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Potential Increases in Hurricane Damage in the United States: Implications for the Federal Budget

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Summary

Damage from hurricanes is expected to increase significantly in the coming decades because of the effects of climate change and coastal development. In turn, potential requests for federal relief and recovery efforts will increase as well. The Congressional Budget Office has estimated the magnitude of the increases in hurricane damage and the associated amounts of federal aid if historical patterns hold. In addition, CBO examined three approaches to reducing the amount of such federal assistance: limiting greenhouse gas emissions; shifting more costs to state and local governments and private entities, thereby reducing coastal development; and investing in structural changes to reduce vulnerability to hurricanes. The accompanying working paper provides a detailed discussion of the data and methodology CBO used to estimate hurricane damage.[1]

What Are CBO's Estimates of Hurricane Damage and of Related Federal Spending?

CBO concludes that, over time, the costs associated with hurricane damage will increase more rapidly than the economy will grow. Consequently, hurricane damage will rise as a share of gross domestic product (GDP), which provides a measure of the

1. See Terry Dinan, *CBO's Approach to Estimating Expected Hurricane Damage*, Working Paper 2016-02 (Congressional Budget Office, June 2016), www.cbo.gov/publication/51610.

Notes: Unless otherwise indicated, all monetary values are expressed in 2015 dollars and all years are calendar years.

Percentages in tables and figures may not add to 100 because of rounding.

nation's ability to pay for that damage. According to the agency's estimates, expected annual damage currently amounts to 0.16 percent of GDP (or about $28 billion); by 2075, however, that figure reaches 0.22 percent (equivalent to about $39 billion in today's economy; see Summary Figure 1). Roughly 45 percent of that increase is attributable to climate change and 55 percent to coastal development.

The percentage of the population exposed to substantial damage is likely to grow as well. In CBO's estimation, less than 0.4 percent of the U.S. population, or about 1.2 million people, currently lives in counties where expected hurricane damage per capita is greater than 5 percent of the county's average per capita income. By 2075, that share will rise to 2.1 percent of the population, or about 10 million people, CBO estimates.

In its analysis, CBO estimated annual federal spending for relief and recovery as a percentage of expected hurricane damage. If that percentage stays roughly the same as it has been over the past decade—a prospect referred to in this report as a historical cost scenario—it will rise from 0.10 percent of GDP under current conditions (equal to $18 billion) to 0.13 percent of GDP in 2075 (about $24 billion in today's economy).[2] If federal spending as a percentage of hurricane damage changed, those amounts could be larger or smaller.

How Did CBO Estimate Hurricane Damage?

CBO estimated the change in damage from hurricanes by comparing expected damage under current conditions with expected damage in selected future years—2025, 2050, and 2075—under the conditions that are expected to prevail at the time. Expected hurricane damage in any given year will depend on four conditions:

- Sea levels in different states,
- The frequency of hurricanes of various intensities,
- The population in coastal areas, and
- Per capita income in coastal areas.

For each set of conditions, CBO estimated expected damage using commercially developed, state-of-the-art "damage functions" (which translate hurricane occurrences, state-specific sea levels, and current property exposure into state-specific expected damage) and the agency's own assessment of the relationship between changes in population and per capita income and changes in hurricane damage.

2. Those estimates are not related to CBO's 10-year baseline projection for disaster-related spending in the federal budget, which relies on different conventions. As directed by the law governing the construction of that baseline, federal funding for most discretionary disaster-related accounts in the federal budget is equal to the most recent year's annual appropriations for those accounts plus an increase to factor in the effects of inflation.

Two of the four conditions—sea levels and the frequency of hurricanes—are affected by climate change. Strong consensus exists within the scientific community that climate change, the result of growing emissions of greenhouse gases worldwide, will cause sea levels to rise, leading to more-destructive storm surges. The effect of climate change on hurricanes is less certain, but scientists find that it could increase the frequency of hurricanes in the North Atlantic, particularly the most intense categories of hurricanes.

The other two conditions—population and per capita income in counties that are vulnerable to damage from hurricanes—are affected by coastal development. Ongoing trends in coastal development will similarly exacerbate hurricane damage, even in the absence of any increase in sea levels or in the frequency of hurricanes.

In its analysis, CBO used projections made by leading researchers to construct distributions (indicating the range and probability of alternative outcomes) of future sea levels and the frequency of hurricanes. The agency used its own projections to construct distributions of population and per capita income. On the basis of those projections, CBO constructed a distribution of expected damage for each future year considered in this report by conducting thousands of simulations. Each simulation included a unique set of draws (random selections) from the distributions of the four underlying conditions and yielded an estimate of expected damage based on those draws.

How Did CBO Estimate Future Federal Spending Related to Hurricane Damage?

Federal aid that is provided following hurricanes supports emergency relief operations, long-term recovery activities, and a variety of programs that are designed to improve the resiliency of infrastructure and to prepare communities for future disasters. Most such spending is not mandated by law; rather, it is the outcome of decisions made by policymakers in the aftermath of disasters and is funded primarily through supplemental appropriations.

Federal spending in response to hurricanes varies from storm to storm. However, measured as a percentage of total damage—estimates of which are produced by the National Oceanic and Atmospheric Administration (NOAA)—such spending has averaged about 60 percent for the nine hurricanes that made landfall since August 2005, when Hurricane Katrina struck the Gulf Coast. For CBO's historical cost scenario, the agency estimates that federal expenditures would continue to average 60 percent of total damage from hurricanes.

What Policies Might Decrease the Pressure for Federal Spending in the Aftermath of Hurricanes?

In considering how to ease the pressure to spend federal dollars on relief and recovery from hurricane damage, CBO examined three diverse approaches.

Limit Greenhouse Gas Emissions. A coordinated global effort to significantly reduce emissions could lessen hurricane damage in the United States between now and 2075, but the extent of the reduction would be uncertain and it would probably occur in the latter half of this century because the rise in sea levels has already been set in motion and would be hard to slow down. However, a significant reduction in U.S. greenhouse gas emissions, without corresponding decreases in the emissions of other large economies, would probably not reduce hurricane damage appreciably between now and 2075, in part because U.S. emissions constitute a shrinking share of global emissions.

Shift More Costs to State and Local Governments and Private Entities, Thereby Reducing Coastal Development. CBO projects that, continuing historical trends, the population in coastal areas will grow more rapidly than in the United States as a whole. To the extent that households, businesses, and state and local governments in coastal areas do not bear the full cost of hurricane damage, such growth is subsidized by U.S. taxpayers in general. Boosting the share borne by private and public entities at the state and local levels would give people an incentive to more fully account for expected hurricane damage when choosing where to live and locate businesses, thereby reducing development in vulnerable areas. Policies that would accomplish those goals include the following:

- Expanding the use of flood insurance and raising premiums to more accurately reflect the costs of expected damage;
- Increasing the minimum amount of statewide per capita damage that is the primary consideration for providing federal assistance; and
- Reducing the share of costs borne by the federal government (as opposed to state and local governments) for assistance provided from the Federal Emergency Management Agency's (FEMA's) Disaster Relief Fund (DRF), which accounts for roughly one-half of federal spending on relief and recovery from hurricanes.

Invest in Structural Changes to Reduce Vulnerability to Hurricanes. In recent years, federal agencies have placed a greater emphasis on measures designed to reduce vulnerability to future hurricane damage, such as elevating roads and using flood-resistant building materials. Such hazard-mitigation measures typically increase the up-front costs of construction or restoration but reduce costs associated with future damage. To the extent that up-front investment pays off, the federal government could reduce its hurricane-related spending by undertaking more hazard mitigation or by providing incentives for individuals, businesses, and state and local governments to do so.

Overview of Climate Change and Coastal Development and Their Effects on Hurricane Damage

The magnitude of hurricane damage in future years will be affected both by climate change and by coastal development. Each individual factor is likely to increase the amount of damage; moreover, each factor will amplify additional damage caused by the other. For example, rising sea levels will lead to stronger storm surges, which will compound the additional damage that will occur if more homes and businesses are built in vulnerable coastal areas.

Climate Change

Human activities around the world—primarily the burning of fossil fuels and widespread changes in land use—are producing growing emissions of greenhouse gases. Experts in the scientific community have concluded that a portion of those emissions are absorbed by the oceans, but a substantial fraction persists in the atmosphere for centuries, trapping heat and warming the Earth's atmosphere.

Accumulating heat in the atmosphere has disrupted the natural balance that is normally maintained between heat in the atmosphere and heat in the oceans. The oceans respond to that imbalance by absorbing heat from the atmosphere; however, that absorption occurs very slowly. As a result, even if greenhouse gas emissions were to cease, the oceans would continue to become warmer for centuries until they eventually came into balance with the atmosphere. Continued warming of the oceans will cause sea levels to rise through two processes: First, it will cause oceans to expand because the volume of water increases as it warms; second, in concert with the warming of the atmosphere, it will trigger melting of sections of the ice sheets in Greenland and Antarctica.

CBO's estimates of hurricane damage in selected future years—2025, 2050, and 2075—are based on experts' assessments of the degree to which climate change will alter sea levels along the U.S. coastline and affect the frequency of hurricanes (the average number of occurrences in a given year). Although scientists generally agree that climate change will cause sea levels to rise, the pace at which that will occur is uncertain. Considerably less agreement exists about the effect of climate change on the frequency of hurricanes of various strengths. (There are five categories of hurricanes, which are classified on the basis of their wind speed. Category 5 storms are the most intense.) Effects on hurricane frequency are complicated by the fact that scientists expect climate change to increase some factors, such as sea surface temperatures, that increase the likelihood of hurricanes forming, while also increasing other factors, such as wind shear, that decrease that likelihood. Models produce a wide range of potential outcomes, but many predict an increase in the probability of major hurricanes (Category 3 and higher) in the North Atlantic. (That possibility is discussed in greater detail below.)

Coastal Development

Between 2000 and 2010, the most recent decade for which census data are available, the population of counties that are susceptible to hurricane damage grew 22 percent faster than the overall U.S. population. (Even more rapid growth occurred between 1950 and 2000, when the population of coastal counties grew over three times faster than that of the United States. That growth was fueled, in part, by the increased availability of air-conditioning and is unlikely to be repeated.)

Continued development along the East and Gulf coasts of the United States is likely to amplify hurricane damage—even in the absence of climate change—simply by putting more people and property in harm's way. Moreover, rising sea levels and changes in the frequency of hurricanes will compound the growth in damage caused by coastal development. CBO approximated increases in property exposure by estimating increases in population and per capita income in areas that are vulnerable to hurricane damage. The agency's analysis also accounted for the possibility that substantial increases in hurricane damage could slow the rate of coastal development. Finally, CBO considered alternative estimates of the relationship between increases in exposed property and increases in hurricane damage, accounting, for example, for the possibility that taller buildings could lessen per capita damage from storm surges.

Projecting Hurricane Damage: CBO's Methodology

Actual hurricane damage in any given future year could vary enormously for several reasons. First, hurricanes—particularly the most intense hurricanes—occur infrequently and irregularly. Second, the magnitude of damage caused by a hurricane of a particular strength, such as a Category 3 storm, could vary greatly depending on where it makes landfall. The same category of hurricane could result in minor damage if it struck an unpopulated section of the coast or major damage if it struck a large city. Finally, the timing of impact can be important. A hurricane that makes landfall at high tide, as Hurricane Sandy did in 2012, will result in far more damage than if the same hurricane hit at low tide. In combination, those factors make it difficult to discern changes in long-term trends in hurricane damage from changes in actual damage over time.

Unlike *actual* damage, which varies substantially from year to year, *expected* damage is constant for a given set of climatic and demographic conditions (see Box 1). CBO's analysis isolates the effects of long-term trends caused by climate change and coastal development by comparing expected damage at various points in time.

Overview of CBO's Methodology

CBO's analysis involved three steps. First, the agency estimated expected hurricane damage under current conditions—that is, current sea levels and hurricane frequency, as well as current population and per capita income in coastal areas. That estimate served as a "reference case" against which to compare expected damage in future years.

Next, CBO projected how those conditions would change over time. Specifically, for 2025, 2050, and 2075, CBO estimated the likelihood of potential changes of various amounts in each of the four types of underlying conditions—that is, changes in sea levels for affected states, hurricane frequency, population in counties vulnerable to hurricane damage, and per capita income in those counties—that would lead to differences in expected hurricane damage. For each of those conditions, the agency's estimates indicated a range of possible values and the probability that the actual value would fall within various sections of that range.

Finally, CBO determined expected damage under the new conditions for 2025, 2050, and 2075. To do so, the agency produced a distribution of expected damage by simulating expected damage for each of those years 5,000 times. Each simulation used a unique set of projected changes for each of those four underlying conditions—obtained by making random draws (or selections) from the distributions of potential changes in those conditions that CBO estimated. (That technique is often referred to as a Monte Carlo analysis.) The agency assessed changes in expected damage over time by comparing the distributions of such damage in the selected future years to expected damage in the reference case. For each distribution of expected damage in a future year, CBO reports the mean (that is, the average) and the "likely range," which includes the middle two-thirds of the distribution of estimates from the simulations. The accompanying working paper provides a detailed discussion of the data and methodology CBO used to estimate hurricane damage.[3]

Step 1. Estimating Expected Damage on the Basis of Current Conditions: The Reference Case

The first step in estimating changes in future hurricane damage involved creating a reference case of expected damage under current conditions for climate and coastal development. CBO's estimate, which includes the adverse effects of high winds and storm surges on property, contents, and business activity, was obtained using damage functions provided by Risk Management Solutions, or RMS (see Box 2).[4] Those damage functions incorporate the probability of landfall at various locations for hurricanes of different categories and indicate expected damage, taking into account the following:

3. See Terry Dinan, *CBO's Approach to Estimating Expected Hurricane Damage,* Working Paper 2016-02 (Congressional Budget Office, June 2016), www.cbo.gov/publication/51610.

4. RMS is a catastrophe risk modeling company. Results produced by those models are used worldwide by many insurance companies, reinsurers, and financial institutions to assess their exposure to risk. RMS has developed damage functions that translate U.S. hurricane occurrences into state-specific estimates of expected damage. A more detailed discussion of the damage functions and CBO's assessment of their validity is provided in the working paper that accompanies this report. For a description of the RMS model, see Michael Delgado and others, "Technical Appendix: Detailed Sectoral Models," in Trevor Houser and others, *American Climate Prospectus: Economic Risks in the United States* (Rhodium Group and Risk Management Solutions, October 2014), p. C-6, http://climateprospectus.org/publications.

- Existing sea levels in each state,
- The expected number of hurricanes of each category that will make landfall in the United States under current conditions, and
- The current value of residential and nonresidential property exposed to hurricane damage in each state.

In CBO's reference case, wind damage accounts for 64 percent of overall expected damage from hurricanes, and storm surges account for 36 percent; however, the actual percentages can vary widely from storm to storm (see the table in Box 2). Hurricane damage is expected to be greater in some coastal areas than in others. The top three states in terms of expected damage (in descending order) are Florida, Texas, and Louisiana. Those states make up over three-quarters of the total expected annual hurricane damage; Florida alone accounts for more than half of the damage (see Figure 1).

Step 2. Estimating Changes in the Four Types of Underlying Conditions That Affect Expected Damage: Inputs to CBO's Analysis

For 2025, 2050, and 2075, CBO estimated the range and likelihood of potential changes in each of the four types of underlying conditions that would lead to changes in expected hurricane damage: sea levels (which vary by state), the frequency of hurricanes, population in counties that are vulnerable to hurricane damage, and per capita income in those same counties.

Effects of Climate Change on Underlying Conditions. Two of the four types of conditions that underlie CBO's analysis—rising sea levels and changes in the frequency of hurricanes—are attributable to climate change.

Changes in Sea Levels. Scientists generally expect sea levels to rise as a result of climate change, but the magnitude of that increase is uncertain. That uncertainty is complicated by the fact that such increases will vary along the East and Gulf coasts. In its analysis, CBO anticipated that future sea levels will change over time and vary by state, consistent—by design—with the range of increases in sea levels that the Intergovernmental Panel on Climate Change (IPCC) predicts will occur globally.[5]

5. The state-specific projections that CBO used were supplied by RMS, which based its projections on Robert E. Kopp and others, "Probabilistic 21st and 22nd Century Sea-Level Projections at a Global Network of Tide-Gauge Sites," *Earth's Future*, vol. 2, no. 8 (August 2014; corrected, October 2014), pp. 383–406, http://onlinelibrary.wiley.com/doi/10.1002/2014EF000239/full. (The fact that the estimates were, by design, consistent with the IPCC's global projections was confirmed in a personal communication with Robert E. Kopp on September 17, 2015.)

Increases in sea levels—for any given change in the climate—will vary among states for several reasons, including differences in heat content and salinity at various locations.[6] That variation among states can be significant. For example, Florida, which accounts for the largest share of expected damage in the reference case, has the smallest projected average increase in sea level among the 22 states included in CBO's analysis. The average increase for Florida is projected to be 0.8 feet in 2050 and 1.4 feet in 2075 (see Figure 2). By contrast, the average increase for Texas, which accounts for the second-largest share of expected damage, is 1.2 feet in 2050 and 2.1 feet in 2075. The state with the largest projected increase in sea level is Louisiana, which is projected to experience an average rise of 1.7 feet in 2050 and 2.8 feet in 2075. Louisiana accounts for the third-largest share of expected damage in the reference case.

Changes in the Annual Frequency of Hurricanes. Although scientists find that climate change will affect the conditions that give rise to hurricanes, significant uncertainty surrounds the ultimate effect of climate change on the frequency of hurricanes in the United States. That effect is unclear because of uncertainties about the following:

- Future emissions of greenhouse gases,
- The effects of those emissions on the climatic conditions that affect hurricane formation in the North Atlantic Basin, and
- The relationship between those conditions and the frequency of hurricanes of different categories.

Climate change is expected to alter some conditions in ways that *increase* the probability of hurricanes forming in the North Atlantic and to change other conditions in ways that *decrease* that probability. For example, climate change is expected to increase sea-surface temperatures, which, in turn, increases instability in the atmosphere and creates conditions favorable to hurricane formation.[7] By contrast, climate change is also expected to increase wind shear over the tropical Atlantic, which tends to disrupt the formation of hurricanes. (Wind shear is the difference in the direction and speed of wind over a relatively short distance in the atmosphere.)

For its analysis, CBO used 18 different sets of projections of annual hurricane frequency in the United States. (Each set consisted of a projection of frequency for each

6. For a more complete discussion of the reasons that increases in sea levels will vary among locations, see ibid., pp. 383–384, http://onlinelibrary.wiley.com/doi/10.1002/2014EF000239/full. See also National Oceanic and Atmospheric Administration, "Sea Level Trends: Frequently Asked Questions," *Tides & Currents* (revised October 15, 2013), http://tidesandcurrents.noaa.gov/sltrends/faq.htm.

7. For a discussion of these offsetting effects, see National Oceanic and Atmospheric Administration, Geophysical Fluid Dynamics Laboratory, *Large-Scale Climate Projections and Hurricanes* (updated December 8, 2015), www.gfdl.noaa.gov/global-warming-and-21st-century-hurricanes.

of the five categories of hurricanes). Those sets, which were developed by two leading researchers, Thomas Knutson and Kerry Emanuel, include a wide range of possible outcomes but generally find an increased frequency of major hurricanes (Category 3 and higher; see Figure 3).[8]

Effects of Coastal Development on Underlying Conditions. Continued development along the East and Gulf coasts of the United States is likely to increase hurricane damage simply by increasing the amount of property that is exposed to damage. CBO approximated increases in property exposure by estimating increases in population and per capita income by county.

CBO's model included 777 counties, situated in 22 states, that were found to have some probability of hurricane damage. For each selected year—2025, 2050, and 2075—CBO produced a set of estimates of each county's population and per capita income. Those estimates were based on a combination of the counties' individual historical growth rates and the projected growth rate for the United States as a whole. To account for the uncertainty inherent in those estimates, CBO built a distribution around each estimate, allowing unforeseen circumstances to affect either individual counties or the regions in which they are located (see the working paper that accompanies this report). Those distributions included values above the projected average (resulting from some positive influence, such as the construction of a new manufacturing plant) and values below it (resulting from a negative influence, such as a major oil spill).

Step 3. Constructing Estimates of Expected Damage: The Simulations

CBO simulated expected damage for future selected years thousands of times. Each simulation used the damage functions described above (in the discussion of the reference case) and a unique set of randomly selected projections of the four types of underlying conditions that affect hurricane damage: state-specific sea levels, the frequency of hurricanes, county-specific populations, and county-specific per capita income.

CBO used the projections of sea levels and the frequency of hurricanes, along with the damage functions provided by RMS, to assess a range of possible effects of climate change on expected damage in each state. CBO adjusted the resulting "climate change only" damage estimate for each state on the basis of the agency's projections of population increases in the state's counties and per capita income. CBO's

8. Thomas Knutson is a climate modeler at the U.S. Geophysical Fluid Dynamics Laboratory, a division of the National Oceanic and Atmospheric Administration. He is also an associate editor at the American Meteorological Society's *Journal of Climate* and is co-chair of the World Meteorological Organization Expert Team on Climate Change Impacts on Tropical Cyclones. Kerry Emanuel is a professor of meteorology at the Massachusetts Institute of Technology and specializes in the mechanisms acting to intensify hurricanes. He is a member of the U.S. National Academy of Sciences.

adjustment accounted for the relative vulnerability of counties within a given state to damage from wind and storm surges (giving more weight to growth in population and per capita income in relatively vulnerable counties).

To determine a set of stylized "medium response" estimates, the agency relied on its own judgment and on the limited literature that is available on the response of damage to changes in population and per capita income in coastal areas:

- *Responses to Changes in Population*. CBO estimated that a 10 percent increase in population would trigger a relatively small (2.5 percent) increase in damage from wind and a somewhat larger (5 percent) increase in damage from storm surges. The responses reflect the fact that greater density would generate some protection from wind damage and, in the case of taller structures, from storm surges.

- *Responses to Changes in per Capita Income*. CBO estimated that a 10 percent increase in per capita income would trigger a proportionate (10 percent) increase in damage from wind and a less than proportionate (7.5 percent) increase in damage from storm surges. Those responses reflect the judgment that increases in income might result in upgrades to infrastructure—such as the construction of seawalls or the raising of buildings—that would better guard against storm surges than wind.

CBO also projected expected damage under alternative assessments of the effect of growth in the population and per capita income on the growth in damage (described below).

Results: Estimates of Expected Hurricane Damage for Selected Future Years

The combined effects of climate change and coastal development will cause hurricane damage to increase in the future, CBO estimates—both in dollar terms (expressed as a share of GDP, which provides a measure of the nation's ability to pay for the damage), and in terms of the percentage of the U.S. population living in counties where expected damage is particularly burdensome.

Damage as a Share of GDP

The growth in expected hurricane damage is expected to exceed the growth in the nation's ability to pay for such damage. The U.S. economy, and thus the nation's ability to pay for hurricane damage, is projected to grow over time: CBO estimates that GDP will be nearly four times larger in 2075 than it is today. However, CBO also estimates that the combined forces of climate change and coastal development will cause expected hurricane damage to grow more quickly than the size of the economy.

The two measures would grow proportionately through 2025: Mean expected damage in 2025 is projected to be 0.16 percent of GDP in that year, essentially the same share that is projected in CBO's reference case (0.16 percent of GDP—or about

$28 billion—today). But mean expected damage rises to 0.19 percent in 2050 and to 0.22 percent in 2075, relative to projected GDP for those years (see Figure 4). Applied to today's economy, those percentages would indicate annual expected damage of about $34 billion and $39 billion, respectively.

Uncertainty about those estimates grows over time. For example, the likely range of expected damage is one-third wider in 2075 (when the difference between the upper and lower ends of the likely range amounts to 0.16 percent of GDP) than in 2050 (when the difference amounts to 0.12 percent of GDP).[9] Based on today's economy, the middle two-thirds of CBO's estimates in 2075 lie between $27 billion and $56 billion.

The Relative Contribution of Climate Change and Coastal Development to Increasing Damage. Climate change and coastal development will occur simultaneously, and each factor will compound the increase in expected damage caused by the other. For example, rising sea levels—and the resulting increase in expected damage from storm surges—compound the increase in expected damage resulting from expanding state populations. As a result, the combined effects of climate change and coastal development increase expected damage by a greater amount than the sum of the increase in expected damage that each would bring about on its own.[10]

Considering those combined effects, CBO attributes roughly 45 percent of the increase in expected damage in 2075—that is, the rise from 0.16 percent of GDP in the reference case to 0.22 percent of GDP in 2075—to climate change and 55 percent to coastal development.[11]

Sensitivity of Results to Estimates of Hurricane Frequency by Different Researchers. The results discussed above are based on CBO's combination of estimates of hurricane frequency developed by Knutson and Emanuel. CBO repeated the analysis using predictions of hurricane frequency made by each researcher. That sensitivity analysis indicated that average expected damage was not sensitive to the choice of researcher, varying by only 0.01 percent of GDP (see Table 1).

9. The likely range in 2075 is from 0.15 percent of GDP to 0.31 percent. In 2050, it is from 0.14 percent to 0.26 percent.

10. Hypothetically, if coastal development was the only condition affecting hurricane damage—that is, if sea levels and the frequency of hurricanes were held constant—damage would increase more slowly than GDP, CBO estimates. In particular, accounting only for changes in population and per capita income between now and 2075, CBO estimates, hurricane damage would increase at a rate that was roughly 60 percent less than the projected growth in GDP during that same period, resulting in expected damage in 2075 equal to roughly 0.10 percent of GDP.

11. That attribution was based on the ratio between the increase in expected damage caused by the *individual factor* in isolation (climate change, holding population and per capita income constant and vice versa) to the *sum* of the increases in expected damage obtained when each factor was modeled in isolation. For additional information, see "Appendix A: Attributing Growth in Expected Hurricane Damage to Climate Change and to Coastal Development."

In contrast, the width of the likely range varied significantly depending on which researcher's estimates were used. Relative to the likely range in 2075 that was obtained when both researchers' predictions were used (from 0.15 to 0.31 percent of GDP), the range was much wider (from 0.10 to 0.34 percent of GDP) when only Knutson's predictions were used but much narrower (from 0.17 to 0.26 percent of GDP) when only Emanuel's predictions were used.

Sensitivity of Results to Alternative Estimates of How Much Changes in Population and per Capita Income Affect Estimates of Damage. CBO's estimates of expected damage are sensitive to assessments of how much increases in population and per capita income will increase hurricane damage. Given the importance of those effects, CBO examined the extent to which its estimate of expected damage in 2075 would change if hurricane damage was more, or less, sensitive to changes in population and per capita income. Specifically, CBO calculated a distribution of damage in 2075 under two alternative scenarios:

- *Higher-response case.* CBO assumed that damage associated with a 10 percent increase in population or per capita income is 2.5 percentage points greater than in the medium-response case described above. For example, rather than a 10 percent increase in per capita income resulting in a 10 percent increase in damage from wind, as was estimated in the medium-response case, a 10 percent increase in per capita income results in a 12.5 percent increase in damage in the higher-response case (see Table 2).[12] That change makes expected damage more sensitive to increases in population and per capita income, implying that communities would develop in a way that would not limit expected damage (for example, if increases in population did not increase housing density enough to limit wind damage) and that communities and individuals would make fewer adjustments (such as constructing storm walls) to limit potential damage from hurricanes.

- *Lower-response case.* CBO assumed that damage associated with a 10 percent increase in population or per capita income is 2.5 percentage points less than in the medium-response case. That change makes expected damage less sensitive to increases in population and per capita income, implying, for example, that increases in population would lead to denser housing or that increases in per capita income would cause individuals and businesses to invest in more hurricane-resistant houses and buildings.

CBO found that the mean estimate of expected damage for 2075 is roughly 20 percent higher in the higher-response case (0.26 percent of GDP) and roughly 20 percent lower

12. That more-than-proportionate response has been estimated by some researchers. See Laura A. Bakkensen and Robert O. Mendelsohn, *Risk and Adaptation: Evidence From Global Hurricane Damages and Fatalities* (forthcoming).

in the lower-response case (0.17 percent of GDP) than in the medium-response case (0.22 percent of GDP).

Percentage of the U.S. Population Facing Substantial Expected Damage

The expected damage from hurricanes will constitute a larger share of per capita income for people living along the East and Gulf coasts than for the average person in the United States (approximated by damage as a share of GDP). Currently, roughly 1.2 million people—0.4 percent of the U.S. population—live in counties facing substantial expected damage. For the purposes of this analysis, "substantial expected damage" is defined as expected per capita damage that is greater than 5 percent of the county's average per capita income. CBO projects that by 2050, 5.8 million people—1.4 percent of the population—will face expected damage that exceeds the 5 percent threshold and that by 2075 those amounts will rise to 10 million people, or 2.1 percent of the population (see Figure 5). The percentage of the U.S. population likely to exceed the 5 percent threshold in 2075 ranges from 0.3 percent (or 1.6 million people) to 5.2 percent (or about 25 million people).

The low end of the likely range includes the people in 13 counties, while the high end includes the people in 68 counties (roughly five times as many counties). Because CBO estimates that damage grows more slowly than population, the agency's estimates of per capita damage in 2075 tend to be higher in states with smaller populations than in states with larger populations. Consequently, the 13 counties exceeding the 5 percent threshold at the low end of the likely range (corresponding to lower damage estimates) have an average population that is less than one-third of the average population for the 68 counties exceeding the threshold at the high end of the likely range (corresponding to higher estimates of damage). This result leads to the very wide likely range that CBO estimates.

Budgetary Implications of Hurricane Damage

Hurricane damage can affect the federal budget in a variety of ways. When a disaster overwhelms the capacity of state and local resources to provide relief, the governor of a state or a tribal leader may request federal assistance under the Stafford Disaster Relief and Emergency Assistance Act (the Stafford Act). In response, the President may declare such an event to be a major disaster, which authorizes certain federal agencies to provide various types of financial and technical assistance to state, local, and tribal governments, as well as to individuals and businesses in affected areas.

For the most part, decisions about whether to provide federal funding for disaster relief in the aftermath of a hurricane, about amounts of funding for specific agencies and programs, and about what conditions should be placed on the spending are not mandated by law. Rather, such funding is largely discretionary and is the outcome of choices made by policymakers on a case-by-case basis. The disaster-related accounts, such as FEMA's Disaster Relief Fund, generally receive annual appropriations sufficient for noncatastrophic events, but lawmakers typically rely on supplemental appropriations to provide sufficient funds to respond to major hurricanes.

There is one exception to that general rule. Unlike spending from disaster-relief programs that are funded through discretionary appropriations, claim payments made through the National Flood Insurance Program (NFIP) are a form of mandatory spending—that is, the government is required by statute to make those payments. To the extent that those payments are not fully covered by insurance premiums, they represent costs to the federal government (in addition to the discretionary appropriations).

Hurricane damage can also have indirect effects on the federal budget through changes that it causes in the overall amount of economic activity (GDP) and the use of income support programs and special tax provisions. Those indirect effects were not quantified in CBO's analysis, but as discussed on pages 20 through 21, they are likely to be relatively small.

Since Hurricane Katrina, federal spending for the storms that were included in CBO's analysis—specifically, those that occurred between August 2005 and December 2015 and resulted in at least $1 billion in damage—has exceeded 60 percent of total hurricane damage. CBO estimates that climate change and coastal development will result in an increase in expected hurricane damage measured as a share of GDP. That increase, in turn, will lead to an increase in federal spending as a share of GDP unless disaster relief, measured as a share of damage, falls enough to compensate.

Discretionary Spending

Discretionary spending aimed at helping individuals, businesses, and communities address hurricane damage has totaled $209 billion since 2000 (see Table 3). More than half of that amount was spent responding to Hurricane Katrina, and one-quarter was spent in the aftermath of Hurricane Sandy.

Many federal agencies help administer and coordinate assistance to communities affected by hurricane damage.[13] However, over the past 15 years, roughly three-quarters of federal funding for such disaster assistance has been spent through programs administered by three agencies: the Federal Emergency Management Agency, the Department of Housing and Urban Development (HUD), and the Army Corps of Engineers (see Figure 6).

13. Agencies' roles are defined under the National Response Framework, which guides the nation's emergency response to a major disaster, and the National Disaster Recovery Framework, which guides recovery activities. See Department of Homeland Security, *National Response Framework* (May 2013), http://tinyurl.com/gud8tw3; and Federal Emergency Management Agency, *National Disaster Recovery Framework: Strengthening Disaster Recovery for the Nation* (September 2011), http://go.usa.gov/cVMDd (PDF, 11 MB).

Federal Emergency Management Agency: Disaster Relief Fund. FEMA administers the Disaster Relief Fund, which accounted for about 45 percent of all discretionary spending on hurricanes over the past 15 years. The DRF is used to pay for current emergencies and ongoing recovery projects from past disasters.[14] Since 2000, it has provided $95 billion for hurricane relief, mostly funded by supplemental appropriations. Three programs account for the bulk of spending from the DRF (see Figure 7).

Public Assistance Program. The largest of the three programs, the Public Assistance Program, helps communities cover the costs of repairing or replacing public buildings, infrastructure, and utilities, as well as emergency measures, such as removing debris, establishing temporary shelters, and providing emergency power. The federal government covers at least 75 percent of the cost of activities that are eligible for such assistance, but that share can be higher if certain per capita damage thresholds are met. From fiscal years 2000 to 2013, support provided through the Public Assistance Program accounted for 47 percent of total spending from the DRF.[15]

Individual Assistance Program. This program accounted for 25 percent of spending from the DRF between fiscal years 2000 and 2013. Individual assistance includes temporary housing for displaced people, grants for the repair or replacement of a home and other damaged property, grants for medical treatment, cleaning, moving, or other needs not covered by insurance, and disaster-related unemployment insurance.

Hazard Mitigation Grant Program. This program, which accounted for 6 percent of spending from the DRF between fiscal years 2000 and 2013, supports mitigation measures that are designed to prevent or reduce the loss of life or property damage from a future disaster.[16] Mitigation projects are categorized as structural and nonstructural. Structural activities include retrofitting or strengthening facilities so that they will be more resistant to future damage, elevating structures to reduce flooding, and implementing building codes that are designed to increase structural resiliency. Nonstructural activities include community planning initiatives, creating disaster mitigation and flood plans, and implementing disaster warning systems.

Department of Housing and Urban Development: Community Development Block Grant Disaster Recovery Program. Following major disasters, the Congress has often provided large supplemental appropriations for HUD to fund disaster recovery activities through its Community Development Block Grant Disaster Recovery Program. Such

14. See Bruce R. Lindsay, *FEMA's Disaster Relief Fund: Overview and Selected Issues*, Report for Congress R43537 (Congressional Research Service, May 7, 2014).

15. See Jared T. Brown and Daniel J. Richardson, *FEMA's Public Assistance Grant Program: Background and Considerations for Congress,* Report for Congress R43990 (Congressional Research Service, April 16, 2015), p. 29.

16. Because this report focuses on the budgetary implications of hurricanes, the estimates of expected damage do not take into account the loss of life caused by hurricanes.

grants have accounted for 20 percent of discretionary spending related to hurricane damage since 2000, and reliance on them has increased over time (particularly since Hurricane Katrina). State and local governments have considerably more leeway about how they may use funds provided by the block grants than is the case with other forms of assistance. Those grants are generally used for activities that fall into three categories.[17]

- *Short-Term Disaster Relief*. Such support meets immediate needs following a disaster. Eligible activities include debris removal not covered by FEMA, relocation payments for displaced individuals and businesses, provision of security patrols in damaged areas, and restoration of essential services, such as water, sewer, power, and telecommunications.
- *Mitigation*. Such activities are designed to anticipate and reduce the amount of damage that a future disaster might cause. They include both structural measures (such as strengthening houses and other buildings or implementing flood-control measures) and nonstructural measures (such as funding training exercises, preparedness plans, and buyouts of real estate that is prone to flooding).
- *Long-Term Recovery*. Such activities are designed to rebuild and economically revitalize affected areas. This type of assistance includes grants to homeowners to repair or replace residences, grants and loans to businesses that have suffered economic damage, and grants to local governments to fund infrastructure improvements.

Army Corps of Engineers: Civil Works and Disaster Response. The Army Corps of Engineers administers civil works programs and disaster-response programs that have accounted for 11 percent of discretionary spending related to hurricane damage since 2000. To prevent damage from hurricanes, the Corps constructs and manages an array of flood-control and infrastructure projects, including dams, levees, and seawalls, as well as natural barriers such as sand dunes. The Corps also assists with disaster-response activities, such as debris removal, demolition, commodity distribution, temporary housing, emergency power, and support for urban search and rescue.[18] Those activities are carried out using a variety of contracts awarded in advance that can be quickly activated, usually at FEMA's request.

In recent years, major hurricanes have led the Congress to provide large supplemental appropriations to the Corps to repair infrastructure and control flooding, including over $17 billion to rebuild and strengthen levees and floodwalls damaged by the 2005

17. See Eugene Boyd, *Community Development Block Grant Funds in Disaster Relief and Recovery*, Report for Congress RL33330 (Congressional Research Service, November 1, 2012).

18. See U.S. Army Corps of Engineers, "Emergency Operations: Disaster Response Missions and Information," www.usace.army.mil/Missions/EmergencyOperations.aspx.

hurricanes (primarily Hurricane Katrina) and $5.2 billion to repair damage caused by Hurricane Sandy in 2012.

Other Federal Agencies. Depending on the nature of damage caused by a hurricane, other federal agencies have received notably large supplemental appropriations. For example, in response to the three hurricanes that occurred in 2005 (Katrina, Rita, and Wilma), the Congress provided these amounts (measured in 2015 dollars):

- $9.5 billion to the Department of Defense (not including the Army Corps of Engineers) to fund the repair of military facilities, equipment, and ships, as well as the costs of deployments for relief operations;
- $4.5 billion to the Department of Transportation, primarily for the repair and reconstruction of roads that make up the federal-aid highway system and other critical transportation infrastructure;
- $1.9 billion to the Small Business Administration (SBA) to cover the subsidy costs of low-interest, long-term loans for individuals and businesses to repair and replace homes and property.[19] The SBA used that appropriation to disburse a total of $6.7 billion in disaster loans for the 2005 hurricanes; and
- $2.1 billion to the Department of Education to fund reconstruction of local schools and provide aid to displaced students and teachers.

Supplemental appropriations to the Department of Transportation were particularly large in response to Hurricane Sandy, totaling over $13 billion.

Mandatory Spending: The National Flood Insurance Program

The NFIP was created in 1968 to provide property owners flood insurance, which was virtually unavailable at that time because it would have been prohibitively costly for the private market to provide. The NFIP is the main source of such insurance in the United States.

Eligibility for flood insurance coverage under the program is based on flood-hazard maps developed by FEMA and requires that participating communities comply with building-code requirements and floodplain-management practices set by FEMA. Property owners in participating communities may purchase NFIP policies through private insurance companies.

Because NFIP claim payments are not fully covered by insurance premiums, the gap between payments and premiums represents a cost to the federal government. About one-fifth of NFIP policies—generally those covering older structures in areas at high

19. The $1.9 billion includes the cost of reducing interest rates on SBA loans and the expected costs associated with the probability that some amount of the loans would not be paid back.

risk of flooding—are explicitly subsidized by the federal government. On the basis of information provided by NFIP actuaries, CBO estimates that federal subsidies have, on average, covered 50 percent of the premiums for those explicitly subsidized policies, resulting in a total subsidy cost of $6.3 billion for hurricanes occurring since 2000. As discussed below, that sum underestimates federal spending to the extent that FEMA's estimates of flood risks—and the corresponding premiums (including premiums for the four-fifths of policies that are not explicitly subsidized)—are too low.

Indirect Federal Budgetary Effects Not Included in This Analysis

Hurricanes can affect the federal budget in ways beyond those included in this analysis. Major hurricanes can temporarily slow the growth of GDP, for instance, resulting in reductions in revenues. Moreover, the hardship caused by hurricanes can increase the number of people who qualify for means-tested programs and for reductions in taxes.

Effects on Revenues Caused by Changes in GDP. Major hurricanes can have effects on GDP, as well as associated adverse effects on tax revenues. The immediate impact on GDP would be negative. For example, in September 2005, CBO estimated that GDP would grow about one-half of one percent more slowly in the second half of 2005 as a result of Hurricane Katrina, which struck in August of that year.[20] For small changes in GDP, CBO finds that federal tax revenues respond roughly proportionately. Thus, federal revenues that were ultimately collected for taxes owed during that period were probably also about one-half of one percent lower.

The initial negative effect of Katrina on economic output stemmed from lost production in affected regions and from temporary spikes in energy costs that resulted from damage to energy infrastructure. The effects of other hurricanes on GDP, and thus on federal revenues, vary depending on both the magnitude of the damage and the type of damage—the share of damage incurred by businesses and production facilities as opposed to houses, for example.

Following the immediate negative impact, the effects on GDP would depend on the hurricane's impact on investment (spending by businesses to rebuild damaged plants and replace damaged equipment, as well as spending by individuals to repair or replace damaged housing, for example); spending by consumers on durable goods (to replace damaged cars, for instance); and the government's spending for goods and services, and households' consumption expenditures. Rebuilding efforts could even cause growth in GDP to be temporarily higher than it would have been in the absence of the hurricane; however, it is unlikely that the loss in revenues caused by the initial drop in GDP would be fully recovered.

20. See Congressional Budget Office, *The Macroeconomic and Budgetary Effects of Hurricanes Katrina and Rita: An Update* (September 2005), www.cbo.gov/publication/17204.

In general, CBO concludes that, over the long run, a single hurricane would have no significant impact on the nation's GDP. That outcome reflects the fact that, in the long run, GDP is determined by the size of the capital stock (which is determined by national saving and capital inflows, neither of which is likely to be permanently affected by the hurricane) and by the labor supply and technological progress (which also are not likely to be permanently affected). In contrast, if climate change were to increase the frequency of major hurricanes, the economy might not fully recover from one catastrophic storm before it was hit by another. Consequently, negative effects on economic output could persist for longer periods of time.[21]

Other Effects on Federal Receipts. In addition to the loss in tax revenues associated with any reduction in the growth of GDP, a major hurricane can delay tax payments collected from households and businesses in affected areas and cause increases in tax deductions associated with personal property losses. Lawmakers also have occasionally enacted legislation providing more extensive assistance on a temporary basis. For example, following Hurricane Katrina, they enacted the Katrina Emergency Tax Relief Act of 2005, which allowed individuals to deduct more personal property losses from their taxable income and gave them more time to replace damaged property without being assessed income taxes on the insurance proceeds. It also allowed businesses and individuals to deduct more charitable donations from taxable income.

Furthermore, a hurricane that affects oil-producing facilities, as was the case with Hurricane Katrina, could cause a reduction in royalty payments made by firms to the federal government for oil and gas leases.[22] In September 2005, CBO estimated that Katrina reduced such payments by a few hundred million dollars, which was more than offset by the roughly $700 million that the government received by selling 11 million barrels of oil from the Strategic Petroleum Reserve in response.[23]

Effects on Spending From Means-Tested Programs. The hardship and loss of income caused by hurricanes can cause people to become eligible for benefits they would not normally collect. For example, people could qualify for support through the Supplemental Nutrition Assistance Program (a program designed to provide nutritional

21. See Testimony of Douglas Holtz-Eakin, Director, Congressional Budget Office, *Macroeconomic and Budgetary Effects of Hurricanes Katrina and Rita* (October 6, 2005), www.cbo.gov/publication/17233. A recent working paper finds effects that extend over several decades, particularly for countries that experience frequent hurricanes. See Solomon M. Hsiang and Amir S. Jina, *The Causal Effect of Environmental Catastrophe on Long-Run Economic Growth: Evidence From 6,700 Cyclones*, Working Paper 20352 (National Bureau of Economic Research, July 2014), www.nber.org/papers/w20352.

22. In the federal budget, those payments are classified as offsetting receipts, which are a credit against mandatory spending.

23. See Congressional Budget Office, *The Macroeconomic and Budgetary Effects of Hurricanes Katrina and Rita: An Update* (September 2005), www.cbo.gov/publication/17204.

assistance to low-income individuals and families), Medicaid, and unemployment insurance.[24]

Federal Spending Relative to Hurricane Damage

It is difficult to identify how much spending is attributable to a specific hurricane. Emergency supplemental funds, for example, have often been appropriated as part of larger bills that contain funds for multiple disasters (for instance, Hurricanes Katrina, Rita, and Wilma in 2005). To estimate spending for each major hurricane, CBO relied on information from numerous sources, including spending data and program documents from federal agencies, the text of enacted legislation and accompanying reports, and analyses of appropriations and spending produced by the Congressional Research Service. (The sources that CBO used to estimate federal spending are listed in Appendix B.) Since 2000, federal spending on relief from hurricane damage has been dominated by two storms: Hurricane Katrina accounted for over 50 percent of all federal spending between 2000 and 2015, and Hurricane Sandy accounted for 25 percent (see Table 3 on page 42).

Although federal spending as a percentage of hurricane damage varies widely from storm to storm—ranging from a low of 9 percent for Hurricane Lili (which occurred in 2002) to a high of nearly 80 percent for Hurricane Sandy—that percentage has tended to be larger since Hurricane Katrina (see Figure 8). For all of the hurricanes for which CBO had data, federal spending as a percentage of damage rose from 17 percent before Katrina struck to 62 percent from Katrina forward.[25]

Future Federal Spending in Response to Hurricane Damage

If federal spending remained at roughly 60 percent of hurricane damage—a prospect referred to in this report as a historical cost scenario—it would total 0.13 percent of GDP in 2075 (equivalent to about $24 billion in today's economy), compared with 0.10 percent of GDP (or $18 billion) projected under current conditions. That estimate is based on CBO's assessment of *average* expected damage in 2075. Taking into account the likely range of expected damage in 2075, federal spending under the historical cost

24. In addition, following Katrina, lawmakers enacted the TANF [Temporary Assistance for Needy Families] Emergency Response and Recovery Act of 2005, which provided additional funds to states that were damaged by Hurricane Katrina or those that were hosting evacuees.

25. The recent increase in the ratio of federal spending to total damage is a continuation of a longer-term trend. According to some researchers, federal assistance, measured as a proportion of hurricane damage, has grown significantly over the past 30 years and is dramatically larger than it was earlier in the 20th century. See J. David Cummins, Michael Suher, and George Zanjani, "Federal Financial Exposure to Natural Catastrophe Risk" in Deborah Lucas, ed., *Measuring and Managing Federal Financial Risk* (University of Chicago Press, 2010), pp. 61–92; and David A. Moss, "The Peculiar Politics of American Disaster Policy: How Television Has Changed Federal Relief," in Erwann Michel-Kerjan and Paul Slovic, eds., *The Irrational Economist: Making Decisions in a Dangerous World* (Public Affairs Books), pp. 151–160.

scenario would range from 0.09 percent to 0.19 percent of GDP, which would amount to between $16 billion and $34 billion in today's economy (see Figure 9).[26]

Because federal spending on hurricane disaster relief is largely discretionary and mostly the result of supplemental appropriations, it could be higher or lower than the 60 percent of hurricane damage that the historical cost scenario implies. Consequently, CBO considered the implications of two alternative measures for federal spending as a percentage of future hurricane damage: 40 percent and 80 percent. Based on the likely range of hurricane damage estimated in the previous section and those two alternative measures, federal spending resulting from hurricane damage in 2075 could range from 0.06 percent to 0.25 percent of GDP, which would equal $11 billion to $45 billion in today's economy (see Table 4).

Approaches to Reducing Federal Spending on Hurricane Damage

In considering how policymakers might seek to reduce future federal spending on hurricane damage, CBO examined several diverse options: limiting greenhouse gas emissions; shifting a greater share of the cost of hurricane damage onto households, businesses, and state and local governments, thereby reducing coastal development; and investing in structural changes, such as elevating buildings and roads, that would cause vulnerable coastal areas to suffer less damage when hurricanes occur.

Limit Greenhouse Gas Emissions

A coordinated effort to significantly reduce global emissions could lessen the potential for increased hurricane damage in the United States between now and 2075; but, the extent of the reduction would be uncertain and would probably be small, particularly in the first half of the century.[27] However, significantly reducing U.S. greenhouse gas emissions without corresponding decreases in emissions generated by other large

26. Those estimates of hurricane-related spending are not related to CBO's 10-year baseline forecast for disaster-related spending in the budget. Whereas, for its 10-year baseline, CBO projects federal spending from discretionary disaster-related accounts by inflating the most recent year's annual appropriations for those accounts, this report presents the annual demand for federal spending in a given year on the basis of the results of modeling expected damage. In its baseline for fiscal year 2016, CBO estimates federal spending from disaster-related accounts of approximately $10 billion. That figure is lower than the $18 billion in expected federal spending estimated in the analysis presented in this report (equal to roughly 60 percent of the $28 billion in expected damage under current conditions), in part because there has been little hurricane activity in the past few years and, therefore, smaller appropriations for disaster-related accounts. Conversely, if a storm comparable to Hurricane Sandy—which caused damage that resulted in lawmakers providing over $50 billion in supplemental appropriations—had struck in 2015, then CBO's baseline estimate of disaster-related spending would have exceeded the expected damage.

27. In December 2015, nearly 200 nations pledged to keep global temperatures well below 3.6 degrees Fahrenheit above preindustrial times. Countries agreed to make nationally determined contributions (NDCs), which indicate their goals for reducing emissions, and to pursue domestic measures aimed at achieving those reductions. Every five years, countries are committed to reporting on progress in meeting their existing NDCs and to submit new ones.

economies would probably not significantly reduce hurricane damage between now and 2075 because U.S. emissions make up a shrinking share of global emissions.

Of the two ways in which climate change is expected to increase hurricane damage—a rise in sea levels and an increase in the frequency of hurricanes—the first is the more certain; however, increases in sea levels between now and 2075 are expected to be relatively insensitive to changes in emissions over the same period. Experts find that once sea levels begin to rise, the process is hard to slow down.[28] Specifically, in the first half of the 21st century, the global increase in sea levels will be caused primarily by expansion of the oceans resulting from the warming of the water. That response is relatively insensitive to changes in emissions. Differences in emissions will begin to be more important in the second half of the century, when the melting of ice sheets is projected to play a more significant role.[29]

Therefore, the IPCC projects that the likely range of the rise in sea levels by 2065 would be similar under a high-emissions scenario (wherein only limited efforts would be made to reduce emissions) or under a low-emissions scenario (wherein greenhouse gas emissions would be rapidly reduced starting immediately and completely eliminated by 2040). Reductions in global emissions would begin to have more significant effects on the rise in sea levels by the end of the century; but, even then, the extent of that rise under the low-emissions scenario is projected to be roughly two-thirds of that under the high-emissions scenario.[30]

Some of the factors affecting the frequency of hurricanes—including atmospheric temperatures, sea-surface temperatures, water vapor, and wind shear—respond relatively quickly to changes in emissions.[31] For example, the IPCC projects a significantly higher range of increases in the global mean surface temperature under the high-emissions

28. See Stefan Rahmstorf, "Sea Level in the 5th IPCC Report," *Real Climate* (October 15, 2013), www.realclimate.org/index.php/archives/2013/10/sea-level-in-the-5th-ipcc-report.

29. See Robert E. Kopp and others, "Probabilistic 21st and 22nd Century Sea-Level Projections at a Global Network of Tide-Gauge Sites," *Earth's Future*, vol. 2, no. 8 (August 2014; corrected, October 2014), pp. 383–406, http://onlinelibrary.wiley.com/doi/10.1002/2014EF000239/full.

30. For the period from 2046 through 2065, sea levels are projected to rise by between 0.6 and 1.1 feet under the scenario with the lowest emissions and by between 0.7 and 1.3 feet under the scenario with the highest emissions. For the period from 2081 through 2100, the rise in sea levels is projected to be between 0.9 and 1.8 feet (with a mean of 1.3 feet) under the scenario with the lowest emissions and between 1.5 and 2.7 feet (with a mean of 2.1 feet) under the scenario with the highest emissions. See Intergovernmental Panel on Climate Change, "Summary for Policymakers," in T.F. Stocker and others, eds., *Climate Change 2013: The Physical Science Basis. Contribution of Working Group 1 to the Fifth Assessment Report of the IPCC* (Cambridge University Press, 2013), Table SPM.2, p. 23, www.ipcc.ch/report/ar5/wg1.

31. See Thomas Knutson and Robert E. Tuleya, "Impact of CO_2-Induced Warming on Simulated Hurricane Intensity and Precipitation: Sensitivity to the Choice of Climate Model and Convective Parameterization," *Journal of Climate*, vol. 17, no. 18 (September 2004).

scenario than under the low-emissions scenario.[32] Nonetheless, the relationship between climate change and hurricanes is not very well understood, which is why researchers project a wide range of changes in the frequency of hurricanes. Hence, the effect that a global reduction in greenhouse gas emissions would have on the frequency of hurricanes is unclear.

Moreover, even with U.S. efforts, stabilizing the concentration of greenhouse gases in the atmosphere would be virtually impossible if countries with rapidly growing economies, such as China, India, Brazil, and South Korea, did not substantially cut their emissions. Until about eight years ago, the United States generated more emissions than any other single country; China is now the single largest emitter. Whereas the United States currently accounts for about 15 percent of global emissions, China accounts for roughly 30 percent. The United States' share is projected to remain roughly constant over the next 25 years, while China's share is projected to grow to nearly 35 percent by 2040.[33]

Shift More Costs to State and Local Governments and Private Entities, Thereby Reducing Coastal Development

Providing federal assistance in the aftermath of hurricanes helps hard-hit communities, but it also reduces incentives for people to take into account the full impact on expected damage of their decisions about where to live and locate businesses. In essence, federal assistance subsidizes growth in areas that are vulnerable to hurricane damage by shielding households, businesses, and state and local governments in those areas from the financial consequences of such decisions. Requiring greater cost sharing by private entities and state and local governments would provide an incentive for them to more fully account for the extent of expected damage and thereby reduce the pace of coastal development.

Approaches for reducing the federal government's share of costs—and increasing the share borne by private entities and state and local governments—include:

- Increasing insurance requirements for households and businesses,

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32. For the period from 2046 through 2065, the global mean surface temperature is projected to increase by 0.7 to 2.9 degrees Fahrenheit under the scenario with the lowest emissions and by 2.6 to 4.7 degrees Fahrenheit under the scenario with the highest emissions. See Intergovernmental Panel on Climate Change, "Summary for Policymakers," in T.F. Stocker and others, eds., *Climate Change 2013: The Physical Science Basis. Contribution of Working Group 1 to the Fifth Assessment Report of the IPCC* (Cambridge University Press, 2013), Table SPM.2, p. 23, www.ipcc.ch/report/ar5/wg1.

33. See Energy Information Administration, *International Energy Outlook 2013* (July 2013), www.eia.gov/forecasts/archive/ieo13. For a general discussion of energy use and greenhouse gas emissions in China and their implications, see Andrew Stocking and Terry Dinan, *China's Growing Energy Demand: Implications for the United States*, Working Paper 2015-05 (Congressional Budget Office, June 2015), www.cbo.gov/publication/50216.

- Increasing the minimum amount of statewide per capita damage that is used as the primary criterion for providing federal assistance, and
- Reducing the statutorily set minimum share of costs borne by the federal government (as opposed to state and local governments) for assistance provided from FEMA's Disaster Relief Fund.

Increase Insurance Requirements. Administered by FEMA, the National Flood Insurance Program is the primary source of coverage for flood damage in the United States. Under the program, FEMA develops flood-hazard maps that indicate varying amounts of flood risk. Communities participating in the program become eligible for NFIP coverage, which is administered by private insurance companies, if they comply with building-code requirements and floodplain management practices established by FEMA. Moreover, residents who have a federally backed mortgage and live in an area where the annual flood risk is estimated to be at least 1 percent—called a special flood hazard area (SFHA)—are required to have flood insurance.

The existence of the NFIP, however, does not mean that businesses and households bear the full cost of flood risk. The federal government bears a significant share of the cost of such risk for two reasons. First, many property owners do not purchase flood insurance. A study conducted in 2006 by the RAND Corporation estimated that, nationwide, only 3 percent of single-family homes in communities participating in the NFIP had flood insurance, and only about half of the homes in SFHAs had insurance (in part because of incomplete compliance with the coverage requirement for properties with federally insured mortgages).[34] The availability of disaster assistance may affect people's decisions about purchasing flood insurance, but there is limited evidence about that relationship. One study found that for most households, the provision of federal assistance grants for damaged property did not affect the decision about whether to purchase flood insurance but did reduce the amount of insurance coverage that those households chose to purchase.[35]

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34. See Lloyd Dixon and others, *The National Flood Insurance Program's Market Penetration Rate: Estimates and Policy Implications* (RAND Corporation, February 2006), www.rand.org/pubs/technical_reports/TR300.html.

35. The study found that, in the case of disaster loans provided by the Small Business Administration—which, unlike disaster grants, must be repaid by recipients—the size of a loan had no effect on the amount of insurance purchased. The authors also note that increased reliance on HUD's CDBG Disaster Recovery Program may also reduce insurance coverage because some states have used the flexibility provided under the program to give homeowners larger grants to repair property than would be allowed under FEMA's Individual Assistance Program. Further, the authors caution that because most federal disaster assistance is provided to local governments, such assistance may reduce local governments' incentives for investing in hazard mitigation. For more information, see Carolyn Kousky, Erwann O. Michel-Kerjan, and Paul A. Raschky, *Does Federal Disaster Assistance Crowd Out Private Insurance?* Working Paper (Wharton Risk Center, 2014), http://tinyurl.com/gu83bls (PDF, 235 KB).

Second, premium rates charged for insurance provided under the NFIP do not cover the full cost of insuring the property. About one-fifth of NFIP policies—generally those covering older structures—are explicitly subsidized, with the federal government covering about 50 percent to 55 percent of the premiums.[36] Moreover, subsidized policies are disproportionately subject to repetitive losses.[37] The Government Accountability Office (GAO) estimated that, in fiscal year 2013, the cost to the federal government of forgone premiums from subsidized policies was approximately $1.5 billion.[38] However, recent legislation (discussed below) will gradually phase out some of those subsidies through annual rate increases. In addition, some state insurance programs also subsidize policies covering hurricane risk.[39]

In addition, "full-risk" premium rates—that is, rates that are not explicitly subsidized—could underestimate the actual cost of insuring the properties. The flood maps that FEMA uses to set insurance rates may not accurately reflect changes in flood risk associated with development that has reduced wetlands and permeable ground area or with climate change that has begun to increase sea levels and may be changing the frequency and severity of hurricanes and rainstorms. Moreover, even when FEMA updates its maps, properties that might be classified as being in a higher-risk zone or at a lower elevation relative to expected flood heights are often "grandfathered" at their previous classifications.[40]

Explicit and implicit subsides to NFIP policyholders increase the likelihood that the premiums received will not cover claim payments, as occurred following Hurricanes Katrina and Sandy. Because the NFIP has had to borrow from the Treasury to pay claims, it now owes the Treasury about $23 billion.[41]

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36. Subsidized policies cover certain properties in areas at high risk of damage from flooding—primarily those built before flood insurance rate maps (FIRMs) became available and, thus, without a clear understanding of their vulnerability to flooding. In 2013, FEMA estimated that people and businesses holding such policies were paying premiums that were 45 percent to 50 percent of their full-risk value. For more information, see Congressional Budget Office, *The National Flood Insurance Program: Factors Affecting Actuarial Soundness* (November 2009), p. 6, www.cbo.gov/publication/41313.

37. Ibid., p. 24.

38. See Government Accountability Office, *Flood Insurance: Forgone Premiums Cannot Be Measured and FEMA Should Validate and Monitor Data System Changes*, GAO-15-111 (December 2014), p. 25, www.gao.gov/products/GAO-15-111.

39. See Kent Smetters and David Torregrosa, *Financing Losses From Catastrophic Risks*, Working Paper 2008-09 (Congressional Budget Office, November 2008), pp. 32–33, www.cbo.gov/publication/20400.

40. In some cases, the grandfathering does not adversely affect total premiums paid to the NFIP but instead raises the rates paid by other policyholders, resulting in cross-subsidies within the program. See Congressional Budget Office, *The National Flood Insurance Program: Factors Affecting Actuarial Soundness* (November 2009), pp. 14–17, www.cbo.gov/publication/41313.

41. See TreasuryDirect, Department of the Treasury, "Federal Borrowings Program Reports: Detail Principal and Accrued Interest Balances and Summary General Ledger Balances (All Funds)," Fund 70x4236 (January 2016), www.treasurydirect.gov/govt/reports/tbp/tbp_2016_01.htm.

One option for decreasing the federal cost of hurricane damage is to set rates for coverage under the NFIP that would more closely parallel rates set by private insurers, while maintaining or strengthening requirements for homeowners and businesses to carry flood insurance. One study has found that greater coverage may reduce the need for disaster assistance, but the reduction is small.[42] However, the NFIP was designed to balance the goals of reducing the nation's long-term exposure to flood losses, making the program solvent, and meeting the statutory mandate to make the rates affordable. Balancing those objectives can be difficult. For example, raising premiums to more fully cover flooding risks would make it more difficult to expand participation in the flood insurance program. The NFIP was recently reauthorized through the Biggert-Waters Flood Insurance Reform Act of 2012 (subtitle A of Title II of Public Law 112-141), which included a number of reforms to address the future solvency and efficiency of the program. Those reforms included phasing out, and in some cases eliminating, subsidized premium rates for certain types of property in areas at high risk of flooding. However, the Homeowner Flood Insurance Affordability Act of 2014 (Public Law 113-89) reinstated certain premium subsidies and slowed down certain rate increases that had been mandated by the Biggert-Waters Act.[43]

Set a Higher Minimum Threshold for Disaster Declarations. Federal assistance provided through Stafford Act programs is authorized only when the President declares a major disaster in response to a request by a governor or tribal leader. Some analysts and policymakers maintain that such declarations have been made for incidents that could have been handled by the states.

Since 1986, FEMA has used the estimated amount of statewide damage relative to a state's population as an indicator of the burden of the disaster and generally relied on that indicator as a threshold in determining whether to recommend that the President declare a major disaster in a state. Although current law prohibits FEMA from making disaster determinations solely on the basis of population or income-based formulas, the statewide per capita indicator is the principal criterion FEMA uses for determining whether damage is sufficiently severe to warrant recommending a major disaster

42. Ibid.

43. As a result of the Biggert-Waters Act and the Homeowner Flood Insurance Affordability Act, FEMA is phasing out subsidies for the following property-rate classes by implementing annual rate increases of 25 percent: any property that has experienced severe repetitive losses; nonprimary residences; business properties; any property that has incurred flood-related damage for which the cumulative amount of NFIP payments has equaled or exceeded the property's fair-market value; and any property that has sustained substantial damage or had substantial improvement exceeding 50 percent of the property's fair-market value. FEMA is phasing out subsidies for the following property-rate classes by implementing annual rate increases of 5 percent to 15 percent: primary residences purchased after July 6, 2012, and primary residences not insured by the NFIP as of July 6, 2012. FEMA has eliminated subsidies for NFIP policies that have lapsed and for any policies for which the insured refuses to accept any offer of mitigation assistance following a major disaster or in connection with a repetitive loss. For a more detailed discussion of the cost of forgone premiums from subsidized policies, see Government Accountability Office, *Flood Insurance: Forgone Premiums Cannot Be Measured and FEMA Should Validate and Monitor Data System Changes*, GAO-15-111 (December 2014), www.gao.gov/products/GAO-15-111.

declaration.[44] That indicator, however, may underestimate a given state's capacity to recover from a disaster using its own resources. The Government Accountability Office reported in 2012 that the threshold for declaring a disaster is artificially low because it does not reflect the increase in per capita personal income that has occurred since the indicator was introduced in 1986 and because it only began to be adjusted upward for inflation in 1999.[45] As a result, the indicator understates the amount of economic resources available to states to fund their own responses to disasters. Adjusting the indicator upward, or setting some other more stringent requirement for measuring a state's need and capacity, could reduce the number of disaster declarations and, in turn, reduce federal spending on disaster assistance.

Another proposal that has been considered would require states to have their own disaster programs in place before they would be eligible to receive federal assistance under the Stafford Act. Such a requirement might increase states' capacity to handle emergencies without federal assistance.[46]

Reduce Federal Aid for Declared Disasters. The federal share of costs for relief activities funded by the Disaster Relief Fund (which has accounted for almost half of all federal spending on hurricane disaster relief since 2000) is designated by the Stafford Act to be at least 75 percent, with state and local governments funding the remaining 25 percent of disaster assistance; however, the federal share can increase if damage reaches certain thresholds.[47] Some analysts and policymakers have proposed that the federal share of costs could be reduced—to 50 percent, for example—whereas others argue that such an adjustment might place too great a burden on state and local governments.

Another approach that has been discussed would convert some or all of the federal assistance provided to states into low-interest or no-interest loans. Such loans could be

44. Section 320 of the Stafford Act prohibits FEMA from denying Stafford Act assistance to an area solely on the basis of a mathematical formula or sliding scale that is based on income or population. See Bruce R. Lindsay, *FEMA's Disaster Relief Fund: Overview and Selected Issues,* Report for Congress R43537 (Congressional Research Service, May 7, 2014), p. 16.

45. Originally set at $1.00 per person in 1986, FEMA's statewide per capita indicator was $1.35 in 2012, having been periodically adjusted for inflation since 1999. GAO estimated in 2012 that the indicator would have increased to $3.57 in 2011 had it been adjusted for increases in per capita income since 1986 and would have increased to $2.07 in 2012 had it been adjusted for inflation since 1986. GAO estimated that, of disaster declarations made from 2004 to 2011, 44 percent would not have met the threshold to qualify for assistance if the statewide indicator had been adjusted for per capita income, and 25 percent would not have qualified if the indicator had been adjusted for inflation since 1986. For more information, see Government Accountability Office, *Federal Disaster Assistance: Improved Criteria Needed to Assess a Jurisdiction's Capability to Respond and Recover on Its Own*, GAO-12-838 (September 2012), www.gao.gov/products/GAO-12-838.

46. For a more detailed discussion of these options, see Bruce R. Lindsay and Justin Murray, *Supplemental Appropriations for Disaster Assistance: Summary Data and Analysis*, Report for Congress R43665 (Congressional Research Service, October 1, 2014).

47. See Bruce R. Lindsay, *FEMA's Disaster Relief Fund: Overview and Selected Issues*, Report for Congress R43537 (Congressional Research Service, May 7, 2014), p. 20.

structured to encourage states to plan for disasters—for example, by providing lower rates (or a larger share of assistance in the form of aid rather than loans) for states that have taken steps to prepare for disasters.

Setting limits on the circumstances for providing federal assistance—or on the share of costs borne by the federal government when a major disaster is declared—could reduce the amount of hurricane damage by providing state and local governments with greater incentives to put limits (such as zoning restrictions or stricter building-code requirements) on development in areas that are at relatively high risk of damage. Such limits could also increase the incentives of state and local governments to invest in infrastructure that is designed to reduce damage, such as seawalls.

Invest in Structural Changes to Reduce Vulnerability to Hurricane Damage

In recent years, federal agencies have placed greater emphasis on funding measures designed to reduce the vulnerability of property to future hurricane damage—typically referred to as hazard-mitigation measures. Investments in hazard mitigation typically increase up-front costs of construction or restoration but reduce the costs associated with future damage.

One option for reducing federal expenditures on hurricane damage is to increase mitigation efforts. To the extent that the up-front costs of such measures are more than offset by the decrease in expected costs resulting from hurricane damage, the federal government could reduce total hurricane-related spending by undertaking more hazard mitigation or by providing incentives for state and local governments to do so.

In 2007, CBO examined a subset of mitigation efforts—FEMA's Pre-Disaster Mitigation Program—and concluded that projects undertaken as a result of that program reduced expected future losses (measured in discounted present value) by about $3 for each $1 spent on the projects.[48] Significant uncertainty surrounds that estimate, however, and the information available on past projects may not reliably indicate the effectiveness of additional mitigation projects in the future. Moreover, a complete assessment would need to consider whether mitigation measures, such as building seawalls, have the unintended effect of encouraging development in vulnerable areas.

FEMA lists a wide variety of hazard-mitigation measures that might be cost-effective (although assessing costeffectiveness would require case-specific analyses). Such measures include elevating roads, redesigning or relocating bridges, enlarging culverts, elevating buildings, using flood-resistant construction materials, restoring and maintaining natural barriers such as sand dunes, installing hurricane clips between roof framing and walls, installing storm-resistant window shutters, and anchoring or repositioning rooftop equipment.[49]

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48. Present value is a single number that expresses a flow of future income (or payments) in terms of an equivalent lump sum received (or paid) today.

49. See Federal Emergency Management Agency, *Hurricane Mitigation: A Handbook for Public Facilities* (May 2005), www.fema.gov/media-library/assets/documents/16562 .

Appendix A: Attributing Growth in Expected Hurricane Damage to Climate Change and to Coastal Development

The future increases in expected hurricane damage described in the main text of this report are the result of the combined forces of climate change (represented by changes in sea levels and in hurricane frequency) and coastal development (represented by changes in population and per capita income). The Congressional Budget Office attributes the increase in expected damage in 2075 to each of those forces.

CBO's results, as presented in the main text, express damage as a share of gross domestic product (GDP) because GDP is a measure of the nation's ability to pay for hurricane damage. To attribute growth in damage to the underlying forces of climate change and coastal development, however, it is necessary to measure damage on a dollar basis. Accordingly, in this section, CBO describes expected damage in constant 2015 dollars.

CBO's estimate of expected annual hurricane damage at present—the "reference case"—is based on estimates of the current frequency of hurricanes, current state-specific sea levels, and the current valuation of property exposed to hurricanes. According to CBO's estimates, mean expected hurricane damage in 2075 would be $150 billion, $120 billion more than the roughly $30 billion in expected damage that the agency estimates under current conditions. Because the $120 billion increase reflects the interaction of climate change and coastal development, that amount is larger than the sum of the increases that would occur if additional damage was the result only of climate change (holding property exposure—approximated by population and per capita income—at its current value) or if additional damage was the result only of coastal development (holding sea levels and hurricane frequencies at their current values). That is, the $120 billion increase includes the additional damage caused by climate change on the additional property exposure caused by coastal development. CBO attributes shares of that interaction to climate change and to coastal development (see Table A-1).

Climate Change Only

Accounting only for the effects of climate change, CBO estimates that mean expected damage in 2075 would be $65 billion, $35 billion higher than the estimate of expected damage under current conditions. The $65 billion was obtained by estimating expected damage using 2075 distributions for hurricane frequencies and sea levels, but holding population and per capita income constant at their levels in the reference case.

Coastal Development Only

Accounting only for the effects of coastal development, CBO estimates that mean expected damage in 2075 would be $70 billion, $40 billion higher than expected damage under current conditions. The $70 billion was obtained by estimating expected damage using the 2075 distributions for population and per capita income, but holding hurricane frequencies and sea levels constant at their levels in the reference case.

Climate Change and Coastal Development: Shares of Combined Effects

In combination, climate change and coastal development are estimated to increase hurricane damage by $45 billion more than the sum of the increase in damage that would occur as a result of each force on its own ($75 billion). That $45 billion reflects the *additional damage* that climate change has on the *additional property exposure* attributable to coastal development.

CBO allocates that $45 billion to climate change and to coastal development on the basis of the ratio of the increase in damage caused by each individual force on its own and the sum of the increase in damage caused by each of the two individual forces. For example, on its own, climate change is estimated to increase damage by $35 billion, or roughly 45 percent of the $75 billion sum of the increases in hurricane damage resulting from climate change only and from coastal development only. As a result, CBO allocated 45 percent of the $45 billion interaction effect to climate change ($20 billion) and the remaining 55 percent to coastal development ($25 billion).

On the basis of the allocation method described above, climate change accounts for $55 billion of the $120 billion increase in the average expected hurricane damage in 2075 (or 45 percent)—relative to CBO's reference case—and coastal development accounts for the remaining $65 billion (or 55 percent.)

Appendix B: Sources Used by CBO to Estimate Federal Spending for Hurricane Damage

To estimate spending for each of the 16 major hurricanes that occurred between 2000 and 2015, the Congressional Budget Office relied on information from numerous sources.

- To estimate spending by the Federal Emergency Management Agency (FEMA) from the Disaster Relief Fund, which accounts for nearly half of all federal spending on damage from hurricanes, CBO drew from obligations data available in FEMA's monthly reports to the Congress, as well as obligations data available on FEMA's website.

- To estimate spending by the Department of Housing and Urban Development (HUD), CBO drew from obligations data provided by HUD that detail the disbursement of Community Development Block Grants to affected states, as well as information on HUD's website about those grants.

- To estimate spending by the Army Corps of Engineers for its civil works and disaster-response programs, CBO drew from obligations data and the Corps' spending plans for future projects.

- To estimate spending by the Small Business Administration for its disaster loans, CBO drew from loan disbursement data provided by that agency.

- To estimate spending by all other agencies, CBO drew from obligations data as available, the text of legislation and accompanying reports, and analyses of appropriations and agency spending produced by the Congressional Research Service.

- To estimate spending from FEMA's National Flood Insurance Program, CBO drew from claims payment data from FEMA's website.

In the case of recent major hurricanes for which there is an ongoing obligation of funds in some programs—specifically, for Sandy and Isaac (both of which occurred in 2012) and Irene (which occurred in 2011)—CBO used information on historic "spend-out" rates (that is, the rate at which agencies are expected to spend funds) and feedback from agencies to estimate ultimate amounts of spending. In cases in which federal assistance was provided to states affected by more than one hurricane or a different type of disaster, CBO used agency program documents and state implementation plans to assign spending to individual hurricanes in proportion to the amount of damage they caused.

About This Document

This Congressional Budget Office report was prepared at the request of the Ranking Member of the Senate Committee on the Budget. In keeping with CBO's mandate to provide objective, impartial analysis, the report makes no recommendations.

The analysis was prepared by Terry Dinan, with contributions from Tristan Hanon and Jon Sperl and with guidance from Joseph Kile and Chad Shirley. David Austin provided technical assistance. Robert Arnold, Perry Beider, Mark Booth, Kim Cawley, Eva de Francisco, Daniel Hoople, Benjamin Page, Robert Shackleton, Aurora Swanson, David Torregrosa, and David Weiner provided helpful comments.

Kerry Emanuel of the Massachusetts Institute of Technology and Thomas Knutson of the National Oceanic and Atmospheric Administration provided data and constructive comments. Risk Management Solutions (RMS) provided hurricane damage functions, and Paul Wilson of RMS provided helpful comments. Carolyn Kousky of Resources for the Future, David Kreutzer of the Heritage Foundation, and Roger Pielke Jr. of the University of Colorado at Boulder also provided constructive comments. The assistance of external reviewers implies no responsibility for the final product, which rests solely with CBO.

Robert Sunshine, Jeffrey Kling, and John Skeen reviewed the report, and Loretta Lettner edited it. Maureen Costantino designed the cover, and Jeanine Rees prepared the report for publication. An electronic version is available on CBO's website (www.cbo.gov/publication/51518).

Keith Hall Director

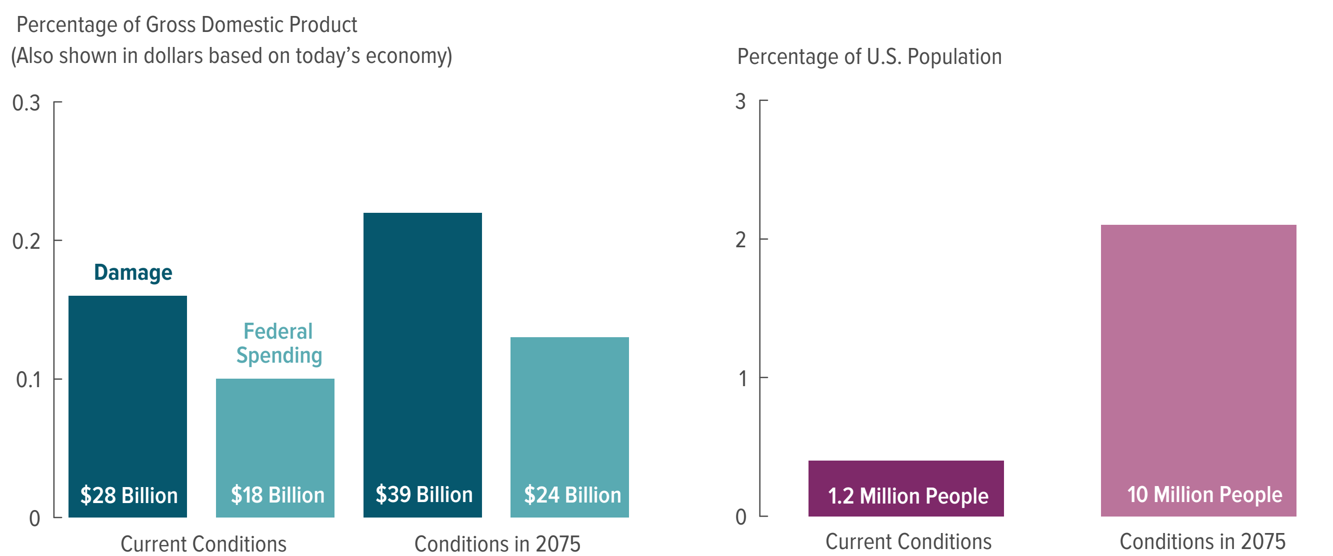
June 2016

Summary Figure 1. Return to Reference

Estimates of Hurricane Damage, Federal Spending, and the Substantially Affected Population

Expected Hurricane Damage and Related Federal Spending

Percentage of the U.S. Population Living in Counties With Substantial Hurricane Damage[a]



Source: Congressional Budget Office.

CBO's estimate of expected annual hurricane damage at present—the "reference case"—is based on estimates of the current frequency of hurricanes, current state-specific sea levels, and the current valuation of property exposed to hurricanes.

CBO's estimates of federal spending are based on a scenario in which federal aid for relief and recovery—measured as a percentage of the damage resulting from hurricanes—stays roughly the same as it has been over the past decade.

CBO's estimates of expected hurricane damage in 2075 are based on the average results of 5,000 simulations, with each simulation using a unique set of draws (random selections) for the underlying conditions that determine expected damage.

a. People exposed to substantial hurricane damage are defined as those living in counties in which per capita expected damage is greater than 5 percent of the county's per capita income.

Box 1. Return to Reference

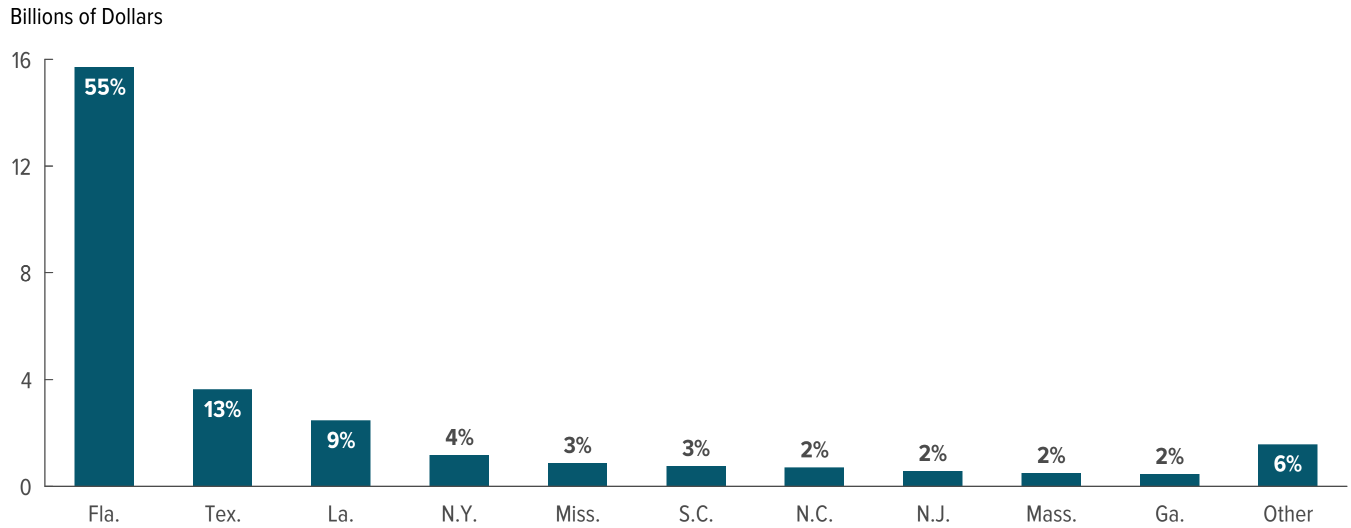
Expected Versus Actual Hurricane Damage in a Given Year

Expected damage reflects the average annual frequency of hurricanes and the average annual damage that a particular category of hurricane would impose for a given sea level and amount of coastal development. That average annual damage accounts for all of the paths that a hurricane of a given category could follow—for instance, whether it heads harmlessly out to sea or makes landfall at different points along the coast of the United States.

Expected damage includes the potential for the most intense hurricanes to strike major cities—such as a Category 5 storm striking Miami. As a result, expected damage is typically higher than actual damage in most years, although it is less than actual damage in an exceptionally high-cost year. Because expected damage does not depend on the idiosyncratic factors that determine actual hurricane damage, changes in expected damage reflect only changes in underlying conditions.

Figure 1. Return to Reference

Expected Annual Hurricane Damage in CBO's Reference Case, by State



Source: Congressional Budget Office, using data from Risk Management Solutions.

CBO's estimate of expected annual hurricane damage at present—the "reference case"—is based on estimates of the current frequency of hurricanes, current state-specific sea levels, and the current valuation of property exposed to hurricanes.

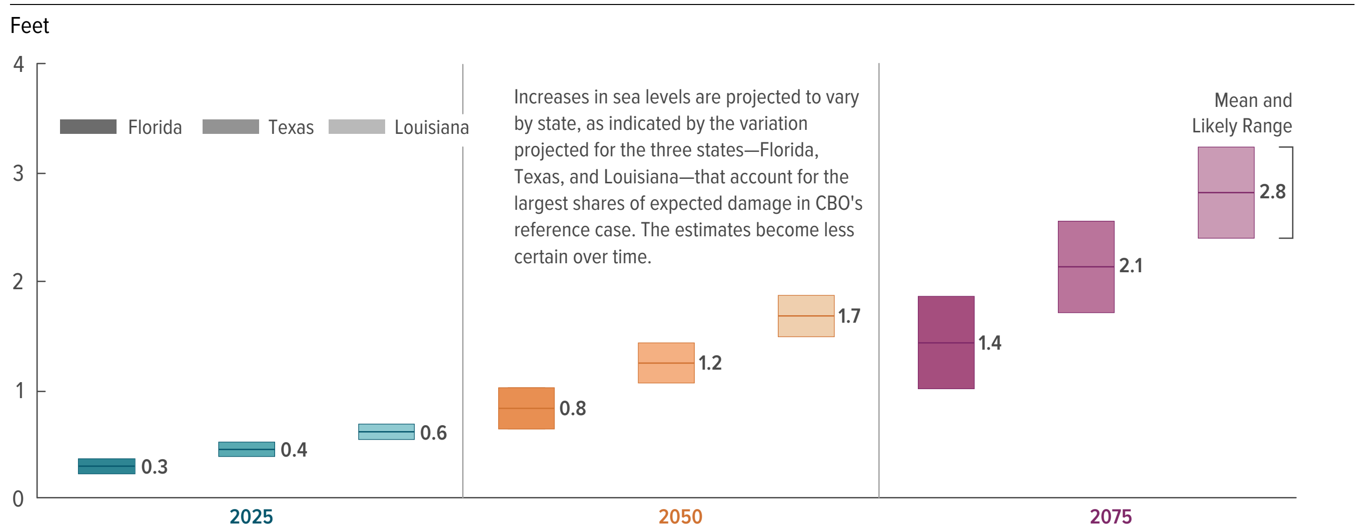
Percentages indicate each state's share of the total damage in CBO's reference case.

Dollar amounts are expressed in 2015 dollars.

"Other" includes the following: Alabama, Connecticut, Delaware, Maine, Maryland, New Hampshire, Pennsylvania, Rhode Island, Vermont, Virginia, Washington, D.C., and West Virginia.

Figure 2. Return to Reference

Projected Rise of Sea Levels in Florida, Texas, and Louisiana in Selected Future Years



Source: Congressional Budget Office, using data from Risk Management Solutions; Robert E. Kopp and others, "Probabilistic 21st and 22nd Century Sea-Level Projections at a Global Network of Tide-Gauge Sites," *Earth's Future*, vol. 2, no. 8 (August 2014; corrected, October 2014), http://onlinelibrary.wiley.com/doi/10.1002/2014EF000239/full.

CBO's estimate of expected annual hurricane damage at present—the "reference case"—is based on estimates of the current frequency of hurricanes, current state-specific sea levels, and the current valuation of property exposed to hurricanes.

The "likely range" includes the middle two-thirds of the distribution of estimates from CBO's simulations.

Box 2.

Return to Reference

Risk Management Solution's Damage Functions

Risk Management Solution's (RMS's) damage functions—which translate hurricane occurrences in the United States into state-specific estimates of expected damage—were determined by simulating tens of thousands of physically realistic hurricane seasons under current conditions, including current sea levels and property exposure in coastal areas. In those simulations, the number of hurricanes of each category (the number of Category 3 storms, for example) making landfall in the United States is consistent with experience during the period from 1900 through 2014. However, the locations of impact are not limited to those of historical storms; in contrast, the simulations account for all the *possible paths* that a given hurricane could follow.

RMS differs from the National Oceanic and Atmospheric Administration (NOAA) in how it categorizes hurricanes. RMS considers their intensity in *advance* of landfall, whereas NOAA—which records historical occurrences—categorizes hurricanes at the *point* of landfall. Because hurricanes generally lose energy as they begin to interact with land—becoming lower-category hurricanes or tropical storms—that difference in categorization means RMS's estimates of hurricane frequencies do not match those that NOAA recorded between 1900 and 2014; RMS's method of categorizing storms results in a greater number of occurrences of all categories of hurricanes.

Because RMS's calculation of expected damage is based on the hurricane's entire wind field and the extent of storm surges as the hurricane moves over land, its estimate of expected damage is not affected by the manner in which it categorizes hurricanes. For example, a hurricane categorized by RMS as a Category 4 storm (based on its wind speed measured at a point in advance of landfall) might have Category 3 wind speeds when it actually makes landfall; in that case, RMS's damage estimate for the storm would be consistent with the Category 3 wind speeds.

According to RMS's simulations, which serve as the basis for the Congressional Budget Office's reference case, Category 1 hurricanes have an expected annual frequency of 0.76, implying that one such hurricane makes landfall, on average, once every 1.3 years (see the table). Although Category 1 storms are the most frequent type of hurricane, they account for less than 8 percent of the total expected hurricane damage of $28 billion in CBO's reference case. (Expected annual damage for storms of a given category is the product of the annual frequency with which such storms occur and the average damage that they create when they do occur.) In contrast, the most intense hurricanes—Category 5 events—account for about 12 percent of total damage even though they only occur (according to RMS's method of measurement), on average, fewer than four times per century. The largest fraction of expected damage comes from Category 4 storms, which, on the basis of RMS's method of categorizing frequency, occur once every four years, on average.

Continued

Box 2. Continued

Risk Management Solution's Damage Functions

Hurricane Characteristics and Estimated Expected Damage in CBO's Reference Case, by Category of Hurricane

Category of Hurricane[a]	Wind Speed (Miles per hour)	Expected Frequency per Year[b]	Expected Number of Years Between Storms	Expected Annual Damage: Billions of Dollars	Expected Annual Damage: Percentage From Storm Surges	Expected Annual Damage: Percentage From Wind	Expected Annual Damage: Percentage Of Total
1	74–95	0.76	1.3	2	45	55	8
2	96–110	0.34	3.0	3	43	57	12
3	111–129	0.32	3.1	9	45	55	31
4	130–156	0.25	4.1	11	30	70	38
5	157+	0.04	26.3	3	22	78	12
Total or Average		1.70	0.6[c]	28	36	64	100

Source: Congressional Budget Office, using data from Risk Management Solutions (RMS).

CBO's estimate of expected annual hurricane damage at present—the "reference case"—is obtained from RMS and is based on current hurricane frequencies, state-specific sea levels, and the valuation of property exposure by state.

Expected annual damage is expressed in 2015 dollars.

a. There are five categories of hurricane, which are classified on the basis of their peak wind speed. Category 5 storms are considered the most intense.

b. The frequency of hurricanes indicates the estimated average number of occurrences in a given year. The frequencies in this table are based on data from RMS, which categorizes hurricanes in advance of landfall. In contrast, the National Oceanic and Atmospheric Administration (NOAA), which records historic occurrences, categorizes hurricanes at the point of landfall. Because hurricanes typically lose energy as they begin to interact with land, RMS's measures of frequency are not comparable to the historic occurrences reported by NOAA. (However, because RMS's calculation of expected damage is based on the hurricane's entire wind field and the extent of storm surges as the hurricane moves over land, its estimate of expected damage is not affected by the manner in which it categorizes hurricanes.)

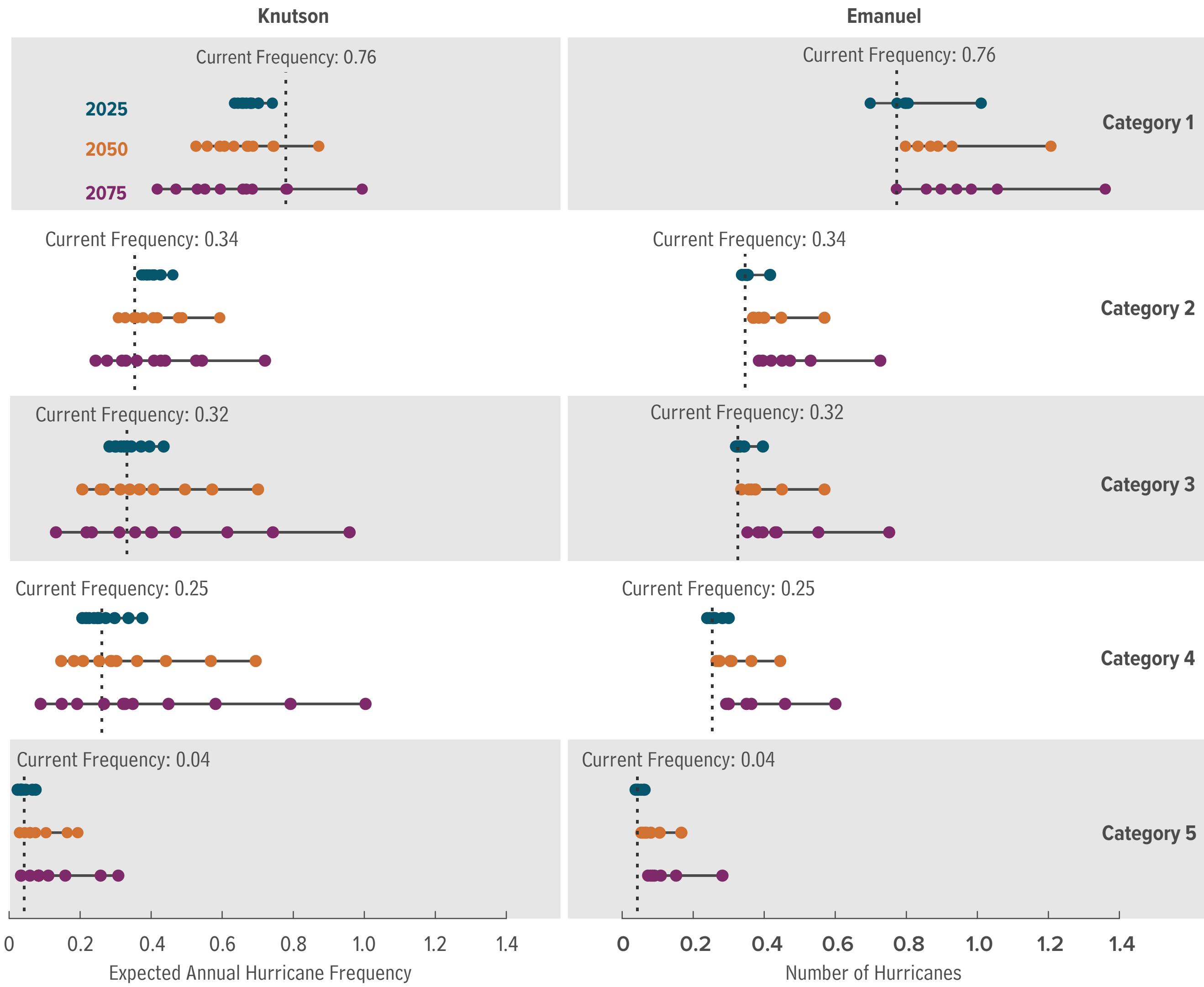
c. The expected number of years between hurricanes of any category.

Figure 3.

Return to Reference

Expected Hurricane Frequency by Researcher, Category, and Year

Estimates of hurricane frequency vary by researcher. In general, Knutson more consistently estimates increases in the frequency of Category 4 and 5 hurricanes than in the frequency of Category 1 and 2 hurricanes. By contrast, Emanuel generally estimates increases in the frequency of all categories of hurricanes. Both researchers' projections become less certain over time.



Source: Congressional Budget Office, using information from Kerry A. Emanuel, "Downscaling CMIP5 Climate Models Shows Increased Tropical Cyclone Activity Over the 21st Century," *Proceedings of the National Academy of Sciences*, vol. 110, no. 30 (July 2013), www.pnas.org/content/110/30/12219; Thomas R. Knutson and others, "Dynamical Downscaling Projections of Twenty-First-Century Atlantic Hurricane Activity: CMIP3 and CMIP5 Model-Based Scenarios," *Journal of Climate*, vol. 26, no. 17 (September 2013), http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-12-00539.1; and additional information from Emanuel and Knutson.

Each circle indicates a projection made by the researcher on the basis of a unique set of factors that influence hurricanes, such as sea surface temperature and wind shear. Those factors were obtained from various atmospheric oceanic general circulation models, with each model projecting outcomes based on a given concentration of greenhouse gases in the atmosphere.

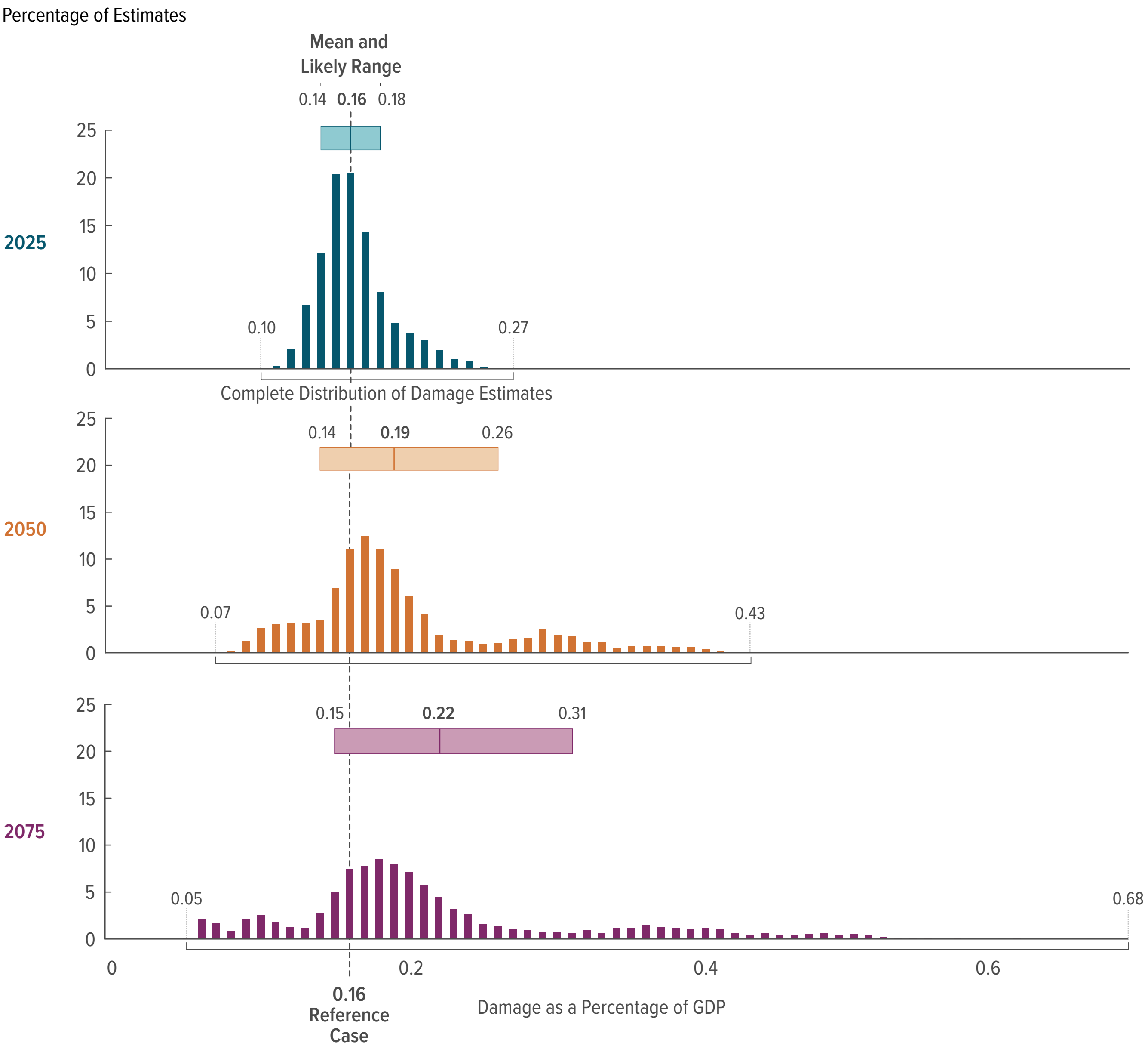
Frequency indicates the estimated average number of occurrences in a given year.

Figure 4.

Return to Reference

Estimates of Expected Hurricane Damage as a Percentage of GDP in Selected Future Years

CBO estimates that expected hurricane damage, measured as a percentage of GDP, will be nearly 40 percent higher (at 0.22 percent) in 2075 than under current conditions (0.16 percent). The uncertainty surrounding estimates of expected damage grows substantially over time.



Source: Congressional Budget Office, using data from Risk Management Solutions; Kerry A. Emanuel, “Downscaling CMIP5 Climate Models Shows Increased Tropical Cyclone Activity Over the 21st Century,” *Proceedings of the National Academy of Sciences*, vol. 110, no. 30 (July 2013), www.pnas.org/content/110/30/12219; Thomas R. Knutson and others, “Dynamical Downscaling Projections of Twenty-First-Century Atlantic Hurricane Activity: CMIP3 and CMIP5 Model-Based Scenarios,” *Journal of Climate*, vol. 26, no. 17 (September 2013), http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-12-00539.1; and additional information provided by Emanuel and Knutson.

CBO’s estimate of expected annual hurricane damage at present—the “reference case”—is based on estimates of the current frequency of hurricanes, current state-specific sea levels, and the current valuation of property exposed to hurricanes.

CBO’s estimates of the distribution of expected hurricane damage in selected years are based on the results of 5,000 simulations, with each simulation using a unique set of draws (random selections) for underlying conditions that determine expected damage.

The “likely range” includes the middle two-thirds of the distribution of estimates from CBO’s simulations.

GDP = gross domestic product.

Table 1.

Return to Reference

Estimates of Expected Damage in 2075, Based on Projections of Hurricane Frequency by Two Researchers

Percentage of GDP

		Likely Range		
Researcher	Mean	Low End	High End	Width
Knutson	0.21	0.10	0.34	0.24
Emanuel	0.22	0.17	0.26	0.09
Both	0.22	0.15	0.31	0.16

Source: Congressional Budget Office, using data from Risk Management Solutions; Kerry A. Emanuel, "Downscaling CMIP5 Climate Models Shows Increased Tropical Cyclone Activity Over the 21st Century," *Proceedings of the National Academy of Sciences*, vol. 110, no. 30 (July 2013), www.pnas.org/content/110/30/12219; and Thomas R. Knutson and others, "Dynamical Downscaling Projections of Twenty-First-Century Atlantic Hurricane Activity: CMIP3 and CMIP5 Model-Based Scenarios," *Journal of Climate*, vol. 26, no. 17 (September 2013), http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-12-00539.1.

The "likely range" includes the middle two-thirds of the distribution of estimates from CBO's simulations.

CBO's main results, which are presented in Figures 4 and 5, combine the predictions of both Knutson and Emanuel.

GDP = gross domestic product.

Table 2.

Return to Reference

The Extent to Which Changes in Population and per Capita Income Affect Estimates of Expected Damage in 2075

	Medium Response[a]	Higher Response	Lower Response
Change in Wind Damage Given a 10 Percent Change in . . .			
Per capita income	10.0	12.5	7.5
Population	2.5	5.0	0
Change in Storm-Surge Damage Given a 10 Percent Change in . . .			
Per capita income	7.5	10.0	5.0
Population	5.0	7.5	2.5
Expected Damage (Percentage of GDP)			
Mean	0.22	0.26	0.17
Likely range[b]			
Low end	0.15	0.17	0.11
High end	0.31	0.37	0.25

Source: Congressional Budget Office, using data from Risk Management Solutions; Kerry A. Emanuel, "Downscaling CMIP5 Climate Models Shows Increased Tropical Cyclone Activity Over the 21st Century," *Proceedings of the National Academy of Sciences*, vol. 110, no. 30 (July 2013), www.pnas.org/content/110/30/12219; and Thomas R. Knutson and others, "Dynamical Downscaling Projections of Twenty-First-Century Atlantic Hurricane Activity: CMIP3 and CMIP5 Model-Based Scenarios," *Journal of Climate*, vol. 26, no. 17 (September 2013), http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-12-00539.1.

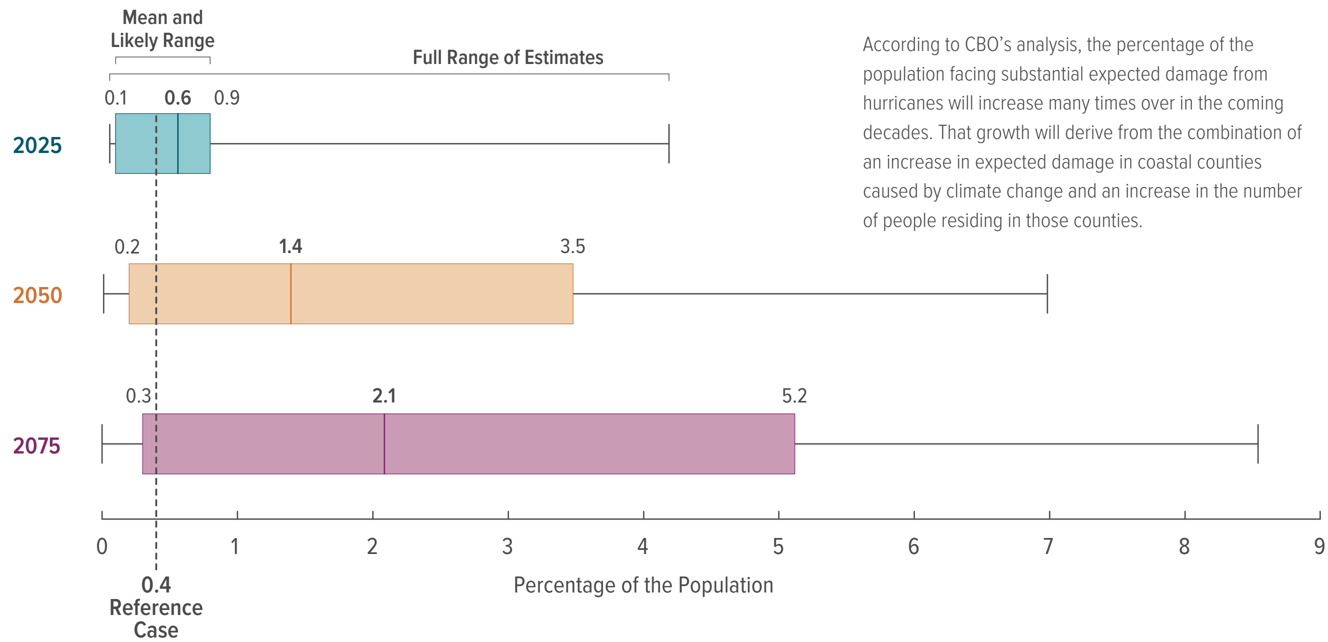
GDP = gross domestic product.

a. The changes in wind damage and storm-surge damage that constitute the "medium response" underlie CBO's estimates of hurricane damage and the affected population, which are provided in Figures 4 and 5.

b. The "likely range" includes the middle two-thirds of the distribution of estimates from CBO's simulations.

Figure 5. Return to Reference

Percentage of the U.S. Population Living in Counties With Substantial Expected Hurricane Damage in Selected Future Years



According to CBO's analysis, the percentage of the population facing substantial expected damage from hurricanes will increase many times over in the coming decades. That growth will derive from the combination of an increase in expected damage in coastal counties caused by climate change and an increase in the number of people residing in those counties.

Source: Congressional Budget Office, using data from Risk Management Solutions; Kerry A. Emanuel, "Downscaling CMIP5 Climate Models Shows Increased Tropical Cyclone Activity Over the 21st Century," *Proceedings of the National Academy of Sciences*, vol. 110, no. 30 (July 2013), www.pnas.org/content/110/30/12219; and Thomas R. Knutson and others, "Dynamical Downscaling Projections of Twenty-First-Century Atlantic Hurricane Activity: CMIP3 and CMIP5 Model-Based Scenarios," *Journal of Climate*, vol. 26, no. 17 (September 2013), http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-12-00539.1.

People exposed to substantial hurricane damage are defined as those living in counties in which per capita expected damage is greater than 5 percent of the county's per capita income.

CBO's estimate of expected annual hurricane damage at present—the "reference case"—is based on estimates of the current frequency of hurricanes, current state-specific sea levels, and the current valuation of property exposed to hurricanes.

CBO's estimates of the distribution of expected hurricane damage in selected years are based on the results of 5,000 simulations, with each simulation using a unique set of draws (random selections) for four underlying conditions that determine expected damage.

The "likely range" includes the middle two-thirds of the distribution of estimates from CBO's simulations.

Table 3.

Return to Reference 1, 2

Total Federal Spending and Total Economic Damage for Selected Hurricanes, 2000 to 2015

Hurricane	Date	Total Federal Spending in Response to Hurricanes (Billions of dollars): Discretionary	Mandatory	Total	Percentage of Total Federal Spending in Response to Hurricanes	Total Economic Damage (Billions of dollars)	Percentage of Total Economic Damage
Lili	Oct-02	0.1	0	0.1	0.1	1.3	0.3
Isabel	Sep-03	1.1	0.1	1.2	0.6	7.7	1.9
Charley	Aug-04	2.0	0	2.1	1.0	20.9	5.2
Frances	Sep-04	2.8	0	2.8	1.3	12.3	3.0
Ivan	Sep-04	3.8	0.1	3.9	1.8	25.8	6.4
Jeanne	Sep-04	3.3	0	3.3	1.6	9.8	2.4
Dennis	Jul-05	0.3	0	0.3	0.2	3.5	0.9
Katrina	Aug-05	107.9	2.3	110.2	51.3	147.4	36.5
Rita	Sep-05	8.6	0.1	8.7	4.0	22.4	5.5
Wilma	Oct-05	6.1	0.1	6.2	2.9	22.4	5.5
Dolly	Jul-08	0.2	0	0.3	0.1	1.1	0.3
Gustav	Sep-08	4.0	0	4.0	1.9	6.7	1.7
Ike	Sep-08	12.0	0.4	12.3	5.7	33.7	8.4
Irene	Aug-11	3.8	0.5	4.3	2.0	15.5	3.8
Isaac	Aug-12	1.2	0.0	1.3	0.6	3.2	0.8
Sandy	Oct-12	51.2	2.6	53.9	25.1	69.9	17.3
Total		208.6	6.3	214.9	100.0	403.6	100.0

Source: Congressional Budget Office, using information from the sources listed in Appendix B.

Estimates of total economic damage are from the National Oceanic and Atmospheric Administration, National Hurricane Center, "Tropical Cyclone Reports" (June 5, 2015), www.nhc.noaa.gov/data/tcr/index.php?season=2014&basin=atl.

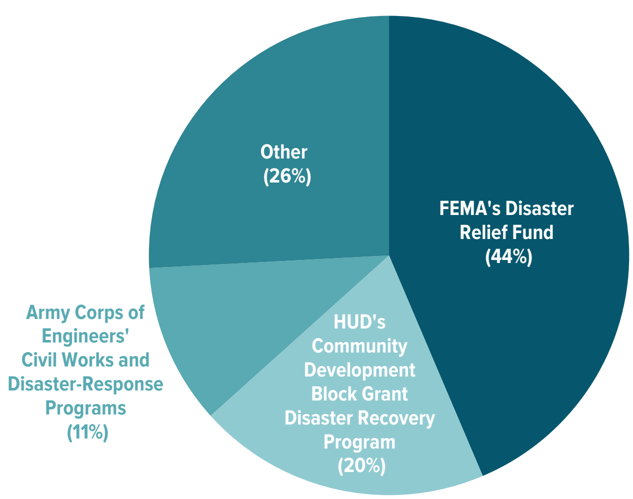
Dollar amounts are expressed in 2015 dollars.

Includes all hurricanes resulting in at least $1 billion in damage between 2000 and 2015. (Not all years included such hurricanes.)

Figure 6.

Return to Reference

Share of Discretionary Federal Spending on Selected Hurricanes, by Agency, Fiscal Years 2000 to 2015



Source: Congressional Budget Office, using information from the sources listed in Appendix B.

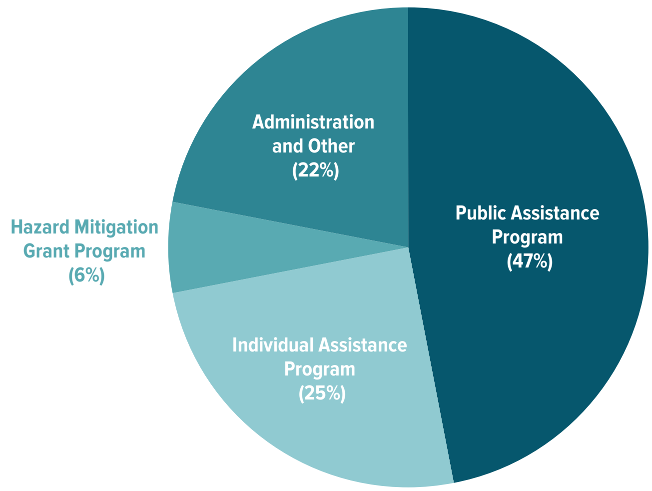
"Other" includes the Department of Transportation, Department of Education, Department of Defense (not including the Army Corps of Engineers), and Small Business Administration.

Includes all hurricanes resulting in at least $1 billion in damage between 2000 and 2015. (Not all years included such hurricanes.)

FEMA = Federal Emergency Management Agency; HUD = Department of Housing and Urban Development.

Figure 7. Return to Reference

Share of Spending From FEMA's Disaster Relief Fund, by Type of Activity, Fiscal Years 2000 to 2013



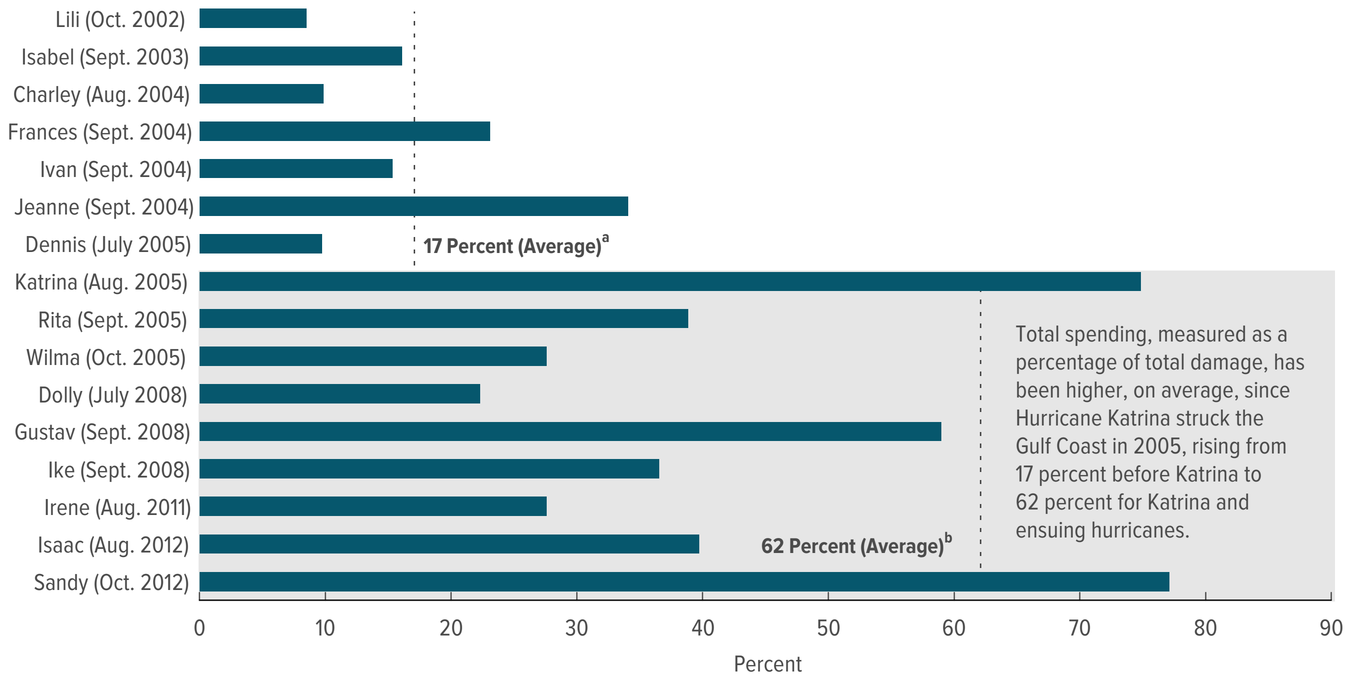
Source: Congressional Budget Office, using data from the Federal Emergency Management Agency.

The Public Assistance Program helps communities cover the costs of repairing or replacing public buildings and infrastructure, restoring utilities, establishing emergency shelters, and so on. The Individual Assistance Program provides temporary housing for displaced people, grants for medical treatment and for the repair of damaged property, and other assistance. The Hazard Mitigation Grant Program includes measures that are designed to prevent or reduce the loss of life or property damage that could result from a future disaster, such as elevating structures to reduce damage from flooding and implementing warning systems. "Administration and Other" includes FEMA's administrative costs, technical assistance contracts, and mission assignments.

FEMA = Federal Emergency Management Agency.

Figure 8. Return to Reference

Total Federal Spending as a Percentage of Total Economic Damage for Selected Hurricanes, 2000 to 2015



Source: Congressional Budget Office, using information from the sources listed in Appendix B.

The hurricanes included here were ones for which CBO was able to obtain detailed data on federal spending.

Includes all hurricanes resulting in at least $1 billion in damage between 2000 and 2015. (Not all years included such hurricanes.)

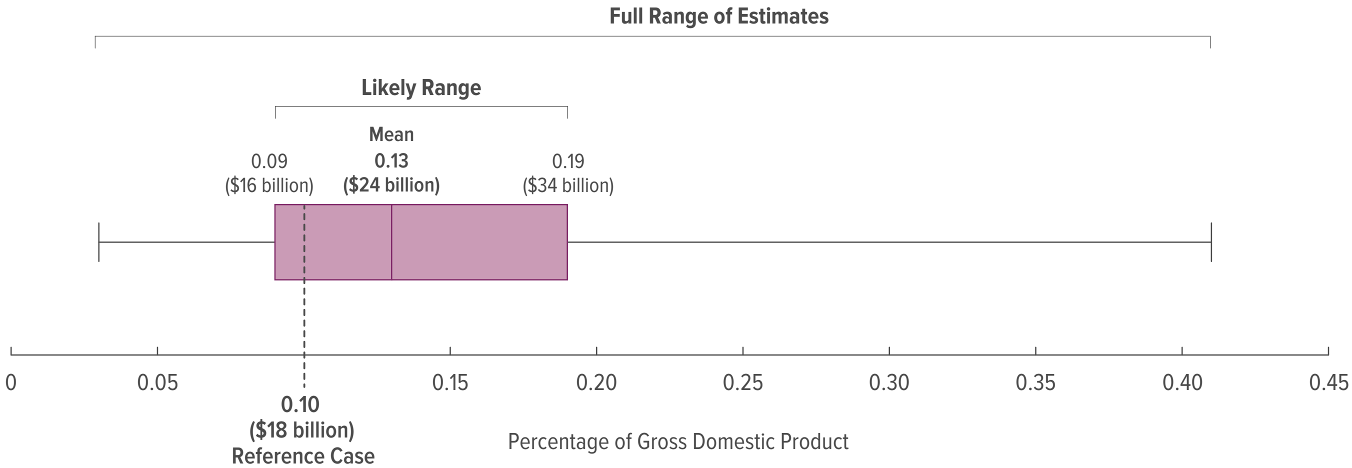
a. Total federal spending as a percentage of total economic damage for hurricanes Lili through Dennis.

b. Total federal spending as a percentage of total economic damage for hurricanes Katrina through Sandy.

Figure 9.

Return to Reference

Estimates of Federal Spending on Hurricane Damage in 2075, Based on the Historical Cost Scenario



Source: Congressional Budget Office.

Dollar amounts in parentheses are based on today's economy.

In the historical cost scenario, federal spending is estimated to be 60 percent of expected hurricane damage. CBO's estimate of expected annual hurricane damage at present—the "reference case"—is based on estimates of the current frequency of hurricanes, current state-specific sea levels, and the current valuation of property exposed to hurricanes. CBO's estimates of the distribution of expected hurricane damage in 2075 are based on the results of 5,000 simulations, with each simulation using a unique set of draws (random selections) for the underlying conditions that determine expected damage.

The "likely range" includes the middle two-thirds of the distribution of estimates from CBO's simulations.

Table 4.

Return to Reference

Estimates of Federal Spending in 2075, Based on Likely Ranges of Expected Damage and Alternative Scenarios About Spending as a Percentage of Expected Damage

Likely Range of Federal Spending in 2075 if . . .	
Spending Equals 40% of Damage	
Measured as a percentage of GDP	0.06–0.13
Measured in billions of dollars based on today's economy	11–24
Spending Equals 60% of Damage	
Measured as a percentage of GDP	0.09–0.19
Measured in billions of dollars based on today's economy	16–34
Spending Equals 80% of Damage	
Measured as a percentage of GDP	0.12–0.25
Measured in billions of dollars based on today's economy	22–45

Source: Congressional Budget Office.

On the basis of historical data on federal spending as a percentage of economic damage for hurricanes occurring from August 2005 to the present, which averaged 60 percent, and on CBO's estimate of expected damage under current conditions, which is 0.16 percent of gross domestic product (GDP), expected federal spending under current conditions is 0.10 percent of GDP, or $18 billion.

Dollar amounts are expressed in 2015 dollars.

The "likely range" includes the middle two-thirds of the distribution of estimates from CBO's simulations.

Table A-1.

Return to Reference

Combined and Individual Effects of Climate Change and Coastal Development

Source of Change in Damage	1 Mean Damage Estimate in 2075 (Billions of dollars)	2 Increase in Mean Damage Estimate in 2075 Relative to $30 Billion in the Reference Case (Billions of dollars)[a]	3 Share of Sum of Individual Effects[b] (Percent)	4 Allocation of Interaction Effect (Billions of dollars)[c]	5 Contribution to Increase in Mean Damage Estimate of Total Combined Effect of Climate Change and Coastal Development (Billions of dollars)[d]
Combined Effect of Climate Change and Coastal Development	150	120	n.a.	n.a.	n.a.
Individual Effect: Climate Change Only	65	35	45	20	55
Individual Effect: Coastal Development Only	70	40	55	25	65
Sum of Individual Effects	n.a. [e]	75	n.a.	n.a.	n.a.
Interaction Effect (Equals the combined effect minus the sum of individual effects)	n.a.	45	n.a.	n.a.	n.a.

Source: Congressional Budget Office, using data from Risk Management Solutions; Kerry A. Emanuel, "Downscaling CMIP5 Climate Models Shows Increased Tropical Cyclone Activity Over the 21st Century," *Proceedings of the National Academy of Sciences*, vol. 110, no. 30 (July 2013), www.pnas.org/content/110/30/12219; and Thomas R. Knutson and others, "Dynamical Downscaling Projections of Twenty-First-Century Atlantic Hurricane Activity: CMIP3 and CMIP5 Model-Based Scenarios," *Journal of Climate*, vol. 26, no. 17 (September 2013), http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-12-00539.1.

CBO's estimate of expected annual hurricane damage at present—the "reference case"—is based on estimates of the current frequency of hurricanes, current state-specific sea levels, and the current valuation of property exposed to hurricanes.

Dollar amounts are expressed in 2015 dollars and rounded to the nearest $5 billion. All shares are rounded to the nearest 5 percent.

n.a. = not applicable.

a. Equals the mean damage estimate reported in Column 1 minus the $30 billion of expected damage in CBO's reference case.

b. Equals the increase in expected damage when individual effects are estimated in isolation ($35 billion for climate change only, for example) divided by the sum of the individual effects ($75 billion).

c. Equals the share of the sum of individual effects caused by one factor reported in Column 3 (45 percent for climate change only, for example) multiplied by the interaction effect reported in Column 2 ($45 billion).

d. Equals the sum of the individual increase in mean damage resulting from a single effect reported in Column 2 ($35 billion for climate change only, for example) plus the dollar amount of the interaction effect allocated to the individual effect reported in Column 4 ($20 billion for climate change only, for example).

e. The mean individual effects cannot be summed because doing so would double count the $30 billion of damage in the reference case.