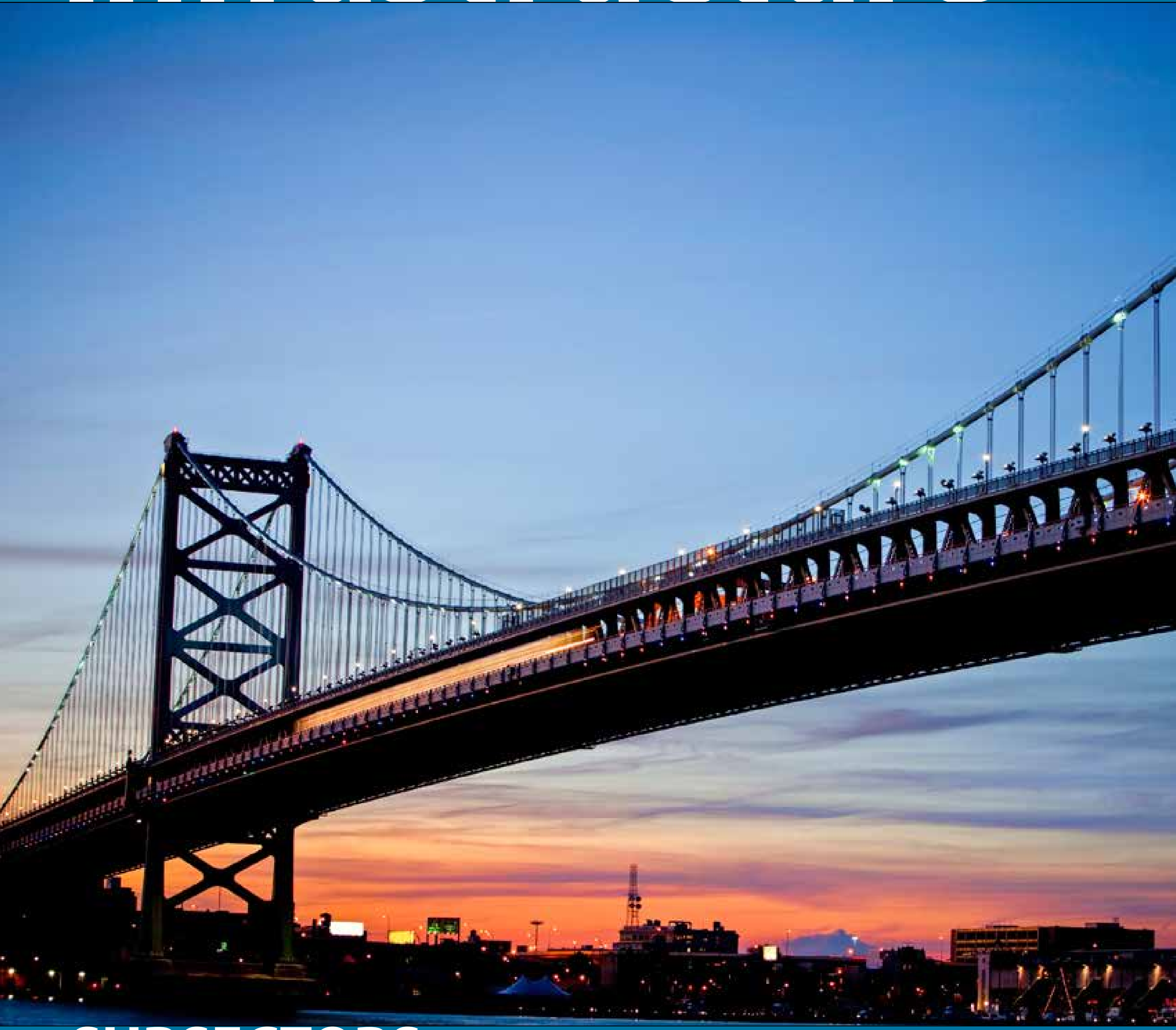
Infrastructure



SUBSECTORS

Bridges

Roads

Infrastructure makes up the basic physical and organizational structure of our society and is by design interdependent and interconnected. Built infrastructure includes urban buildings; systems for energy, transportation, water, wastewater, drainage, and communication; industrial structures; and other products of human design and construction.[1] U.S. infrastructure has enormous value, both directly as a capital asset and indirectly to support human well-being and a productive economy.

Total public spending on transportation and water infrastructure exceeds $300 billion annually; roughly 25 percent of that total is spent at the federal level and accounts for three percent of total federal spending.[2] Recent analyses point to large gaps between existing capital and maintenance spending and the level of expenditure necessary to maintain current levels of services.[3]

HOW IS INFRASTRUCTURE VULNERABLE TO CLIMATE CHANGE?

Experience over the past decade provides compelling evidence of how vulnerable infrastructure can be to climate change effects, including sea level rise, storm surge, and extreme weather events.[4] Climate change will put added stress on the nation's aging infrastructure to varying degrees over time. Sea level rise and storm surge, in combination with the pattern of heavy development in coastal areas, are already resulting in damage to infrastructure such as roads, buildings, ports, and energy facilities. Floods along the nation's rivers, inside cities, and on lakes following heavy downpours, prolonged rains, and rapid melting of snowpack are damaging infrastructure in towns and cities, on farmlands, and in a variety of other places across the nation. In addition, extreme heat is damaging transportation infrastructure such as roads, rails, and airport runways.

WHAT DOES CIRA COVER?

CIRA analyzes potential climate change impacts and damages to four types of infrastructure in the U.S.: roads, bridges, urban drainage, and coastal property. Analyses of several important types of infrastructure are not included in CIRA, particularly telecommunications and energy transmission networks, and the Urban Drainage analysis only analyzes impacts in 50 cities of the contiguous U.S. Further, some analyses in this sector assume that adaptation measures will be well-timed. This likely results in conservative estimates of future damages, as history has shown that infrastructure investment and maintenance are often not implemented in optimal, well-timed ways.

Urban Drainage

Coastal Property

Bridges

KEY FINDINGS

1. Without reductions in global GHG emissions, an estimated 190,000 inland bridges across the nation will be structurally vulnerable because of climate change by the end of the century. In some areas, more than 50% of bridges are projected to be vulnerable as a result of unmitigated climate change. This analysis estimates the damages of climate change in terms of increased costs to maintain current levels of service (i.e. adaptation costs). Without adaptation, climate change could render many bridges unusable, leading to large economic damages.

2. Global GHG mitigation is estimated to substantially reduce the number of bridges across the U.S. that become vulnerable in the 21st century by reducing the projected increase in peak river flows under the Reference scenario.

3. Global GHG mitigation is projected to reduce adaptation costs that would be incurred under the Reference scenario. The benefits of global GHG mitigation are estimated at $3.4-$42 billion from 2010-2050 and $10-$15 billion from 2051-2100 (discounted at 3%).

Climate Change and Bridges

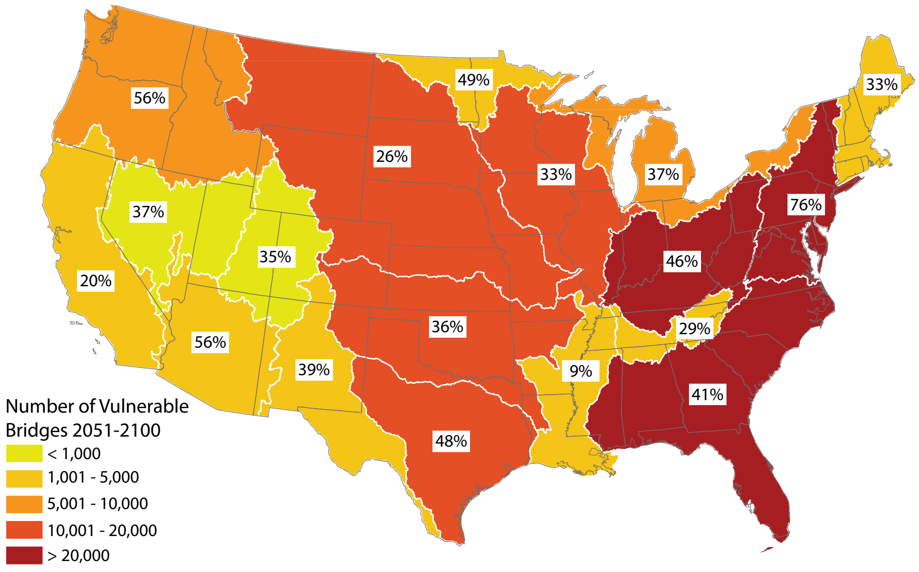
Road bridges are a central component of the U.S. transportation system. With the average U.S. bridge now over 40 years old, however, more than 250 million vehicles cross structurally deficient bridges on a daily basis.[5] Similar to other transportation infrastructure, bridges are vulnerable to a range of threats from climate change.[6] Currently, most bridge failures are caused by scour, where swiftly moving water removes sediment from around bridge structural supports, weakening or destroying their foundations. Increased flooding and long-term river flow changes caused by climate change are expected to increase the frequency of bridge scour, further stressing the aging U.S. transportation system.

Risks of Inaction

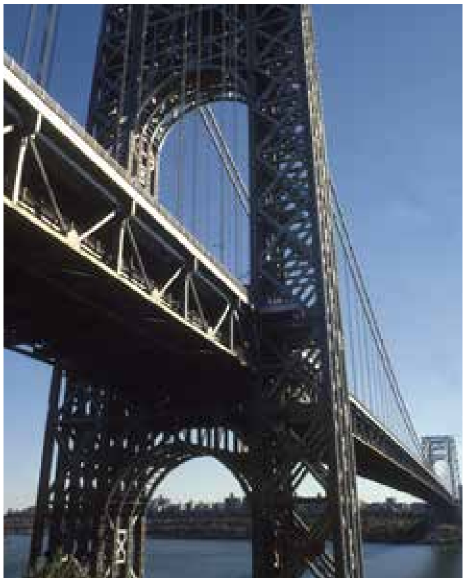
Increased inland flooding caused by climate change threatens bridges across the U.S. and risks a net increase in maintenance costs. Figure 1 shows the number and percent of bridges in each hydrologic region of the contiguous U.S. identified as vulnerable to climate change in the late 21st century under the Reference scenario using the IGSM-CAM climate model. In total, approximately 190,000 bridges are identified as vulnerable. In addition, the costs of adapting bridges to climate change under the Reference scenario are estimated at $170 billion for the period from 2010 to 2050, and $24 billion for the period from 2051 to 2100 (discounted at 3%). The higher costs during the first half of the century are primarily due to the large number of vulnerable bridges that require strengthening in the near term in the face of increasing peak river flows due to climate change. These findings regarding near-term bridge vulnerability and adaptation costs due to unmitigated climate change are consistent with the findings of the assessment literature.[7]

Figure 1. Bridges Identified as Vulnerable in the Second Half of the 21st Century Due to Unmitigated Climate Change

Estimated number of vulnerable bridges in each of the 2-digit hydrologic unit codes (HUCs) of the contiguous U.S. in the period from 2051-2100 under the Reference scenario using the IGSM-CAM climate model. The map also shows the percentage of inland bridges in each HUC that are vulnerable due to climate change.



Reducing Impacts through GHG Mitigation

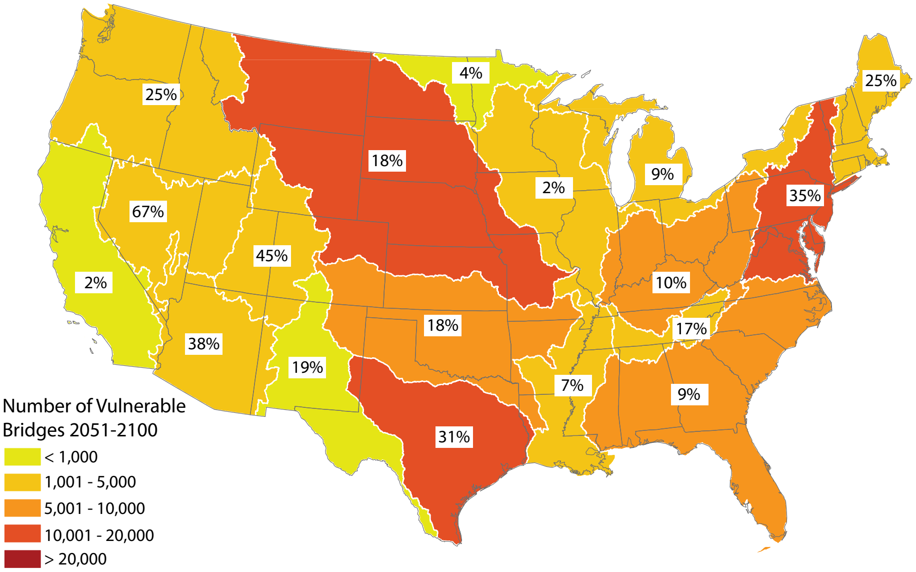


As shown in Figure 2, global GHG mitigation is projected to substantially reduce the number of vulnerable bridges in many areas of the contiguous U.S. compared to the Reference scenario (Figure 1). For example, the percentage of vulnerable bridges in the Northwest region, which includes Washington and parts of Oregon and Idaho, is reduced from 56% under the Reference to 25% under the Mitigation scenario. At the national scale, the total number of vulnerable bridges is reduced by roughly 40,000 through 2050 compared to the Reference scenario, and by over 110,000 in the second half of the century.

In addition, the analysis estimates that global GHG mitigation reduces the costs of adaptation substantially relative to the Reference scenario. In the period from 2010 to 2050, costs under the Mitigation scenario are approximately $42 billion lower than under the Reference (discounted at 3%). Although adaptation costs are lower in the second half of the century, costs under the Mitigation scenario are nearly 60% lower than they are under the Reference scenario, with savings estimated at $15 billion (discounted at 3%). These results rely upon climate projections using the IGSM-CAM, which projects a relatively wetter future for most of the U.S. compared to the MIROC climate model (see the Levels of Certainty section of this report for more information). The projected benefits of global GHG mitigation are lower with the drier MIROC model (not shown) for the 2010-2050 period, at approximately $3.4 billion, but are higher in the 2051-2100 period, at approximately $10 billion (discounted at 3%).

Figure 2. Bridges Identified as Vulnerable in the Second Half of the 21st Century with Global GHG Mitigation

Estimated number of vulnerable bridges in each of the 2-digit HUCs of the contiguous U.S. in the period from 2051-2100 under the Mitigation scenario using the IGSM-CAM climate model. The map also shows the percentage of inland bridges in each HUC that are vulnerable due to climate change.



APPROACH

The CIRA analysis identifies inland bridges in the contiguous U.S. that may be vulnerable to increased peak river flows due to climate change and estimates the costs to adapt the at-risk infrastructure.[8] The analysis relies upon climate projections from two climate models: IGSM-CAM, which projects a relatively wetter future for most of the U.S., and the drier MIROC model. Bridge performance and vulnerability are determined using the National Bridge Inventory database and are based on the following four elements:

- substructure condition;
- channel and channel protection condition;
- waterway adequacy; and
- vulnerability to scour.

The analysis estimates the timing of bridge vulnerability (based on the 100-year, 24-hour storm event), and the adaptation costs of maintaining the current condition and level of service of the at-risk bridges. Two types of bridge fortification and the costs of their implementation are analyzed: the use of riprap (large rocks and rubble) to stabilize bridge foundations and the use of additional concrete to strengthen bridge piers and abutments. Although there will likely be significant changes to the nation's bridges over the course of the century—some bridges will be strengthened, some will deteriorate, some will be removed, and new bridges will be built—this analysis estimates the costs of adapting the nation's existing bridge infrastructure to different future climates based on its current state (i.e., the additional costs due to climate change are isolated).[9,10]

For more information on the CIRA approach and results for the bridges sector, please refer to Neumann et al. (2014)[11] and Wright et al. (2012).[12]

Roads

KEY FINDINGS

1. Climate change is projected to increase the cost of maintaining road infrastructure. This analysis estimates the damages of climate change in terms of increased costs to maintain current levels of service (i.e. adaptation costs). Without adaptation, climate change could render many roadways unusable, leading to large economic damages.

2. In all regions, adaptation costs associated with the effects of higher temperatures on paved roadways are estimated to increase over time. In the central regions of the country, in particular, changes in precipitation patterns are projected to increase costs associated with re-grading unpaved roadways.

3. Without global GHG mitigation, adaptation costs in 2100 in the U.S. roads sector are estimated to range from $5.8-$10 billion.

4. Global GHG mitigation is projected to avoid an estimated $4.2-$7.4 billion of the damages under the Reference scenario in 2100.

Climate Change and Roads

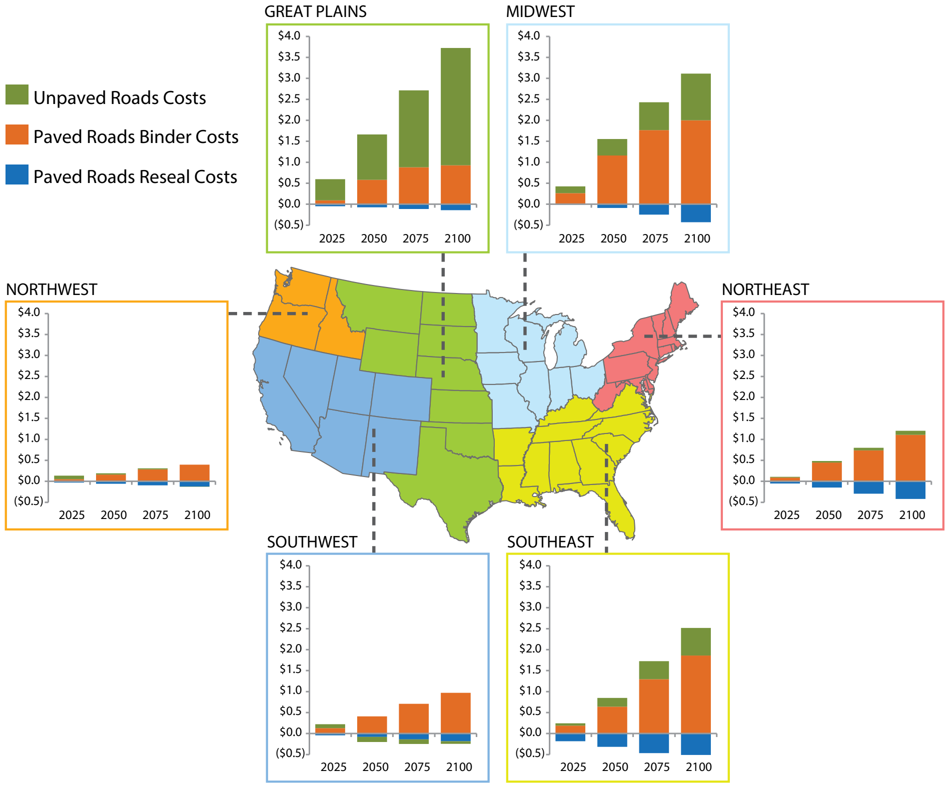
The U.S. road network is one of the nation's most important capital assets. Climate stress on roads will likely change in the future, with various potential impacts and adaptation costs.[13] For example, roads may experience more frequent buckling due to increased temperatures, more frequent washouts of unpaved surfaces from increases in intense precipitation, and changes in freeze-thaw cycles that cause cracking.[14]

Risks of Inaction

Without reductions in global GHG emissions, the costs of maintaining, repairing, and replacing pavement are projected to increase, which is consistent with the findings of the assessment literature regarding adaptation costs for road infrastructure.[15] Figure 1 presents the estimated regional damages (in the form of adaptation costs) to the U.S. road network under the Reference scenario using the ISGM-CAM climate model. The greatest impacts are projected to occur in the Great Plains region, where costs are mainly due to erosion of unpaved roads associated with increased precipitation. Costs associated with the use of different pavement binders to avoid cracking of paved roads are also high, particularly in the Midwest and Southeast regions, and they increase over time in all regions due to the projected rise in temperature. Costs of resealing roads after freeze-thaw events decrease over time as the climate changes, but the magnitude of the decrease does not offset the projected increase in other costs.

Figure 1. Projected Impacts of Unmitigated Climate Change on U.S. Road Infrastructure

Adaptation costs (billions 2014$, undiscounted) under the Reference scenario using the IGSM-CAM climate model. Results are presented for the six regions used in the Third National Climate Assessment.



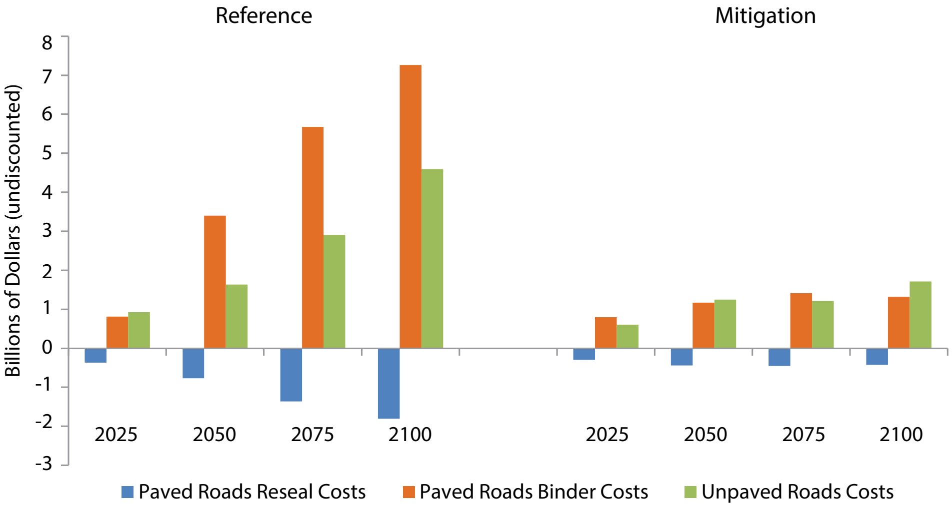
Reducing Impacts through GHG Mitigation

Adaptation costs for the U.S. road network are substantially reduced with global GHG mitigation compared to the Reference scenario (Figure 2). These reductions are due in large part to the effect of lower temperatures under the Mitigation scenario on maintenance needs for paved roads. Specifically, costs associated with asphalt binders account for a large share of the adaptation costs nationally under the Reference, and these costs are significantly lower with mitigation. Costs associated with adaptation for unpaved roads are also substantially lower under the Mitigation scenario, as heavy precipitation events are projected to be less severe compared to the Reference. Costs of resealing roads after freeze-thaw cycles are projected to decrease under both scenarios, but the magnitude of the decrease does not offset the projected increase in other costs.

By 2050, the adaptation costs under the Reference scenario are substantially higher, illustrating the benefits that accrue over time with GHG mitigation. In addition, although the costs of adaptation increase over the course of the century under both scenarios, they do so at a much faster rate under the Reference. Under the Reference, adaptation costs are estimated at approximately $10 billion in 2100, whereas under the Mitigation scenario costs are estimated at $2.6 billion. As a result, global GHG mitigation is projected to avoid over $7 billion in damages in 2100. These results rely upon climate projections from the IGSM-CAM, which projects a relatively wetter future for most of the U.S. compared to the MIROC climate model (see the Levels of Certainty section of this report for more information). The projected benefits of global GHG mitigation are lower with the drier MIROC model (not shown), at $4.2 billion in 2100, reflecting the reduced impact of precipitation on unpaved roads under both scenarios.[16]

Figure 2. Projected Impacts on U.S. Road Infrastructure with and without Global GHG Mitigation

Costs of adaptation for the Reference and Mitigation scenarios using the IGSM-CAM climate model (billions 2014$). The reduction in adaptation costs under the Mitigation scenario relative to the Reference reflects the benefits of global GHG mitigation.



APPROACH

The CIRA approach assesses four risks to road infrastructure associated with climate change:

- rutting of paved roads from precipitation;
- rutting of paved roads caused by freeze-thaw cycles;
- cracking of paved roads due to high temperatures; and
- erosion of unpaved roads from precipitation.

The CIRA analysis examines the implications of changes in climate over time for the U.S. road network based on stressor-response functions for each of the above effects. The analysis considers the effects of temperature and precipitation, but does not include impacts due to sea level rise and storm surge, which would likely increase damages to roads. The analysis relies upon climate projections from two climate models: IGSM-CAM, which projects a relatively wetter future for most of the U.S., and the drier MIROC model.

The costs of adaptation to effectively counteract the climate change impacts and maintain roads at their current levels of service are estimated for each of the CIRA scenarios. As there will be continued maintenance needs over time, this analysis focuses on the additional costs due to climate change. The response measures include more frequent resealing to avoid rutting; use of different pavement binders during resurfacing to avoid cracking of asphalt-paved roads; and more frequent re-grading of unpaved roads to minimize erosion impacts. This analysis assumes well-timed adaptation to maintain service levels, a potentially overly optimistic assumption given that infrastructure investments are oftentimes delayed.

For more information on the CIRA approach and results for the roads sector, please refer to Neumann et al. (2014)[17] and Chinowsky et al. (2013).[18]

Urban Drainage

KEY FINDINGS

1. Climate change is projected to result in increased adaptation costs for urban drainage systems in cities across the U.S., particularly in the Great Plains region.
2. Without global GHG mitigation, adaptation costs in 2100 associated with the 50-year, 24-hour storm in 50 major U.S. cities are projected to range from $1.1-$12 billion.
3. Global GHG mitigation is projected to result in cost savings for urban drainage systems in these cities ranging from $50 million to $6.4 billion in 2100 for the 50-year, 24-hour storm, depending on the climate model used. Inclusion of all U.S. cities would likely increase the cost savings by a substantial amount.

Climate Change and Drainage

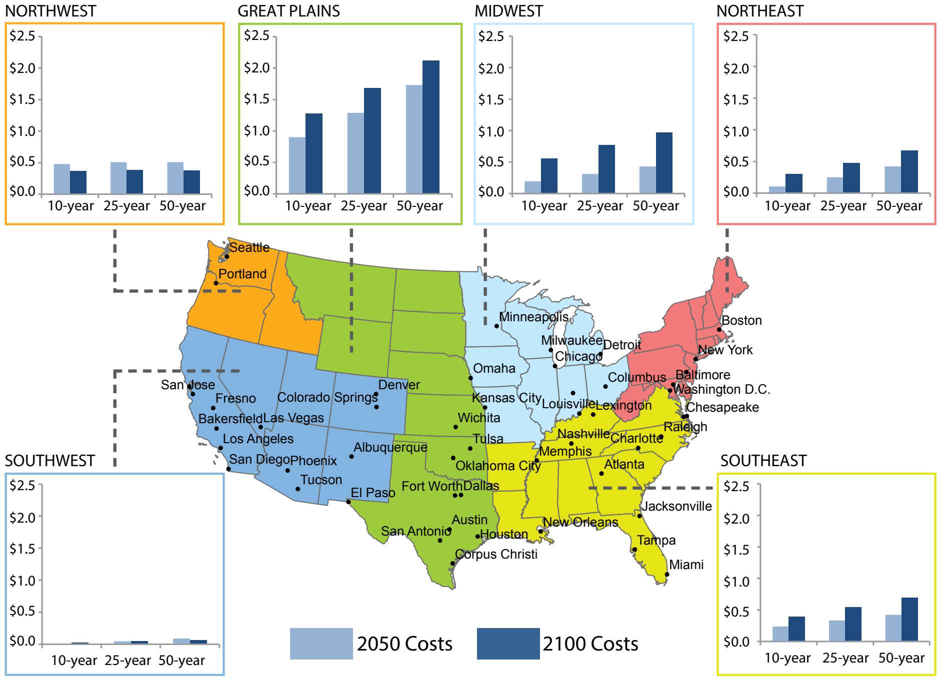
Urban drainage systems capture and treat stormwater runoff and prevent urban flooding. During storm events, the volume of runoff flowing into drainage systems and the ability of these systems to manage runoff depend on a variety of site-specific factors, such as the imperviousness of the land area in the drainage basin. Changes in storm intensity associated with climate change have the potential to overburden drainage systems, which may lead to flood damage, disruptions to local transportation systems, discharges of untreated sewage to waterways, and increased human health risks.[19] In areas where precipitation intensity increases significantly, adaptation investments may be necessary to prevent runoff volumes from exceeding system capacity.

Risks of Inaction

Without global GHG mitigation, climate change is projected to result in increased adaptation costs for urban drainage infrastructure, a finding that is consistent with the conclusions of the assessment literature.[20] Figure 1 presents the projected costs for the 50 modeled cities in 2050 and 2100 under the Reference scenario using the IGSM-CAM climate model for the three categories of storm events modeled (24-hour events with precipitation intensities occurring every 10, 25, and 50 years).[21] The average per-square-mile costs are projected to be highest in the Great Plains region in both 2050 and 2100 due to the projected increase in heavy precipitation in that region. Adaptation costs are estimated to be relatively low in the Southwest due to the projected reduction in precipitation in that region.

Figure 1. Projected Impacts of Unmitigated Climate Change on U.S. Urban Drainage Systems

Weighted average per-square-mile adaptation costs (millions 2014$, undiscounted) in 2050 and 2100 for the 10-, 25-, and 50-year storms under the Reference scenario using the IGSM-CAM climate model. Costs for each of the 50 modeled cities (shown) are aggregated to the six regions used in the Third National Climate Assessment.

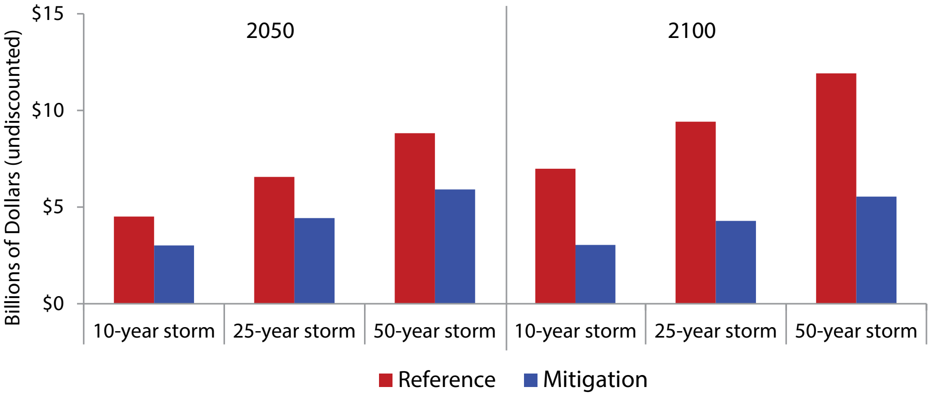


Reducing Impacts through GHG Mitigation

Global GHG mitigation is projected to result in substantial adaptation cost savings for urban drainage systems in the 50 modeled cities (Figure 2). Overall, cost savings are projected to be higher in 2100 than in 2050, and increase according to the intensity of the storm modeled, with the greatest savings occurring for the 50-year, 24-hour storm. For this particular storm event, total adaptation costs for the modeled cities are projected to be $12 billion in 2100 under the Reference. Under the Mitigation scenario, these costs are reduced to approximately $5.5 billion, which represents a cost savings of approximately $6.4 billion. Cost savings for the 10- and 25-year storms under the Mitigation scenario are approximately $3.9 billion and $5.1 billion, respectively, in 2100. Looking across the contiguous U.S., the Great Plains region is projected to experience the largest reductions in adaptation costs as a result of global GHG mitigation. These results rely upon climate projections from the IGSM-CAM, which projects a relatively wetter future for most of the U.S. compared to the MIROC climate model (see the Levels of Certainty section of this report for more information). Using the drier MIROC model, projected benefits of GHG mitigation for the modeled cities associated with the 50-year, 24-hour storm event are estimated at $50 million.

Figure 2. Projected Impacts on Urban Drainage Systems in 50 U.S. Cities with and without Global GHG Mitigation

Projected adaptation costs in 2050 and 2100 for the Reference and Mitigation scenarios using the IGSM-CAM climate model (billions 2014$). The values of the red bars represent the sum of all adaptation costs shown in Figure 1 for the years 2050 and 2100.



APPROACH

The CIRA analysis estimates the costs of adapting urban drainage systems to meet future demands of increased runoff associated with more intense rainfall under climate change. The analysis relies upon climate projections from two climate models: IGSM-CAM, which projects a relatively wetter future for most of the U.S., and the drier MIROC model. Adaptive actions focus on the use of best management practices to limit the quantity of runoff entering stormwater systems. While many site-specific factors influence the effect of climate change on a given drainage system, the CIRA analysis uses a streamlined approach that allows for the assessment of potential impacts in multiple U.S. cities under the CIRA scenarios.[22] Specifically, the analysis uses a reduced-form approach for projecting changes in flood depth and the associated costs of flood prevention, based on an approach derived from EPA's Storm Water Management Model (SWMM).

The simplified approach yields impact estimates in units of average adaptation costs per square mile for a total of 50 cities across the contiguous U.S. (see Figure 1) for three categories of 24-hour storm events (those with precipitation intensities occurring every 10, 25, and 50 years—metrics commonly used in infrastructure planning) and four future time periods (2025, 2050, 2075, and 2100). The analysis assumes that the systems are able to manage runoff associated with historical climate conditions, and estimates the costs of implementing the adaptation measures necessary to manage increased runoff under climate change.

For more information on the CIRA approach and results for the urban drainage sector, please refer to Neumann et al. (2014)[23] and Price et al. (2014).[24,25]

Coastal Property

KEY FINDINGS

1. A large area of U.S. coastal land and property is at risk of inundation from global sea level rise, and an even larger area is at risk of damage from storm surge, which will intensify as sea levels continue to rise.

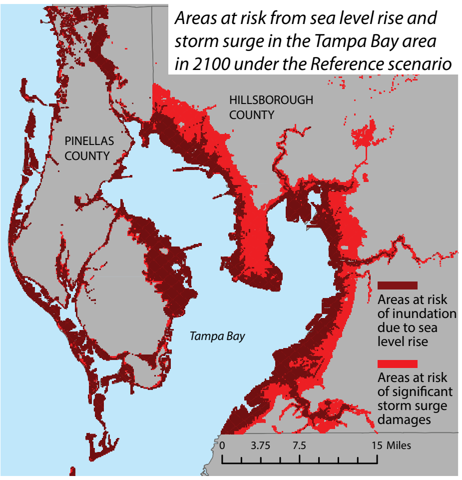
2. Without adaptation, unmitigated climate change is projected to result in $5.0 trillion in damages for coastal property in the contiguous U.S. through 2100 (discounted at 3%). Protective coastal adaptation measures significantly reduce total costs to an estimated $810 billion.

3. Global GHG mitigation reduces adaptation costs for coastal areas, but the majority of benefits occur late in the century.

4. Areas of higher social vulnerability are more likely to be abandoned than protected in response to unmitigated sea level rise and storm surge. GHG mitigation decreases this risk.

Climate Change and Coastal Property

Coastal areas in the U.S. are some of the most densely populated, developed areas in the nation, and they contain a wealth of natural and economic resources. Rising temperatures are causing ice sheets and glaciers to melt and ocean waters to expand, contributing to global sea level rise at increasing rates. Sea level rise threatens to inundate many low-lying coastal areas and increase flooding, erosion, wetland habitat loss, and saltwater intrusion into estuaries and freshwater aquifers. The combined effects of sea level rise and other climate change factors, such as increased intensity of coastal storms, may cause rapid and irreversible change.[26]



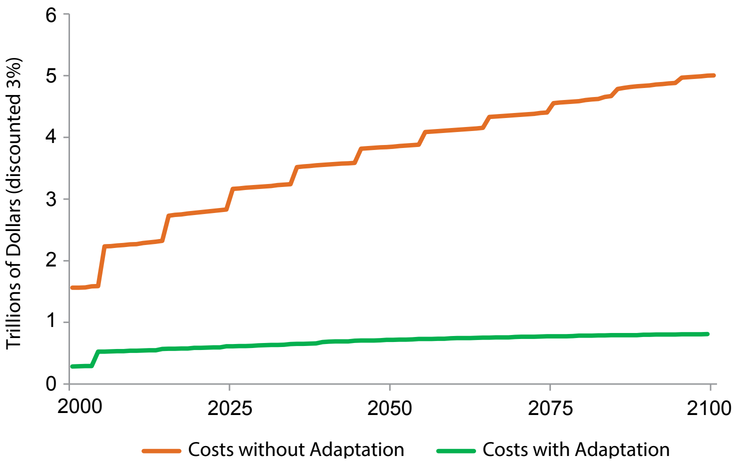
Areas at risk from sea level rise and storm surge in the Tampa Bay area in 2100 under the Reference scenario

Risks of Inaction

Sea level rise and storm surge pose increasingly large risks to coastal property, including costs associated with property abandonment, residual storm damages, and protective adaptation measures (e.g., elevating properties and armoring shorelines). As shown in Figure 1, the analysis estimates that under the Reference scenario the cumulative damages to coastal property across the contiguous U.S. will be $5.0 trillion through 2100 (discounted at 3%) if no adaptation measures are implemented. If adaptation measures are taken, these damages are reduced to $810 billion. Projections of increasing risks of sea level rise and storm surge for coastal property, and of the potential for adaptation to reduce overall costs, are consistent with the findings of the assessment literature.[27] The graphic above illustrates the importance of these potential impacts at a local scale by identifying at-risk land in the Tampa Bay, FL area. In this locale, approximately 83,000 acres are projected to be at risk of inundation due to sea level rise by 2100, and an additional 51,000 acres are projected to be at risk of significant storm surge. The total area at risk (130,000 acres) is approximately one and a half times the size of the City of Tampa.

Figure 1. Costs of Sea Level Rise and Storm Surge to Coastal Property with and without Adaptation under the Reference Scenario

The step-wise nature of the graph is due to the fact that storm surge risks are evaluated every ten years, beginning in 2005. Costs with adaptation include the value of abandoned property, residual storm damages, and costs of protective adaptation measures (trillions 2014$).



Reducing Impacts through GHG Mitigation

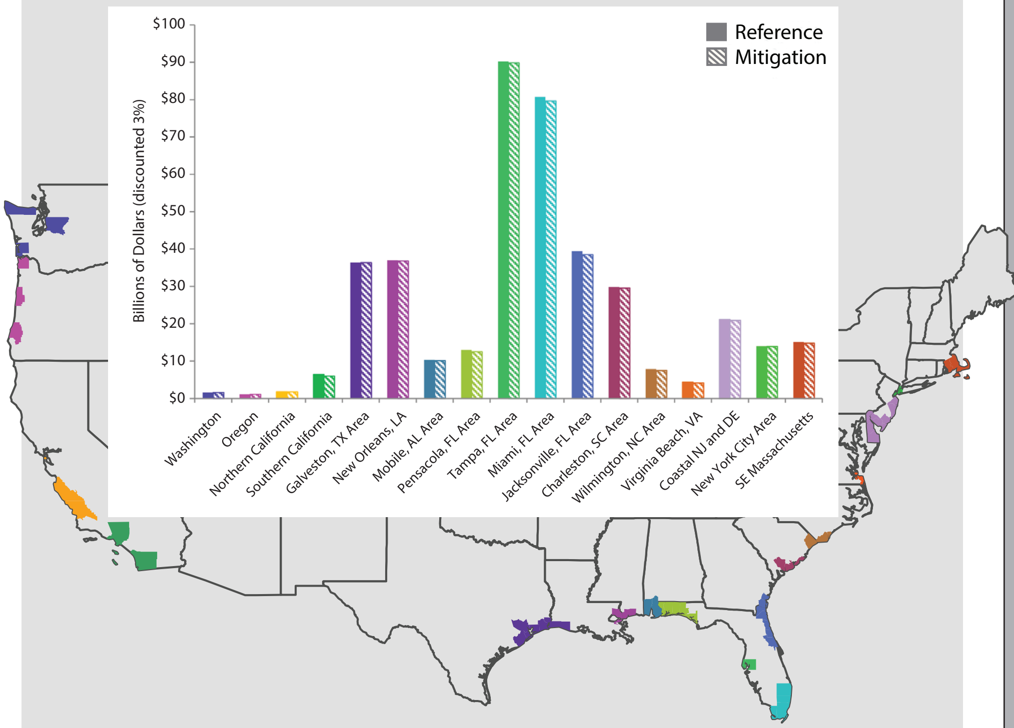
Under the Mitigation scenario, total costs (i.e., property damages and protective investments) across the contiguous U.S. are estimated at $790 billion through 2100 (discounted at 3%), about 3% less than the Reference scenario.[28] The effect of global GHG mitigation in reducing adaptation costs is modest and is likely underestimated in this analysis for several reasons. First, as described in the CIRA Framework section, global sea level rise is similar under the Reference and Mitigation scenarios through mid-century. It is not until the second half of the century when the benefits of reduced sea level rise under the Mitigation scenario become apparent. Further, the proportional effect of global GHG mitigation in reducing the rate of sea level rise is smaller under the CIRA scenarios compared to other scenarios in the literature.[29]

Second, when considering the present value total cost under the Reference and Mitigation scenarios, avoided adaptation costs accrued in later years are more heavily affected by discounting.[30] Third, the analysis assumes that coastal areas will implement cost-efficient and well-timed adaptation measures in response to the risks under both the Reference and Mitigation scenarios. Since many parts of the coastline are not sufficiently protected today, and because adaptation measures that are taken are oftentimes not well-timed, the CIRA estimates for this sector likely underestimate damages. For comparison purposes, the benefits of global GHG mitigation increase by a factor of ten if adaptation measures are not implemented.

Figure 2 shows the costs of adaptation for coastal properties (including the value of properties that are abandoned due to the severity of sea level rise or storm surge damages) for 17 key sites under the Reference and Mitigation scenarios. As shown, costs are only modestly lower under the Mitigation scenario. Costs vary across sites primarily due to the value of property at risk and the severity of the storm surge threats. For example, adaptation costs are comparatively higher in sites, such as Tampa and Miami, where there are many high-value properties in low-lying areas and high levels of storm surge are projected in the future.

Figure 2. Costs to Coastal Property of Sea Level Rise and Storm Surge through 2100

Costs are shown for 17 multi-county coastal areas that were modeled for sea level rise and storm surge impacts and potential adaptation response (billions 2014$).



APPROACH

The CIRA analysis identifies at-risk coastal property across the contiguous U.S. and estimates the costs that would be incurred due to climate change, with and without adaptation. Importantly, impacts to other coastal assets (e.g., roads and ecological resources) are not estimated in this analysis. The analysis relies upon sea level rise projections through 2100[31] that account for dynamic ice-sheet melting based on a semi-empirical model,[32] and are adjusted for regional land movement using local tide gauge data.[33] The analysis then uses a tropical cyclone simulator[34] and a storm surge model[35] to estimate the joint effects of sea level rise and storm surge for East and Gulf Coast sites, and an analysis of historic tide gauge data to project future flood levels for West Coast sites.[36]

Using EPA's National Coastal Property Model, the CIRA analysis estimates how areas along the coast may respond to sea level rise and storm surge and calculates the economic impacts of adaptation decisions (i.e., damages due to climate change). The approach uses four primary responses to protect coastal land and property: beach nourishment; property elevation; shoreline armoring; and property abandonment. The model projects an adaptation response for areas at risk based on sea level rise, storm surge height, property value, and costs of protective measures. Developed using a simple metric to estimate potential adaptation responses in a consistent manner for the entire coastline, the estimates presented here should not be construed as recommending any specific policy or adaptive action. Further, additional adaptation options not included in this analysis, such as marsh restoration, may be appropriate and potentially more cost-effective for some locales. The analysis also explores the potential impact of climate change on socially disadvantaged populations (see the Environmental Justice section of this report).

For more information on the CIRA approach and results for the coastal property sector, please refer to Neumann et al. (2014a)[37] and Neumann et al. (2014b).[38]

COASTAL PROPERTY

Environmental Justice

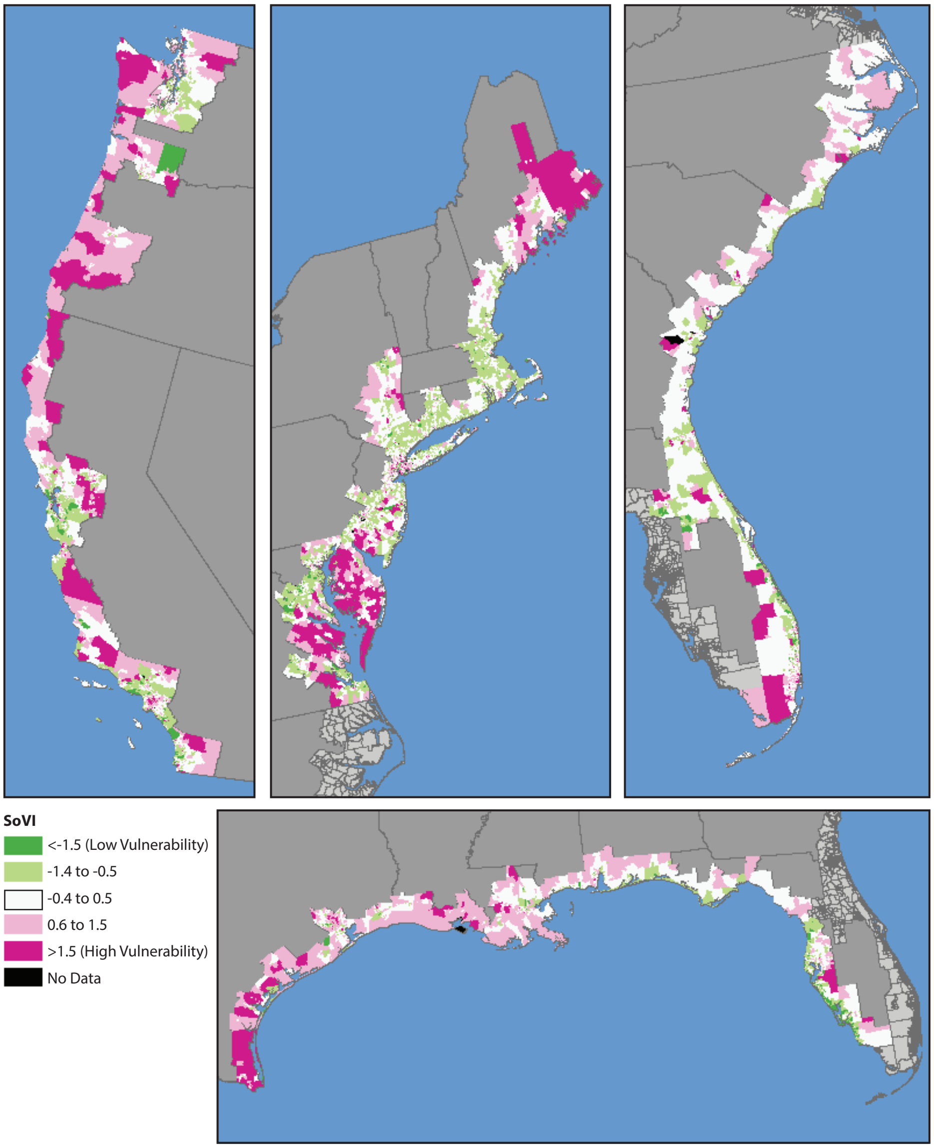
Building on the coastal property impacts described in the previous section, this analysis examines the environmental justice implications of projected sea level rise and storm surge in the contiguous U.S. Specifically, the approach quantifies how sea level rise and storm surge risks are distributed across different socioeconomic populations along the U.S. coastline; how these populations are likely to respond; and what adaptation costs (i.e., property damage and protection investments) will potentially be incurred.

The Social Vulnerability Index

The CIRA analysis uses the Social Vulnerability Index (SoVI) to identify socially vulnerable coastal communities in the U.S.[39] SoVI was developed to quantify social vulnerability using county-level (and later Census tract-level) socioeconomic and demographic data. The index is a well-vetted tool, and does not include any environmental risk factors, thereby eliminating the risk of double counting climate risk when socioeconomic and demographic data are combined with sea level rise and storm surge vulnerability.[40] The CIRA analysis uses Census tract-level SoVI values based on 2000 Census data for 26 demographic variables, capturing information on wealth, gender, age, race, and employment. Figure 1 shows the SoVI index values for the four coastal regions used in the analysis: Pacific (California through Washington), North Atlantic (Maine through Virginia), South Atlantic (North Carolina through Monroe County, Florida), and Gulf (Collier County, Florida through Texas).

Figure 1. Social Vulnerability Index for the Coastal U.S.

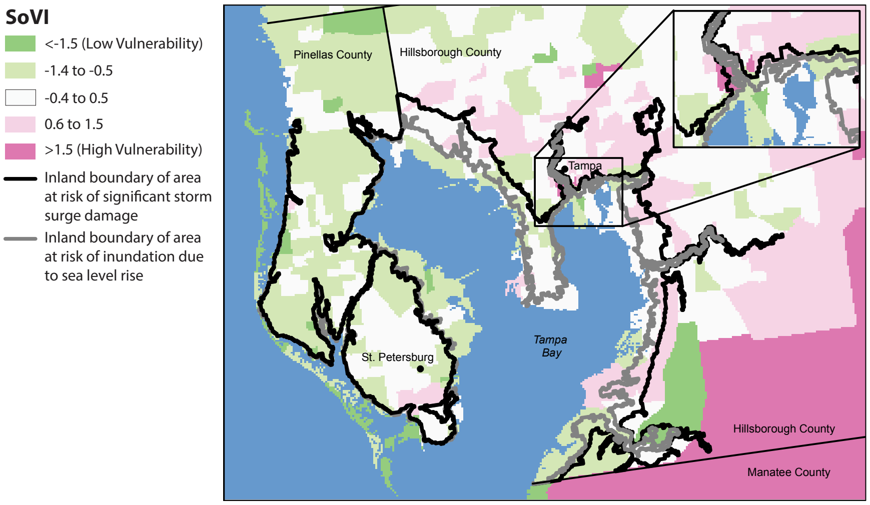
Census tract-level SoVI values are regionally normalized to allow for comparisons of the SoVI scores within each area. Areas with low SoVI scores (i.e., people with lower social vulnerability) are shaded in green and areas with higher SoVI scores (i.e., people with greater social vulnerability) are shaded in pink.



Case Study: Tampa Bay Area

EPA's National Coastal Property Model identifies areas along the contiguous U.S. coastline that are likely to be at risk from sea level rise and storm surge through 2100.[41, 42] By layering these projections on top of the SoVI results, following the approach described in Martinich et al. (2013),[43] the analysis assesses the potential impact of sea level rise and storm surge on socially disadvantaged populations in coastal areas. Figure 2 presents a case study of the Tampa Bay, Florida area (Pinellas and Hillsborough Counties). The area from the water to the gray lines represents the projected area at risk of inundation due to sea level rise, while the area from the water to the black lines represents projected areas at risk from significant storm surge damage in 2100.[44] As shown, there are areas with higher socially vulnerable populations (pink shading) near the city of Tampa, in particular, that are projected to be at risk of significant storm surge damages.

Figure 2. Social Vulnerability of Areas at Risk from Sea Level Rise and Storm Surge in the Tampa Bay Area by 2100 under the Reference Scenario



National Results

Figure 3 compares the number of people in the 17 multi-county coastal areas (see previous section for locations) identified as at risk due to climate change under the Reference and Mitigation scenarios, by SoVI category. As shown, the Mitigation scenario reduces the number of at-risk people compared to the Reference scenario for all SoVI categories. The benefits of global GHG mitigation are particularly high for the population identified by the SoVI as most socially vulnerable; for this population, the number of at-risk people is reduced by 23% under the Mitigation scenario compared to the Reference.

The CIRA analysis also projects adaptation responses based on sea level rise, storm surge height, property value, and costs of adaptation.[45] The model estimates whether people living in coastal areas are likely to respond to climate threats by: 1) protecting property through beach nourishment, property elevation, or shoreline armoring; 2) abandoning property, or 3) incurring storm surge damages without adapting. Figure 4 presents the adaptation results, by area, for the five SoVI categories in the Reference. More area is likely to be abandoned than protected across all social vulnerability categories. However, in the most vulnerable SoVI categories (0.6-1.5 and greater than 1.5), a relatively larger proportion of the area inhabited is likely to be abandoned (89% and 86%, respectively) rather than protected through adaptation measures (8% and 10%, respectively).

Figure 3. Social Vulnerability of Populations at Risk from Sea Level Rise and Storm Surge through 2100 with and without Global GHG Mitigation

Vulnerability estimated in 17 multi-county coastal areas in the contiguous U.S., along with the estimated percent changes from Reference to Mitigation.

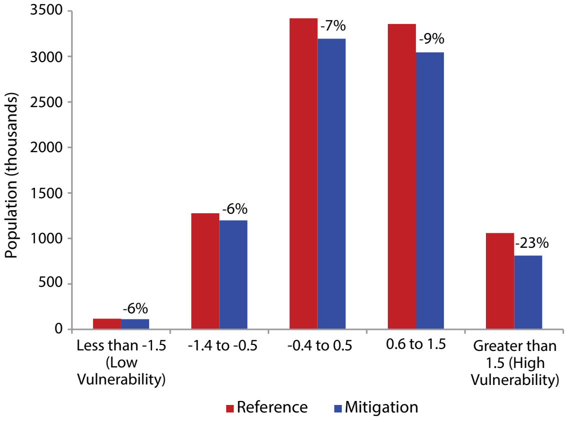


Figure 4. Adaptation Measures by SoVI Category under the Reference Scenario