOM 2011).

Mental Health

In addition to the damage to physical health, personal property, and communities, extreme weather events are also a threat to mental health. An Australian study found that as many as one in five people will suffer from the effects of extreme stress, emotional injury, and despair after a severe weather event (Climate Institute 2011). These conditions, as well as depression and post-traumatic stress disorder (PTSD), can last for months or even years after a flood as victims continue to grapple with issues such as the loss of their homes or displacement from their communities.

Six months after Hurricane Andrew struck Florida in 1992, 20 to 30 percent of the area's adults and children met criteria for PTSD and 33 to 45 percent of adults were depressed (Norris et al. 1999; La Greca et al. 1996; David et al. 1996). A full two years later, those numbers remained largely unchanged as the residents of South Florida struggled to cope with the aftermath (Norris et al. 1999). Hurricane Ike (2008) and Hurricane Katrina (2005) tell similar stories about the prevalence and persistence of PTSD after a storm. The majority of adults who developed PTSD following Katrina, for example, had not recovered within 18 to 27 months after the event (McLaughlin et al. 2011; Norris, Sherrieb, and Galea 2010).

Other manifestations of mental health problems, such as domestic violence and alcohol abuse, may also rise after a flood. Rates of domestic violence nearly doubled after Hurricane Katrina—from 4.2 to 8.3 percent—and extensive floods in the Midwest floods of 1993 were followed by increases both in domestic violence and alcohol abuse (Axelrod et al. 1994).

Recovering from depression and post-traumatic stress disorder brought on by a flood can take years.

The increased use of mental health services in the wake of a flood contributes to its overall economic cost. Studies of severe flooding events in the United Kingdom in 2007 demonstrated that 90 percent of the public health costs of the floods were attributable to mental health problems (US Environment Agency 2010).*

* Based on estimates of people's willingness to pay to avoid exposure to the distress caused by flooding.

© Randy L. Rasmussen/The Oregonian

An elderly couple contemplates their water-filled basement caused by Oregon's 2009 winter floods. Long after floodwaters have dried up, many flood victims continue to be plagued by depression, post-traumatic stress disorder, and other mental health problems. The enormous cost of mental health services aimed at helping flood victims has yet to be fully considered.

Strains on Our Health Care Systems

Some of the public health costs of flooding—such as those associated with gastrointestinal symptoms—are incurred very soon after the event and thus are clearly attributable to the flood itself. But other costs can be more long-term and hidden to the public eye—such as those associated with stress and other ongoing mental health problems. While these long-term costs can be more difficult to track, there is clear evidence that the public health challenges arising in the wake of a flood place strains on our already taxed health care systems. Hurricane Floyd of 1999, for example, had substantial long-term consequences regarding the use of health care services. After the storm, the percentage of Medicaid enrollees accessing services remained at normal levels, but there were significant increases in emergency-room visits, outpatient care, and pharmacy use even one year after the storm. These increased demands for health care services caused average state and federal expenditures to rise by $7.14 per enrollee per month in the hurricane-affected counties. All told, this increase in spending added up to more than $13.3 million in Medicaid expenditures in the wake of the storm (Domino et al. 2003).

After Hurricane Floyd, there were significant increases in emergency-room visits, outpatient care, and pharmacy use even one year after the storm.

The Top Five Hidden Health Risks of Extreme Precipitation and Flooding

Flooding presents immediate dangers to human life, such as drowning, physical trauma, and electrocution. Other health hazards associated with flooding, however, are less visible. Here we summarize five of the more hidden health risks and we refer you to some resources to help you protect your family.

© FEMA/Jeannie Mooney

HIDDEN HEALTH RISK #1:

Drowning While Driving

Where It Comes From: Of the people killed in U.S. floods in 2010, 44 percent died in vehicles (NOAA 2010). Strong rains or rapid snowmelt can bring fast-moving water that is very unpredictable, and people make the poor decision to drive down a flooded road either because the vehicle in front of them makes it or because they think the water doesn't look too deep. Only 18 inches of water can lift your car or SUV; once buoyant, the water will easily push the vehicle sideways. Most vehicles will then tend to roll over, trapping those inside and washing them downstream (NOAA 2012).

Ideas to Protect Your Family:

- Monitor local news sources for vital weather related information.
- Do not attempt to drive through or wade into floodwater; instead, turn around.
- Do not attempt to cross streams. If flooding occurs, get to higher ground.

For more information: Consult your local health department or the National Oceanic and Atmospheric Administration (NOAA), which provides useful information through its "Turn Around, Don't Drown" campaign *(www.srh.noaa.gov/tadd)*.

© FEMA/Patsy Lynch

HIDDEN HEALTH RISK #2:

Waterborne Diseases Contaminating Drinking Water

Where It Comes From: Extreme precipitation and flooding can sometimes overwhelm potable water infrastructure and wells, which reduces or prevents water purification.

Ideas to Protect Your Family:

- Sign up for local boiled-water alerts and have bottled water stored for emergencies.
- Always be wary of foul-smelling or discolored water.

For more information: Consult your local drinking water treatment facility, health department, or CDC (*www.cdc.gov/healthywater/emergency/toolkit/helpful-tips-drinking-water-outbreak.html#general).*

HIDDEN HEALTH RISK #3:

Sewage Backup in Plumbing or Basements

Where It Comes From: Extreme preciptation and flooding can cause local sewage lines and septic tanks to overflow, sometimes resulting in sewage backing up into people's residences. Areas with combined rainwater-evacuation and sewage-transport networks (called combined sewer overflow systems) often experience such overflows. Combined sewer systems serve about 772 U.S. communities totaling some 40 million people.

© John Magruder

Most communities with combined sewer systems are located in the Northeast, Great Lakes, and Pacific Northwest regions, as shown in the map on page 6.

Ideas to Protect Your Family:

- Install plumbing (a backwater valve) to prevent sewage backup if at risk.
- If you suspect that raw sewage has backed up into your home, hire professionals to do the cleaning.

For more information: Consult your local health department, sewage treatment facility, or the CDC *(http://emergency.cdc.gov/disasters/floods/after.asp).*

© D. Falconer/PhotoLink

HIDDEN HEALTH RISK #4:

Bacteria and Sewage in Local Waterways, Swimming Holes

Where It Comes From: During flooding, untreated sewage can contaminate local rivers, lakes, ponds, and even ocean beaches; sometimes raw sewage and street contaminants (e.g., motor oil, dog excrement) or pesticides can flow directly into nearby streams or lakes.

Ideas to Protect Your Family:

- Sign up for local swimming alerts and pay attention to warnings from local health departments regarding the community's lakes, rivers, and ocean beaches.
- It may not be safe to swim in local water bodies immediately after a strong storm.

For more information: Consult your local health department or the CDC *(www.cdc.gov/healthywater/emergency/toolkit/rwi-outbreak-toolkit.html).*

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HIDDEN HEALTH RISK #5:

Dangerous Mold in Indoor Air

Where It Comes From: Water intrusion anywhere in your home can cause toxic mold to grow in ceilings, walls, or insulation.

Ideas to Protect Your Family:

- Try to prevent leaks, maintain gutters, and raise the land around the house so that water can flow away.
- After leakage try to dry affected area thoroughly with a dehumidifier or replace moldy drywall, ceiling panels, carpets, or insulation.
- Plan and implement remediation activities with professional help if possible—or when cleaning, always wear an N95 protective face mask (available at local home supply stores).
- Discard mattresses, furniture pieces, or rugs that are waterlogged.

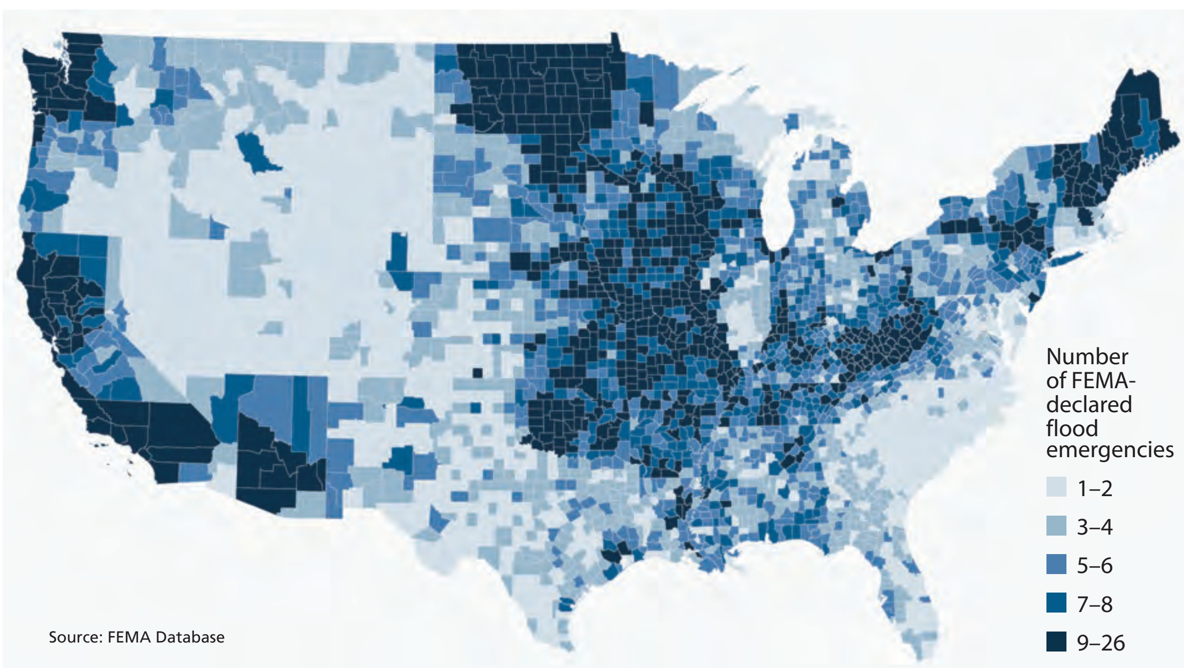
For more information: Consult your local health department or the CDC *(http://emergency.cdc.gov/disasters/ mold/protect.asp).*

Growing Risk: Development, Climate, and Flooding in the United States

How Does Development Affect Flood Risk?

Our exposure to flooding risks depends heavily on where we live, how we develop our land, and the precautionary measures we choose to invest in (such as levees, stormwater drainage systems and healthy ecosystems that reduce flood risks). The population of Americans living along coastlines and within the floodplains of rivers, streams, and lakes has grown twice as fast as the general population, putting more people and homes at risk for flood-related hazards. Over half (53 percent) of all U.S. residents now live in coastal counties—including those surrounding the Great Lakes—that could be susceptible to flooding (Glaeser 2011; US Census Bureau 2010). And estimates from the Federal Emergency Management Agency (FEMA) suggest that about 10 million households (approximately 11 percent of the U.S. total) are located within floodplains. The average annual U.S. flood losses in the

FIGURE 5. **FEMA-Declared Flood Emergencies by County, 1965–2009**



If a flood emergency is too severe or large to be managed by state and local resources, the state governor can seek federal assistance. As this map shows, federal emergencies have been declared in every region of the continental United States in the last half century. The Federal Emergency Management Agency (FEMA) works together with states to do a formal damage assessment and makes a recommendation to the president for additional disaster assistance. Threats to public health and safety, along with other measures of flood impacts, form a key part of the damage assessment.

past 10 years (2001–2010), were more than $10.2 billion (NOAA 2011).* But extreme rainfall does not just flood the homes of people in floodplains. Anyone can be vulnerable, both physically and financially, to extreme precipitation and flooding—including people who live outside of floodplains. Furthermore, extreme precipitation without flooding can cause major damage to residential and commercial properties, such as roof damage, rising ground water tables, and seepage into basements. People outside of high-risk areas file over 20 percent of National Flood Insurance Program claims and receive one-third of disaster assistance for flooding (NFIP 2010). Almost every county in the United States has experienced a flood disaster in the last 50 years (Figure 5).

The movement of people into coastal areas and floodplains also affects the terrain, which in turn affects vulnerability. The cutting of trees and clearing of land associated with building homes and roads leave the land less able to absorb rainfall, which increases the volume of runoff into rivers and sewers during a storm (Greenough et al. 2001). As a result, as we increasingly develop the land within floodplains, we reduce the land's natural defenses—and heighten our own exposure—to flooding. Thus many communities are choosing to restrict development in floodplains. These communities are working to buy repetitive-loss properties, preserve floodplains as open spaces or convert them to recreational use (such as for golf courses), and enforce disaster-resistant building codes.

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Record-breaking rains throughout the Midwest in July 2008 led to overflowing rivers and flash floods that inundated towns such as this one in Wisconsin. The number of Americans living along coastlines and within the floodplains of rivers, streams, and lakes has grown twice as fast as the general population, putting more people and homes at risk for flood-related hazards.

How Does Climate Change Increase Flood Risk?

CLIMATE CHANGE IS EXPECTED TO make extreme rainfall events more frequent and more intense, which can translate into an overall increase in the risk of flooding (IPCC 2011, Meehl et al. 2007). Flooding occurs when heavy precipitation events exceed the land's capacity to absorb water. The frequency of heavy rainfall events in the United States on average has been increasing over the past four decades (see Figure 6). Large snowmelts and strong storms (such as hurricanes) that push ocean water inland from the shore (a condition known as storm surge) also cause flooding.

As Earth's climate warms, the air is able to hold more water vapor, allowing for more intense downpours that can lead to flooding. At the same time, more frequent and prolonged droughts may lead to wildfires that can

* These figures include damages from freshwater flooding (associated with rainfall), but not coastal flooding caused by storm surge. Therefore, although the total for 2005 is very large ($43 billion), it still does not account for most of the flooding damages produced by Katrina since they were largely due to storm surge.

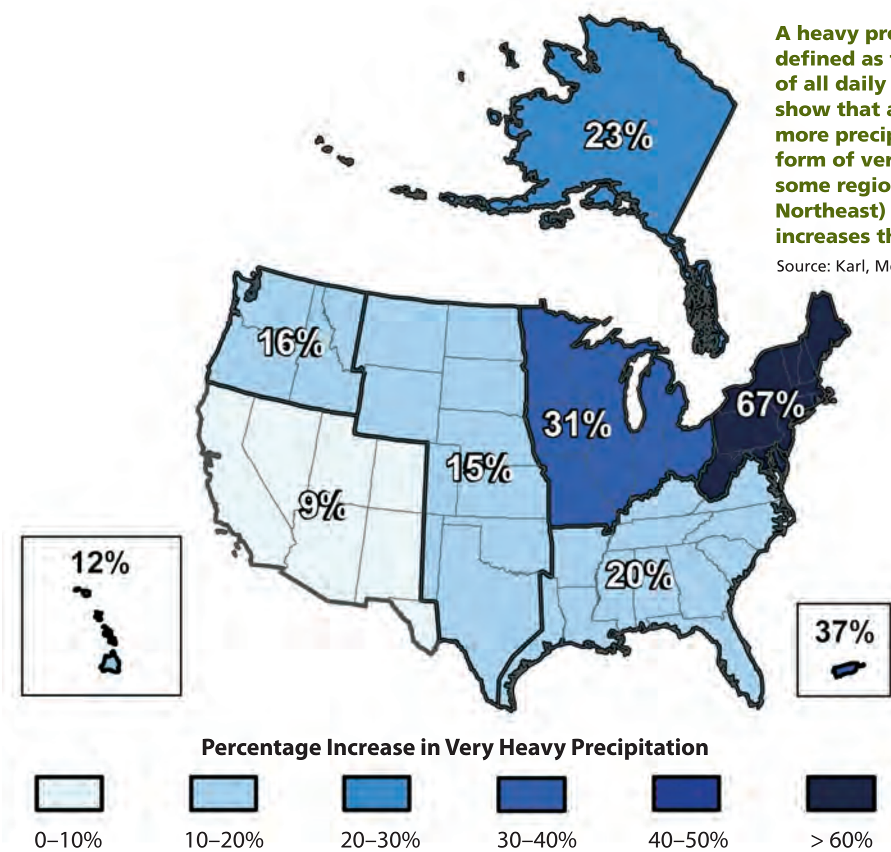
change soil surface properties and lead to increased runoff when rainstorms do occur (DeBano et al. 1998).

As emissions of heat-trapping gases continue to rise and our climate continues to warm, scientific models project an increase in the intensity of extreme precipitation events both within the continental United States and throughout North America (Karl, Melillo, and Peterson 2009; Tebaldi et al. 2006). These models show that more and more rain will come in the form of heavy events, with lesser amounts from more manageable (light or moderate) rainfalls (see Figure 7). The extent of the shift to heavy rainfall will depend on the amount of heat-trapping gases emitted; the higher the emissions, the greater the risk of heavy downpours.

However, the story is not just about the future; mounting evidence suggests these changes are already under way. Heavy precipitation events across the United States have increased in number by more than 30 percent since 1900, and they represent a greater proportion of the total annual rainfall (Groisman, Knight, and Karl 2001). In the Midwest and Northeast regions, such events increased by 31 percent and 67 percent, respectively, over the course of the 20th century (Karl, Melillo, and Peterson 2009). To begin determining the driver of these changes, some attribution ("fingerprinting") studies have been conducted; they found that emissions of heat-trapping gases are contributing to heavier precipitation and increased flood risk in some cases (Min et al. 2011; Pall et al. 2011).

Climate change can also increase flooding risk through the combination of sea-level rise and intense storms, which leave coastal areas more exposed to storm surge. As our climate continues to warm, global sea level is projected to increase between 0.18 and 0.59 meters (0.6 to 1.9 feet), depending on the emissions scenario, by the end of the century (IPCC 2007). Subsequent studies (Rahmstorf 2010; Pfeffer et al. 2008) have generally projected ranges with even greater sea-level rise—some of the high values of the ranges are around 2 meters (6.6 feet) by 2100. The high ends of the projections should be treated as plausible, though less likely to occur. Meanwhile, sea-level rise is already occurring. Over the period 1958–2008, much of the U.S. coastline experienced increased sea level (Karl,

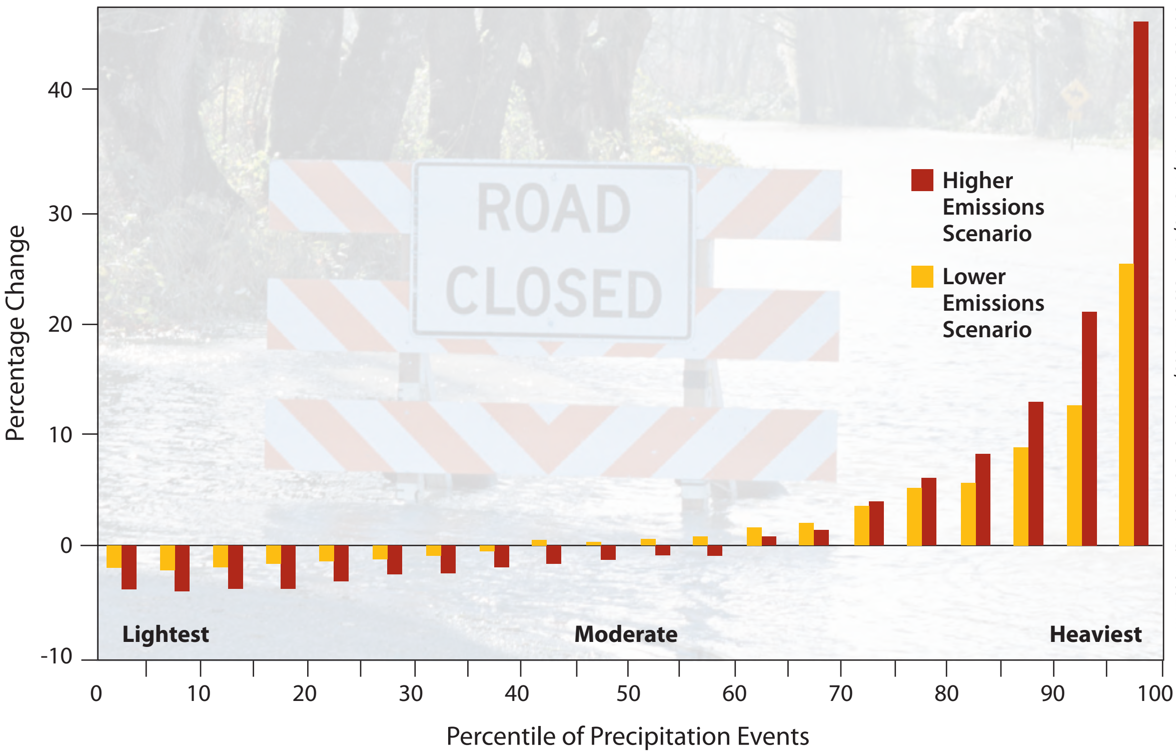
FIGURE 6. Measured increases in the heaviest precipitation events for the United States over the period 1958–2007



A heavy precipitation event is defined as the heaviest 1 percent of all daily events. The observations show that across the entire country more precipitation is coming in the form of very heavy events, with some regions (i.e., Midwest and Northeast) showing much larger increases than others.

Source: Karl, Melillo, and Peterson 2009

FIGURE 7. **Projected changes by the end of the century in precipitation falling in light, moderate, and heavy events for North America**



Source: Based on Karl, Melillo, and Peterson 2009; Photo: © C. Sherburne/PhotoLink

The projections are based on the climate models used in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment report. Two scenarios represent continued carbon emissions. The lower emissions scenario (yellow bars) is the IPCC B1 scenario and the higher scenario (red bars) is IPCC A2 (IPCC 2000). Both scenarios show increases in the heaviest precipitation events with decreases in the lightest. The actual degree of change will depend on the amounts of heat-trapping gases emitted.

Melillo, and Peterson 2009). Given the same magnitude of storm surge, more land area is affected when sea level is high than when sea level is low (Najjar et al. 2000).

Hurricanes and tropical storms can also increase the risk of flooding, as they often bring strong wind and heavy rain and may be affected by a changing climate (Knutson et al. 2010). Projections made under various assumptions of 21st century warming generally show an increase in wind speed and also increased precipitation with these storms, although these variables depend on location and other factors (IPCC 2011; Karl, Melillo, and Peterson 2009; and IPCC 2007).

Projections also show an overall decrease in the total number of storms but an increase in the likelihood of intense storms. These intense events pack high winds that can increase storm surge and heavy rains, which may lead to coastal and inland flooding. Overall, climate change is increasing our risk of flooding on a number of fronts—including heavier precipitation, more intense hurricanes and increased sea levels.

Climate change is increasing our risk of flooding on a number of fronts—including heavier precipitation, more intense hurricanes and increased sea levels.

Where Do We Go From Here?

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Reducing carbon emissions requires a multi-pronged approach that includes improving energy efficiency and increasing renewable energy alternatives, such as solar and wind. Pictured above are some efforts already under way: a wind farm in Somerset, PA, and solar panels at the Chicago Center for Green Technology. Policy action and market-based programs are crucial to spurring this shift to a clean energy economy. The Regional Greenhouse Gas Initiative (RGGI), for example, is a cooperative effort among nine Northeastern states that has capped carbon emissions from the power sector and generated revenue that has been invested in efficiency and renewables projects.

SCIENTISTS WARN THAT CONTINUING to overload the atmosphere with carbon dioxide and other heat-trapping gases will increase the risk of many types of extreme weather events, including those leading to floods (IPCC 2011). Unfortunately, global emissions of carbon dioxide, the heat-trapping gas that is the primary driver of climate change, saw their largest ever increase in 2010 (CDIAC 2011). Emissions now exceed the worst-case scenarios that scientists analyzed in the most recent assessment of the Intergovernmental Panel on Climate Change (IPCC 2007).

The most likely projections of climate change mean heavier precipitation, more flooding, and, in turn, greater potential for severe flood-related health threats—not only immediate threats but also those that are more hidden and persistent. These health risks place significant burdens on our families, health care systems, and national economy. The quantifiable health costs of flooding are in the billions of dollars—and that doesn't include significant costs such as those related to mental health, unreported disease cases, and lost school and work days. Families and communities can take steps to reduce their chances of getting sick or worse because of flooding. But it's important to understand that these risks will only grow unless we act to reduce emissions of heat-trapping gases and thus slow the pace of climate change.

The states continue to lead the way. California, for example, has instituted a state economy-wide program for cutting emissions and 28 states and the District of Columbia have requirements for utilities to switch to renewable energy sources (UCS 2012). There is action on the national level as well—the Environmental Protection Agency is expected to soon move forward under the Clean Air Act to reduce carbon emissions from power plants and refineries. But more action is needed in Congress to protect our families and communities with effective policies on climate, energy, and preparedness.

Building Flood-Resilient Communities: Two Case Studies

The United States needs to take aggressive measures to reduce carbon emissions in order to minimize the risks of climate change, but it also needs to effectively prepare for whatever climate changes do occur. We must build on current federal and state actions to implement a comprehensive national strategy for creating more resilient communities.

The adaptations required to cope with greater flood risk in particular will vary from place to place, depending on the type of flooding that is most likely in a given locale, the severity of that flooding, and the existing infrastructure. Many states have adopted climate action plans that include the updating of infrastructure and improvement of emergency-management plans.

At the local level, efforts to strengthen stormwater-management structures, sewer systems, and naturally protective landscapes can build a town's resilience to flooding. Below we briefly discuss the adaptation programs in two altogether different municipalities.

CASE STUDY 1:

Chicago, IL

Based on its record-breaking floods in recent years and on projections that call for a growing number of extreme precipitation events through the middle of this century, the City of Chicago is implementing plans to protect its residents from the growing risk of flooding. Since 1997 the city installed about 200,000 rain blockers to limit the amount of water entering sewers during storms. While the program is still a work in progress, areas with rain blockers have experienced reduced rates of basement flooding during heavy rains (City of Chicago 2010). Because Chicago's sewer system combines water and sewage, the success of the rain blockers means that fewer people are exposed to sewage in their homes after storms.

The city is also working to minimize the potential volume of floodwaters by expanding the area of permeable surfaces within the city. As of 2010, 100 green alleys had been installed as a way of reducing the amount of rainfall landing on impermeable pavement and concrete. These alleys, in combination with rooftop gardens and rain barrels, help to reduce runoff that contributes to flooding. Overall, the city has increased its permeable area by 55 acres since 2008 (City of Chicago 2010).

Chicago is also assessing its drainage infrastructure and preparing a drainage-solutions strategy as part of a larger citywide effort to adapt to climate change (Coffee et al. 2010). The city has released preparedness brochures to help residents protect themselves and their property from flooding and is actively encouraging people to install rain barrels and backup power for sump pumps.

No one silver bullet will prevent flooding, but the City of Chicago has invested in a suite of successful practices that have increased its permeable surface area, which reduces stormwater runoff, by over 55 acres. For example, the city has seen a proliferation of rooftop gardens (left), rain barrels, and permeable pavements (middle). Rain gardens, such as the one that students constructed as part of the Green Affordable Housing Initiative (right), also reduce runoff.

Photos: Center for Neighborhood Technology

CASE STUDY 2:

Ocean City, MD

Ocean City, located on a narrow strip of barrier island on Maryland's Atlantic coast, recognized as early as 1875 the need to protect its shoreline from flood damage caused by hurricanes and other storms. In 1985, after suffering extensive damage inflicted by Hurricane Gloria, the city began a beach-replenishment project that continues to this day. By constructing 8.3 miles of new sand dunes, a 1.5-mile seawall, and a berm made of sand along the coastline, the city has experienced very little damage during recent storms such as Hurricane Irene. Since 1991, when the first phase of the project was completed, there have been no injuries, deaths, or structural damage resulting from ocean flooding (McGean 2011).

In addition to protecting its shoreline, Ocean City has enacted measures to keep its residents out of harm's way during potential flooding events. State laws firmly restrict oceanfront development (McGean 2011) and the city has developed a flood-warning system to alert the public of potentially hazardous conditions (Houston 2012). Because Ocean City's beaches and residents are protected from storms, they continue to provide an important source of revenue for the city and state. Ocean-related tourism in and around Ocean City generates more than $500 million per year (Cicin-Sain et al. 2006).

Ocean City, MD, keeps its residents and economic assets safe by implementing diligent upkeep and forward-thinking planning. For example, the city has protected its well-developed shoreline (left) through construction of new sand dunes, a sea wall, and a sand berm (right), visible between the buildings and beach. Some severe coastal storms require beach maintenance (middle) afterward.

(Left to right) © Wikimedia; © Eric Lynch; © iStockphoto.com/Chris Parypa

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CLIMATE CHANGE AND YOUR HEALTH

Over the past 30 years, floods have proved to be one of the most deadly and expensive types of natural disaster in the United States. Most cost estimates, however, fail to account for the public health impacts that follow a flood—and the toll inflicted on families long after the waters have receded. With climate change projected to worsen the extreme precipitation events that can lead to flooding, this burden on American families may soon grow even heavier.

After the Storm: The Hidden Health Risks of Flooding in a Warming World illuminates the hidden health hazards of extreme precipitation and flooding in the United States and describes what can be done to protect our families. The report also explains how climate change may increase the risk of extreme precipitation events and flooding, and how development decisions made today can lessen the impact of these disasters.

Protecting Americans from the dangers of extreme rainfall and floods requires both reductions in carbon emissions and strong local preparedness actions. We can all make choices that build community resilience and reduce these risks. The students pictured below, for example, worked with Chicago's Center for Neighborhood Technology to build a rain garden that absorbs excess water and protects the nearby St. Margaret Mary Church from flooding.

© Center for Neighborhood Technology

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