United States
Environmental Protection
Agency






CLIMATE CHANGE AND SOCIAL VULNERABILITY IN THE UNITED STATES

A Focus on Six Impacts

SEPTEMBER 2021

FRONT MATTER

Acknowledgments

This report was developed by EPA's Office of Atmospheric Programs and contains modeling contributions from Federal agency analysts, academic experts, and consultants, including Industrial Economics, Inc. Support for the report's production was provided by Industrial Economics, Inc. EPA gratefully acknowledges the use of inland flooding risk data from the First Street Foundation.

Peer Review

The methods of the climate change impacts analyses described herein have been peer reviewed in the scientific literature. In addition, this report was peer reviewed by five external and independent experts in a process independently coordinated by ICF International. EPA gratefully acknowledges the following peer reviewers for their useful comments and suggestions: Amit Armstrong, David Hondula, Klaus Moeltner, Colin Polsky, Benjamin Ruddell. The information and views expressed in this report do not necessarily represent those of the peer reviewers, who also bear no responsibility for any remaining errors or omissions. Appendix A provides more information about the peer review.

Recommended Citation

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Data Availability

Data used in and generated from the analyses of this report can be accessed on the following website: www.epa.gov/cira/technical-appendices-and-data.

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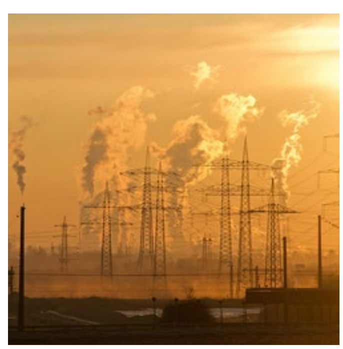
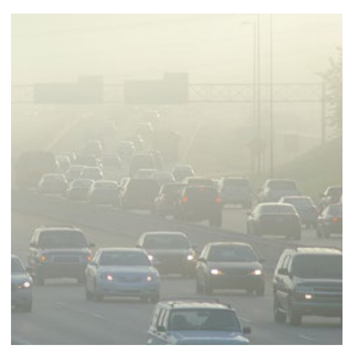
Technical Appendices

Technical appendices that provide detailed documentation and additional results are accessible at https://epa.gov/cira/technical-appendices-and-data. Three additional appendices provide more details on information quality and the peer review process; climate change and social vulnerability; and inputs and projections. Lastly, this website also contains the underlying data and results for each analysis.





EXECUTIVE SUMMARY

Climate change affects all Americans—regardless of socioeconomic status—and many impacts are projected to worsen as temperatures and sea levels continue to rise, snow and rainfall patterns shift, and some extreme weather events become more common.[1] A growing body of literature focuses on the disproportionate and unequal risks that climate change is projected to have on communities that are least able to anticipate, cope with, and recover from adverse impacts. Many studies have discussed climate change impacts on socially vulnerable populations, but few have quantified disproportionate risks to socially vulnerable groups across multiple impacts and levels of global warming.[2,3]

Table ES.1 – Socially Vulnerable Groups Analyzed in this Report

CATEGORY	DEFINITION
Low Income	Individuals living in households with income that is at or below 200% of the poverty level.
Minority	Individuals identifying as Black or African American; American Indian or Alaska Native; Asian; Native Hawaiian or Other Pacific Islander; and/or Hispanic or Latino.
No High School Diploma	Individuals ages 25 and older with a maximum educational attainment of less than a high school diploma or equivalent.
65 and Older	Individuals ages 65 and older.

This report contributes to a better understanding of the degree to which four socially vulnerable populations—defined based on income, educational attainment, race and ethnicity, and age (Table ES.1)—may be more exposed to the highest impacts of climate change in six categories: Air Quality and Health; Extreme Temperature and Health; Extreme Temperature and Labor; Coastal Flooding and Traffic; Coastal Flooding and Property; and Inland Flooding and Property (Figure ES.1).

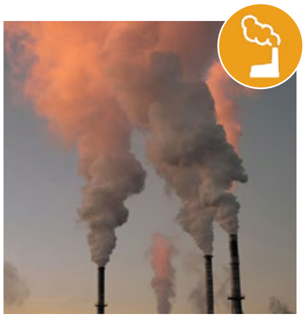
Notes on Terminology

This report adopts the term "minority" for the sake of consistency with government publications and datasets pertaining to environmental justice and climate change. There are important differences, however, in the social vulnerability of the individual communities that are included under the "minority" umbrella. The chapters and appendices of this report therefore include, where possible, results for individual racial and ethnic groups. The report uses the U.S. Census terminology for racial and ethnic groups, as presented in Table ES.1.

Due to data limitations, this report does not analyze the impacts of climate change on socially vulnerable populations living in Hawai'i or Alaska. However, the analyses use demographic data from the U.S. Census which includes individuals living in the contiguous U.S. who identify as "American Indian or Alaska Native" and "Native Hawaiian or Other Pacific Islander." For more information, please see Appendix C.

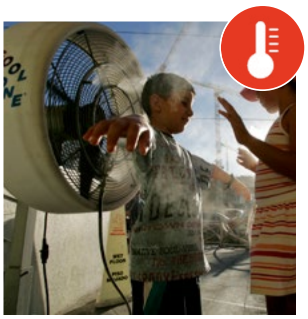
EXECUTIVE SUMMARY

Figure ES.1 – Primary Climate Change Impacts Analyzed in this Report



AIR QUALITY AND HEALTH
New asthma diagnoses in children age 0 to 17 due to particulate air pollution, and premature deaths in adults ages 65 and older due to particulate air pollution.[4]

COASTAL FLOODING AND TRAFFIC
Traffic delays due to high-tide flooding and extreme temperature and precipitation.[5]



EXTREME TEMPERATURE AND HEALTH
Deaths due to extreme temperatures.

COASTAL FLOODING AND PROPERTY
Property inundation due to sea level rise, and exclusion from protective adaptation measures.

EXTREME TEMPERATURE AND LABOR
Labor hours lost by weather-exposed workers due to high-temperature days.

INLAND FLOODING AND PROPERTY
Property damage or loss due to inland flooding.

Specifically, the analyses presented in this report first identify the areas in the contiguous United States (U.S.) where impacts are projected to be the highest under future global temperature change and sea level rise. For example, the Extreme Temperature and Labor analysis estimates where weather-exposed workers are projected to lose the most labor hours due to high-temperature days, and the Coastal Flooding and Property analysis estimates where the highest percentage of property is projected to be inundated due to sea level rise. Next, the analyses estimate the likelihood that those who are socially vulnerable live in these areas compared to those who are not. This determination is based on current demographic distributions and projected changes in climate hazards under different levels of global warming and sea level rise. The result is a consistent measure of the disproportionate risk to socially vulnerable individuals, which can be compared across groups, regions, and impact categories.

Due to data limitations, the analyses are limited to the contiguous U.S. Future work will enhance both the coverage of important areas such as Hawai'i and Alaska, and will explore additional impacts. Furthermore, additional dimensions of social vulnerability (e.g., gender and linguistic isolation) are not included and warrant additional analysis. Please see the Introduction and Approach chapters for more information on the analytic scope and limitations.

EXECUTIVE SUMMARY

Key Findings

Figure ES.2 summarizes the results of the six analyses described in this report. These summary findings focus on national-level results for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to the year 2000). Results for additional scenarios and geographic regions are provided in the following chapters and appendices. Note the analyses in this report estimate risks to each socially vulnerable group independently and do not analyze interconnections between the four measures of social vulnerability examined.

Of the four socially vulnerable groups examined, minorities are most likely to currently live in areas where the analyses project the highest levels of climate change impacts with 2°C of global warming or 50 cm of global sea level rise.[6,7]

- Black and African American individuals are 40% more likely than non-Black and non-African American individuals to currently live in areas with the highest projected increases in mortality rates due to climate-driven changes in extreme temperatures. In addition, Black and African American individuals are 34% more likely to live in areas with the highest projected increases in childhood asthma diagnoses due to climate-driven changes in particulate air pollution.
- Hispanic and Latino individuals are 43% more likely than non-Hispanic and non-Latino individuals to currently live in areas with the highest projected labor hour losses in weather-exposed industries due to climate-driven increases in high-temperature days. Hispanic and Latino individuals are also 50% more likely to live in coastal areas with the highest projected increases in traffic delays from climate-driven changes in high-tide flooding.
- American Indian and Alaska Native individuals are 48% more likely than non-American Indian and non-Alaska Native individuals to currently live in areas where the highest percentage of land is projected to be inundated due to sea level rise.[8] American Indian and Alaska Native individuals are also 37% more likely to live in areas with the highest projected labor hour losses in weather-exposed industries due to climate-driven increases in high-temperature days.
- Asian individuals are 23% more likely than non-Asian individuals to currently live in coastal areas with the highest projected increases in traffic delays from climate-driven changes in high-tide flooding.

EXECUTIVE SUMMARY

Key Findings (continued)

Those with low income or no high school diploma are approximately 25% more likely than non-low income individuals and those with a high school diploma to currently live in areas with the highest projected losses of labor hours due to increases in high-temperature days with 2°C of global warming. In addition, individuals in these socially vulnerable groups are approximately 15% more likely to currently live in areas with the highest projected increases in childhood asthma diagnoses due to climate-driven increases in particulate air pollution, and in areas where the highest percentage of land is projected to be inundated due to sea level rise.[9, 10, 11]

In general, adults ages 65 and older are not projected to be significantly more likely than younger individuals to currently live in areas with the highest projected impacts of climate change. Across all six categories of impacts, the differences in risk to adults ages 65 or older of living in the high-impact areas is only -5% to +4% compared to younger individuals.

With higher levels of global warming and sea level rise, the risks to socially vulnerable groups are generally projected to remain approximately the same or increase. For some groups and in some impact categories, however, the risks of disproportionate impacts are projected to decrease as climate change worsens.

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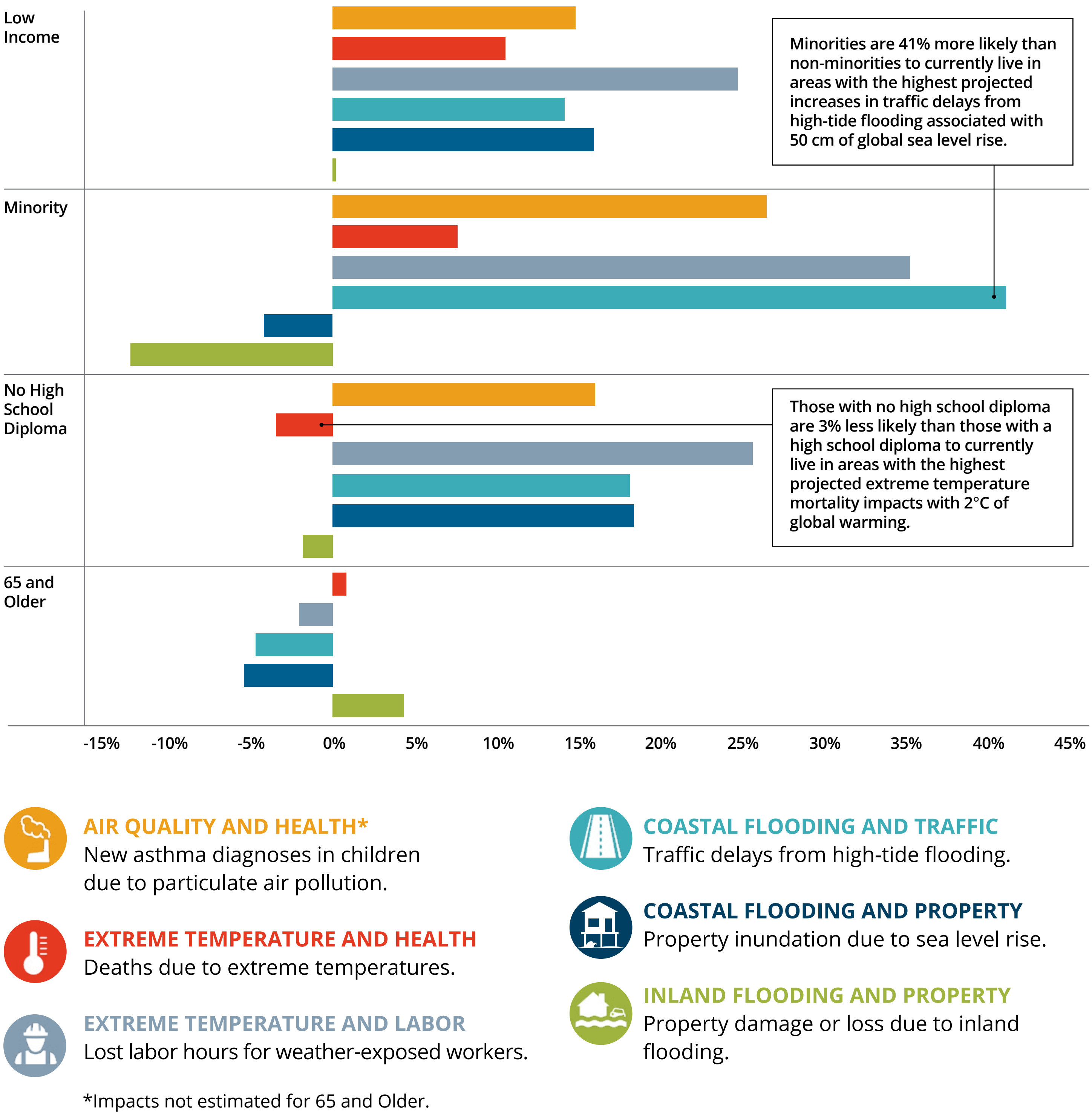
Figure ES.2 – Differences in Risks to Socially Vulnerable Groups Relative to Reference Populations with 2°C of Global Warming or 50 cm of Global Sea Level Rise

The estimated risks for each socially vulnerable group are relative to each group's "reference" population, defined as all individuals other than those in the group being analyzed. The estimated risks presented in the chart are for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to 2000). For the inland flooding analysis, the baseline is 2001-2020. Results for additional scenarios are provided in the following chapters and appendices.



CHAPTER 1
INTRODUCTION

About this Report

The Earth's changing climate is affecting human health and the environment in many ways. Across the U.S., temperatures and sea levels are rising, snow and rainfall patterns are shifting, and some extreme weather events are becoming more common. Many climate change impacts are expected to increase in both magnitude and frequency over the coming decades, with risks to human health, the economy, and the environment.[1]

According to the Fourth National Climate Assessment (NCA4), the impacts of climate change will not be equally distributed across the U.S. population.[2] Those who are already vulnerable due to a range of social, economic, historical and political factors have a lower capacity to prepare for, cope with, and recover from climate change impacts.[3,4] Understanding the comparative risks to vulnerable populations is critical for developing effective and equitable strategies for responding to climate change.

A growing body of literature focuses on the impacts of climate change on socially vulnerable populations, but few studies have quantified disproportionate risks across multiple impacts and levels of global warming.[5,6] This report contributes to a better understanding of the degree to which socially vulnerable populations may be more exposed to the highest impacts of climate change in six categories: Air Quality and Health; Extreme Temperature and Health; Extreme Temperature and Labor; Coastal Flooding and Traffic; Coastal Flooding and Property; and Inland Flooding and Property.

Figure 1.1 depicts the conceptual framework for this report, which is adapted from the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).[7] It illustrates how risk to climate change impacts is a product of both exposure and vulnerability to climate hazards. An individual may be vulnerable to climate hazards, but if they are not exposed to those hazards then they are not at risk. Likewise, an individual may be exposed to climate hazards but not vulnerable, rendering their risk far less than an individual who is vulnerable.

This report contributes to a better understanding of the degree to which socially vulnerable populations may be more exposed to the highest impacts of climate change.

Differential exposure to climate hazards can take many forms; for example, some may be more exposed to hazards due to their occupation or where they work. This report uses current data on where people live as an indicator of exposure, recognizing that demographic patterns may change in the future. Similarly, differential vulnerability can result from a wide range of social, economic, and political factors that make some populations less able to anticipate, respond to, recover from, and adapt to climate hazards.[8,9,10] This report focuses on four categories of social vulnerability for which there is evidence that differential vulnerability exists. These groups are based on income, educational attainment, race and ethnicity, and age.

Consistent with the conceptual framework in Figure 1.1, the analyses in this report estimate comparative risks to socially vulnerable groups by first identifying where impacts from climate hazards are projected to be highest and then estimating the likelihood that those who are socially vulnerable live in these areas compared to those who are not. This determination is based on current demographic distributions and projected changes in climate hazards under future levels of warming and sea level rise. For a more detailed discussion of the conceptual framework, please refer to Appendix B.

INTRODUCTION

Figure 1.1 – Climate Change Risk Framework

People are at risk of experiencing climate change impacts when they are both **exposed** and **vulnerable** to **climate hazards.**

This report focuses on whether those who are **socially vulnerable** are **disproportionately exposed** to projected **climate hazards.**

Interpreting the Results

The analyses presented in this report are part of the Climate Change Impacts and Risk Analysis (CIRA) project, a multi-model framework using consistent inputs to enable comparison of impacts across time and space.[11] The data and methods used in the analyses have been peer-reviewed and published in the scientific literature; the corresponding research papers are cited throughout this report and in the technical appendix.

This report is intended to provide insights about disproportionate risks to socially vulnerable groups across multiple impacts and levels of global warming, with consideration of important sources of uncertainty involved with projecting risks in the future. None of the estimates should be interpreted as definitive predictions of future impacts at a particular time or place. Instead, the intention is to produce estimates using the best available data and methods, which can be revisited and updated as science and modeling capabilities continue to advance.

This report analyzes impacts that are well established in the scientific literature and that pose substantial public health and/or economic risks across the U.S.[12] However, there are many impacts of climate change that are not explored in this report. Therefore, the results capture only a portion of the potential disproportionate risks to socially vulnerable populations.

The report considers four categories of social vulnerability based on income, education, age, and race and ethnicity. Additional dimensions of social vulnerability (e.g., linguistic isolation, gender, single parent household, religion, disability, and others) are not included and warrant additional analysis. There are also many ways in which the measures of social vulnerability analyzed could contribute to adverse health outcomes, both independently and jointly, and not all of these pathways and interactions are explored in this report.

Similarly, there are many reasons why socially vulnerable populations may be more likely to currently live in areas where impacts from climate change are projected to be highest. The purpose of this report is to estimate the degree to which the four socially vulnerable populations are disproportionately at risk in the six categories of impacts analyzed. However, investigating the reasons why a particular group is found to be more or less likely to live in a high-impact area is outside the scope of the report.

Importantly, the CIRA analyses do not evaluate or assume specific greenhouse gas (GHG) mitigation or adaptation policies in the U.S. or in other world regions. Therefore, the results should not be interpreted as supporting any particular domestic or global mitigation policy or target. In addition, the costs of reducing GHG emissions, including how these costs are distributed across U.S. populations, as well as the health benefits associated with co-reductions in other air pollutants are beyond the scope of this report.

CHAPTER 2
APPROACH

This chapter describes the four-step approach employed in each of the six analyses presented in this report. Figure 2.1 summarizes the four steps, which are described in detail in the following sections. For more information, please refer to Appendix C.

Step 1: Project Changes in Climate Across the U.S.

Temperature

The analyses presented in this report quantify the impacts of climate change associated with different levels of global temperature change. Instead of estimating impacts for a specific time period under a particular scenario of future GHG emissions, the analyses evaluate impacts that are projected to occur if global average temperature increases by 1°C, 2°C, 3°C, 4°C, and 5°C (1.8°F, 3.6°F, 5.4°F, 7.2°F, and 9°F) above the 1986 to 2005 average.[1] Figure 2.2 shows the estimated timing for these global temperature increases under three GHG emissions scenarios commonly used in the research literature: higher (RCP8.5), lower (RCP4.5), and even lower (RCP2.6).[2] The figure shows both the average estimated "arrival time" for each level of warming (i.e., the estimated year in which each global average temperature

Figure 2.1 – The Four-Step Approach Used in the Analyses

STEP 1 | Project changes in climate hazards across the contiguous United States.

STEP 2 | Estimate human health and economic impacts.

STEP 3 | Identify the areas where the estimated impacts are highest.

STEP 4 | Estimate the likelihood that those who are socially vulnerable currently live in the high-impact areas compared to those who are not.

Figure 2.2 – Projected Timing for Global Average Temperature Changes

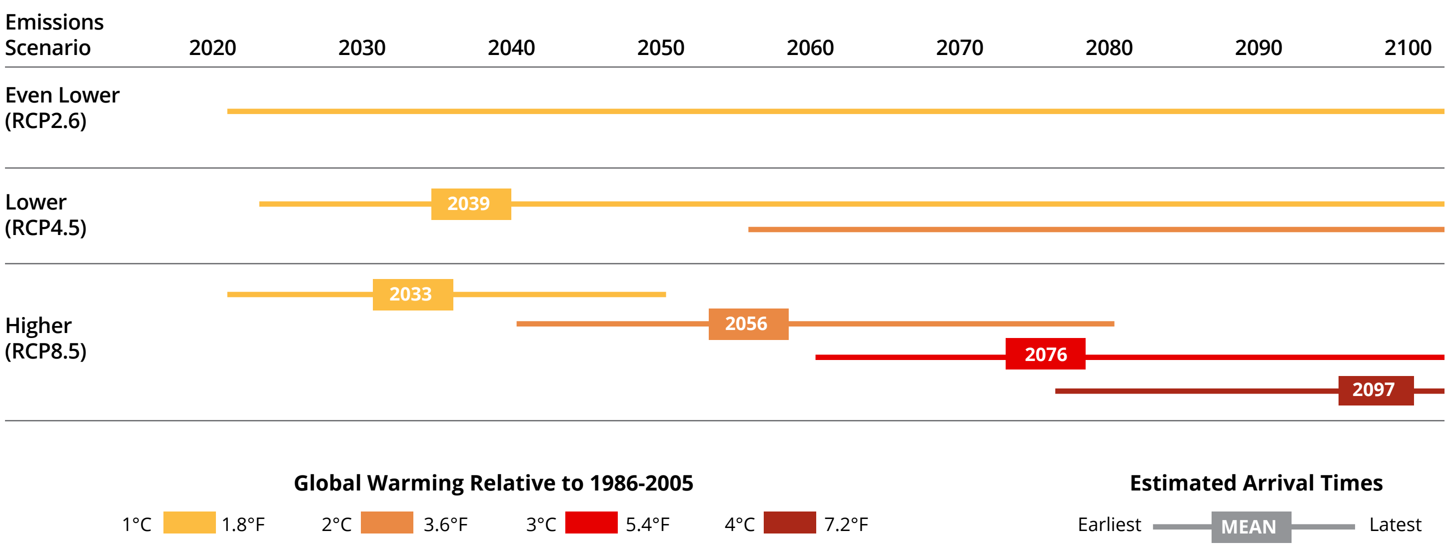
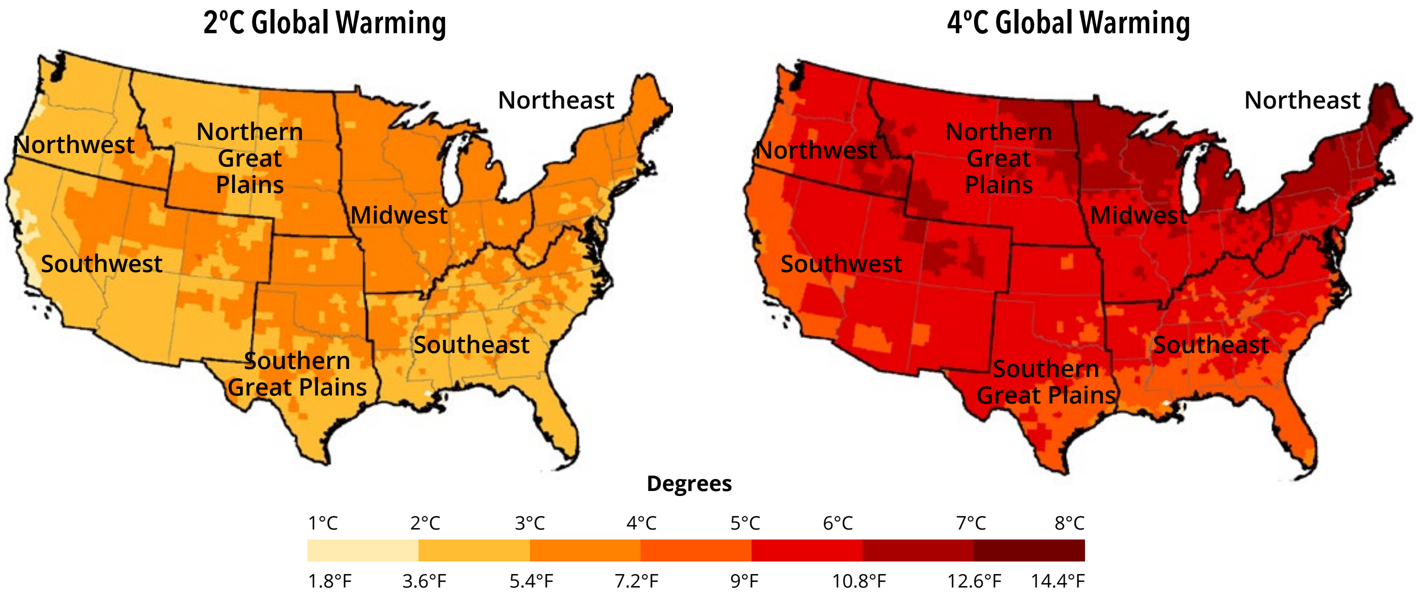


Figure 2.3 – Projected Changes in Average Annual Temperatures Across the U.S. Associated with Global Warming of 2°C and 4°C

Maps show county-level average annual temperature changes associated with global average temperature changes of 2°C and 4°C, relative to the 1986 to 2005 baseline period.



increase is projected occur), as well as the estimated range (i.e., the earliest and latest years in which each global average increase is projected to occur). In the higher emissions scenario, the estimated arrival time for experiencing a global average temperature increase of 1°C of warming ranges from 2020 to 2050, with an average estimate of 2033. The estimated arrival time for experiencing a global average temperature increase of 4°C in this scenario is estimated to occur as early as 2074, with an average estimated arrival time of 2097. In the "even lower" emissions scenario, however, global warming above 1°C is not projected to occur before the end of the century.[3]

Temperature change is not uniform across the globe, and the projected global average temperature changes shown in Figure 2.2 manifest differently in the U.S. Figure 2.3 shows the projected county-level temperature changes that correspond to global warming of 2°C and 4°C. As shown, changes in global temperatures generally result in higher changes in average annual temperatures in the U.S. With 2°C of global warming, large areas of the Southwest, Northern Great Plains, Southern Great Plains, Midwest, and Northeast are projected to experience average annual temperature increases of between 3°C and 4°C (5.4°F and 7.2°F). With 4°C of global warming, the majority of the contiguous U.S. is projected to experience average temperature increases of between 5°C and 6°C (9°F and 10.8°F), with many areas of the Northern Great Plains, Midwest, and Northeast experiencing average annual increases of between 6°C and 7°C (10.8°F and 12.6°F).

To estimate the human health and environmental impacts of climate change, the analyses in this report draw on the rich array of climate data provided in general circulation models (GCMs) to project future climate hazards associated with changes in temperature and precipitation. Specifically, the analyses use six GCMs to project changes in climate variables such as high-temperature days and extreme rainfall.[4] The analyses also derive information from the GCMs about the timing of global mean temperature increases, and then use the GCM results from those time periods to project specific climate hazards (e.g., high-temperature days) needed for each sectoral analysis.

CHAPTER 2

APPROACH

Future Warming In Context

Throughout this report, global mean temperature changes (over land and water) are defined as changes from baseline period from 1986 to 2005. This period is used in the published literature upon which the analyses rely.[5] Other studies, including those by the United Nations' Intergovernmental Panel on Climate Change (IPCC), use a "pre-industrial" baseline period, approximated by IPCC as 1850 to 1900.[6,7] The pre-industrial period is also the reference point for temperature targets established as part of the 21st Conference of the Parties (COP21), also known as the Paris Agreement.[8]

Pre-industrial temperatures were about 0.45°C lower than temperatures observed in the period from 1986 to 2005. Therefore, increases in global mean temperature from the pre-industrial baseline are approximately 0.45°C higher than the projections of global warming presented in this report. For example, global warming of 2°C from the 1986 to 2005 base period used in this report corresponds roughly to an increase of 2.45°C relative to pre-industrial levels.

APPROACH

Sea Level Rise

The Coastal Flooding and Property and Coastal Flooding and Traffic analyses evaluate impacts associated with global average sea level rise of 25 cm (0.8 ft) to 150 cm (4.9 ft) relative to the year 2000 baseline. Changes in global sea levels over this century will depend on the response of the climate system to warming, as well as on future emissions of GHGs and other pollutants from human activities. The NCA4 found that global average sea level has risen by about 16 to 21 cm (7 to 8 in) since 1900. It projects that global average sea level is likely to rise by 9 to 18 cm (0.3 to 0.6 ft) by 2030 (relative to the year 2000), 15 to 38 cm (0.5 to 1.2 ft) by 2050, and 30 to 130 cm (1 to 4 ft) by 2100.[9]

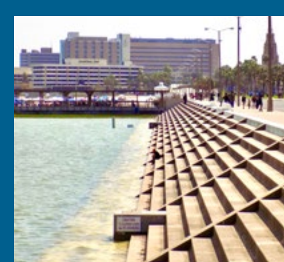
As with temperature, the projected changes in global average sea level generally correspond to higher changes in sea level in the U.S. Table 2.1 shows the projected, relative sea level rise for the 10 most populous U.S. coastal cities that correspond to 50 and 100 cm (1.6 and 3.3 ft) of global average sea level rise. Local sea level rise in the U.S. may be more than 50% greater than global sea level rise, particularly in the Northeast, Southeast, and Southern Great Plains[10] where land levels are falling as sea levels rise.[11] The Coastal Flooding and Property analysis also incorporates the effects of sea level rise on the height of storm surges associated with hurricanes and other coastal storms.

Table 2.1 – Projected Sea Level Rise for the Ten Most Populous Coastal Cities in the U.S. with Global Average Sea Level Rise of 50 cm and 100 cm

COASTAL CITY*	50CM (1.6 FT)	100 CM (3.3 FT)
New York	84 cm (2.8 ft)	154 cm (5.1 ft)
Los Angeles	59 cm (1.9 ft)	122 cm (4.0 ft)
Houston	87 cm (2.9 ft)	158 cm (5.2 ft)
Philadelphia	80 cm (2.6 ft)	148 cm (4.9 ft)
San Diego	61 cm (2.0 ft)	125 cm (4.1 ft)
San Jose	58 cm (1.9 ft)	121 cm (4.0 ft)
Jacksonville	70 cm (2.3 ft)	135 cm (4.4 ft)
San Francisco	59 cm (1.9 ft)	123 cm (4.0 ft)
Seattle	53 cm (1.7 ft)	112 cm (3.7 ft)
Washington, DC	80 cm (2.6 ft)	148 cm (4.9 ft)

**Cities listed in descending order of total population*[12]

Treatment of Adaptation



The approaches for projecting the six impacts differ in their evaluation of how adaptation may reduce overall risk. The Coastal Flooding and Property and Coastal Flooding and Traffic analyses rely on simulation models that explicitly estimate impacts both with and without adaptation to future sea level rise. These estimates include the likelihood that socially vulnerable populations live in areas that might be excluded from adaptation if adaptation investments are made solely based on comparison of economic costs and benefits.

The Air Quality and Health, Extreme Temperature and Health, and Extreme Temperature and Labor analyses use empirical relationships between climate changes and human responses (i.e., premature mortality, allocation of labor hours). To the extent that populations have adapted to past climatic changes and weather variations, these analyses capture these forms of adaptation. Due to data constraints, the Inland Flooding and Property analysis does not consider how adaptation may affect risks to socially vulnerable populations. See each chapter and the accompanying appendices for more detail on the treatment of adaptation.

Step 2: Estimate Human Health and Economic Impacts

Each of the six analyses model the following human health and/or economic impacts stemming from the changes in climate hazards projected in Step 1:

- **Air Quality and Health:** New asthma diagnoses in children age 0 to 17 due to particulate air pollution, and premature deaths in adults ages 65 and older due to particulate air pollution.[13]
- **Extreme Temperature and Health:** Deaths due to extreme temperatures.
- **Extreme Temperature and Labor:** Labor hours lost by weather-exposed workers due to high-temperature days.
- **Coastal Flooding and Traffic:** Traffic delays due to high-tide flooding and extreme temperature and precipitation.[14]
- **Coastal Flooding and Property:** Property inundation due to sea level rise, and exclusion from protective adaptation measures.
- **Inland Flooding and Property:** Property damage or loss due to inland flooding.

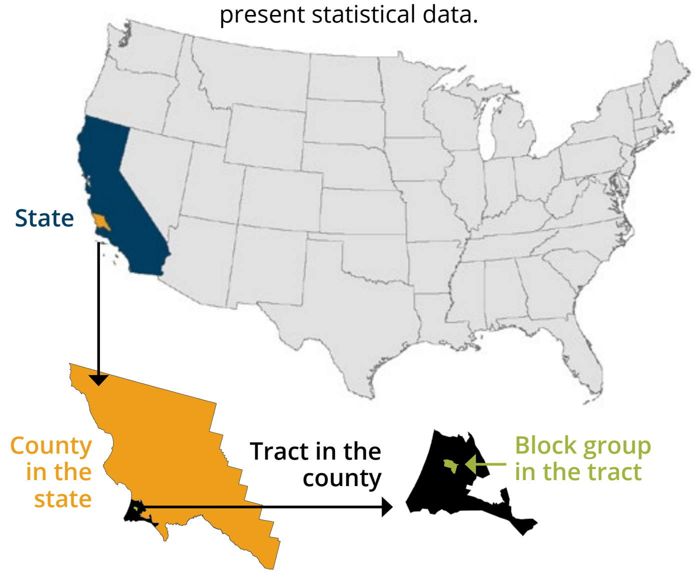
The following chapters include summaries of the modeling approaches used in each analysis and the appendices provide more detailed technical information, as well as additional results.

Step 3: Identify the Areas Where the Estimated Impacts Are Highest

After modeling health and/or economic impacts that result from projected climate hazards, the analyses identify the areas with the highest impacts, which are defined as those with the highest third of impacts.[15] These areas are identified for both the contiguous U.S. and at the regional level; the subsequent chapters present results corresponding to both spatial scales.[16] Note that the spatial resolution of each analysis varies; some results are calculated at the county level while others are calculated at the Census tract or Census block group level.

What is a Census tract and Census block group?

This report often presents information and results at the Census tract and Census block group levels. These geographic areas are standard subdivisions used by the Census to present statistical data.



Step 4: Analyze Comparative Risks to Socially Vulnerable Groups

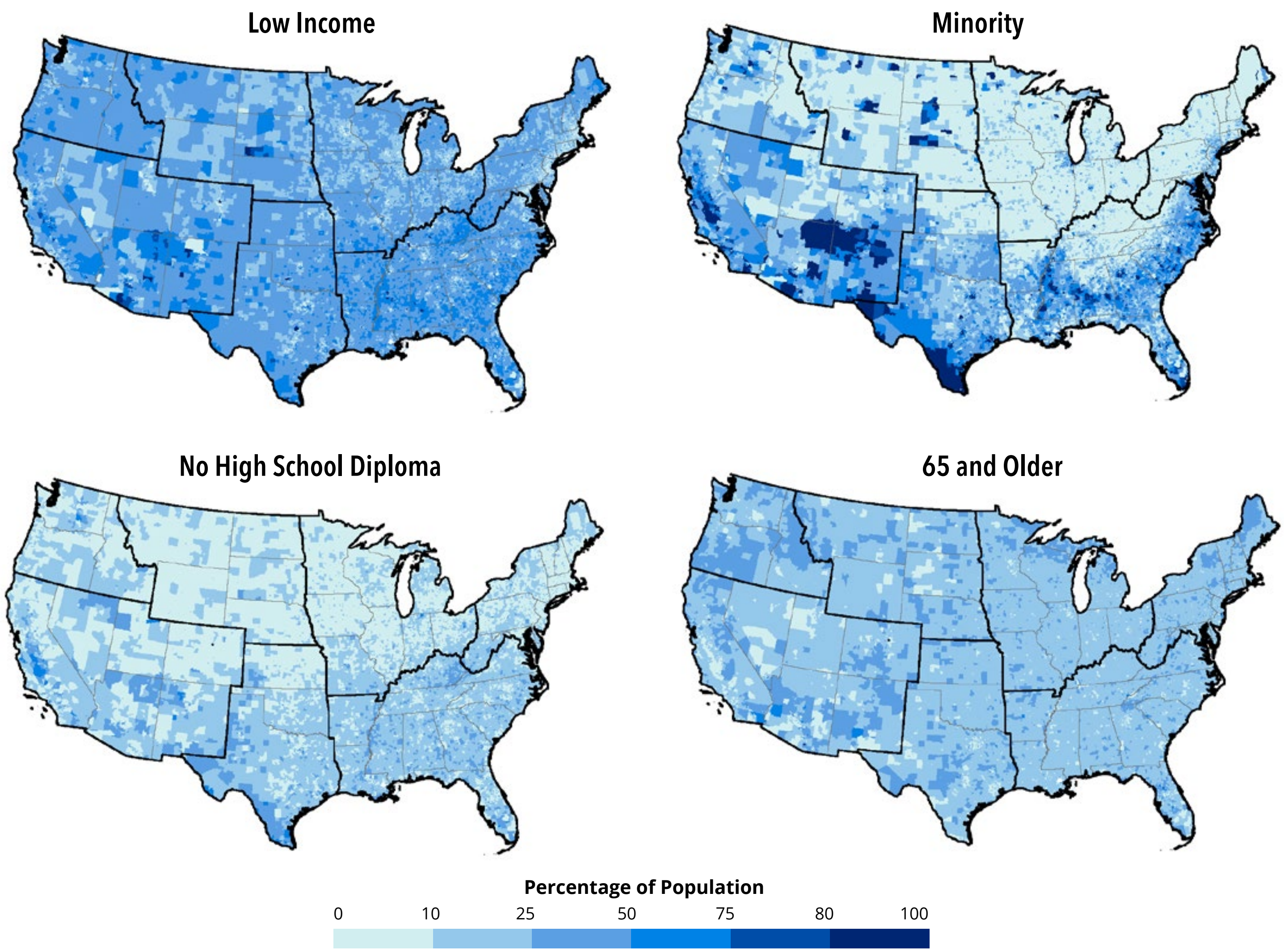
After identifying the areas with the highest projected impacts, the analyses quantify the number of people in each socially vulnerable group who currently live these areas, as well as the number of people in each of the reference populations (i.e., people not included in each socially vulnerable group). The analyses then calculate the likelihood that those who are socially vulnerable live in the high impact areas compared to those who are not, based on current demographic data from the U.S. Census.[17] Figure 2.4 presents the current distribution of each of the four socially vulnerable populations in the U.S. by Census tract.

Table 2.2 provides definitions for each of the four socially vulnerable groups analyzed as well as their reference populations. There are additional dimensions of social vulnerability which are not considered in this report and which warrant further analysis. Further, additional disproportionate risks may be present when evaluating the interconnections between social vulnerability measures, connections that are not explored in this report.

APPROACH

Figure 2.4 – Current Distribution of Socially Vulnerable Populations by Census Tract

Data from the U.S. Census Bureau's 2014-2018 American Community Survey.



Use of the Term "Minority"

This report adopts the term "minority" for the sake of consistency with Executive Order 12898 and other government publications and datasets pertaining to environmental justice and climate change. However, we note that minorities are increasingly being referred to as "people of color." There are important differences in the social vulnerability of the individual communities which are included under the "minority" and "people of color" umbrellas, and that not all non-White communities are comparable. The chapters and appendices of this report therefore include, where possible, results for individual racial and ethnic groups. In addition, we recognize that because of historical systems of discrimination and oppression, Black, Indigenous, and other communities in the United States are often particularly vulnerable to environmental hazards, including the effects of climate change.

Table 2.3 provides sample calculations for calculating risks to a socially vulnerable population (ages 65 and older) in the Coastal Flooding and Traffic analysis.

Sources of Uncertainty

This section reviews some of the key sources of uncertainty that are important to consider when interpreting the results of the analyses presented in this report. For more detailed information on these limitations, please refer to Appendix C. For more information on uncertainties and limitations specific to each of the six analyses, please refer to the relevant chapters and appendices.

- **Projections of Future Changes in Climate:** As described under Step 1 above, the analyses in this report rely on climate projections from six GCMs. While the six models were chosen to capture a wide range of the variability observed across the entire ensemble of GCMs, they are not representative of the full range of variability. However, even the full set of GCMs is unlikely to capture the entire range of potential physical responses of the climate system to changes in the concentration of atmospheric GHGs.[18,19]

- **Socioeconomic and Demographic Change:** This report estimates climate change impacts to socially vulnerable populations based on current demographic distributions, as long-term and robust projections for local changes in demographics are currently unavailable. However, the country's demographics will change in the future. National-scale demographic projections from the U.S. Census suggest the U.S. population will grow older and more diverse in the coming decades. Depending on the impact, socially vulnerable groups may be more or less able to migrate away from adverse climate effects. Therefore, the results of this report should be interpreted with this limitation in mind, as actual impacts could be larger or smaller based on future changes in U.S. demographics.

Table 2.2 – Definitions for the Four Socially Vulnerable Groups and their Reference Populations

CATEGORY	DEFINITION
Low Income	Individuals living in households with income that is 200% of the poverty level or lower.[20] *Reference population: Individuals living in households with income greater than 200% of the poverty level.*
Minority	Individuals identifying as one or more of the following: Black or African American; American Indian and Alaska Native; Asian; Native Hawaiian and Other Pacific Islander; Other; and Hispanic or Latino.[21] *Reference population: Individuals identifying as White and/or non-Hispanic.*
No High School Diploma	Individuals age 25 or older with maximum educational attainment of less than a high school diploma or equivalent.[22] *Reference population: Individuals age 25 or older with educational attainment of a high school diploma (or equivalent) or higher.*
65 and Older	Individuals ages 65 and older.[23] *Reference population: Individuals under age 65.*

Data Source: U.S. Census, American Community Survey 2014-2018

APPROACH

Key Concepts

Social Vulnerability: This report analyzes risks to four specific groups: those with low income, minorities, those with no high school diploma, and people ages 65 and older. These groups have been identified in the literature as socially vulnerable due to a range of social, economic, historical and political factors that reduce their capacity to prepare for, cope with, and recover from climate change impacts. For more information, please see Appendix B.

Risks to Socially Vulnerable Populations: The analyses begin by projecting impacts of climate change and identifying the areas where the highest impacts are projected to occur (defined as areas where impacts are in the highest tercile). Next, the analyses calculate the likelihood that individuals in each of the four socially vulnerable groups currently live in these high-impact areas, relative to individuals in the reference populations (see definition below). The resulting values are measures of the potential risks to these populations of being exposed to future impacts of climate change. For more information, please refer to Appendix C.

Reference Populations: The reference populations for each socially vulnerable group are defined as all individuals who do not possess the defining demographic characteristics of that group. For example, the low income group is defined as those with incomes at or below 200% of the poverty level. The corresponding reference population includes all individuals with incomes above 200% of the poverty level.

- **Coverage of Impacts:** The six impacts analyzed in this report were selected due to the availability of robust methods and data, the demonstrated economic importance of these impacts, and the potential for disproportionate risks to socially vulnerable populations. However, there are many other human health and economic impacts of climate change that will disproportionately affect socially vulnerable populations. Therefore, this report provides only partial insight into the effects of climate change on socially vulnerable populations. Importantly, this report does not assume that socially vulnerable populations will always face disproportionately higher risks from climate change. In fact, there are results presented throughout the report that suggest that risks to reference populations may be higher in some cases compared to socially vulnerable populations.

- **Impacts Modeling:** Each analysis was developed using a single impact model. These models are complex analytical tools, and choices regarding their structure and parameter values can influence the results.[24] The use of additional models would improve the understanding of potential impacts. In addition, the analyses were developed independently and, as a result, the estimated impacts may omit important interactive or correlative effects.[25]

- **Individual Exposure:** The analyses of this report are not designed to project impacts or risks for specific individuals and are instead intended to explore disproportionate risks based on current demographic distributions in areas with higher projected impacts. As a result, the analyses assume uniform and equal exposure to risks by everybody living in these tracts.

- **Treatment of Adaptation:** Populations will adapt to climate change in many ways, with some actions reducing impacts, and others potentially exacerbating impacts. The timeliness and effectiveness of adaption efforts depend on a variety of factors, including socioeconomic status, the condition and accessibility of infrastructure, the accessibility of health care, specific demographic characteristics, and other institutional resources.[26] As described previously, the Coastal Flooding and Property and Coastal Flooding and Traffic analyses directly model the implications of potential adaptation responses.[27] The Air Quality and Health, Extreme Temperature and Labor and Extreme Temperature and Health analyses implicitly incorporate historical adaptation to climate hazards.[28] The general adaptation scenarios or responses considered in the analyses of this report do not capture the complex issues that drive adaptation decision-making at regional and local scales. As such, the adaptation scenarios and estimates presented in all sections of this report should not be construed as recommending any specific policy or adaptive action and do not explicitly address the potential inequities in future adaptation responses.

- **Geographic Coverage:** Due to data and modeling constraints, the analyses presented in this report do not assess impacts of climate change that occur outside of the contiguous U.S., such as those in Hawai'i, Alaska, and the U.S. territories, or the rest of the world. In addition, the Temperature Mortality analysis quantifies impacts in a limited set of major U.S. cities. Incorporation of additional locales would provide a more comprehensive understanding of likely effects on socially vulnerable populations.

Table 2.3 – Demonstration of the Approach for Estimating Disproportionate Risks to Socially Vulnerable Populations

The below steps demonstrate the process for estimating risks to individuals ages 65 and older in the Coastal Flooding and Traffic analysis.

STEPS	EXAMPLE CALCULATIONS
Step 4a. In the area where climate change impacts are projected to occur, count the number of individuals included in the population of individuals ages 65 and older, as well as those in the reference population (see definitions in Table 2).	Individuals ages 65 and older: 49 million Individuals under age 65: 272 million
Step 4b. In the areas where climate change impacts are projected to be the highest (i.e. where impacts are in the top third), count the number of individuals ages 65 and older, as well as those in the reference population.	Individuals ages 65 and older: 17 million Individuals under age 65: 86 million
Step 4c. Calculate the likelihood that an individual age 65 or older currently lives in the high-impact area. Then calculate the likelihood that an individual under age 65 lives in the high-impact area.	Likelihood for individual age 65 or older: 17/49 = 0.35 Likelihood for individual under 65: 86/272 = 0.32
Step 4d. Compare the two likelihoods calculated in Step 4c. The resulting value is the estimated likelihood that those ages 65 and older live in the high-impact areas compared to those under age 65.[29]	Result: Those ages 65 and older have an estimated 9% higher likelihood of living in areas with the highest impacts in the Coastal Flooding and Property analysis.

CHAPTER 3
AIR QUALITY AND HEALTH

Background

Climate change will alter chemical and physical interactions that create, remove, and transport air pollution.[1] The resulting changes in air pollution, including fine particulate matter ($PM_{2.5}$)[2] and ground-level ozone,[3] are likely to have significant respiratory and cardiovascular health effects.[4] Changes in climate, including temperature, humidity, precipitation, and other meteorological factors, can change concentrations of $PM_{2.5}$ and ozone, broadening the distribution of human exposures to these pollutants.[5,6] In addition, climate-driven increases in the intensity and duration of warm seasons are projected to increase the number of days with poor air quality. Furthermore, climate change-driven increases in wildfires and windblown dust events also result in higher $PM_{2.5}$ concentrations.[7]

This analysis estimates changes in the numbers of premature deaths for individuals ages 65 and older and new childhood asthma diagnoses associated with climate change-driven increases in $PM_{2.5}$. The approach considers adaptation responses implemented in recent history, but not new advancements in technology or behavior, or increased access for those who are socially vulnerable. It then estimates the risks that socially vulnerable populations currently live in areas where these impacts are projected to be highest. The next section describes why socially vulnerable populations in the U.S. may be particularly at risk of experiencing air quality impacts.

Social Vulnerability and Air Quality

The relationship between social vulnerability and exposure to air pollution is well established in the literature.[8,9,10] Recent research indicates that although the average concentrations of $PM_{2.5}$ have fallen over time, the spatial distribution remains disproportionate across the population.[11,12] Table 3.1 summarizes findings from the literature on the ways in which the socially vulnerable populations examined in this analysis may be more vulnerable to air pollution. As described in the table, studies have found that minorities, individuals with lower income, and individuals with lower educational attainment are at increased risk of ambient air pollution exposure and health effects related to that exposure.[13] Race, in particular, plays a significant role in determining one's risk of exposure to air pollution, even after controlling for other socioeconomic and demographic factors.[14,15] EPA's most recent Particulate Matter Integrated Science Assessment (ISA) concludes that race and ethnicity are important factors in determining $PM_{2.5}$ related risk, and that Black individuals, in particular, are at increased risk for health effects, in part due to disparities in exposure.[16,17]

Table 3.1 – Social Vulnerability and Air Quality

CATEGORY	DEFINITION
Low Income	Neighborhoods with higher poverty rates have been found to have higher exposures to $PM_{2.5}$ and ozone.[18] Low income communities tend to have greater sources of environmental risk, including higher ambient air pollution concentrations.[19]
Minority*	Studies have found higher exposures to $PM_{2.5}$ and ozone in neighborhoods with more racial minorities[20,21,22] and higher incidence of childhood asthma.[23] One study found that a large portion of non-Hispanic Black individuals reside in communities with the poorest air quality.[24]
No High School Diploma	Studies have found significant differences in educational attainment between areas with air pollution sources and those without,[25,26] though there are complex cause and effect drivers involved with these disproportionate risks.
65 and Older	Air pollution can exacerbate chronic obstructive pulmonary disorder and increase the risk of heart attack in older adults, especially those who are also diabetic or obese.[27] Because the analysis of premature mortality focuses on the population of individuals ages 65 and older, the results do not include separate estimates of disproportionate risks to this group.

METHODS

The steps below outline the general approach to the analysis. For more detailed information, please refer to Appendix D.

STEP 1 | Project changes in $PM_{2.5}$ concentrations in scenarios with 2°C and 4°C of global warming using air quality estimation techniques described in Fann et al. (2021).[28]

STEP 2 | Estimate changes in premature mortality associated with $PM_{2.5}$ for individuals ages 65 and older. Estimate changes in the number of asthma diagnoses associated with $PM_{2.5}$ for individuals ages 0 to 17. The analysis uses methods described in Fann et al. (2021), including the U.S. EPA's Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP-CE).

STEP 3 | For each impact category (premature mortality and asthma diagnoses), identify the Census tracts where impacts are projected to be highest (defined as those in the highest tercile).

STEP 4 | Calculate the likelihood that individuals who are socially vulnerable currently live in these high-impact areas relative to those who are not.[29]

CHAPTER 3

AIR QUALITY AND HEALTH

Key Findings on $PM_{2.5}$ Related Premature Mortality

With 2°C of global warming, climate-driven changes in $PM_{2.5}$ are projected to result in an annual increase of 2,100 premature deaths nationwide among those 65 and older. With 4°C, this estimate increases to 5,800 annual deaths. The Southeast is projected to experience the highest increases in premature deaths, while some Northern and Midwestern areas are projected to experience decreases due to higher numbers of rainy days, which generally reduce $PM_{2.5}$ concentrations and associated health effects.

Climate change is projected to increase annual premature deaths associated with $PM_{2.5}$ across large areas of the country. Figure 3.1 shows the projected changes in annual premature deaths among people ages 65 and older, by Census tract, due to climate-driven changes in $PM_{2.5}$. Table 3.2 shows the projected changes in the number of premature deaths by region. For information on baseline rates, please see Appendix D.

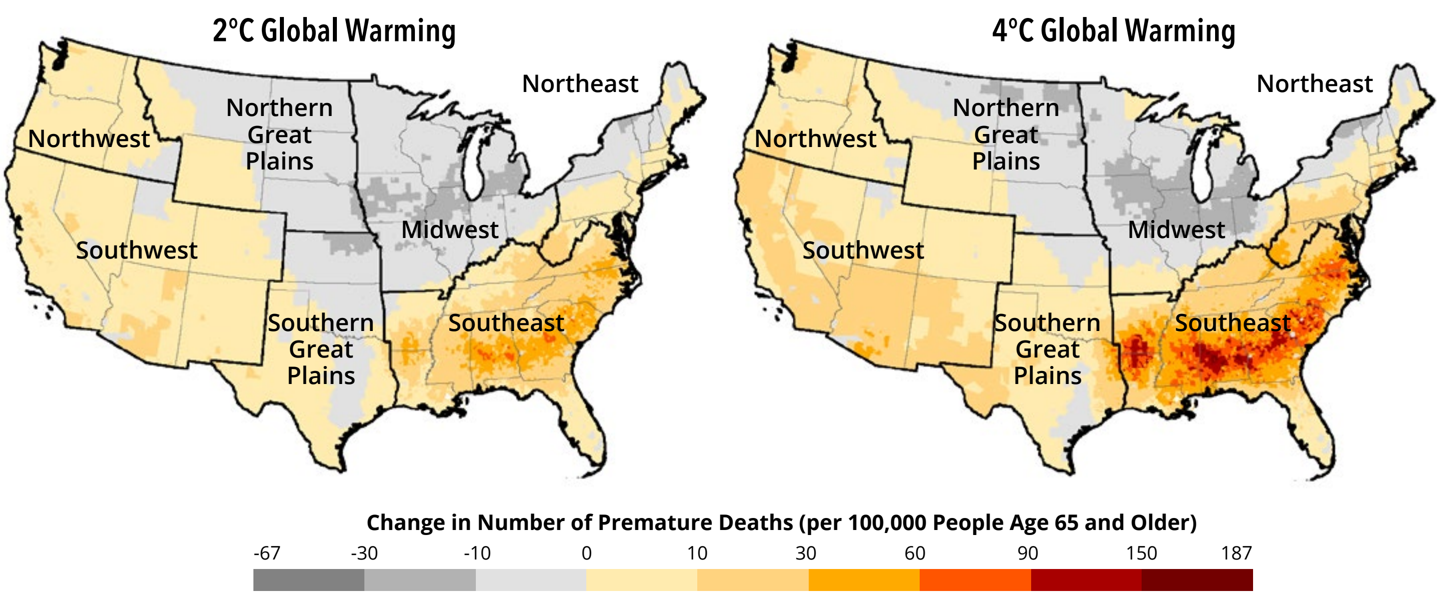
With 2°C of global warming, the Southeast is projected to experience an annual increase of 1,900 premature deaths from climate-driven changes in $PM_{2.5}$. With 4°C of global warming, this estimate increases to 3,900 annual deaths. The Northeast and Southwest are projected to experience annual increases of

Table 3.2 – Projected Regional Changes in Annual Premature Deaths Among People Ages 65 and Older due to Climate-Driven Effects on $PM_{2.5}$

	GLOBAL WARMING (RELATIVE TO 1986-2005)	
REGION	**2°C**	**4°C**
Midwest	-850	-900
Northeast	400	1,200
Northern Great Plains	-43	-29
Northwest	79	180
Southeast	1,900	3,900
Southern Great Plains	-3	290
Southwest	610	1,200
National Total	**2,100**	**5,800**

Figure 3.1 – Projected Changes in Annual Premature Deaths due to Climate-Driven Effects on $PM_{2.5}$

The analysis estimates changes in premature deaths among people ages 65 and older at the Census tract level. Levels of global warming are relative to the 1986-2005 average.



AIR QUALITY AND HEALTH

1,200 premature deaths with 4°C of global warming. Areas of the Midwest, Northern and Southern Great Plains, and parts of the Northeast, however, are projected to experience decreases in annual premature deaths from climate-driven changes in $PM_{2.5}$. This is due to the projected increase in the number of rainy days in these areas, which reduces $PM_{2.5}$ concentrations and corresponding health effects.

Note, the analysis also evaluated changes in the numbers of premature deaths for individuals ages 65 and older associated with climate change-driven increases in ozone. Projected changes in premature mortality were not shown to have large disproportionate risks to socially vulnerable populations, and are therefore summarized in Appendix D.

Actions to reduce pollutants that form $PM_{2.5}$ have been highly successful over the past several decades; since 2000, national average concentrations of $PM_{2.5}$ have been reduced by 41%. However, climate change can hinder these improvements by altering weather patterns and increasing the prevalence of conditions that lead to poor air quality.[30]

CHAPTER 3

AIR QUALITY AND HEALTH

Key Findings on $PM_{2.5}$ Related Premature Mortality and Social Vulnerability

Black and African American individuals ages 65 and older have the most disproportionate risk, relative to their reference population, of currently living in areas with the highest projected increases in premature mortality from climate-driven changes in $PM_{2.5}$. Specifically, with 4°C of global warming, Black and African American individuals are 60% more likely than non-Black and non-African American individuals to currently reside in high-impact areas.

Using the data presented in Figure 3.1, the analysis identifies the Census tracts with the highest increases in premature mortality among those 65 and older from climate-driven changes in $PM_{2.5}$. The high-impact areas are defined as Census tracts where impacts are in the highest tercile. On average, high-impact Census tracts across the contiguous U.S. are projected to experience increases of 7 to 90 annual premature deaths per 100,000 individuals ages 65 and older with 2°C of global warming, and 15 to 187 annual premature deaths with 4°C of global warming.[31] Following the steps outlined in the Approach chapter, the analysis then estimates the likelihood that those who are socially vulnerable currently live in these high-impact areas compared to those who are not.

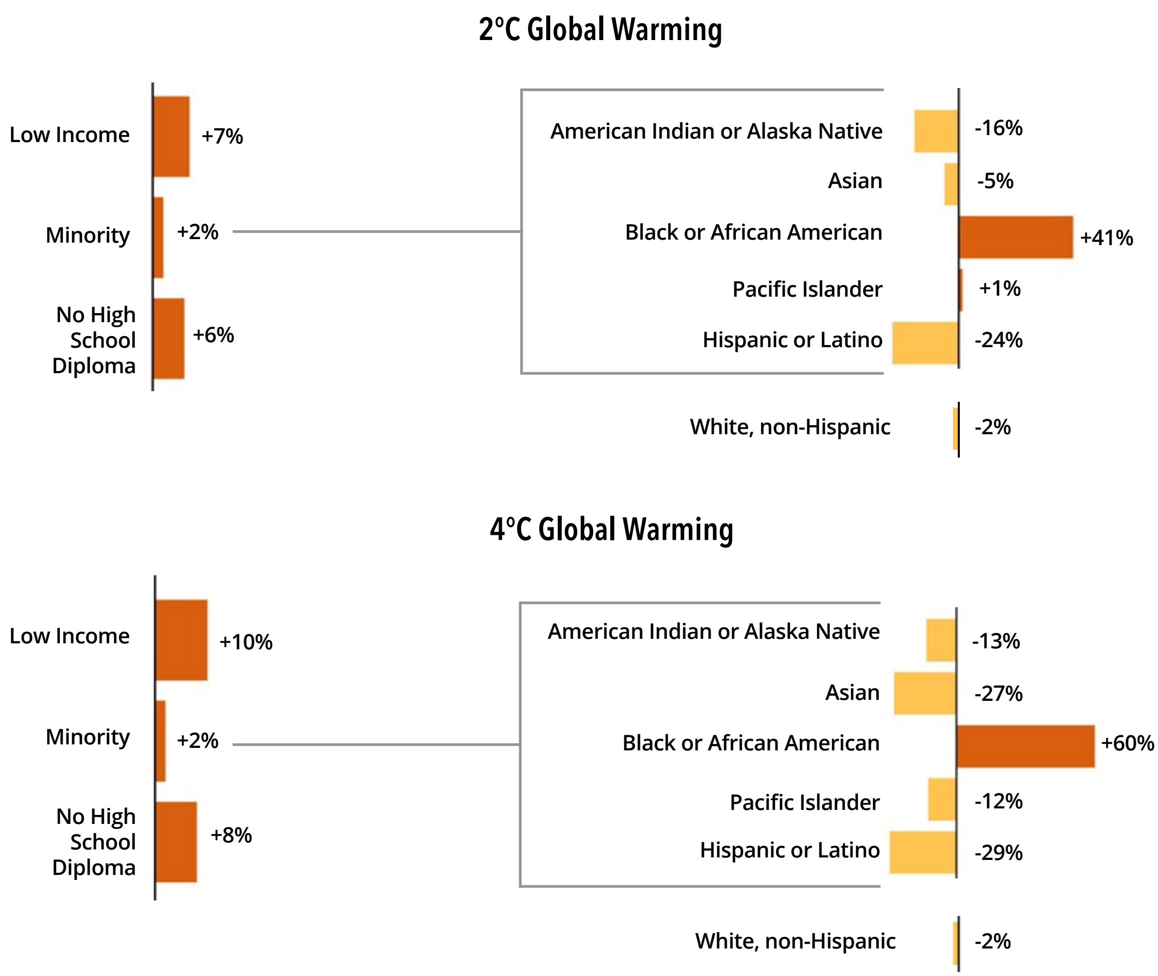
Figure 3.2 presents the relative likelihood that socially vulnerable individuals ages 65 and older currently live in areas with the highest projected increases in premature mortality from climate-driven changes in $PM_{2.5}$, compared to individuals in the reference populations. The analysis finds that Black and African American individuals are 41-60% more likely than non-Black and non-African American

Key Findings on $PM_{2.5}$ Related Premature Mortality and Social Vulnerability (continued)

individuals to currently live in areas with the highest projected increases in premature mortality from climate-driven changes in $PM_{2.5}$. Hispanic and Latino individuals are 24-29% less likely to live in high-impact areas compared to non-Hispanic and non-Latino individuals; this is partially driven by the lower projected impacts in Texas and southern Florida (as shown in Figure 3.1), where there are larger Hispanic and Latino populations. Importantly, this finding does not suggest that Hispanic and Latino individuals will not experience negative impacts from climate-driven changes in $PM_{2.5}$; rather, it refers to the degree to which the estimated impacts on this group are projected to differ from impacts on non-Hispanic and non-Latino individuals.

Figure 3.2 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas with the Highest Projected Increases in Annual Premature Deaths from Climate-Driven Effects on $PM_{2.5}$

The bar charts present the relative likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected increases in premature deaths among those 65 and older relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global warming are relative to the 1986-2005 average.



CHAPTER 3

AIR QUALITY AND HEALTH

Key Findings on $PM_{2.5}$ Related Childhood Asthma

With 2°C of global warming, climate-driven changes in $PM_{2.5}$ are projected to result in an annual increase of 2,500 childhood asthma diagnoses nationwide. With 4°C, this estimate increases to 7,000 annual diagnoses. Southern regions are projected to experience the highest increases in childhood asthma diagnoses, while some Northern and Midwestern areas are projected to experience decreases due to higher numbers of rainy days, which reduce $PM_{2.5}$ concentrations and associated health effects.

Climate change is projected to increase the annual number of asthma diagnoses in children ages 0 to 17 in many regions of the U.S., particularly the Southwest and Southeast. Figure 3.3 shows the projected changes in childhood asthma diagnoses each year, by Census tract, due to climate-driven changes in $PM_{2.5}$.[32] Table 3.3 shows the projected changes at the regional level. For information on baseline rates, please see Appendix D.

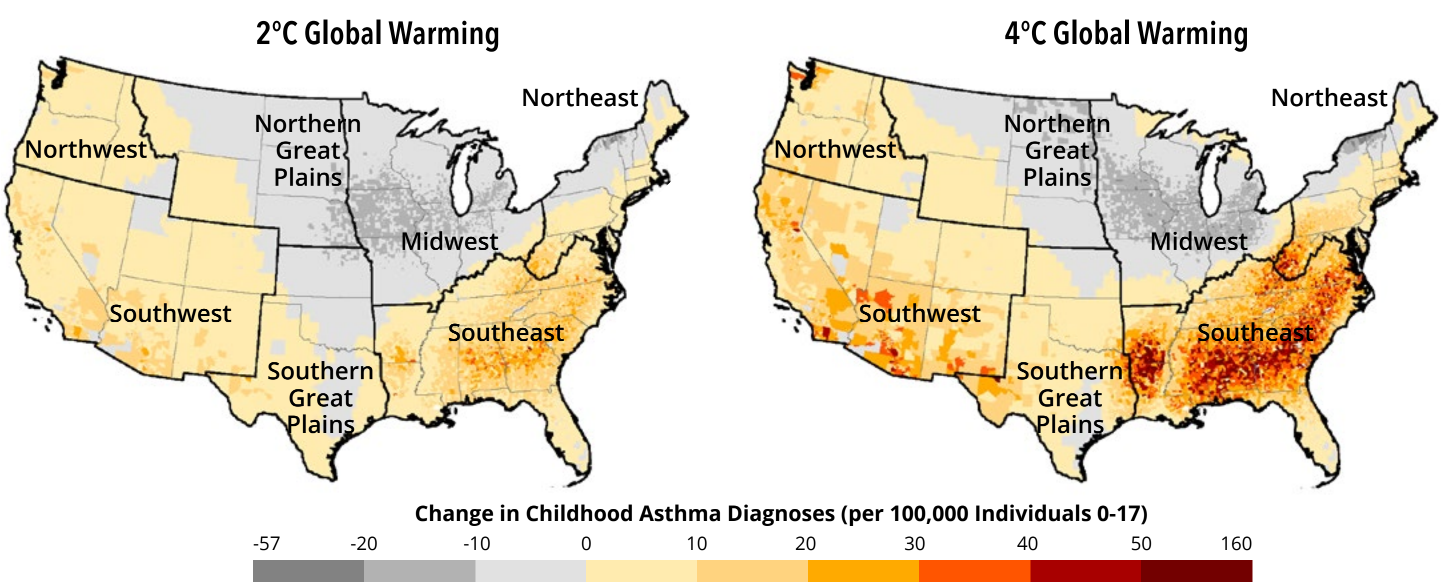
Table 3.3 – Projected Regional Changes in Annual Childhood Asthma Diagnoses Due to Climate-Driven Effects on $PM_{2.5}$

	GLOBAL WARMING (RELATIVE TO 1986-2005)	
REGION	**2°C**	**4°C**
Midwest	-1,100	-1,200
Northeast	450	1,400
Northern Great Plains	-75	-52
Northwest	130	310
Southeast	2,000	4,000
Southern Great Plains	36	490
Southwest	1,000	2,000
National Total	**2,500**	**7,000**

The Southeast is projected to experience an annual increase of 2,000 childhood asthma diagnoses due to climate-driven changes in $PM_{2.5}$ with 2°C of global warming, and an annual increase 4,000 diagnoses with 4°C of global warming. Areas of the Southwest are also projected to experience relatively high impacts. As shown in Figure 3.3, areas of the Midwest, Northern and Southern Great Plains, and parts of the Northeast are projected to experience decreases in the annual number of childhood asthma diagnoses due to the projected increase in the number of rainy days in these areas, which reduces $PM_{2.5}$ concentrations and corresponding health effects.

Figure 3.3 – Projected Changes in Annual Childhood Asthma Diagnoses Due to Climate Change-Driven Effects on $PM_{2.5}$

Levels of global warming are relative to the 1986-2005 average. Results are calculated at the Census tract level.

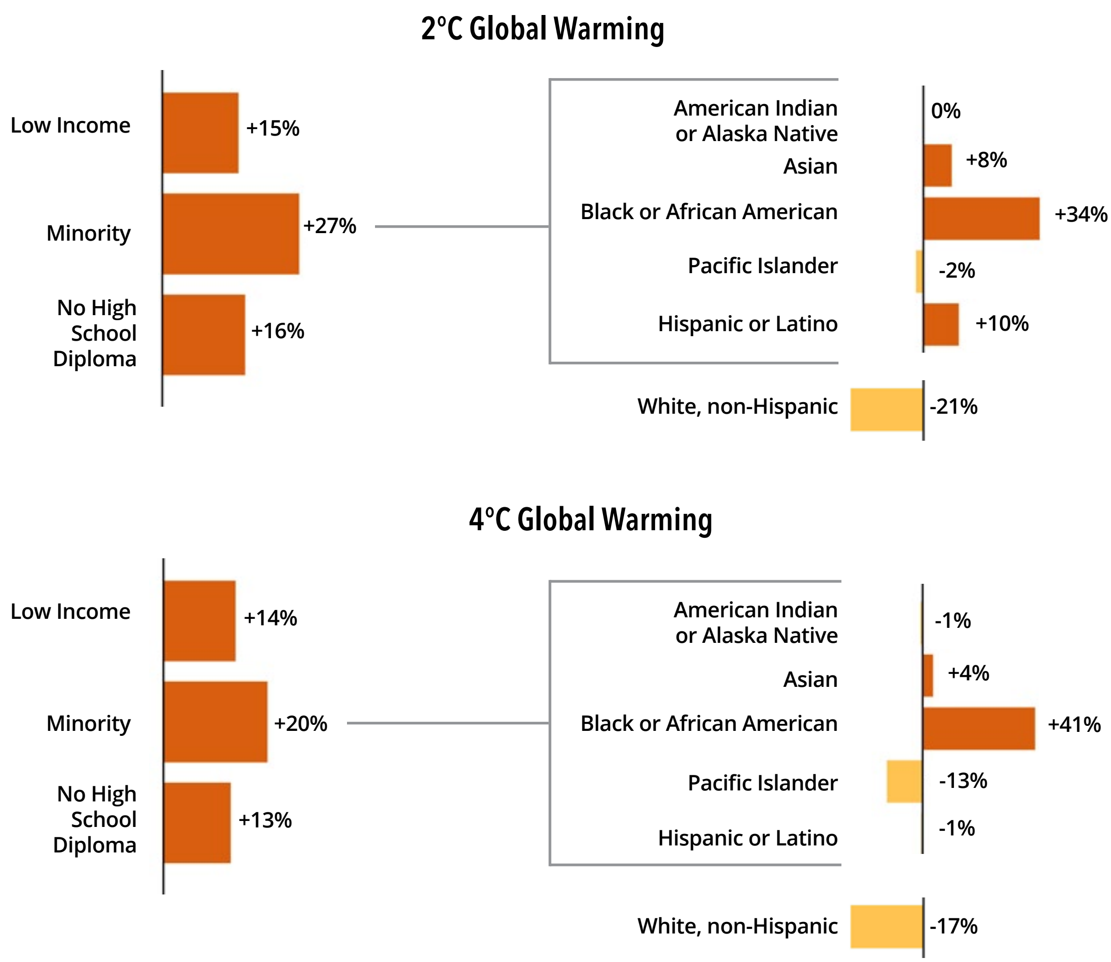


Key Findings on Social Vulnerability and $PM_{2.5}$ Related Childhood Asthma Cases

Black and African American children ages 0 to 17 have the most disproportionately high risk, relative to their reference population, of currently living in areas with the highest projected increases in asthma diagnoses due to climate-driven changes in $PM_{2.5}$. Specifically, with 4°C of global warming, Black and African American children are 41% more likely than non-Black and non-African American children to currently reside in areas with the highest projected impacts.

Figure 3.4 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas with the Highest Projected Increases in Annual Childhood Asthma Diagnoses due to Climate-Driven Effects on $PM_{2.5}$

The bar charts present the relative likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected increases in asthma diagnoses in children ages 0 to 17 relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global warming are relative to the 1986-2005 average.



AIR QUALITY AND HEALTH

Using the data presented in Figure 3.3, the analysis identifies the Census tracts with the highest increases in childhood asthma diagnoses from climate-driven changes in $PM_{2.5}$. The high-impact areas are defined as Census tracts where impacts are in the highest tercile. On average, high-impact tracts across the contiguous U.S. are projected to experience increases of 6 to 65 annual diagnoses per 100,000 individuals ages 0 to 17 with 2°C of global warming and 13 to 160 annual diagnoses with 4°C of global warming.[33] Following the steps outlined in the Approach chapter, the analysis then estimates the likelihood that those who are socially vulnerable currently live in these high-impact areas compared to those who are not.

Figure 3.4 presents the relative likelihood that socially vulnerable individuals ages 0 to 17 currently live in areas with the highest projected increases in childhood asthma diagnoses due to climate-driven changes in $PM_{2.5}$, compared to individuals in the reference populations. The analysis finds that minority children are 20-27% more likely than non-minority children to currently live in areas with the highest projected increases in childhood asthma diagnoses due to climate-driven changes in $PM_{2.5}$, compared to individuals in the reference populations. Black and African American children are 34% more likely than non-Black and non-African American children to currently live in high-impact areas with 2°C global warming and 41% more likely to currently live in high-impact areas with 4°C of global warming. White, non-Hispanic children are 17-21% less likely to live in high-impact areas; this is likely due to the lower projected impacts in the Midwest and other areas of the country (as shown in Figure 3.3) with larger White, non-Hispanic populations. Importantly, this finding does not suggest that White, non-Hispanic children will not experience negative impacts from climate change driven changes in $PM_{2.5}$; rather, it refers to the degree to which the estimated impacts on this group are projected to differ from impacts on minorities.

The analysis also evaluated changes in the numbers of asthma-related emergency department (ED) visits among children ages 0 to 18 associated with climate change-driven increases in $PM_{2.5}$. Projected changes are presented in Appendix D. The analysis finds that minorities have an estimated 53-58% higher likelihood of living in areas with the highest projected increases in childhood asthma ED visits, relative to non-minorities. The magnitude of this effect is tied to the availability of race-stratified estimates for this impact metric; it is possible that the incorporation of race-stratified data for the analysis of impacts on childhood asthma diagnoses may yield even more disproportionate impacts than the results presented in Figure 3.3.[34]

AIR QUALITY AND HEALTH

Key Findings on Regional Impacts for Childhood Asthma

In nearly all regions of the U.S., children in low income households are more likely than those in higher income households to currently live in areas with the highest projected increases in childhood asthma diagnoses due to climate-driven changes in $PM_{2.5}$ In the Southern Great Plains, minority children are 77% more likely than non-minority children to currently live in high-impact areas.

The regional analysis follows the same approach as the national-level analysis, first identifying the areas within each region that are projected to experience the highest impacts of climate change (see Section 4 of Appendix D) and then estimating the likelihood that those who are socially vulnerable currently live in these areas compared to those who are not. For each region, the charts show the likelihood that children in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected increases childhood asthma diagnoses due to climate-driven changes in $PM_{2.5}$, relative to children in the reference groups (e.g., non-low income).

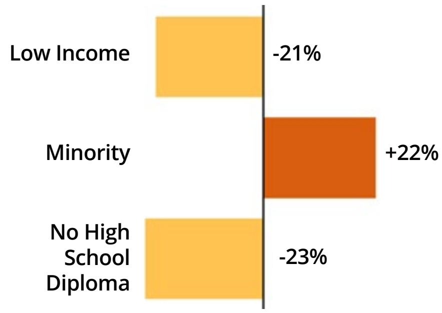
The results are for a scenario with global warming of 2°C relative to 1986 to 2005. Please refer to Appendix D for results in the scenario with 4°C of warming, as well as for regional findings of the premature mortality analysis. As described in the Approach chapter, a finding that a socially vulnerable group is less likely to experience risks does not suggest that they will not experience negative impacts; rather, such findings refer to the degree to which the estimated impacts are projected to be disproportionate relative to the reference population.

AIR QUALITY AND HEALTH

Key Findings on Regional Impacts for Childhood Asthma (continued)

NORTHWEST

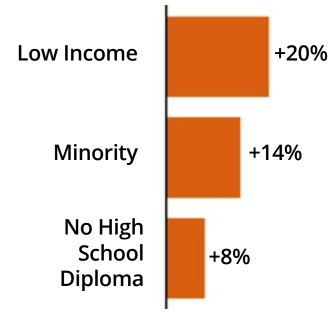
2°C Global Warming



- In the Northwest, minority children are 22% more likely than non-minority children to currently live in areas with the highest projected increases in childhood asthma diagnoses from climate-driven changes in $PM_{2.5}$.
- In the Northwest, children in households with low income or no high school diploma are over 20% *less* likely to currently live in high-impact areas, relative to their reference populations.

SOUTHWEST

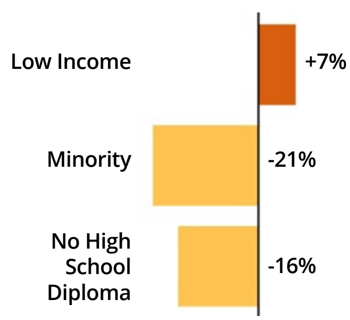
2°C Global Warming



- In the Southwest, children in households with low income are 20% more likely than those with higher income to currently live in areas with the highest projected increases in childhood asthma diagnoses from climate-driven changes in $PM_{2.5}$.
- In the Southwest, minority children are 14% more likely than non-minority children to currently live in high-impact areas.

NORTHERN GREAT PLAINS

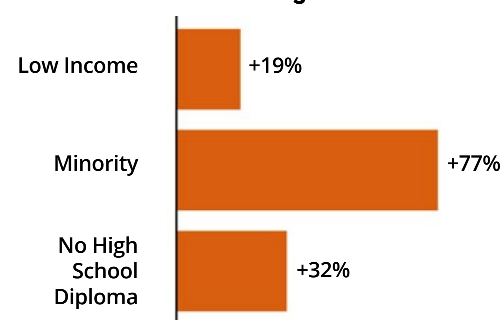
2°C Global Warming



- In the Northern Great Plains, children in households with low income are 7% more likely than those with higher income to currently live in areas with the highest projected increases in childhood asthma diagnoses from climate-driven changes in $PM_{2.5}$.
- In the Northern Great Plains, minority children and those living in households with no high school diploma are *less* likely than their reference populations to currently live in high-impact areas.

SOUTHERN GREAT PLAINS

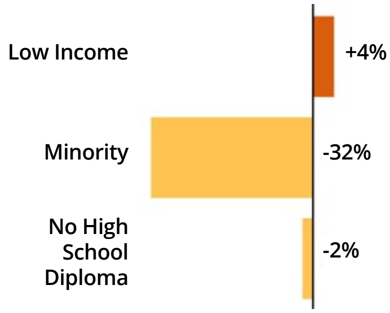
2°C Global Warming



- In the Southern Great Plains, minority children are 77% more likely than non-minority children to currently live in areas with the highest projected increases in childhood asthma diagnoses from climate-driven changes in $PM_{2.5}$.
- Children in households with low income or no high school diploma are 19% and 32% more likely, respectively, to currently live in high-impact areas, relative to their reference populations.

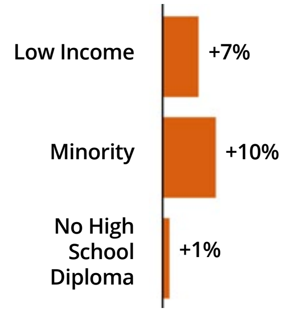
Key Findings on Regional Impacts for Childhood Asthma (continued)

MIDWEST
2°C Global Warming



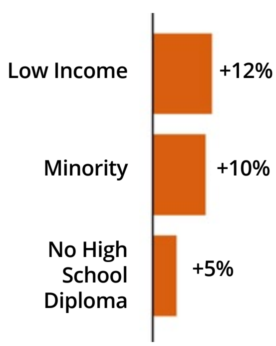
- In the Midwest, children in households with low income are slightly more likely than those with higher income to currently live in areas with the highest projected increases in childhood asthma diagnoses from climate-driven changes in $PM_{2.5}$. Minorities are 32% *less* likely to live in high impact areas relative to non-minorities.
- Overall, individuals in the Midwest region are projected to experience a decrease in childhood asthma cases due to an increase in the number of rainy days, which results in lower $PM_{2.5}$ concentrations.

NORTHEAST
2°C Global Warming



- In the Northeast, minority children are 10% more likely than non-minority children to currently live in areas with the highest projected increases in childhood asthma diagnoses from climate-driven changes in $PM_{2.5}$.
- Children in households with low income are 7% more likely than those with higher income to currently live in high-impact areas.

SOUTHEAST
2°C Global Warming



- In the Southeast, children in households with low income are 12% more likely than those with higher income to currently live in areas with the highest projected increases in childhood asthma diagnoses from climate-driven changes in $PM_{2.5}$.
- In the Southeast, minority children are 10% more likely than non-minority children to currently live in high-impact areas.

CHAPTER 4
EXTREME TEMPERATURE AND HEALTH

Background

Rising temperatures resulting from climate change will lead to an increase in heat-related illnesses and deaths.[1] Extreme temperature days, or days that are substantially hotter than the average seasonal temperature in summer or substantially colder than the average seasonal temperature in winter, cause increases in illnesses and death by compromising the body's ability to regulate its temperature.[2] Exposure to extreme temperature may result in more severe health responses or death because it exacerbates pre-existing conditions, including cerebral, respiratory, and cardiovascular diseases, and because it has greater impact on those who are taking prescribed or other drugs that may already change their circulatory system, and thus their body's ability to regulate its temperature.[3] Studies that have analyzed future temperature mortality related to climate change over the past two decades provide consistent evidence higher temperatures will increase the risk of heat-related illness and death, in the absence of additional societal adaptation.[4] The relationship between exposure to extreme temperatures and socially vulnerable populations has also been examined around the world, across hundreds of studies, reports, and guidance documents.[5]

This analysis estimates changes in the numbers of premature deaths associated with climate-driven changes in extremely hot and extremely cold days across the contiguous U.S. The approach considers adaptation responses implemented in recent history, such as air conditioning, but not new advancements in technology or behavior, or increased access for those who are socially vulnerable. It then estimates the risks to socially vulnerable populations of living in areas where these impacts are projected to be highest. The next section describes why socially vulnerable populations in the U.S. may be particularly at risk of experiencing health impacts from extreme temperatures.

Social Vulnerability and Temperature Mortality

Table 4.1 summarizes findings from the literature on the ways in which the four socially vulnerable populations examined in this analysis may experience higher impacts from exposure to extreme temperatures. Most frequently, the relevant studies analyze impacts on those ages 65 and older and on children under age five.[6] Older individuals tend to experience worse health outcomes due to cardiac strain created by exposure to heat, and young children sweat less, which limits their body's ability to naturally cool.[7] Studies also examine the relationship between extreme temperature mortality and race, poverty, residence in an urban environment, homelessness, social isolation, and working outdoors.[8,9] Access to air conditioning can mitigate one's risk of health impacts from extreme heat, but may be limited depending on income, location, and other factors.[10,11] Similarly, in colder climates, heating can mitigate adverse health effects from extreme cold, but access may be limited for certain socially vulnerable groups.[12]

EXTREME TEMPERATURE AND HEALTH

Table 4.1 – Social Vulnerability and Temperature Mortality

CATEGORY	DEFINITION
Low Income	Neighborhoods in the U.S. and Canada where poverty rates are relatively higher have been found to experience elevated temperature mortality impacts.[13] Individuals without health insurance—a condition which may be more common for low-income populations—have also been found to experience higher rates of temperature mortality impacts.[14]
Minority	Studies have found higher temperature mortality rates among many minority populations, including Black and Hispanic populations.[15]
No High School Diploma	There is a paucity of research on the relationship between one's education and impacts from exposure to extreme temperatures. However, one study found higher temperature mortality among individuals working in outdoor occupations (agriculture and resource extraction),[16] industries where some workers may be more likely to lack a high school diploma.
65 and Older	Older individuals have higher baseline mortality rates and are more susceptible to the negative health consequences of heat exposure, in part due to the exacerbation of heat stress on pre-existing cardiac conditions.[17]

Figure 4.1 – Cities Included in the Temperature Mortality Analysis

Due to the underlying method, the analysis focuses on the 49 cities shown below. Many additional U.S. locations are vulnerable to impacts from climate change-driven increases in extreme temperatures, which are not estimated in this analysis.

METHODS

The analysis quantifies the impact of climate change on mortality from both extreme heat and extreme cold in 49 large cities across the U.S. (Figure 4.1).[18] The steps below outline the general approach to this analysis. For more detailed information, please refer to Appendix E.

STEP 1 | For each of the 49 U.S. cities analyzed, project changes in daily temperature patterns in scenarios with 2°C and 4°C of global warming.

STEP 2 | Estimate changes in mortality in urban areas associated with extreme temperature using U.S. EPA's Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP-CE) and methods described in Mills et al. (2014), updated for U.S. EPA (2017).[19]

STEP 3 | Identify the Census tracts where the change in mortality rates are projected to be highest (defined as those in the highest tercile).

STEP 4 | Calculate the likelihood that individuals who are socially vulnerable currently live in these high-impact areas relative to those who are not.[20]

EXTREME TEMPERATURE AND HEALTH

Key Findings on Temperature Mortality

Climate-driven changes in extreme temperatures—particularly increases in high-temperature days—are projected to result in an annual increase in the number of premature deaths in the 49 cities studied. The projected increases are highest in the cities located in the Midwest, Southeast, and Northeast.

Figure 4.2 shows the estimated changes in combined heat and cold mortality rates per 100,000 people due to climate-driven changes in extreme temperatures in the 49 cities included in the analysis. Although global warming is projected to result in fewer deaths from extremely cold days, these reductions are outweighed by higher mortality rates from increases in extremely hot days. As shown in Figure 4.2, some of the highest projected increases in mortality rates occur in cities in Ohio and Pennsylvania, likely because these cities are not as heat-adapted as many warmer-climate locales (see Appendix E for more details, including baseline mortality rates for these cities).[21,22] Cities in Louisiana and Florida are also projected to experience relatively high increases in mortality rates. To place these rates in context, the combined age-adjusted mortality rates for influenza and pneumonia in 2018 were 14.9 per 100,000.[23]

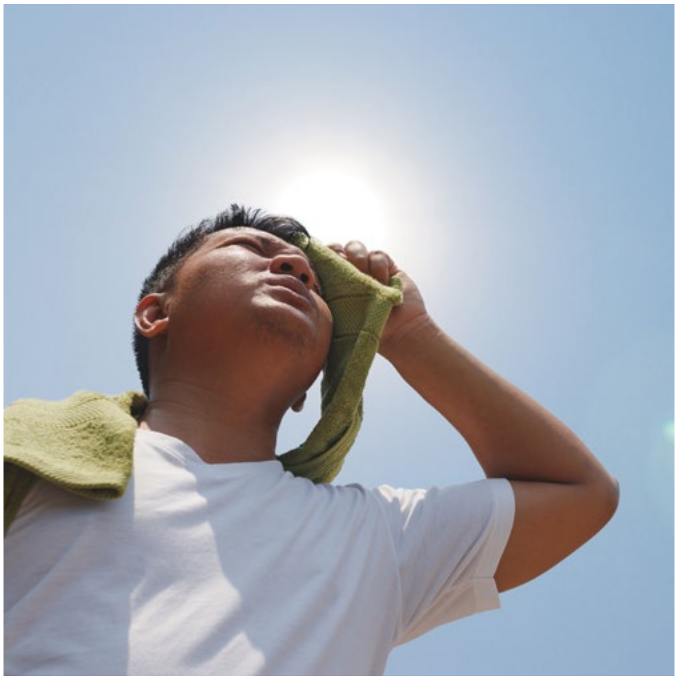
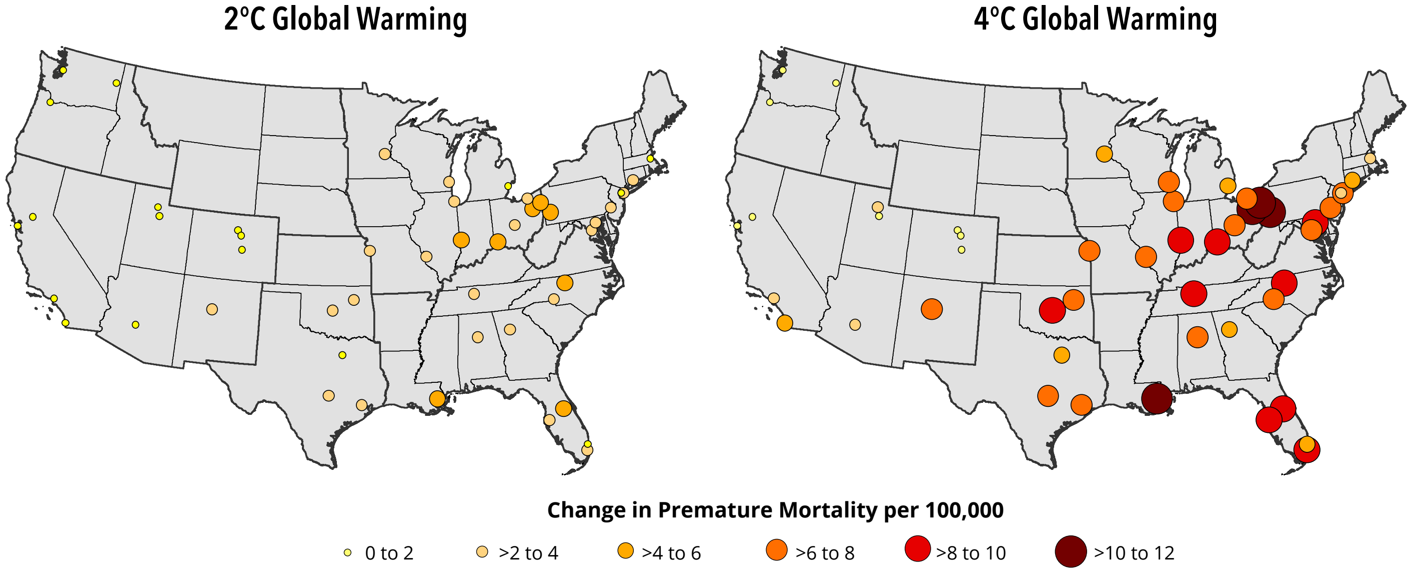


Figure 4.2 – Projected Increase in Annual Premature Mortality Rates due to Extreme Temperatures

Levels of global warming are relative to the 1986-2005 average. Results are calculated for each of the 49 cities included in the analysis (see Figure 4.1). Importantly, cities that are not included in the analysis may still experience significant temperature mortality impacts from climate change.



EXTREME TEMPERATURE AND HEALTH

Key Findings on Social Vulnerability and Temperature Mortality

In the cities analyzed, minorities and those with low income are more likely than non-minorities and those with higher income to currently live in areas with the highest projected increases in temperature mortality from climate-driven changes in extreme temperatures. Black and African American individuals are 40-59% more likely than non-Black and non-African American individuals to currently live in high-impact areas.

Increases in extreme temperature-related premature mortality are projected to occur in many U.S. cities, but the largest increases are expected in areas with larger shares of low income and minority populations. This finding is consistent with the results of prior literature on social vulnerability and temperature mortality.[24] Figure 4.3 presents the likelihoods for each socially vulnerable group at the national level, relative to their reference populations.[25]

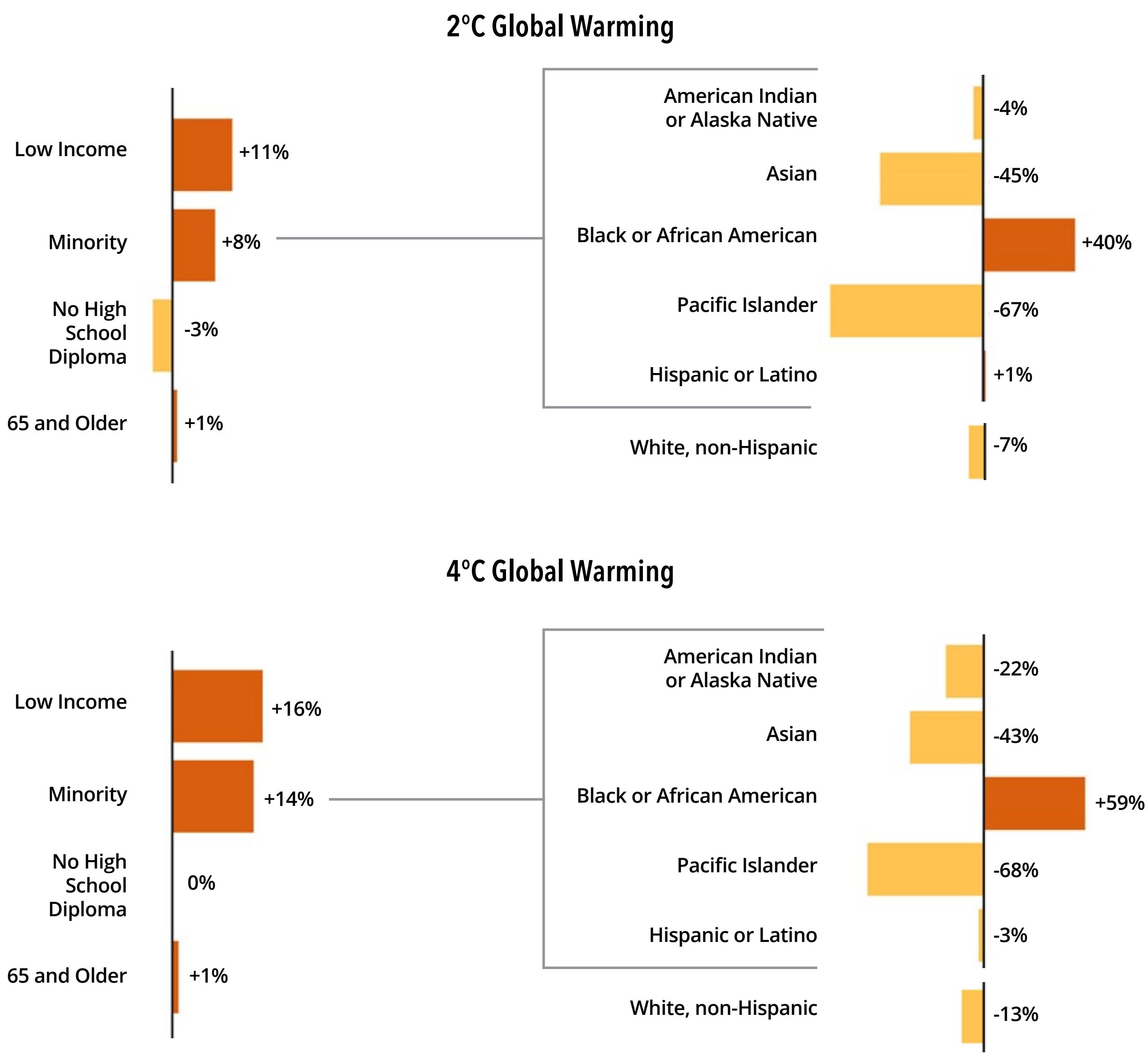
Heat waves are occurring more often than they used to in major cities across the U.S. Their frequency has increased steadily, from an average of two heat waves per year during the 1960s to six per year during the 2010s. For more information, see EPA's Climate Change Indicators website.

In the cities analyzed, Black and African American individuals are 40% more likely than non-Black and non-African American individuals to live in areas with the highest projected increases in extreme temperature related mortality with 2°C of global warming. With 4°C of global warming, this estimate increases to 59%. In contrast, Asian individuals and Pacific Islanders are 43% and 68% less likely to live in high-impact areas with 4°C of global warming. For more information, please refer to Appendix E; note that the chapter and appendix do not present regional results due to the limited spatial domain of the analysis.

Key Findings on Social Vulnerability and Temperature Mortality (continued)

Figure 4.3 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas with the Highest Projected Increases in Premature Mortality due to Climate-Driven Changes in Extreme Temperatures

Results are for the 49 cities included in the analysis (Figure 4.1). The bar charts present the relative likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected increases in mortality relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global warming are relative to the 1986-2005 average.



CHAPTER 5
EXTREME TEMPERATURE AND LABOR

Background

Climate-driven changes in the frequency and intensity of extreme temperatures are expected to result in disruptions in labor sectors where people work outdoors or in indoor environments without air conditioning.[1,2] When temperatures are high, people are at risk of experiencing health and cognitive effects that prevent them from working at optimal levels. As a result, they may spend less time working on hot days, or may not be able to work at all.[3] This results in a shift in the allocation of time to labor, with potentially significant economic implications.

This analysis estimates changes in labor hours in weather-exposed industries associated with climate-driven effects on high-temperature days. Although climate change can also result in fewer extremely cold days, with potential benefits for certain labor sectors in winter months, such benefits were not found in empirical data upon which this analysis is based.[4] In addition, this analysis does not evaluate changes in labor hours that may result from other climate-driven weather events that may affect labor, such as thunderstorms, rain events, and snow.

The analysis focuses on the following weather-exposed industries: agriculture, forestry, fishing, and hunting; mining; construction; manufacturing; and transportation and utilities.[5] The approach considers adaptation responses implemented in recent history, but not new advancements in technology or behavior, or increased access for those who are socially vulnerable. It then estimates the risks that socially vulnerable populations currently live in areas where the estimated labor hour losses are projected to be highest. The next section describes why socially vulnerable populations in the U.S. may be particularly at risk of experiencing labor impacts.

EXTREME TEMPERATURE AND LABOR

Social Vulnerability and Labor

Table 5.1 summarizes findings from the scientific literature on the ways in which socially vulnerable groups may experience greater reductions in labor hours from climate-driven changes in extreme temperature. Workers in weather-exposed industries tend to be lower-income individuals who are particularly reliant on their income for meeting basic needs.[6] For example, the average construction worker earns 25% less than the median worker in the U.S., and laborers in the farming, fishing and forestry sectors earn an average of 48% less.[7] These individuals are therefore very sensitive to any decrease in pay associated with reduced labor hours resulting from high-temperature days. As a result, some workers may opt to work during high-temperature days, if given the choice, thereby putting their health at risk. Or, in some cases, employers might pressure employees to work on extremely hot days. Since having low income may also be associated with a lack of access to quality healthcare, these individuals may be more vulnerable to health risks from heat exposure.[8]

Table 5.1 – Social Vulnerability and Labor

CATEGORY	DESCRIPTION
Low Income	Workers with low income levels may experience more hardship associated with reduced pay from lost labor hours.[9] Low income may also be associated with lack of access to insurance or healthcare, making these individuals more vulnerable to the potential health effects of heat exposure.
Minority	There is a lack of research on the link between minority status and labor impacts from extreme temperatures. However, individual racial and ethnic identity has been strongly associated with heat-associated morbidity and mortality in the U.S.[10]
No High School Diploma	There is a lack of comprehensive literature on the link between educational attainment and labor impacts from extreme temperature. However, as described in Appendix E, those with no high school diploma make up significant percentages of workers in the agriculture sector (31%) and construction sector (19%).
65 and Older	Older individuals are more susceptible to the negative health consequences of heat exposure.[11,12]

METHODS

The steps below outline the general approach to the analysis. For more detailed information, please refer to Appendix E.

STEP 1 | Estimate the change in the number of "degree days" over 90°F for each Census tract in scenarios 2°C and 4°C of global warming.[13]

STEP 2 | Estimate the labor hours lost per weather-exposed worker due to high-temperature days using the approach presented in Neidell et al. (2021).[14]

STEP 3 | Identify the Census tracts with the highest rates of labor hour losses per weather-exposed worker (defined as those in the highest tercile).

STEP 4 | Calculate the likelihood that individuals who are socially vulnerable currently live in these high-impact areas relative to those who are not.[15]

EXTREME TEMPERATURE AND LABOR

Key Findings on Lost Labor Hours

With 2°C of global warming, climate-driven increases in high-temperature days are projected to result in 14 lost labor hours per year, on average, for weather-exposed workers in the U.S. With 4°C of global warming, the average number of hours lost per weather-exposed worker increases to 34 hours per year.

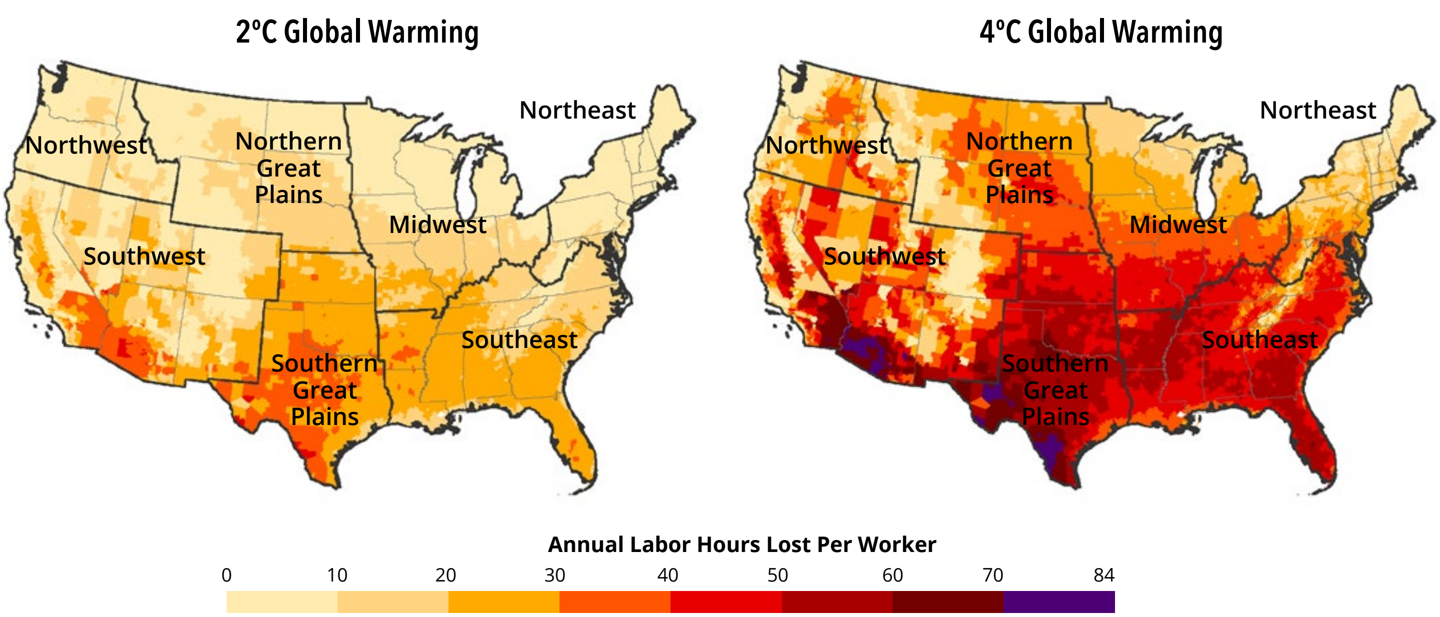
Climate change is projected to result in a significant increase in the number of days above 90°F across the country, resulting in reductions in labor hours for weather-exposed workers.[16] Figure 5.1 shows the projected labor hours lost per weather-exposed worker by Census tract, and Table 5.2 summarizes the average, per-worker hours lost at the national and regional levels. With 2°C of global warming, the average weather-exposed worker in the Southern Great Plains is projected to lose 26 hours of labor per year, and this increases to 50 hours with 4°C of global warming. With 4°C of global warming, weather-exposed workers in some Census tracts located in the Southwest and Southern Great Plains are projected to lose up to 84 hours per worker per year.

Table 5.2 – Projected Average Annual Labor Hours Lost per Weather-Exposed Worker due to Climate-Driven Effects on High-Temperature Days

	GLOBAL WARMING (RELATIVE TO 1986-2005)	
REGION	**2°C**	**4°C**
Midwest	11	30
Northeast	7	24
Northern Great Plains	11	30
Northwest	5	15
Southeast	20	44
Southern Great Plains	26	50
Southwest	17	34
National Total	**14**	**34**

Figure 5.1 – Projected Labor Hours Lost Each Year due to Climate Change

Levels of global warming are relative to the 1986-2005 average. Results are calculated at the Census tract level.



EXTREME TEMPERATURE AND LABOR

Key Findings on Social Vulnerability in the Labor Sector

With 2°C of global warming, minorities are 35% more likely than non-minorities to currently live in areas with the highest projected labor hours losses due to climate-driven increases in high-temperature days. Hispanic and Latino individuals are 43% more likely than non-Hispanic and non-Latino individuals to live in these high-impact areas. In addition, those with low income or no high school diploma are approximately 25% more likely than individuals in their reference populations to live in high-impact areas.

Using the data presented in Figure 5.1, the analysis identifies the Census tracts with the highest labor hour losses due to climate-driven increases in high-temperature days. The high-impact areas are defined as Census tracts where impacts are in the highest tercile. On average, high-impact Census tracts across the contiguous U.S. are projected to experience increases of 19 to 49 lost labor hours per worker with 2°C of global warming, and 42 to 84 lost labor hours per worker with 4°C of global warming.[17] Following the steps outlined in the Approach chapter, the analysis then estimates the likelihood that those who are socially vulnerable currently live in these high-impact areas compared to those who are not.

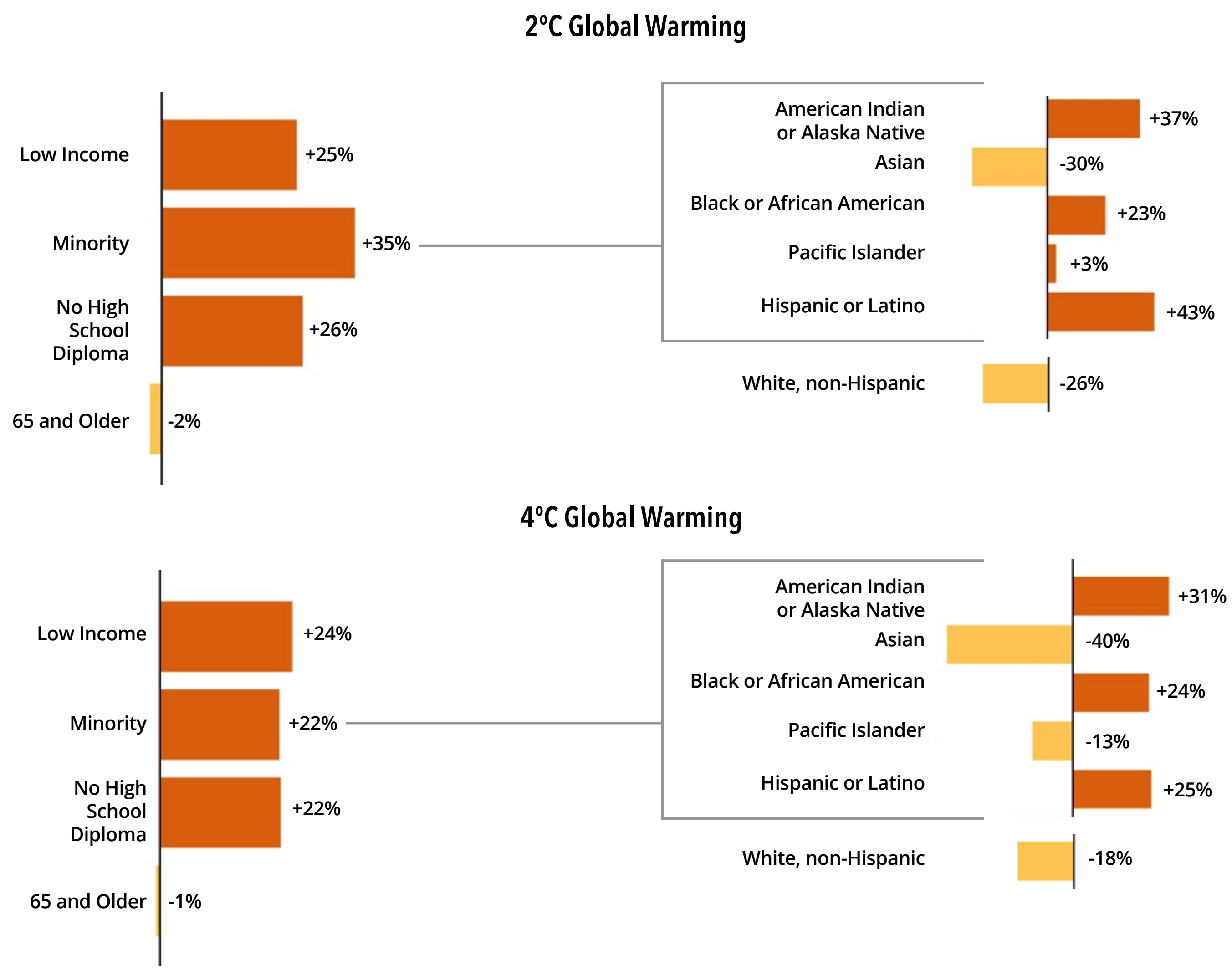
Figure 5.2 presents the likelihood that individuals from each socially vulnerable group examined in this report currently live in areas that are projected to have the highest losses in labor hours due to climate-driven increases in high-temperature days, relative to individuals from their reference populations.[18] The analysis finds that three of the four socially vulnerable populations (minorities, those with low income, and those without a high school diploma) have a higher likelihood compared to their reference populations of living in high-impact areas.[19]

At both levels of future warming, minorities, those with low income, and those without a high school diploma are all estimated to be over 20% more likely than individuals in the reference populations to currently live in areas that are projected to have the greatest labor hour losses due to climate change. Minorities, in particular, are 35% more likely than non-minorities to currently live in areas that are projected to have the highest labor hour losses with 2°C of global warming. Of all the individual racial and ethnic groups that comprise the minority category, Hispanic and Latino individuals are found to have the highest comparative risk (43% higher than non-Hispanic and non-Latino individuals) of living in high-impact areas. Individuals ages 65 and older are not expected to experience impacts that are significantly different from those experienced by younger individuals.

Key Findings on Social Vulnerability in the Labor Sector (continued)

Figure 5.2 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas with the Highest Projected Labor Hour Losses Due to Climate-Driven Increases in High-Temperature Days

The bar charts present the relative likelihood that weather-exposed workers in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected labor hour losses relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global warming are relative to the 1986-2005 average.



CHAPTER 5

EXTREME TEMPERATURE AND LABOR

Key Findings on Regional Impacts

In all regions except the Midwest, minorities are found to have a higher risk than non-minorities of currently living in areas with the highest projected losses in labor hours due to climate-driven increases in high-temperature days. In all regions except the Northeast, those with low income or no high school diploma are found to have a higher risk relative to individuals in their reference populations of currently living in high-impact areas.

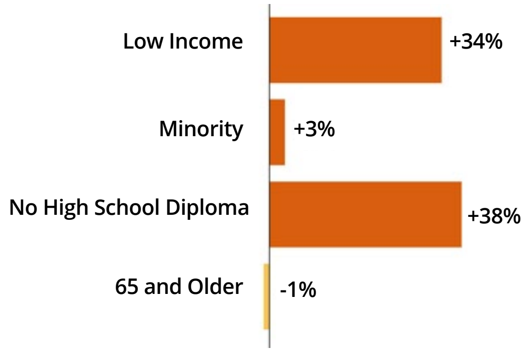
The regional analysis follows the same approach as the national-level analysis, first identifying the areas within each region that are projected to experience the highest impacts of climate change (see Appendix F) and then estimating the likelihood that those who are socially vulnerable currently live in these areas compared to those who are not. For each region, the charts show the likelihood that weather-exposed workers in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected labor hour losses due to climate-driven increases in high-temperature days, relative to weather-exposed workers in the reference groups (e.g., non-low income).

The results shown are for a scenario with global warming of 2°C relative to 1986 to 2005. Please refer to Appendix F for results in the scenario with 4°C of warming. As described in the Approach chapter, a finding that a socially vulnerable group is less likely to experience risks does not suggest that they will not experience negative impacts; rather, such findings refer to the degree to which the estimated impacts are projected to be disproportionate relative to the reference population.

Key Findings on Regional Impacts (continued)

NORTHWEST

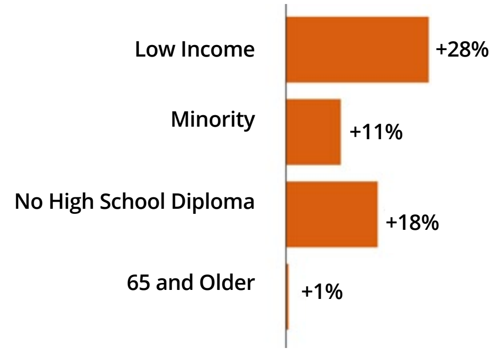
2°C Global Warming



- In the Northwest, individuals without a high school diploma are 38% more likely than those with a high school diploma to currently live in areas with the highest projected losses of labor hours due to climate-driven increases in high-temperature days.
- In the Northwest, low income workers are 34% more likely than those with higher income to currently live in high-impact areas.

SOUTHWEST

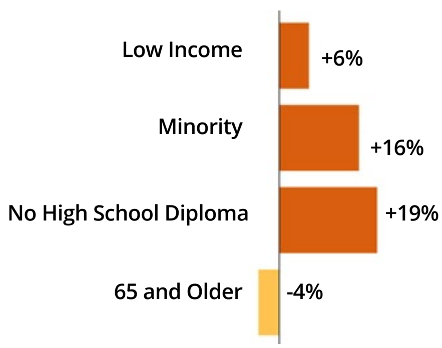
2°C Global Warming



- In the Southwest, low income individuals are 28% more likely than those with higher income to currently live in areas with the highest projected losses of labor hours due to climate-driven increases in high-temperature days.
- In the Southwest, individuals without a high school diploma are 18% more likely than those with a high school diploma to currently live in high-impact areas.

NORTHERN GREAT PLAINS

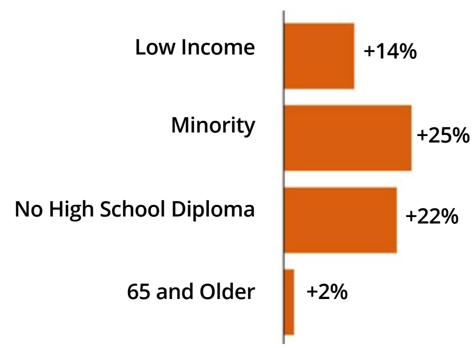
2°C Global Warming



- In the Northern Great Plains, individuals without a high school diploma are 19% more likely than those with a high school diploma to currently live in areas with the highest projected losses of labor hours due to climate-driven increases in high-temperature days.
- In the Northern Great Plains, minorities are 16% more likely than non-minorities to currently live in high-impact areas.

SOUTHERN GREAT PLAINS

2°C Global Warming



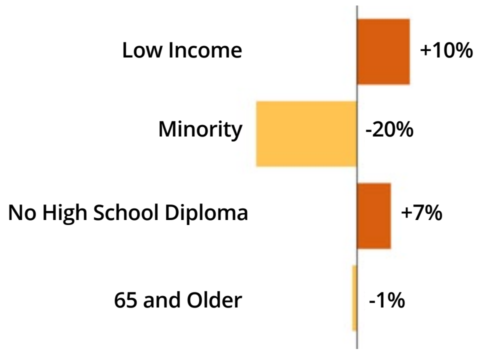
- In the Southern Great Plains, minorities are 25% more likely than non-minorities to currently live in areas with the highest projected losses of labor hours due to climate-driven increases in high-temperature days.
- In the Southern Great Plains, individuals without a high school diploma are 22% more likely than those with a high school diploma to currently live in high-impact areas.

EXTREME TEMPERATURE AND LABOR

Key Findings on Regional Impacts (continued)

MIDWEST

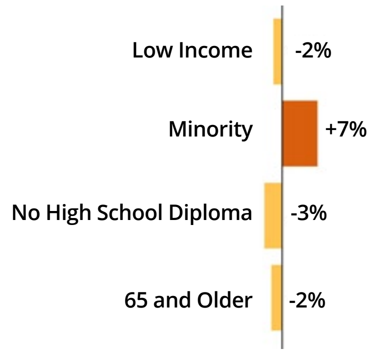
2°C Global Warming



- In the Midwest, those with low income are 10% more likely than those with higher income to currently live in areas with the highest projected losses of labor hours due to climate-driven increases in high-temperature days.
- In the Midwest, minorities are about 20% *less* likely than non-minorities to live in high-impact areas. This is likely because the areas in the Midwest that are projected to experience more substantial increases in high-temperature days are less racially and ethnically diverse areas.

NORTHEAST

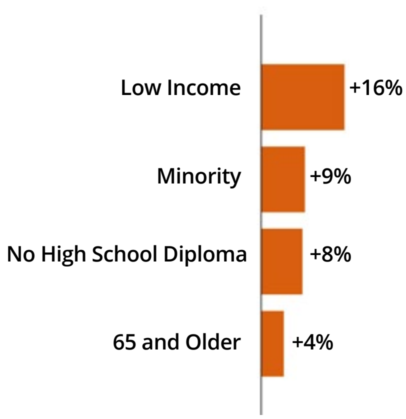
2°C Global Warming



- Compared to other regions, the Northeast is an area where higher losses of labor hours due to climate change are projected to affect socially vulnerable and non-socially vulnerable populations more equally.
- Minorities have a slightly higher likelihood (7%) relative to non-minorities of currently living in areas with the highest projected losses in labor hours.

SOUTHEAST

2°C Global Warming



- In the Southeast, low income individuals are 16% more likely than those with higher income to currently live in areas with the highest projected losses of labor hours due to climate-driven increases in high-temperature days.
- In the Southwest, minorities are 9% more likely than non-minorities to currently live in high-impact areas.

CHAPTER 6
COASTAL FLOODING AND TRAFFIC

Background

Roads represent the primary mode of transportation in the U.S. and are a crucial element of the U.S. economy, facilitating the movement of an ever-growing number of people and goods. According to the latest National Household Travel Survey, the average American takes 1,500 trips per year and the average driver spends almost an hour a day behind the wheel.[1] Already, drivers face weather-related delays across the country, and these delays are projected to worsen under climate change. Specifically, increasing temperatures are likely to cause accelerated aging of road binder materials and rutting of asphalt. Heavy precipitation is likely to cause cracking and erosion. High-tide flooding, also known as "tidal flooding" or "nuisance flooding," is becoming increasingly common as sea levels rise. All these climate hazards can cause traffic delays for drivers as they navigate damaged road surfaces or are forced to take longer routes to avoid roads that are closed for maintenance or repair.

This analysis estimates traffic delays in coastal areas resulting from climate change-driven increases in high-tide flooding. Impacts to socially vulnerable populations are analyzed based on current demographics in the areas most affected by delays from high-tide flooding. In addition, the analysis examines disproportionate impacts associated with potential decisions about which roads should receive protective adaptation that could mitigate these delays. A separate analysis, presented in Appendix G, examines the potential impacts of extreme temperature and precipitation on roads and resulting traffic delays. This analysis finds that although the delays associated with temperature and precipitation are likely to be significant in many areas across the contiguous U.S., there are fewer disproportionate impacts to socially vulnerable populations; as a result, this chapter focuses on the analysis of delays associated with high-tide flooding.

COASTAL FLOODING AND TRAFFIC

Social Vulnerability and Traffic Delays from High-Tide Flooding

Table 6.1 summarizes findings from the scientific literature on the ways in which traffic delays caused by high-tide flooding could disproportionately affect socially vulnerable populations. In general, to the extent that traffic hinders mobility, it is likely to have more significant impacts on those who require reliable transportation for employment, social engagement, and access to health care. As described in Table 6.1, limits on mobility presented by traffic delays have been shown in multiple studies to disproportionately affect socially vulnerable populations through effects on income, employment security, and health status.[2]

Coastal road networks and the communities they support are increasingly at risk of impacts from sea level rise and intensifying coastal flood events.

Table 6.1 – Social Vulnerability and Traffic Delays

CATEGORY	DESCRIPTION
Low Income	Low income workers are more likely to get paid on an hourly basis and work in jobs with fixed hours.[3] As a result, they may be more vulnerable to consequences of unexpected traffic delays.
Minority	Increased travel times may reduce the accessibility of employment or social engagement, exacerbating trends of reduced proximity to job opportunities experienced by minority populations.[4]
No High School Diploma	There is a lack of comprehensive research on the association between educational attainment and vulnerability to traffic delay-related impacts. However, to the extent that those with lower educational attainment have lower job security, road delays could further exacerbate this vulnerability.[5]
65 and Older	Limited access to transportation among older adults has been shown to cause missed or delayed medical care appointments,[6] and more, generally, to limit access to health care.[7] Traffic delays associated with climate change may further exacerbate this vulnerability.

METHODS

The steps below outline the general approach to the analysis. For more detailed information, please refer to Appendix G.

STEP 1 | Project extent and duration of high-tide flooding resulting from SLR using data from Sweet et al. (2018).[8]

STEP 2 | Using the methods of Fant et al. (2021),[9] identify coastal roads that are vulnerable to inundation from high-tide flooding with 50 cm and 100 cm of global SLR. Estimate traffic delays by Census tract using location-specific daily traffic data adjusted for the projected duration of high-tide flooding and the availability of alternative routes. Identify which roads could be excluded from protective adaptation measures, if adaptation decisions were made using a benefit-cost test in which the cost of the adaptation measures is compared to the value of the avoided delays.[10,11]

STEP 3 | Identify the Census tracts with the highest hours of annual traffic delays per person (defined as those in the highest tercile). Identify the Census tracts where the highest percentage of at-risk roads could be excluded from protective adaptation measures that could reduce traffic delays.

STEP 4 | Calculate the likelihood that individuals who are socially vulnerable currently live in these high-impact areas relative to those who are not.[12]

CHAPTER 6

COASTAL FLOODING AND TRAFFIC

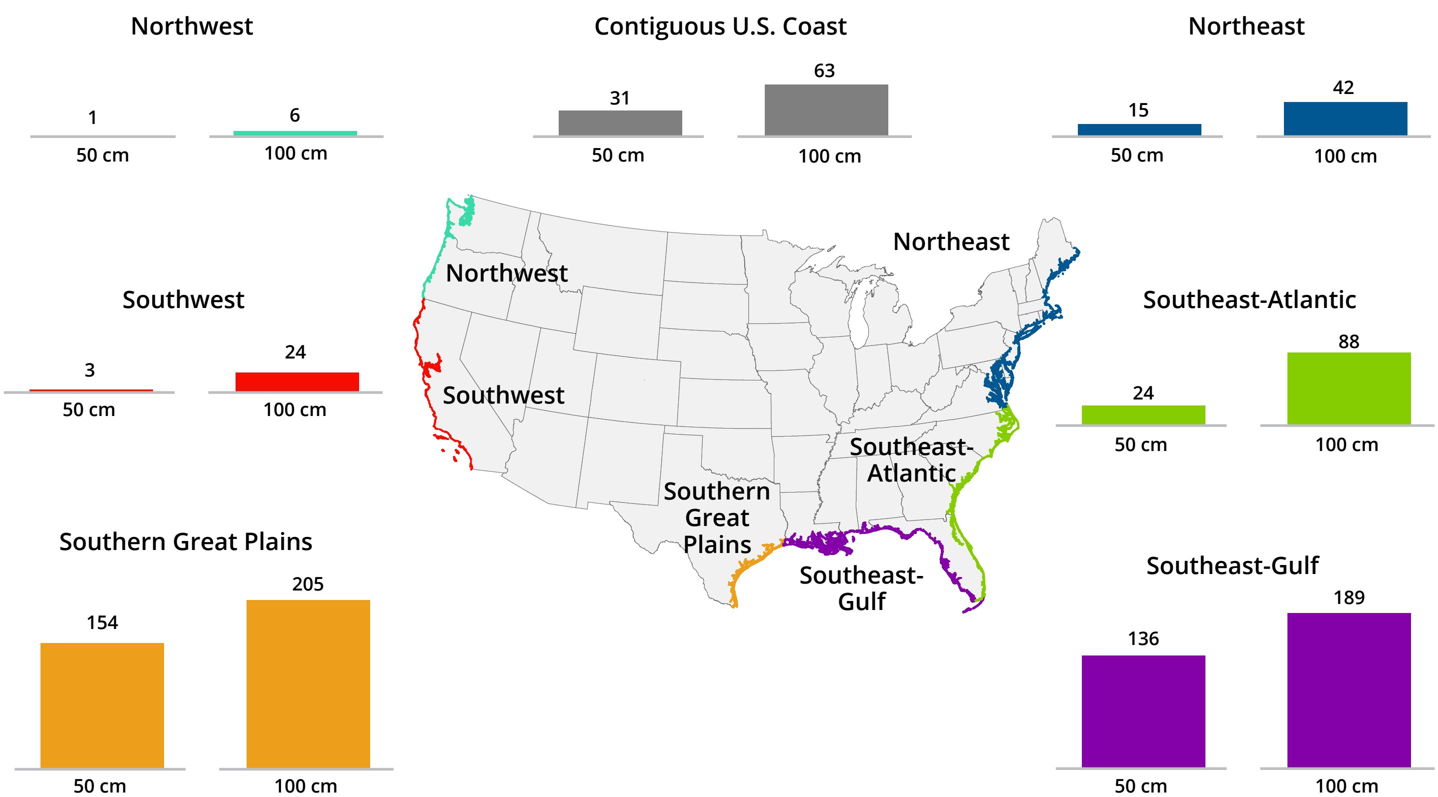
Key Findings on Traffic Delays from High-Tide Flooding

With 100 cm of global mean SLR, coastal traffic delays associated with climate-driven changes in high-tide flooding are projected to increase by an average of 63 hours per person annually. The projected impacts are highest in the Southern Great Plains and Southeast-Gulf regions, where per-person traffic delays are estimated at 205 and 189 hours, respectively, annually.

Figure 6.1 shows the average, annual traffic delays by region and nationwide with 50 cm and 100 cm of global SLR (relative to the year 2000), focusing on the Census tracts with the greatest traffic delays in each geographic area. At 100 cm, projected average traffic delays are highest in the Southern Great Plains and Southeast-Gulf, reaching 205 and 189 hours per person per year, respectively.[13] Although projected traffic delays are relatively low in the western regions, on average, there are some Census tracts that have significant projected delays, especially with global sea level rise of 100 cm or more.

Figure 6.1 – Projected Traffic Delays from High-Tide Flooding in Coastal Areas (Hours Per Person Per Year)

Levels of global sea level rise are relative to the year 2000. The map shows the coastal regions included in the analysis, but does not show the specific areas projected to experience high-tide flooding traffic delays.



COASTAL FLOODING AND TRAFFIC

Key Findings on Social Vulnerability and Traffic Delays from High-Tide Flooding

Traffic delays from high-tide flooding are projected to disproportionately affect those with low income, minorities, and those without a high school diploma. In addition, some racial and ethnic groups–American Indian and Alaska Native individuals, Asian individuals, and Pacific Islanders, in particular–are projected to be disproportionately at risk of living in areas excluded from adaptation measures that could mitigate the impacts of high-tide flooding delays.

Using the data presented in Figure 6.1, the analysis identifies the Census tracts with the highest traffic delays from climate-driven changes in high-tide flooding. The high-impact areas are defined as Census tracts where impacts are in the highest tercile. On average, high-impact Census tracts are projected to experience annual, per-person traffic delays of 101 hours with 50 cm of global SLR, and 324 hours with 100 cm of global SLR. Following the steps outlined in the Approach chapter, the analysis then estimates the likelihood that those who are socially vulnerable currently live in these high-impact areas compared to those who are not.

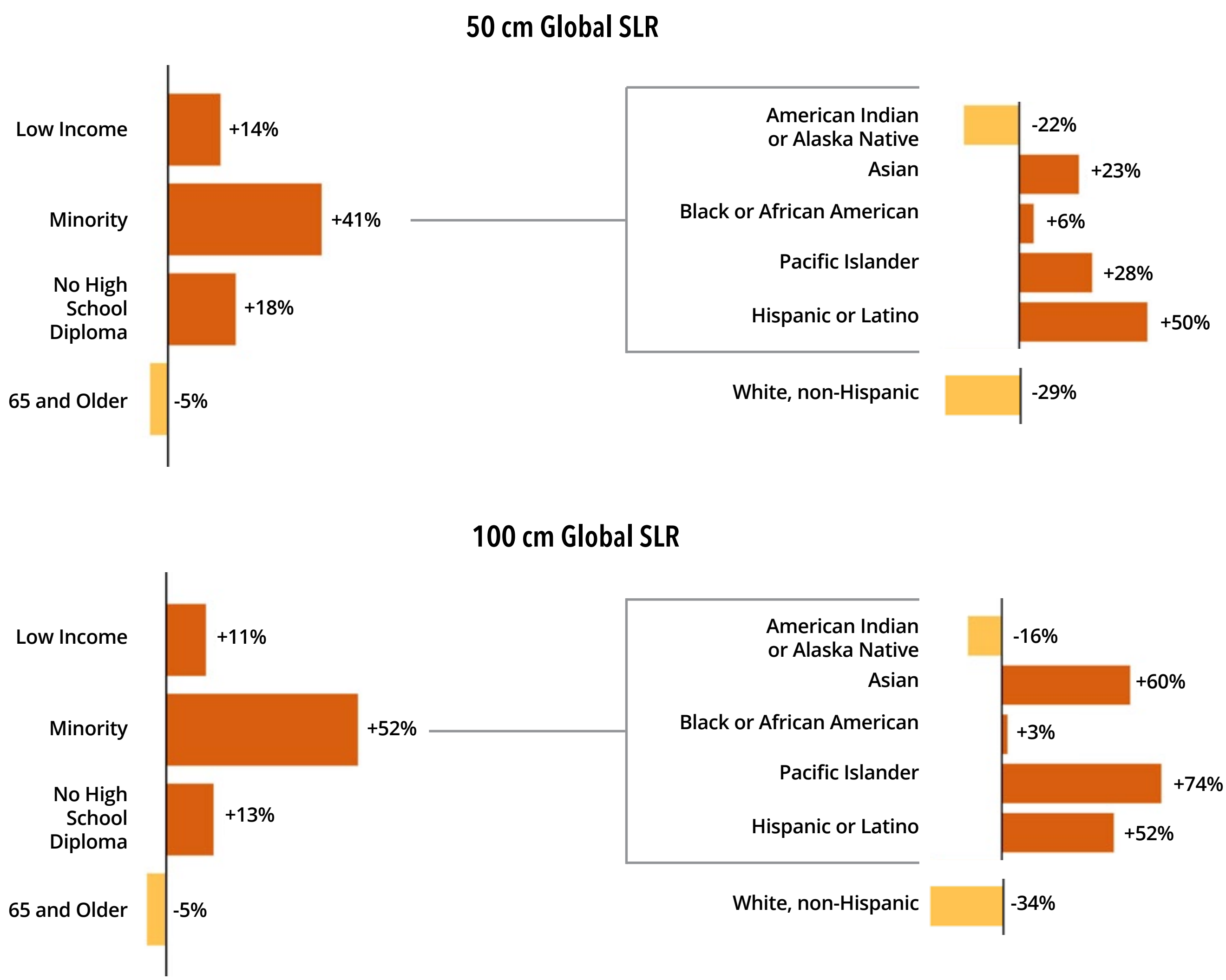
Figure 6.2 presents the likelihoods that individuals from each socially vulnerable group currently live in areas with the highest projected traffic delays from climate-driven high-tide flooding, relative to individuals in their reference populations.[14] With 50 cm of global SLR, minorities are 41% more likely than non-minorities to currently live in areas with the highest projected traffic delays due to climate-driven changes in high-tide flooding. With 100 cm of global SLR, this risk increases to 52%.

Of the racial and ethnic groups comprising the minority population, Hispanic and Latino individuals, Asian individuals, and Pacific Islanders have the highest risks relative to their reference populations (50%, 23%, and 28%, respectively, with 50 cm of global SLR; and 52%, 60%, and 74%, respectively, with 100 cm of global SLR).

Key Findings on Social Vulnerability and Traffic Delays from High-Tide Flooding (continued)

Figure 6.2 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas with the Highest Projected Traffic Delays Due to Climate-Driven Changes in High-Tide Flooding

The bar charts present the relative likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected traffic delays relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global SLR are relative to the year 2000.

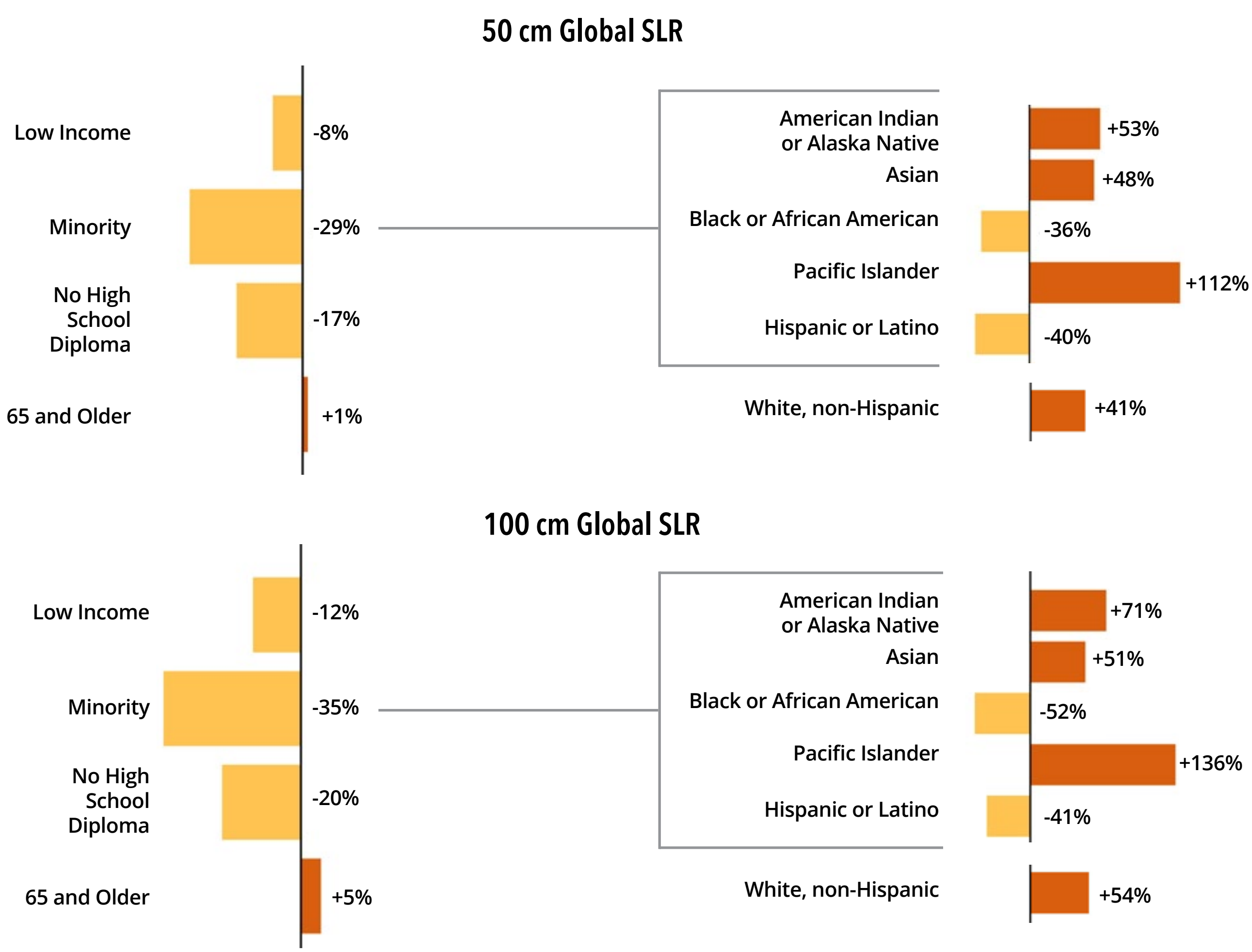


Key Findings on Social Vulnerability and Traffic Delays from High-Tide Flooding (continued)

The analysis also estimates the risks to socially vulnerable populations of living in areas that could be excluded from adaptation, using a benefit-cost test in which the cost of the adaptation measures is compared to the value of the avoided delays. As shown in Figure 6.3, this analysis finds that individuals in several racial and ethnic groups are significantly more likely than individuals in their reference populations to currently live in areas where the highest percentage of at-risk roads could be excluded from protective adaptation measures that could reduce flooding delays. Pacific Islanders, in particular, have a 112% higher risk of living in these areas, relative to non-Pacific Islanders, with 50 cm of global SLR.

Figure 6.3 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas Where the Highest Percentage of At-Risk Roads Could be Excluded from Adaptation

The bar charts present the relative likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas where the highest percentage of at-risk roads could be excluded from adaptation, relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global SLR are relative to the year 2000.



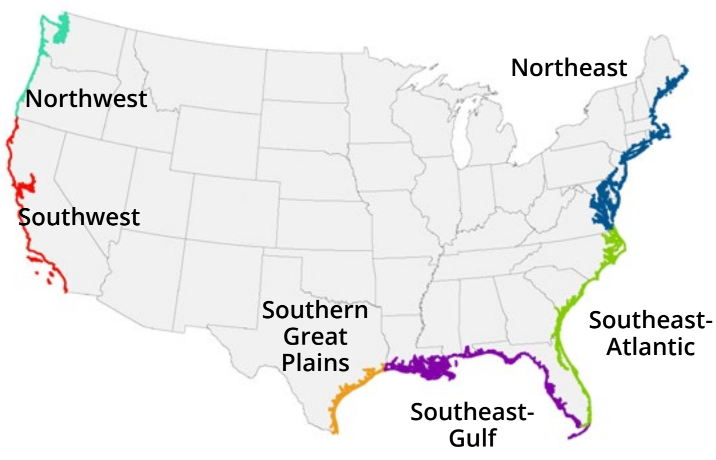
COASTAL FLOODING AND TRAFFIC

Key Findings on Regional Impacts

In the Northwest, Northeast, Southeast-Atlantic, and Southeast-Gulf, those with no high school diploma are significantly more likely than those with a high school diploma to currently live in areas with the highest projected traffic delays due to high-tide flooding. In many regions, the socially vulnerable groups analyzed are not projected to experience disproportionately higher risks of exclusion from adaptation, and in some cases they are projected to experience lower risks. However, in the Southern Great Plains, those with low income are 18% more likely than those with higher income to live in areas excluded from adaptation.

The regional analysis follows a similar approach as the national-level analysis. First, it identifies the areas within each region that are projected to experience the highest impacts of high-tide flooding and areas where the highest percentage of roads could be excluded from adaptation. Next, it estimates the likelihood that those who are socially vulnerable currently live in these high-impact areas compared to those who are not. For each region, the charts show the likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected traffic delays due to increases in high-tide flooding (or the highest percentage of at-risk roads that could be excluded from adaptation) relative to individuals in the reference groups (e.g., non-low income).

The results shown are for a scenario with global SLR of 50 cm relative to 2000. Please refer to Appendix G for results in the scenario with 100 cm of global SLR. As described in the Approach chapter, a finding that a socially vulnerable group is *less* likely to experience risks does not suggest that they will not experience negative impacts; rather, such findings refer to the degree to which the estimated impacts are projected to be disproportionate relative to the reference population.



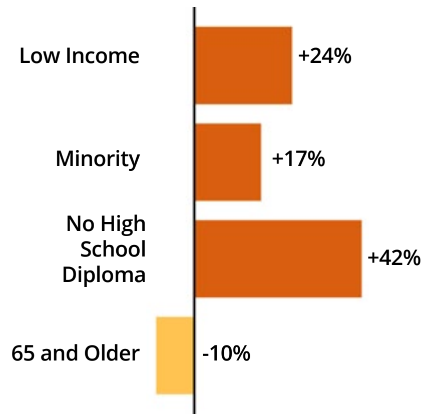
COASTAL FLOODING AND TRAFFIC

Key Findings on Regional Impacts (continued)

NORTHWEST

Higher Traffic Delays

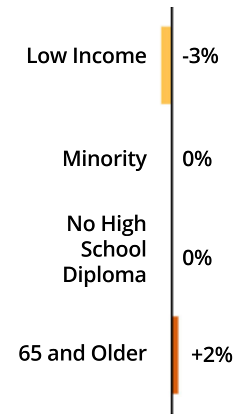
50 cm Global SLR



- In the Northwest, those with no high school diploma are 42% more likely than those with a high school diploma to currently live in areas with the highest projected traffic delays from climate-driven changes in high-tide flooding.

Exclusion from Adaptation

50 cm Global SLR

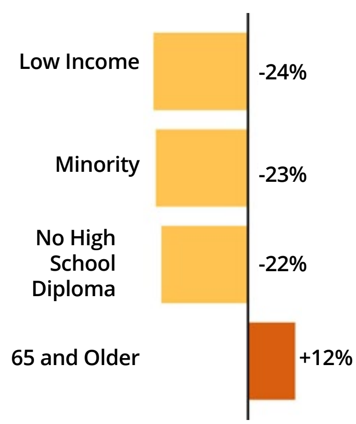


- In the Northwest, the socially vulnerable groups analyzed are not projected to be disproportionately at risk of currently living in areas where the highest percentage of roads could be excluded from adaptation.

SOUTHWEST

Higher Traffic Delays

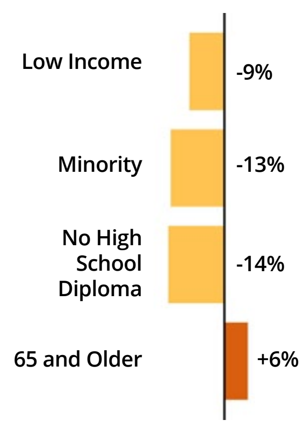
50 cm Global SLR



- In the Southwest, those ages 65 and older are 12% more likely than younger individuals to currently live in areas with the highest projected traffic delays from climate-driven changes in high-tide flooding. However, the other three socially vulnerable groups are 22-24% *less* likely.

Exclusion from Adaptation

50 cm Global SLR



- In the Southwest, the socially vulnerable groups analyzed are projected to be equally or less at risk of exclusion from adaptation relative to their reference populations with 50 cm of global SLR. With 100 cm of global SLR (not shown), those ages 65 and older are projected to be 20% more at risk than younger individuals.

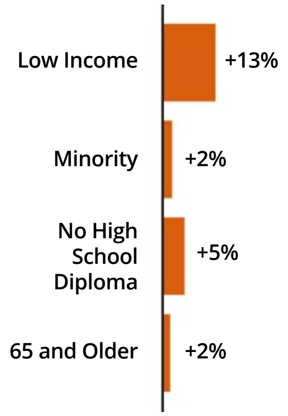
COASTAL FLOODING AND TRAFFIC

Key Findings on Regional Impacts (continued)

SOUTHERN GREAT PLAINS

Higher Traffic Delays

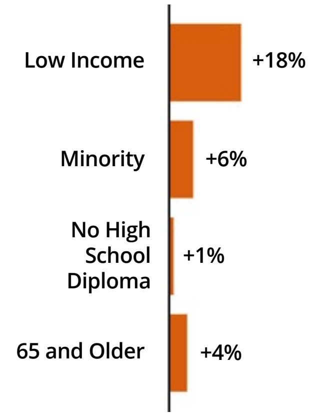
50 cm Global SLR



- In the Southern Great Plains, those with low income are 13% more likely than those with higher income to currently live in areas with the highest projected traffic delays from climate-driven changes in high-tide flooding.

Exclusion from Adaptation

50 cm Global SLR

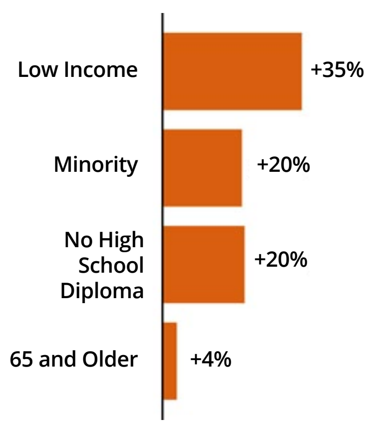


- In the Southern Great Plains, those with low income are 18% more likely than those with higher income to currently live in areas where the highest percentage of at-risk roads could be excluded from adaptation that could reduce traffic delays.

NORTHEAST

Higher Traffic Delays

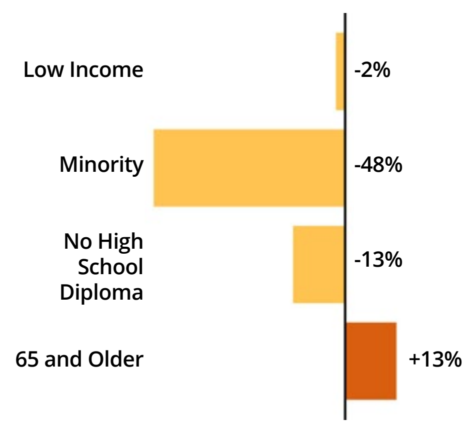
50 cm Global SLR



- In the Northeast, those with low income are 35% more likely than those with higher income to currently live in areas with the highest projected traffic delays from climate-driven changes in high-tide flooding.

Exclusion from Adaptation

50 cm Global SLR



- In the Northeast, those ages 65 and older are 13% more likely than younger individuals to currently live in areas where the highest percentage of at-risk roads could be excluded from adaptation. Minorities are 48% *less* likely than White, non-Hispanic individuals with 50 cm of global SLR.

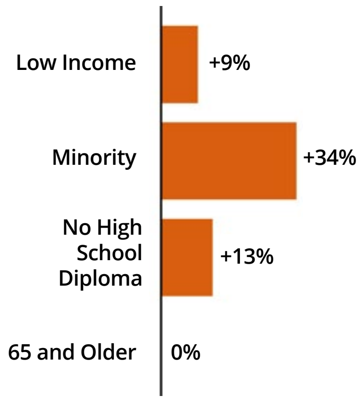
COASTAL FLOODING AND TRAFFIC

Key Findings on Regional Impacts (continued)

SOUTHEAST-ATLANTIC

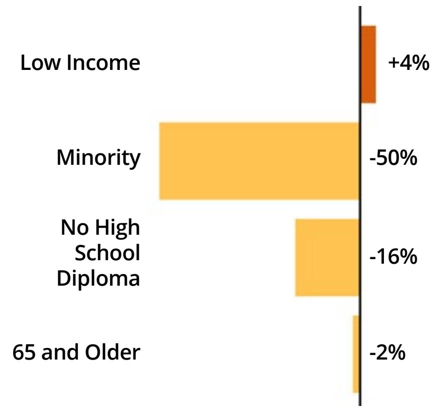
Higher Traffic Delays

50 cm Global SLR



Exclusion from Adaptation

50 cm Global SLR

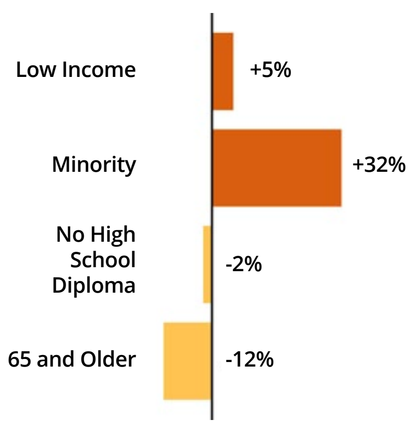


- In the Southeast-Atlantic, minorities are 34% more likely than non-minorities to currently live in areas with the highest projected traffic delays from climate-driven changes in high-tide flooding.
- In the Southeast-Atlantic, the socially vulnerable groups analyzed are projected to be equally or less at risk of exclusion from adaptation relative to their reference populations with 50 cm of global SLR. Minorities are 50% less likely than White, non-Hispanic individuals.

SOUTHEAST-GULF

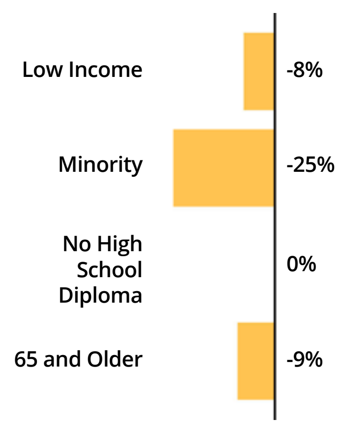
Higher Traffic Delays

50 cm Global SLR



Exclusion from Adaptation

50 cm Global SLR



- In the Southeast-Gulf, minorities are 32% more likely than non-minorities to currently live in areas with the highest projected traffic delays from climate-driven changes in high-tide flooding.
- In the Southeast-Gulf, the socially vulnerable groups analyzed are projected to be equally or less at risk of exclusion from adaptation relative to their reference populations with 50 cm of global SLR. With 100 cm of global SLR (not shown), however, all groups except for those ages 65 and older are found to be more at risk than their reference populations.

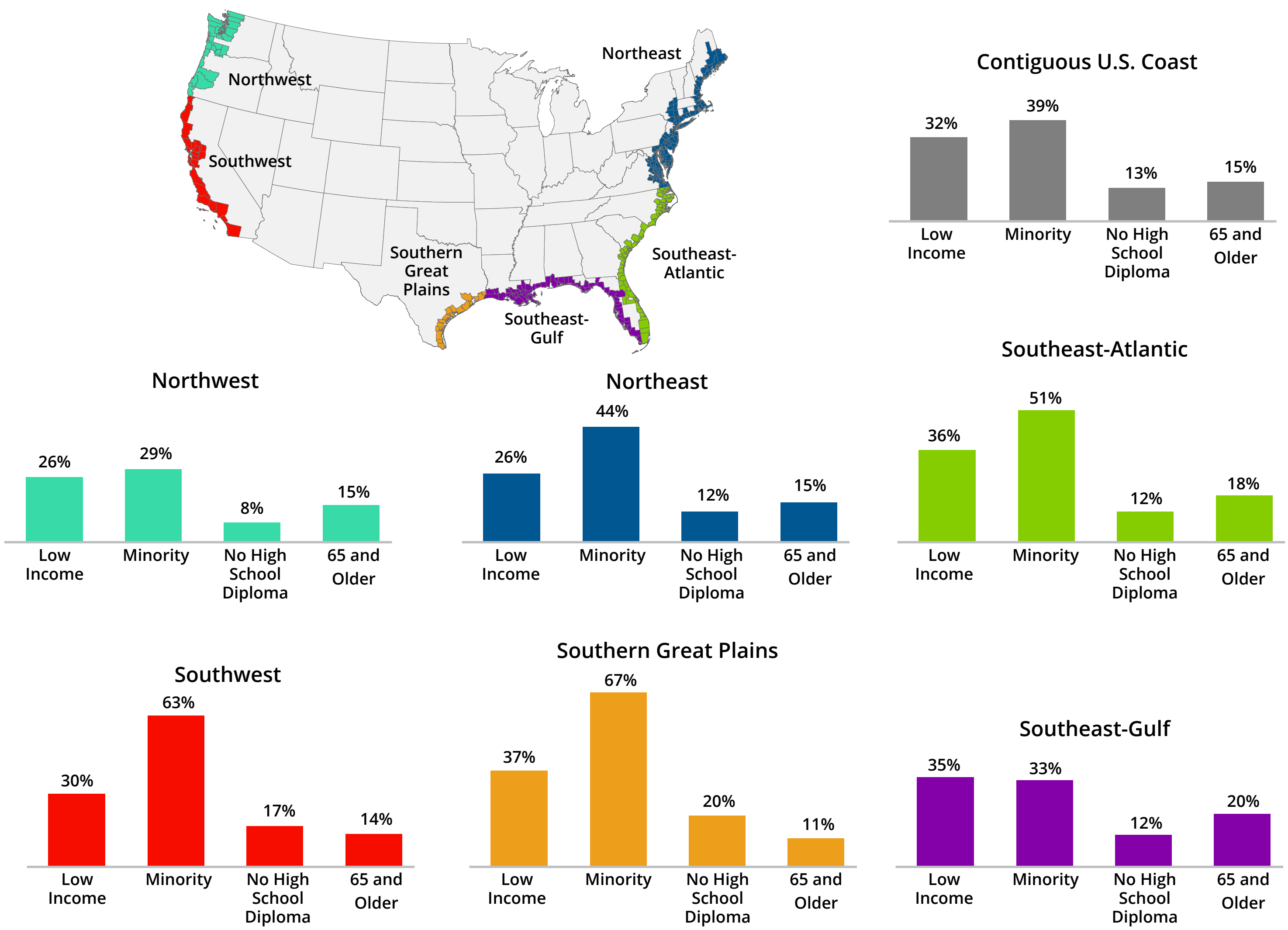
CHAPTER 7
COASTAL FLOODING AND PROPERTY

Background

Coastal counties in the U.S. are home to over 127 million people, or nearly 40% of the nation's total population.[1,2] The coast is a critical component of the U.S. economy; if the U.S. coastal counties were an individual country, it would rank third in the world in gross domestic product, surpassed only by the U.S. and China.[3] Due to climate change, America's coastal properties, infrastructure, and ecosystems—and the economies they support—face increasing threats from ongoing SLR, high tide flooding, storm surge, erosion, ocean acidification, harmful algal blooms, and other hazards.[4]

This analysis estimates the changes in SLR and storm surge resulting from climate change. It then identifies the low-lying properties that are susceptible to these climate hazards and estimates the future damages, with and without adaptation. Next, it estimates risks to socially vulnerable populations of currently living in areas where damages are projected to be highest. The next section describes why socially vulnerable groups may be particularly at risk of property damages from climate-driven SLR and storm surge.

Figure 7.1 – Current Distribution of Socially Vulnerable Populations in the Coastal Counties of the Contiguous U.S.



Social Vulnerability and Coastal Flooding

Climate change, including current and future SLR, is expected to exacerbate many long-standing inequities that affect socially and economically marginalized groups in the coastal zone.[5] Devastating storms in recent years have provided stark examples of the impacts facing these vulnerable coastal residents, and the long-term consequences for these communities remain uncertain.[6] Adaptive measures, such as seawalls, beach nourishment, and other protective measures including green infrastructure, have been shown to be effective in many instances.[7,8] However, questions of which measures to select, finance, and implement, and when and where to implement them, present significant governance challenges and difficult societal choices. In particular, cases where decisions are made based on whether the benefits of protecting vulnerable property outweigh the cost of the adaptation measures can result in the exclusion of areas with lower market values, which is where socially vulnerable communities are more likely to reside.[9]

Table 7.1 summarizes findings from the literature on ways in which socially vulnerable populations may have heightened risk of impacts from coastal flooding. Figure 7.1 presents the distribution of individuals in each of these groups across the coastal counties of the contiguous U.S. As shown, minorities account for 39% of the population in these counties, low income individuals account for 32%, individuals 65 and older account for 15%, and individuals without a high school diploma account for 13%.

Table 7.1 – Social Vulnerability and Coastal Flooding

CATEGORY	DESCRIPTION
Low Income	Residents of low-lying affordable housing in the coastal zone tend to be low income individuals living in old and poor-quality structures, which are especially vulnerable to coastal floods.[10,11] Low income individuals are also more likely to be adversely affected as they have fewer financial resources to protect against and recover from flooding damage or loss of property.
Minority	Racial and ethnic wealth gaps leave many minority groups vulnerable to exclusion from adaptation based on economic factors.[12]
No High School Diploma	There is a lack of research on the link between educational attainment and vulnerability to impacts from SLR and storm surge. However, studies show that socioeconomic and educational factors may impede individuals' ability to prepare for, respond to, and cope with risks of climate change.[13]
65 and Older	Coastal communities are often a preferred retirement destination for older adults, despite the growing risks of SLR and storm surge. The unique physical and psychosocial challenges of the population ages 65 and over may affect their ability to prepare, cope with, and recover from hazardous events.[14]

METHODS

The steps below outline the general approach to the analysis. For more detailed information, please refer to Appendix H.

STEP 1 | Project local SLR associated with global average SLR of 50 cm and 100 cm for 302 coastal counties in the contiguous U.S.[15] Project storm surge heights based on data from local tide gauges.

STEP 2 | Using the National Coastal Property Model (NCPM), identify coastal areas that are projected to be at risk of permanent inundation from SLR. In addition, identify the areas that could be excluded from adaptation, if adaptation decisions are based on a benefit-cost test in which the cost of the adaptation measures is compared to the value of the avoided damages.[16]

STEP 3 | Identify the Census block groups where the highest percentage of land is lost due to inundation from SLR.[17] In addition, identify the Census block groups where the highest percentage of land at risk of inundation is excluded from adaptation in a scenario where adaptation decisions are made using a benefit-cost test.

STEP 4 | Calculate the likelihood that individuals who are socially vulnerable currently live in these high-impact areas relative to those who are not.[18]

CHAPTER 7

COASTAL FLOODING AND PROPERTY

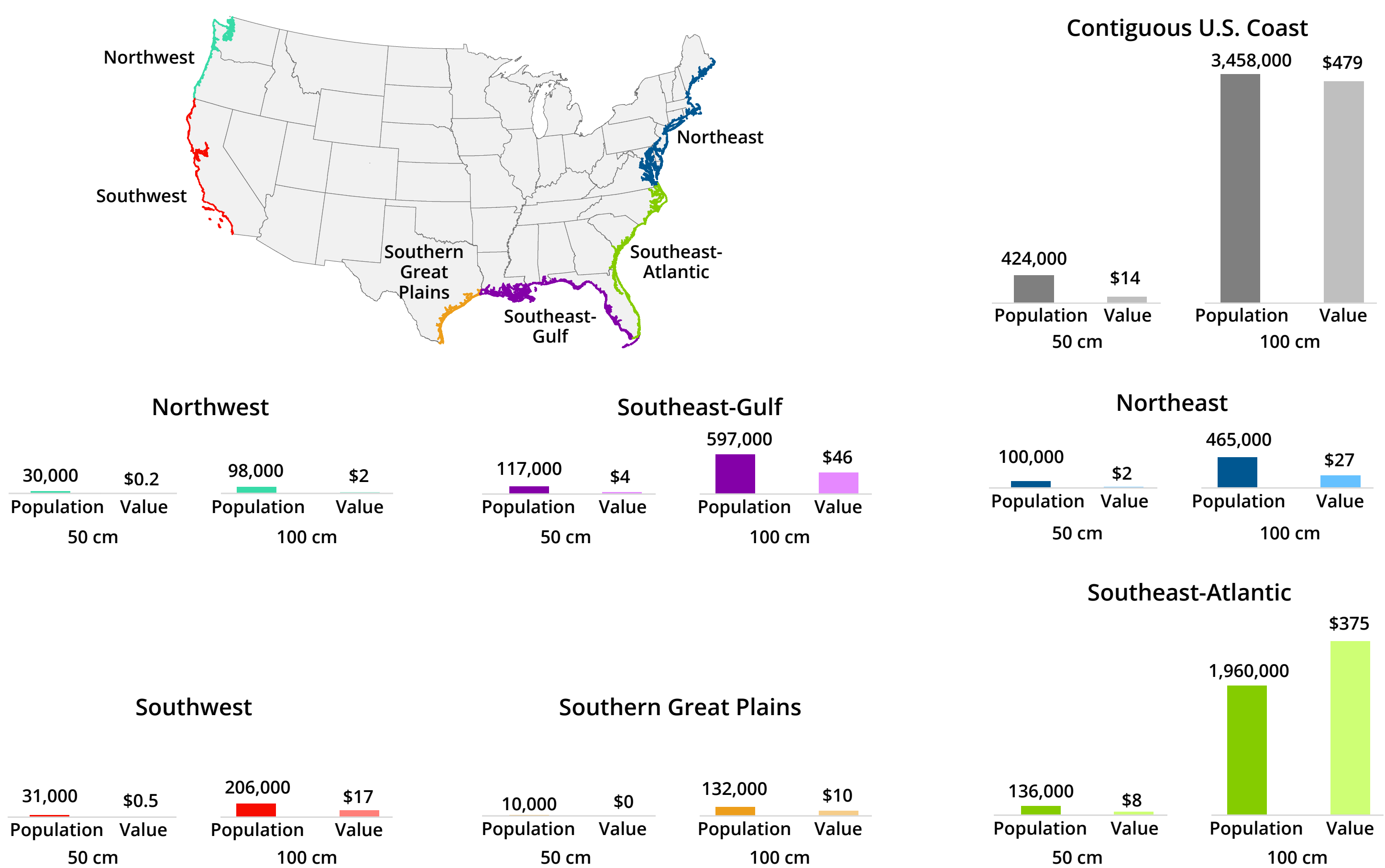
Key Findings on Areas at Risk of Inundation due to Sea Level Rise

With 50 cm of global SLR, coastal areas in the contiguous U.S. that are currently home to over 400,000 people are projected to be at risk of inundation. With 100 cm of global SLR, the number of people living in areas at risk of inundation increases to 3.5 million. The Southeast-Atlantic region is home to the greatest number of people (2.0 million under 100 cm of SLR) who currently reside in areas projected to be vulnerable to inundation, followed by the Southeast-Gulf and Northeast.

For each coastal region of the contiguous U.S., Figure 7.2 identifies the numbers of people and values of properties in areas projected to be at risk of inundation with 50 cm and 100 cm of global SLR.[19] Across all coastal regions, an estimated 424,000 people reside in areas projected to be inundated with 50 cm of global SLR, and this number increases to 3.5 million with 100 cm of SLR.[20] The Southeast-Atlantic is the region with the greatest number of people and highest value of property located in areas vulnerable to inundation: 136,000 people and $8 billion with 50 cm of global SLR, and 2.0 million people and $375 billion with 100 cm of global SLR. As shown in Figure 7.1, 51% of the population in coastal counties of the Southeast-Atlantic identifies as minority, 36% is low income, 18% is 65 and older, and 12% has no high school diploma.

Figure 7.2 – Projected Population and Property Value in Coastal Areas at Risk of Inundation

Levels of global SLR are relative to the year 2000. Value of property shown in billions of $2015. Population data comes from the 2014-2018 American Community Survey of the U.S. Census. Due to uncertainty in future demographic projections, this analysis assumes constant populations along the coast. The map shows the coastal regions included in the analysis but does not show the specific areas at risk of inundation from SLR. Results reflect a scenario with no adaptation.



COASTAL FLOODING AND PROPERTY

Key Findings on Social Vulnerability in Areas at Risk of Inundation due to Sea Level Rise

With 50 cm of global SLR, American Indian and Alaska Native individuals are 48% more likely than non-American Indian and non-Alaska Native individuals to currently live in areas where the highest percentage of land is projected to be inundated. With 100 cm of global SLR, Hispanic and Latino individuals are 47% more likely than non-Hispanic and non-Latino individuals to live in high-impact areas.

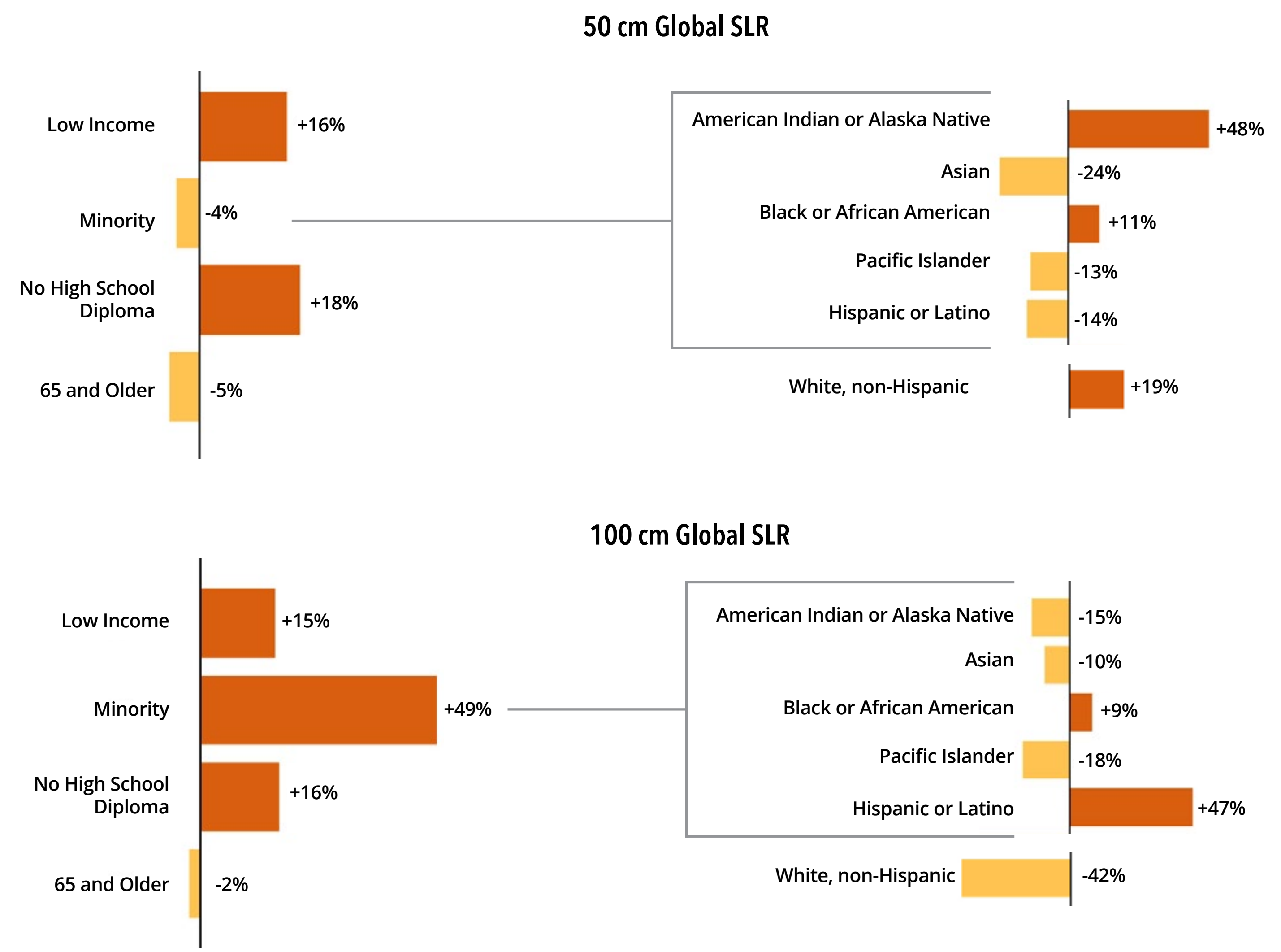
Using the data presented in Figure 7.2, the analysis identifies the Census block groups where the highest percentage of land is projected to be lost to inundation. The high-impact areas are defined as Census tracts where impacts are in the highest tercile. On average, high-impact Census block groups are projected to have between 4% and 90% of land lost with 50 cm of global SLR, and between 20% and 100% of land lost with 100 cm of global SLR. Following the steps outlined in the Approach chapter, the analysis then estimates the likelihood that those who are socially vulnerable currently live in these high-impact areas compared to those who are not.

The analysis evaluates the likelihood that individuals in socially vulnerable groups currently live in areas where the highest percentage of land is projected to be lost to inundation from SLR, relative to their reference populations.[21] With 50 cm of global SLR, the analysis finds that American Indian and Alaska Native individuals[22] are 48% more likely than individuals in their reference populations to live in high-impact areas; these groups are particularly at risk in the Southeast regions. Low income individuals, individuals without a high school diploma, and White, non-Hispanic individuals are 16%, 18%, and 19% more at risk, respectively, than their reference populations.[23] With 100 cm of global SLR, Hispanic and Latino individuals are 47% more likely to live in high-impact areas, particularly in the Southeast-Atlantic region. Those who are low income or do not have a high school diploma are 15% and 16% more at risk, respectively, than their reference populations.

Key Findings on Social Vulnerability in Areas at Risk of Inundation due to SLR (continued)

Figure 7.3 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas with the Highest Percentage of Property Lost to Inundation from SLR

The bar charts present the relative likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas where the highest percentage of land is projected to be lost to inundation relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global SLR are relative to the year 2000.



COASTAL FLOODING AND PROPERTY

Key Findings on Areas That Could be Excluded from Adaptation

With 50 cm of global SLR, areas that are home to an estimated 640,000 people and have $11 billion of property value could be excluded from adaptation if adaptation decisions are based on a benefit-cost test in which the cost of the adaptation measures is compared to the value of the avoided damages. With 100 cm of global SLR, these values increase to 1.0 million people and $19 billion.

AP Photo/Steven Senne

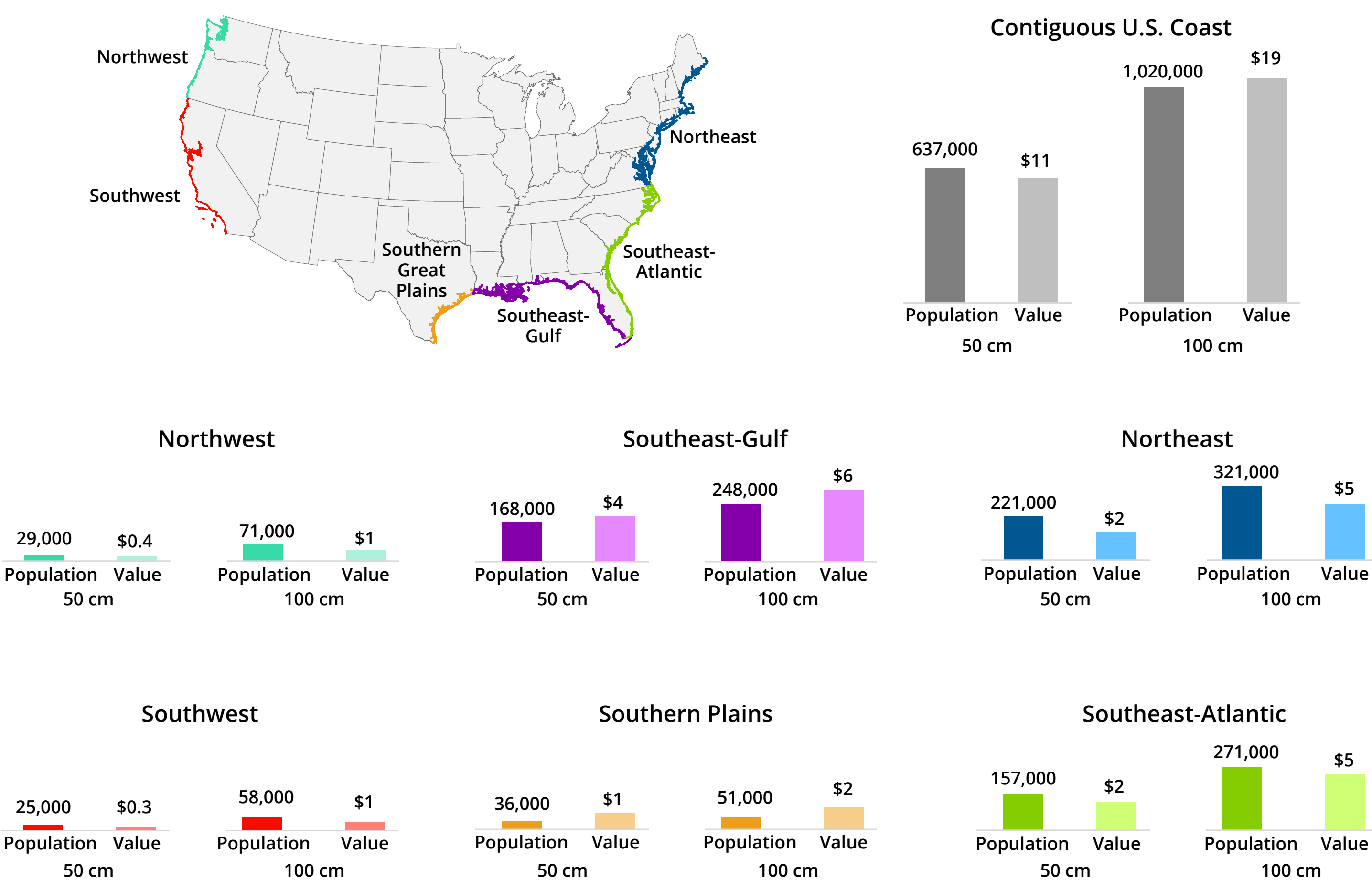
In addition to identifying areas at risk of inundation from SLR, the NCPM estimates which of these areas might receive protective adaptation measures and which might be excluded from adaptation.[24] The model uses a benefit-cost test wherein adaptation measures are implemented in areas where the value of properties outweigh the costs of their protection. In reality, adaptation decisions are made using a complex set of decision criteria that consider more than just property value; however, the NCPM provides a simple decision framework that can be consistently applied for regional and national-scale analysis of the implications of adaptation responses to coastal risks.[25]

Figure 7.4 shows the estimated numbers of people and values of properties in areas that could be excluded from protective adaptation measures based on the benefit-cost decision rule. Across all coastal regions in the contiguous U.S., an estimated 640,000 people and $11 billion worth of property are projected to be excluded from adaptation with 50 cm of global SLR. With 100 cm of global SLR, these values increase to 1.0 million people and $19 billion worth of property. The regions with the highest estimated numbers of people located in areas that are projected to be excluded from adaptation with 100 cm of global SLR are the Northeast (320,000 people excluded) and Southeast-Atlantic (270,000 people excluded).[26] These areas are generally characterized by low population and structure density, which raise technical challenges for cost-effective adaptation (as modeled in this analysis), and/or lower property values.

Key Findings on Areas That Could be Excluded from Adaptation (continued)

Figure 7.4 – Projected Population and Property Value in Coastal Areas That Could be Excluded from Adaptation

Levels of global sea level rise are relative to the year 2000. Value of property shown in billions of $2015. Population data comes from the 2014-2018 American Community Survey of the U.S. Census. Due to uncertainty in future demographic projections, this analysis assumes constant populations along the coast. The map shows the coastal regions included in the analysis but does not show the specific areas at risk of inundation from SLR.



COASTAL FLOODING AND PROPERTY

Key Findings on Social Vulnerability in Areas That Might be Excluded from Adaptation

With 100 cm of global SLR, the analysis estimates that American Indian and Alaska Native individuals are 23% more likely to currently live in areas where the highest percentage of at-risk land is projected to be excluded from adaptation. Those with low income and no high school diploma are 13% and 14% more likely than their reference populations to live in these areas.

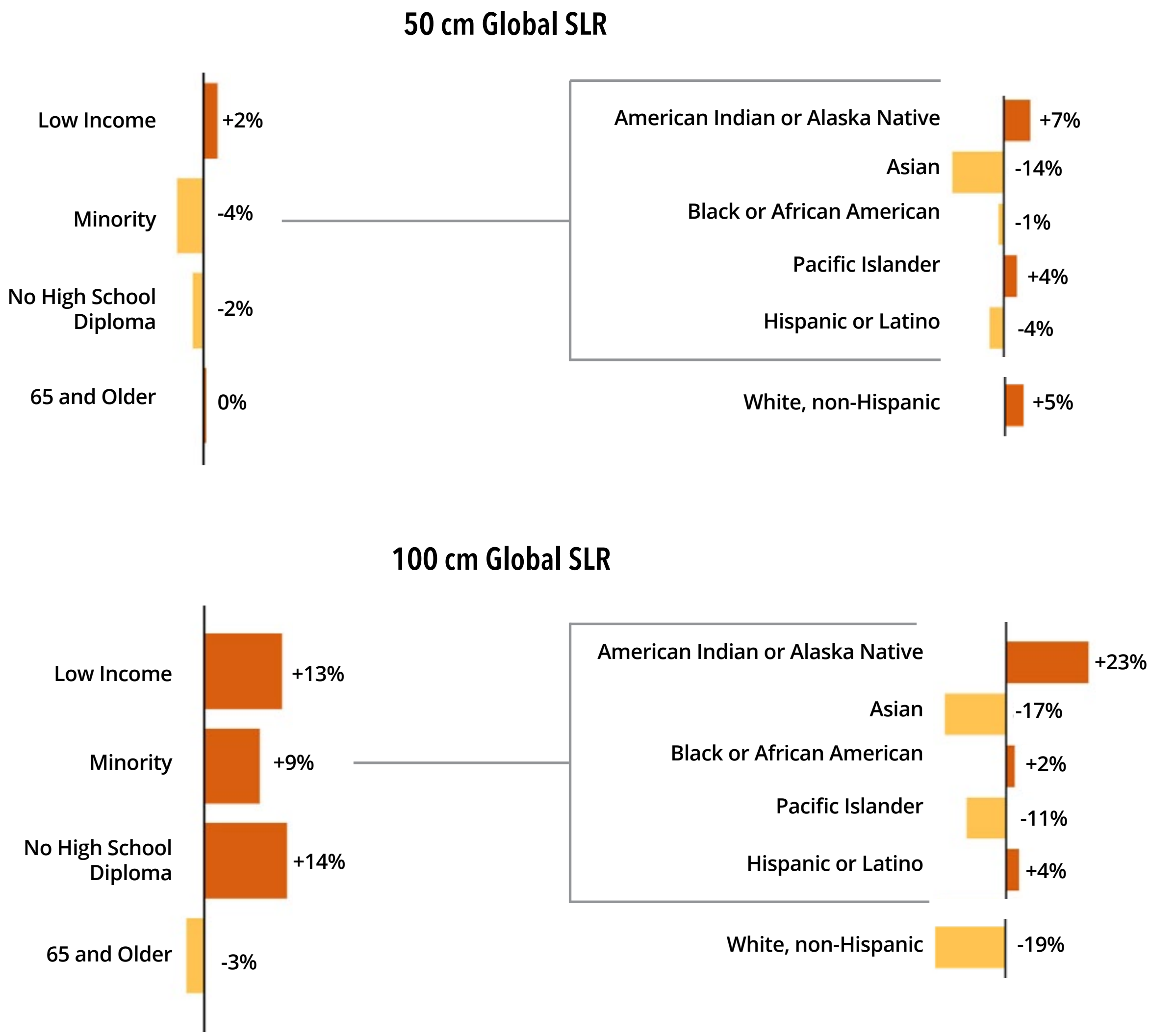
The analysis quantifies the likelihood that individuals in the four socially vulnerable groups currently live in areas where the highest percentage of at-risk land could be excluded from adaptation in a scenario where adaptation decisions are made using a benefit-cost test. As shown in Figure 7.5, the analysis finds relatively small differences between the risks to the socially vulnerable groups examined and their reference populations in a scenario with 50 cm of global SLR. With 100 cm of global SLR, however, the analysis projects that American Indian and Alaska Native individuals are 23% more likely than non-American Indian and non-Alaska Native individuals to currently live in areas where the highest percentage of at-risk land could be excluded from adaptation in a scenario where adaptation decisions are made using a benefit-cost test. These populations have a higher risk particularly in the Northwest and Southeast-Gulf regions. In addition, those with low income and those without a high school diploma are projected to be more likely than their reference populations (13% and 14%, respectively) to currently live in areas with the highest projected rates of exclusion from adaptation.

COASTAL FLOODING AND PROPERTY

Key Findings on Social Vulnerability in Areas That Might be Excluded from Adaptation

Figure 7.5 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas Where the Highest Percentage of At-Risk Land Could be Excluded from Adaptation

The bar charts present the relative likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas where the highest percentage of at-risk land could be excluded from adaptation relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global SLR are relative to the year 2000.



COASTAL FLOODING AND PROPERTY

Key Findings on Regional Impacts

Those with no high school diploma living in the Southwest and Southeast-Gulf are 18% and 31% more likely, respectively, to currently live in areas with the highest percentage of land lost to SLR, relative to those with a high school diploma. In the Southwest, those with low income are 25% more likely than those with higher income to currently live in areas where the highest percentage of at-risk land could be excluded from protective adaptation measures.

The regional analysis follows a similar approach to the national-level analysis. First, it identifies the areas within each region where the highest percentage of land is projected to be lost to SLR and where the highest percentage of at-risk land could be excluded from adaptation. Next, it estimates the likelihood that those who are socially vulnerable currently live in these high-impact areas compared to those who are not. For each region, the charts show the likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in the high-impact areas relative to individuals in the reference groups (e.g., non-low income).

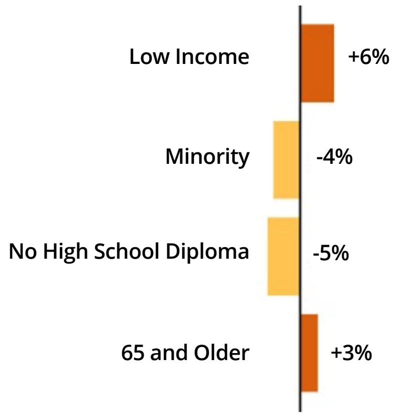
The results shown are for a scenario with global SLR of 50 cm relative to 2000. Please refer to Appendix H for results in the scenario with 100 cm of global SLR. As described in the Approach chapter, a finding that a socially vulnerable group is less likely to experience risks does not suggest that they will not experience negative impacts; rather, such findings refer to the degree to which the estimated impacts are projected to be disproportionate relative to the reference population.

Key Findings on Regional Impacts (continued)

NORTHWEST

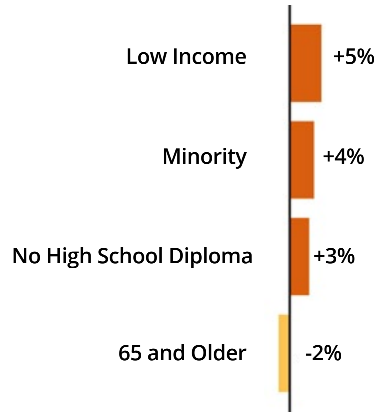
Higher Property Loss

50 cm Global SLR



Exclusion from Adaptation

50 cm Global SLR



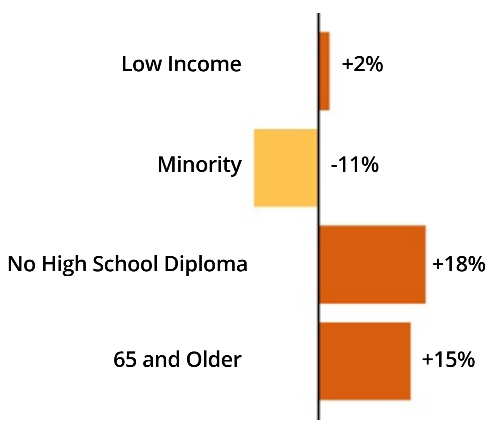
- In the Northwest, individuals in the socially vulnerable groups analyzed are not projected to have significantly disproportionate risks of currently living in areas with the highest projected impacts.

- With 100 cm of global SLR (not shown), low income individuals in the Northwest are estimated to be 11% more likely than higher income individuals to currently live in areas where the highest percentage of at-risk land could be excluded from adaptation.

SOUTHWEST

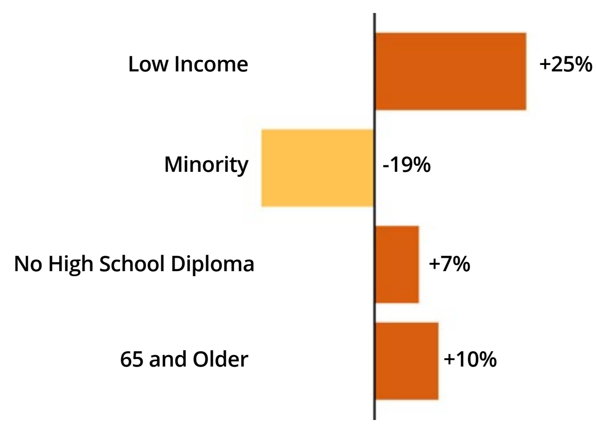
Higher Property Loss

50 cm Global SLR



Exclusion from Adaptation

50 cm Global SLR



- In the Southwest, those with no high school diploma are 18% more likely than those with a high school diploma to currently live in areas with the highest percentage of land lost to inundation.

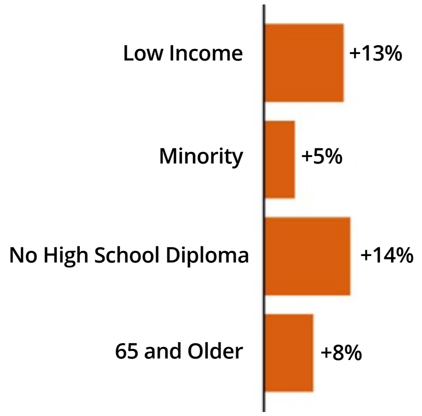
- In the Southwest, those with low income are 25% more likely than those with higher income to currently live in areas where the highest percentage of at-risk land could be excluded from protective adaptation measures.

Key Findings on Regional Impacts (continued)

SOUTHERN GREAT PLAINS

Higher Property Loss

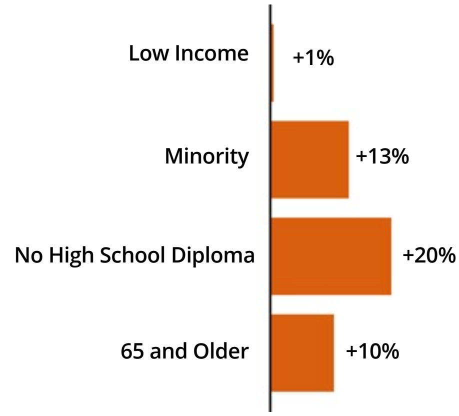
50 cm Global SLR



- In the Southern Great Plains, individuals with no high school diploma are 14% more likely than those with a high school diploma to currently live in areas with the highest projected percentage of land lost to inundation.

Exclusion from Adaptation

50 cm Global SLR

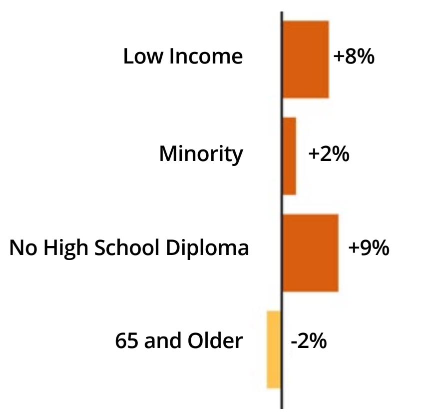


- In the Southern Great Plains, those with no high school diploma are 20% more likely than those with higher income to currently live in areas where the highest percentage of at-risk land could be excluded from adaptation.

NORTHEAST

Higher Property Loss

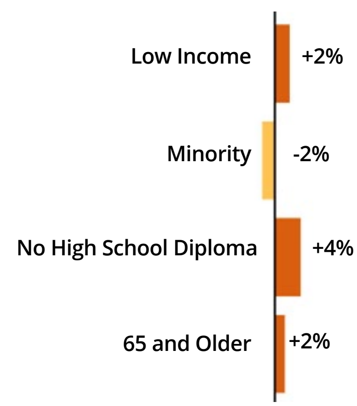
50 cm Global SLR



- In the Northeast, individuals in the socially vulnerable groups analyzed are not projected to experience significantly disproportionate impacts relative to their reference groups.

Exclusion from Adaptation

50 cm Global SLR

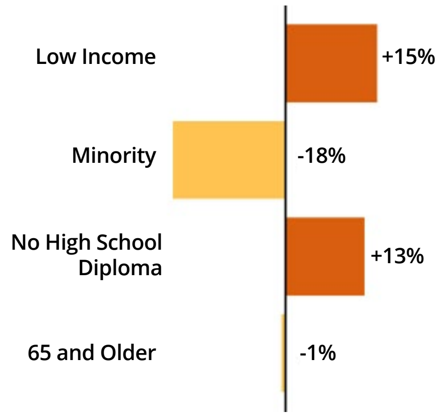


- With 100 cm of global SLR (not shown), individuals with no high school diploma are 11% more likely than those with a high school diploma to currently live in areas where the highest percentage of at-risk land could be excluded from adaptation.

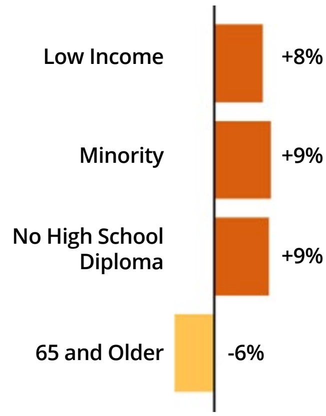
Key Findings on Regional Impacts (continued)

SOUTHEAST-ATLANTIC

Higher Property Loss
50 cm Global SLR



Exclusion from Adaptation
50 cm Global SLR

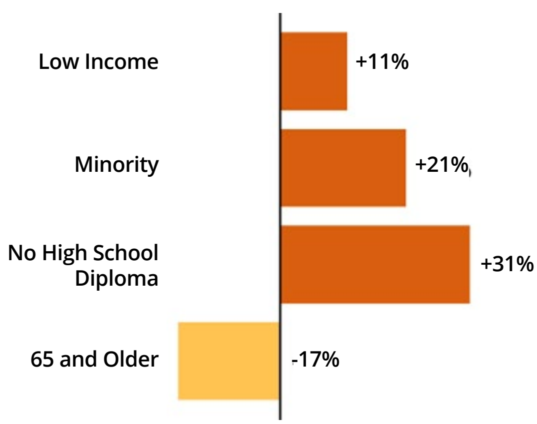


- In the Southeast-Atlantic, individuals with low income are 15% more likely than those with higher income to currently live in areas with the highest projected percentage of land lost to inundation.

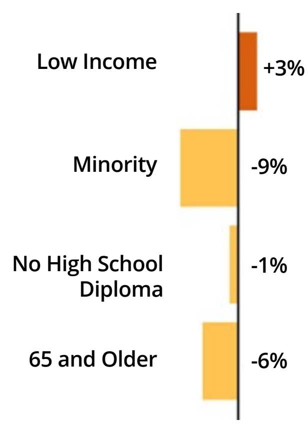
- In the Southeast-Atlantic, all socially vulnerable groups analyzed except for those ages 65 and older have a slightly higher risk of currently living in areas where the highest percentage of at-risk land could be excluded from protective adaptation measures.

SOUTHEAST-GULF

Higher Property Loss
50 cm Global SLR



Exclusion from Adaptation
50 cm Global SLR



- In the Southeast-Gulf, individuals with no high school diploma are 31% more likely than those with a high school diploma to currently live in areas with the highest projected percentage of land lost to inundation.

- In the Southeast-Gulf, individuals in the socially vulnerable groups analyzed are not projected to experience significantly disproportionate risk of exclusion from adaptation relative to their reference groups.

CHAPTER 8
INLAND FLOODING AND PROPERTY

Background

Climate change is expected to cause more frequent and intense precipitation events in many regions of the U.S., increasing the risk of inland flooding and other hazards.[1,2] Inland flooding, also known as riverine flooding, occurs when excessive rainfall collects across a watershed and causes a river to overflow.[3] Heavier downpours can result in more extreme flooding, affecting human health and safety, property, infrastructure, and natural resources.[4] Between 1980 and 2020, inland flooding in the U.S. caused over 600 deaths and nearly $3.7 billion in damages.[5]

This analysis estimates property damage and loss resulting from climate-driven changes in heavy precipitation and associated riverine flooding. It then estimates the risks to socially vulnerable populations of currently living in areas where these impacts are projected to be highest. The next section describes why socially vulnerable populations in the U.S. may be particularly at risk of experiencing negative impacts from inland flooding.

INLAND FLOODING AND PROPERTY

Social Vulnerability and Inland Flooding

In the U.S., minorities, those with low income, people with limited English proficiency, and certain immigrant communities are at increased risk of exposure to flooding given their higher likelihood of living in risk-prone areas and locations with poorly maintained infrastructure.[6,7,8] A 2017 study found that in Houston, TX, and in 20 major metropolitan areas around the country, poorer neighborhoods and those with other socioeconomic indicators of social vulnerability tend to have lower elevations and higher risk of flooding after extreme rainfall.[9] A retrospective analysis of flood events in Texas from 1997-2001 found that lower income communities of color suffered disproportionately high rates of death and injury.[10]

Similarly, a 2021 study found that areas with both high flood exposure and high social vulnerability occur predominantly in rural areas and across the U.S. South.[11]

METHODS

The steps below outline the general approach to the analysis. For more detailed information, please refer to Appendix I.

STEP 1 | Project changes in the frequency of flooding events with an average return period of two to 500 years associated with global warming.[18]

STEP 2 | Using First Street Foundation's flooding risk data and model for the U.S.,[19,20] estimate baseline, average flooding damages at the building level. Project flooding damages with global warming by scaling the per-building baseline damages according to the projected change in frequency of flooding events. Aggregate the results to the Census block group and tract level.[21]

STEP 3 | Identify the Census block groups with the highest projected annual damages relative to the total property value within the area affected by the current 500-year return period flood.

STEP 4 | Calculate the likelihood that individuals who are socially vulnerable currently live in these high-impact areas relative to those who are not.[22]

Table 8.1 – Social Vulnerability and Inland Flooding

CATEGORY	DESCRIPTION
Low Income	Low income and minority residents are more likely to move into high-risk flood zones.[12] In addition, low income populations have been shown to be less likely to evacuate in response to warning systems.[13] Nature-based infrastructure projects, such as those designed to protect against flooding, often exclude socially vulnerable groups and instead end up displacing lower income residents.[14]
Minority	Minorities may have limited access to information and resources designed to prevent or mitigate flooding risk due to language or cultural differences.[15]
No High School Diploma	Those with no high school diploma are more likely to receive lower hourly wages and have less wealth. As a result, they may be forced to live in less desirable areas, such as floodplains.[16]
65 and Older	Since older individuals have lived longer than the younger population, they are more likely to have greater ties to the community or home. Some evidence indicates that those over 65 could see increased riverine flood frequency and magnitude by 2050 because of climate change.[17]

INLAND FLOODING AND PROPERTY

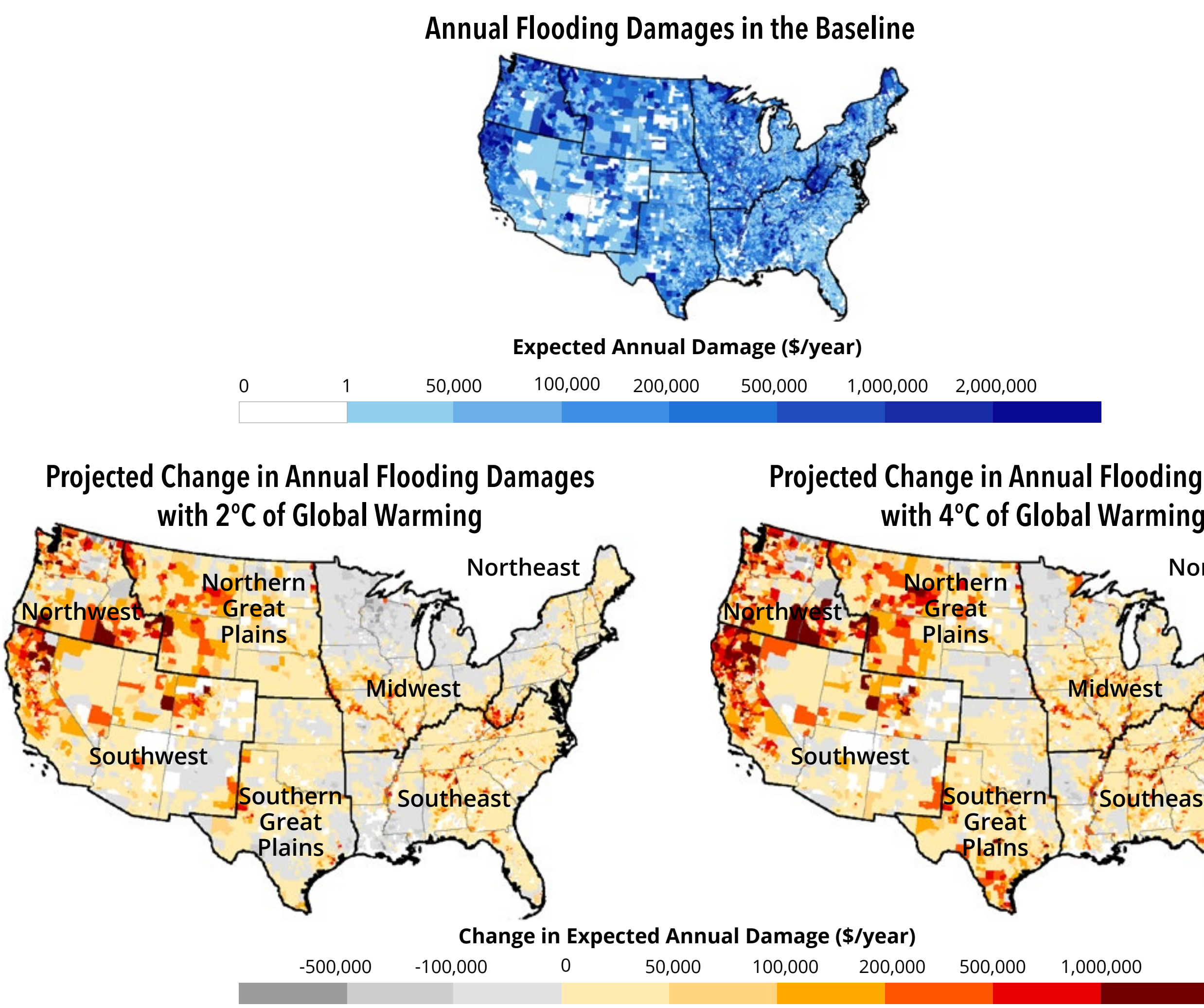
Key Findings on Damages from Inland Flooding

With 2°C of global warming, climate change is projected to increase annual flooding damages throughout the contiguous U.S., but particularly in areas of the Northwest, Southwest, and Northern Great Plains. The areas projected to incur large damages grows substantially with 4°C degrees of warming.

Figure 8.1 shows the estimated annual damages from flooding in the baseline and the change in damages with global warming of 2°C and 4°C.[23] The greatest impacts are projected to occur in the Northern Great Plains and Northwest regions. In addition, the northern areas of the Southwest and Southeast are also estimated to experience high levels of damage. The number of areas with large damages are projected to increase as global warming increases from 2°C to 4°C, especially in parts of the Southwest and Southern Great Plains. The northernmost tracts of the Midwest are projected to experience less damage relative to the baseline, as well as western Arkansas, Louisiana, eastern Oklahoma, and northeast Texas.

Figure 8.1 – Expected Annual Damages from Inland Flooding

Levels of global warming are relative to the 2001-2020 average.[24] Values represent average damages per year at the Census tract level. Census tracts in white are those that are outside of the 500-year floodplain or in the coastal floodplain and are therefore not included in the analysis. The changes in expected annual damages are relative to the baseline.



CHAPTER 8

INLAND FLOODING AND PROPERTY

Key Findings on Social Vulnerability and Inland Flooding

In general, the socially vulnerable groups analyzed in this report are not projected to experience disproportionately higher risks of currently living in areas with the highest projected inland flooding damages compared to their reference populations. However, with global warming of 2°C, Black and African American individuals and Pacific Islanders have a 10% higher risk than their reference populations, and with warming of 4°C, Pacific Islanders have a 21% higher risk than their reference population.

Using the data presented in Figure 8.1, the analysis identifies the areas with the highest property damage due to climate-driven changes in inland flooding. The high-impact areas are defined by Census block groups where impacts are in the highest tercile. Following the steps outlined in the Approach chapter, the analysis then estimates the likelihood that those who are socially vulnerable currently live in these high-impact areas compared to those who are not.

Figure 8.2 describes differences in risk to socially vulnerable groups of currently living in areas with the highest projected rates of flood-related property damage with 2°C and 4°C global warming. At a national scale, the analysis finds that the socially vulnerable groups analyzed in this report do not, in general, experience disproportionate risks compared to their reference populations. Individuals ages 65 and older are slightly more likely to live in areas with the worst flooding damages (this is more evident in the regional results, presented in the next section). Overall, minorities are approximately 12% less likely to live in areas with the worst inland flooding damages with 2°C global warming. When examining the risks for individual racial and ethnic groups, the analysis finds that Black and African American individuals and Pacific Islanders are 10% more likely to currently live in areas with the highest projected impacts relative to their reference populations with 2°C global warming. Notably, the likelihood of White, non-Hispanic individuals living in areas with the highest projected inland flooding damages decreases substantially as warming increases: 32% greater likelihood under the 2°C warming scenario and 1% greater likelihood under 4°C.

A Closer Look at the Inland Flooding Results

The highly localized nature of the occurrence of extreme flooding events, and the substantial variation across regions, means that results in Figure 8.2, averaged to the national level, may obscure some of the more informative results at the regional level (presented in the next section). In addition, national results show substantial changes across social vulnerability measures with increases in warming, likely a result driven by changes in the number of socially vulnerable individuals subject to the worst flooding damages as temperatures change.

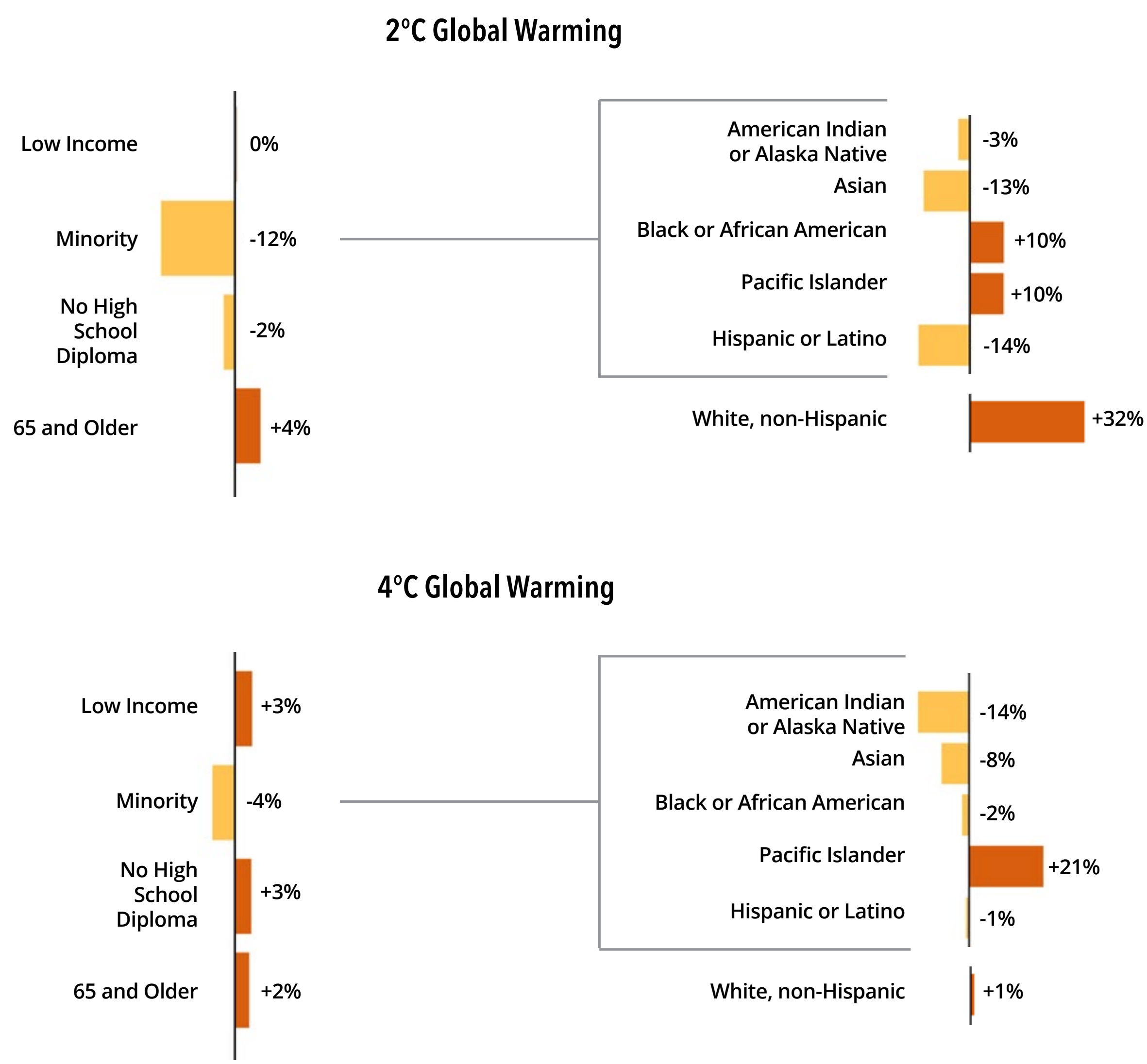
The underlying data used in this analysis excludes flooding events associated with urban drainage, quantifying only riverine floods instead. The focus on riverine flooding, as a result, may not account for flooding events in cities and other urban areas where large populations of socially vulnerable individuals reside. In addition, the underlying flood risk dataset incorporates the mitigating impact of current flood control structures – these structures are likely to be more common in many densely populated urban areas, which also correlate with the locations of some socially vulnerable populations.

Similarly, this analysis did not evaluate the effectiveness of future adaptation measures in reducing flood risk, nor the likelihood that socially vulnerable populations live in areas excluded from protection. Finally, it is important to note that less vulnerable populations are typically more knowledgeable of their flood risk, and generally have the capital and capacity to prepare adequately. Socially vulnerable populations, on the other hand, are less likely to know their risk and may not be prepared for the damages that their properties could face.[25] See Appendix I for details and supporting figures.

Key Findings on Social Vulnerability and Inland Flooding (continued)

Figure 8.2 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas with the Highest Inland Flooding Damages

The bar charts present the relative likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected inland flooding damages relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global warming are relative to the 2001-2020 average.



INLAND FLOODING AND PROPERTY

Key Findings on Regional Impacts

With 2°C of global warming, minorities in the Northeast have a 16% higher risk of currently living in areas with the highest projected inland flooding damages. In the Southwest and Northern Great Plains, individuals ages 65 and older have a 15% higher risk of living in areas with the highest damages.

This section highlights the projected regional differences in risk for the four socially vulnerable groups examined in this report under scenarios with 2°C of global warming (relative to 2001-2020). Please see Appendix I for regional results with 4°C global warming. For each region, the charts show the estimated difference in likelihood that individuals in each socially vulnerable group currently live in areas with the highest projected damages relative to individuals in their reference groups within the same region.

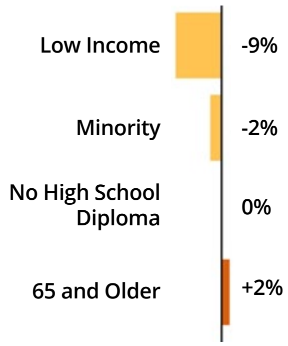
In general, the analysis finds small differences between the risks to the socially vulnerable groups examined and their reference populations at the regional level. Many areas that are projected to experience more substantial damages have lower percentages of socially vulnerable populations, especially low income and minority individuals, which contributes to this pattern. However, some regional results stand out; minorities in the Northeast are approximately 16% more likely to currently live in areas with the highest projected impacts compared to White, non-Hispanic individuals with 2°C of global warming. In addition, individuals ages 65 and older in the Southwest and Northern Great Plains are 15% more likely than younger individuals to live in high-impact areas with 2°C of global warming.

INLAND FLOODING AND PROPERTY

Key Findings on Regional Impacts (continued)

NORTHWEST

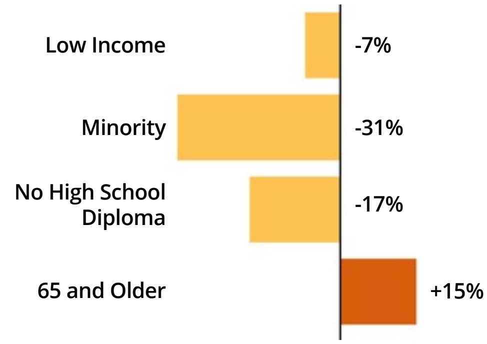
2°C Global Warming



- In the Northwest, socially vulnerable populations are not projected to have a disproportionately higher likelihood of currently living in areas with the highest projected inland flooding damages, relative to their reference groups.
- In the Northwest, low income individuals are 9% *less* likely, relative to those with higher income, to currently live in areas with the highest projected inland flooding impacts.

SOUTHWEST

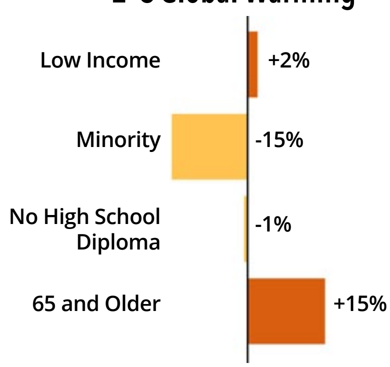
2°C Global Warming



- In the Southwest, individuals ages 65 and older are 15% more likely than younger individuals to currently live in areas with the highest projected inland flooding impacts.
- In the Southwest, minorities are 31% *less* likely than non-minorities to currently live in areas with the highest projected inland flooding impacts.

NORTHERN GREAT PLAINS

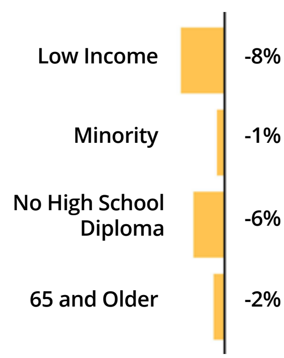
2°C Global Warming



- In the Northern Great Plains, individuals ages 65 and older are 15% more likely to currently live in areas projected to have the worst flooding damages, relative to younger populations.
- In the Northern Great Plains, minorities are 15% *less* likely than non-minorities to currently live in areas with the highest projected inland flooding impacts.

SOUTHERN GREAT PLAINS

2°C Global Warming



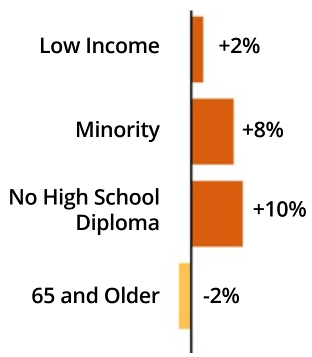
- In the Southern Great Plains, socially vulnerable populations are not projected to have a disproportionately higher likelihood of currently living in areas with the highest projected inland flooding damages, relative to their reference groups.

INLAND FLOODING AND PROPERTY

Key Findings on Regional Impacts (continued)

MIDWEST

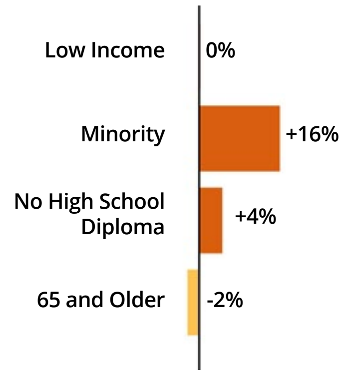
2°C Global Warming



- In the Midwest, those with no high school diploma are 10% more likely to currently live in areas projected to have the worst flooding damages, relative to those with a high school diploma.
- In the Midwest, minorities are 8% more likely than non-minorities to currently live in areas projected to have the worst flooding damages.

NORTHEAST

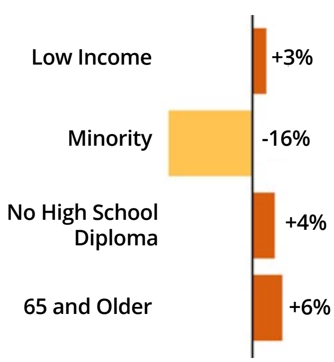
2°C Global Warming



- In the Northeast, minorities are 16% more likely than non-minorities to currently live in areas projected to have the worst flooding damages.
- On average, those with low income, those with no high school diploma, and individuals ages 65 and older are not projected to be disproportionately at risk of currently living in areas with the highest projected inland flooding damages.

SOUTHEAST

2°C Global Warming



- In the Southeast, minorities are 16% *less* likely than non-minorities to currently live in areas projected to have the worst flooding damages.
- On average, those with low income, those with no high school diploma, and individuals ages 65 and older are not projected to be disproportionately at risk of currently living in areas with the highest projected inland flooding damages.

CHAPTER 9
SUMMARY OF NATIONAL RESULTS

This chapter presents a summary of the national-level results from each analysis for each socially vulnerable group analyzed (Low Income, Minority, No High School Diploma, and 65 and Older). In addition, it presents results for each racial and ethnic group included in the Minority category (American Indian and Alaska Native; Asian; Black and African American; Hispanic and Latino; and Pacific Islander), and for the White, non-Hispanic population. The results are presented for scenarios with 2°C of global warming and 50 cm of global sea level rise, as well as for 4°C of global warming and 100 cm of global sea level rise.

Figure 9.1 presents the national-level results for the four socially vulnerable populations. Looking across the results for the four socially vulnerable groups analyzed, minorities are found to be most disproportionately at risk, relative to their reference populations. For example, with 50 cm of global sea level rise, minorities are 41% more likely than non-minorities to currently live in areas with the highest projected increases in traffic delays. By comparison, those with low income are 14% more likely than those with higher income to currently live in these areas, and those with no high school diploma are 18% more likely than those with higher educational attainment to currently live in these areas. In general, those 65 and older are found to have approximately the same levels of risk relative to younger populations for the six impacts analyzed.

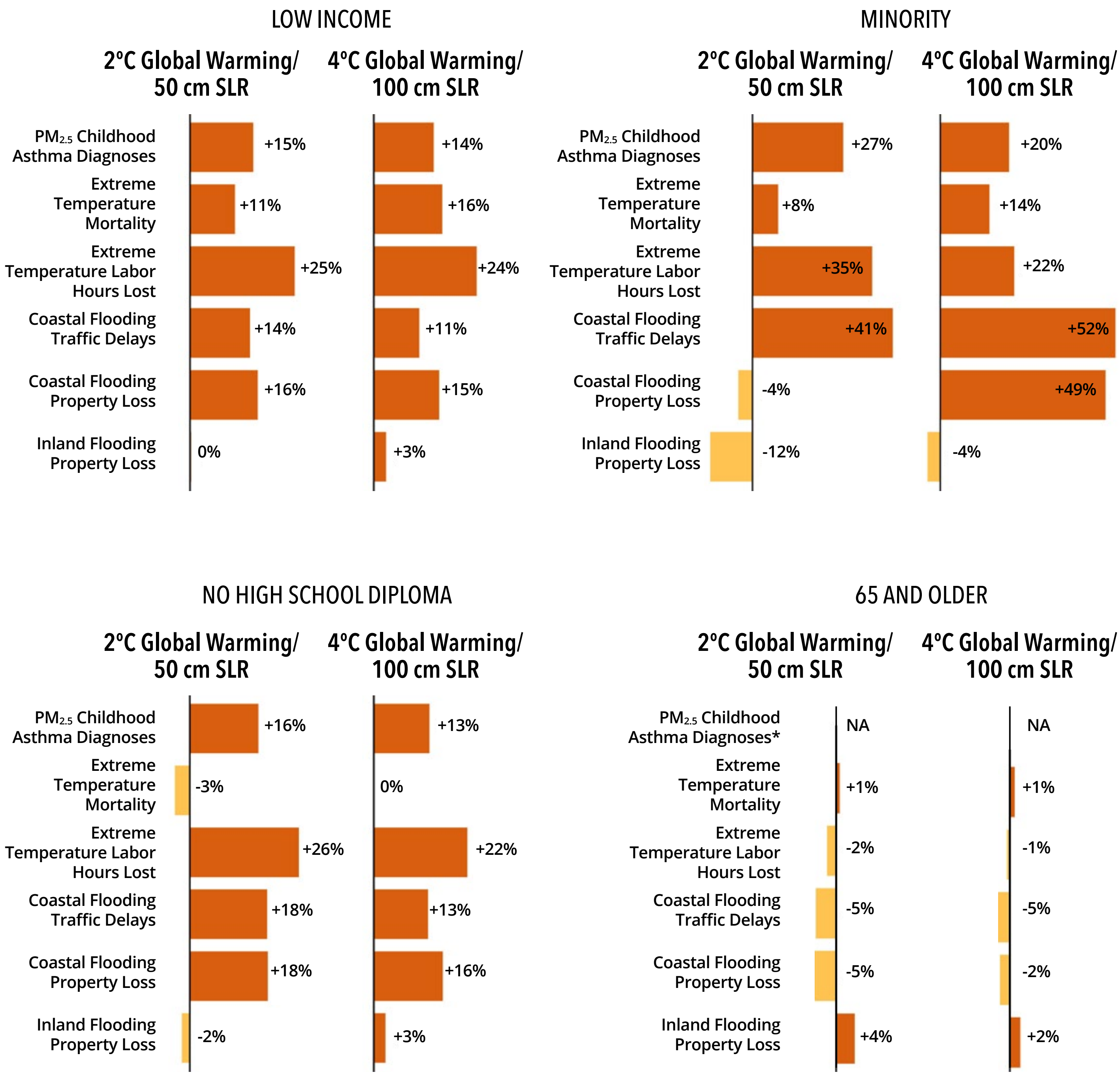
Figure 9.2 presents the results for the individual racial and ethnic groups included in the Minority category, and for White, non-Hispanic individuals. Looking across the results for all the racial and ethnic groups, Black and African American individuals are found to be most disproportionately at risk, relative to non-Black and non-African American individuals. With global warming of 2°C, Black and African American individuals are 40% more likely than non-Black and non-African American individuals to currently live in areas with the highest projected increases in premature mortality from extreme temperatures, and 34% more likely to currently live in areas with the highest projected increases in childhood asthma diagnoses.

Hispanic and Latino individuals are also found to be significantly more likely than non-Hispanic and non-Latino individuals to currently live in areas where impacts are projected to be highest. Specifically, Hispanic and Latino individuals are 43% more likely than their reference population to currently live in areas with the highest projected labor hour losses from extreme temperatures, and they are 50% more likely to currently live in areas with the highest projected traffic delays from coastal flooding. In contrast, White, non-Hispanic individuals are *less* likely than minorities to currently live in areas with the highest projected increases in childhood asthma diagnoses, the highest projected labor hour losses from extreme temperatures, and the highest projected coastal flooding-related traffic delays. White, non-Hispanic individuals are 19% more likely, however, to currently live in areas with the highest projected property damages from coastal flooding and 32% more likely to currently live in areas with the highest projected property damages from inland flooding, relative to their reference population.

SUMMARY OF NATIONAL RESULTS

Figure 9.1 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas with the Highest Projected Impacts Relative to their Reference Populations

Levels of global warming are relative to the 1986-2005 average (except for the inland flooding analysis, for which the baseline is 2001-2020) and levels of global sea level rise are relative to the year 2000. Positive percentages indicate a higher likelihood that individuals in the socially vulnerable population (e.g., low income) currently live in areas with the highest projected impacts relative to the reference population (e.g., non-low income), and negative percentages indicate lower disproportionate likelihood.

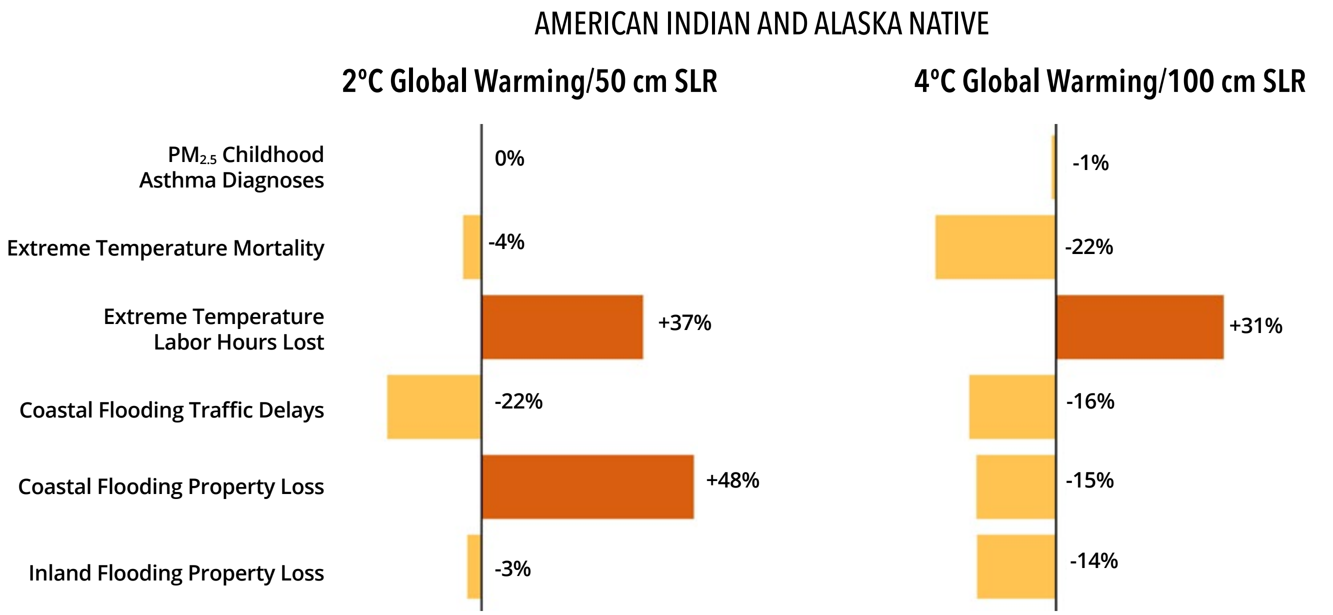


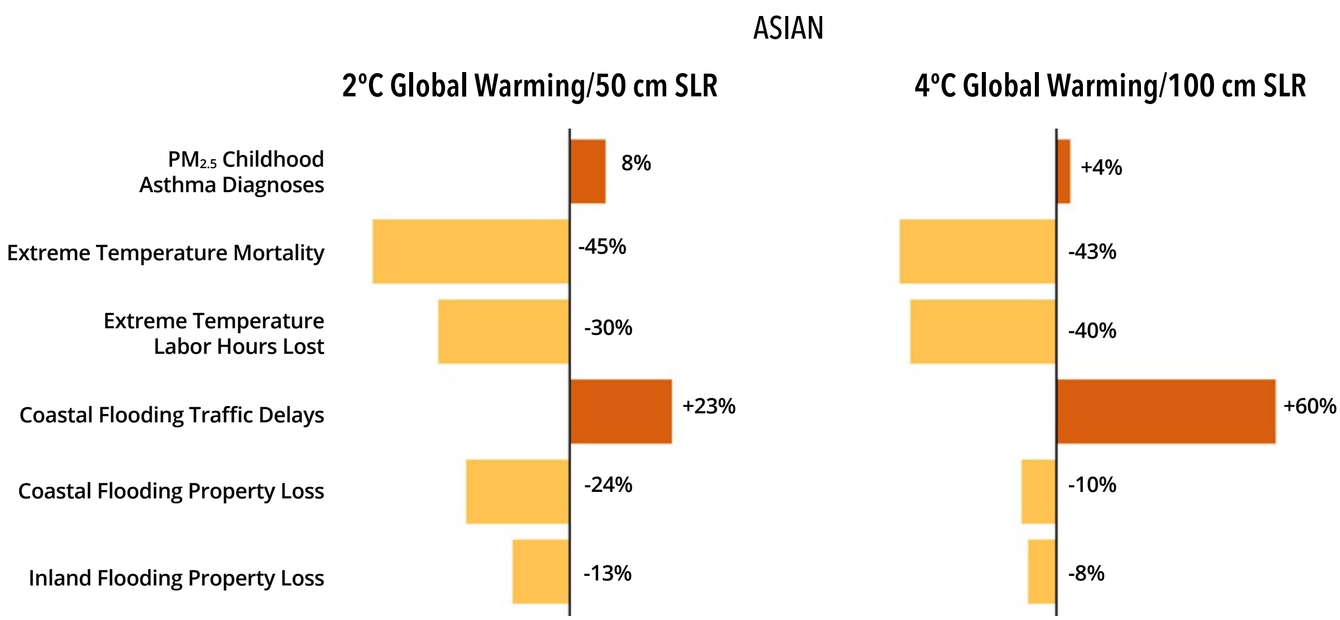
*Impacts not estimated for 65 and Older.

SUMMARY OF NATIONAL RESULTS

Figure 9.2 – Likelihood that Those in Individual Racial and Ethnic Groups Currently Live in Areas with the Highest Projected Impacts Relative to their Reference Populations

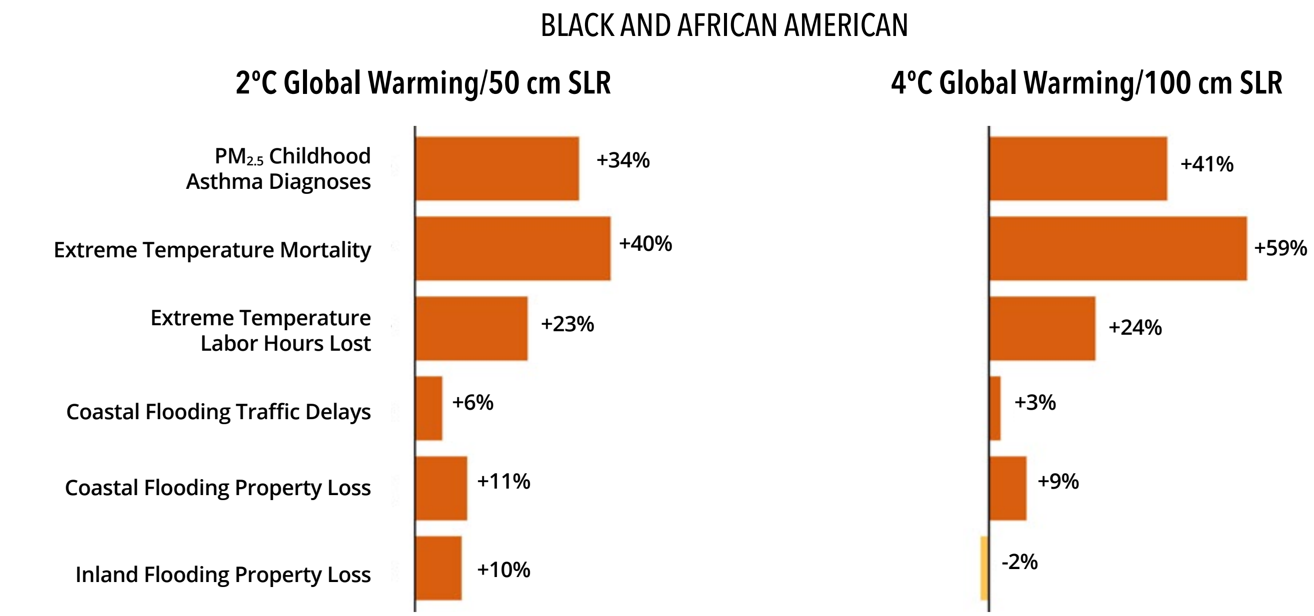
Levels of global warming are relative to the 1986-2005 average (except for the inland flooding analysis, for which the baseline is 2001-2020) and levels of global sea level rise are relative to the year 2000. Positive percentages indicate a higher likelihood that the socially vulnerable population (e.g., low income) currently lives in areas projected to experience the highest impacts relative to the reference population (e.g., non-low income), and negative percentages indicate lower disproportionate likelihood.





SUMMARY OF NATIONAL RESULTS

Figure 9.2 – Continued



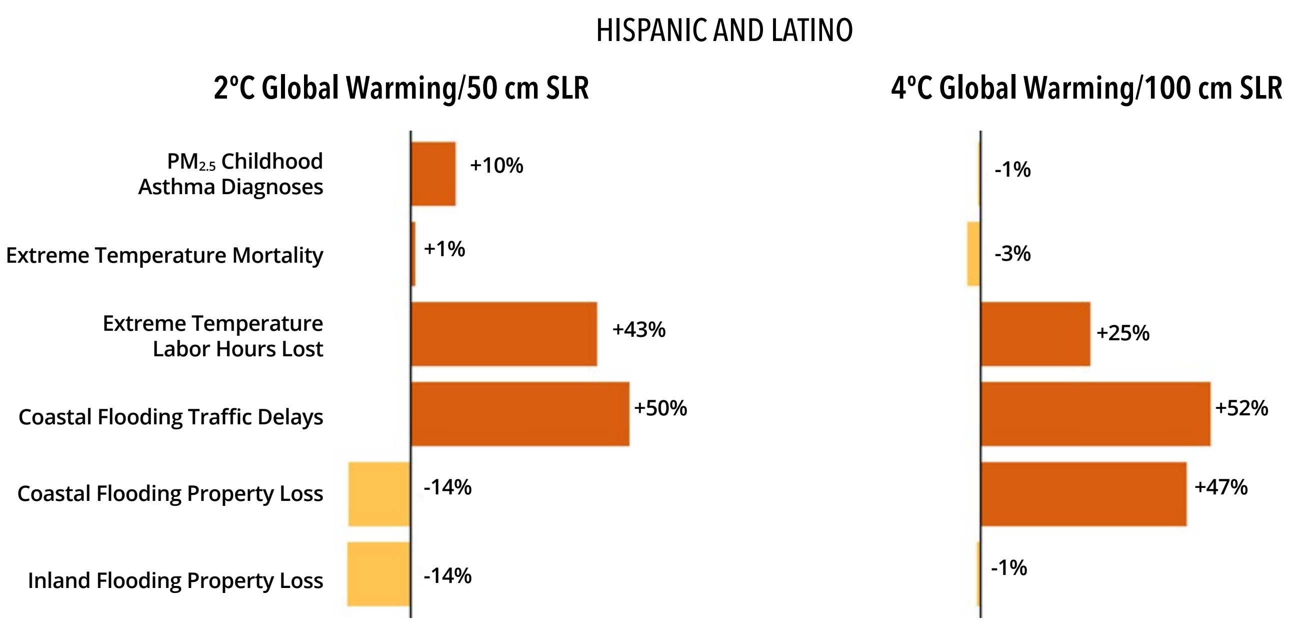
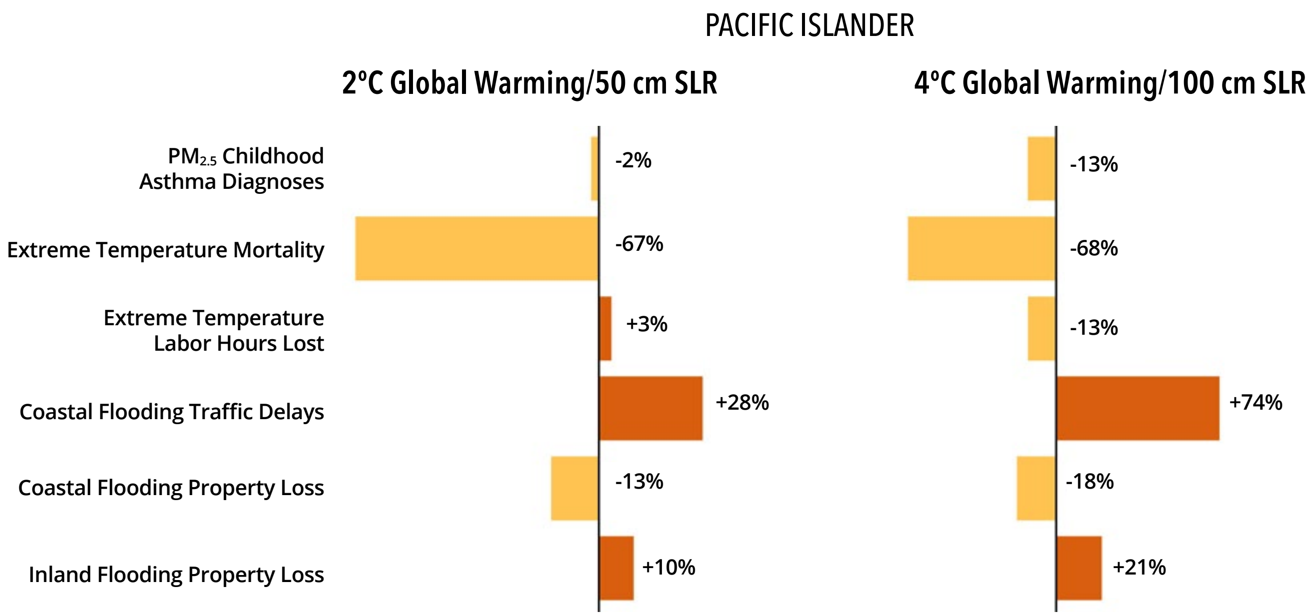
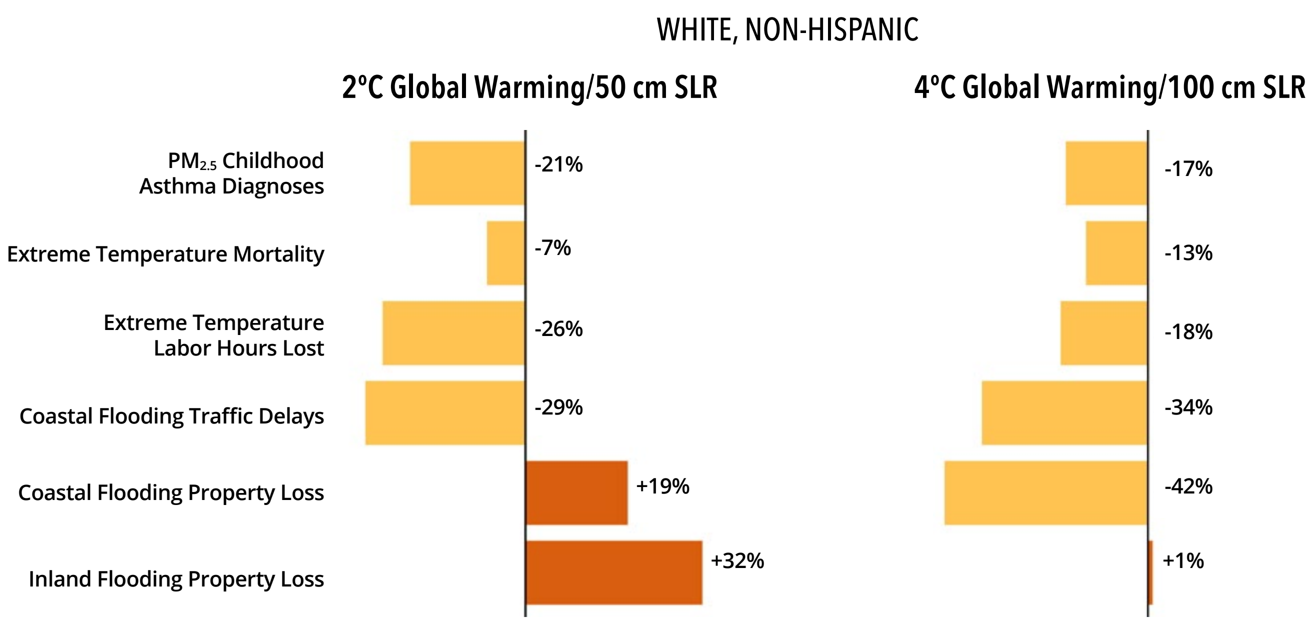


Figure 9.2 – Continued





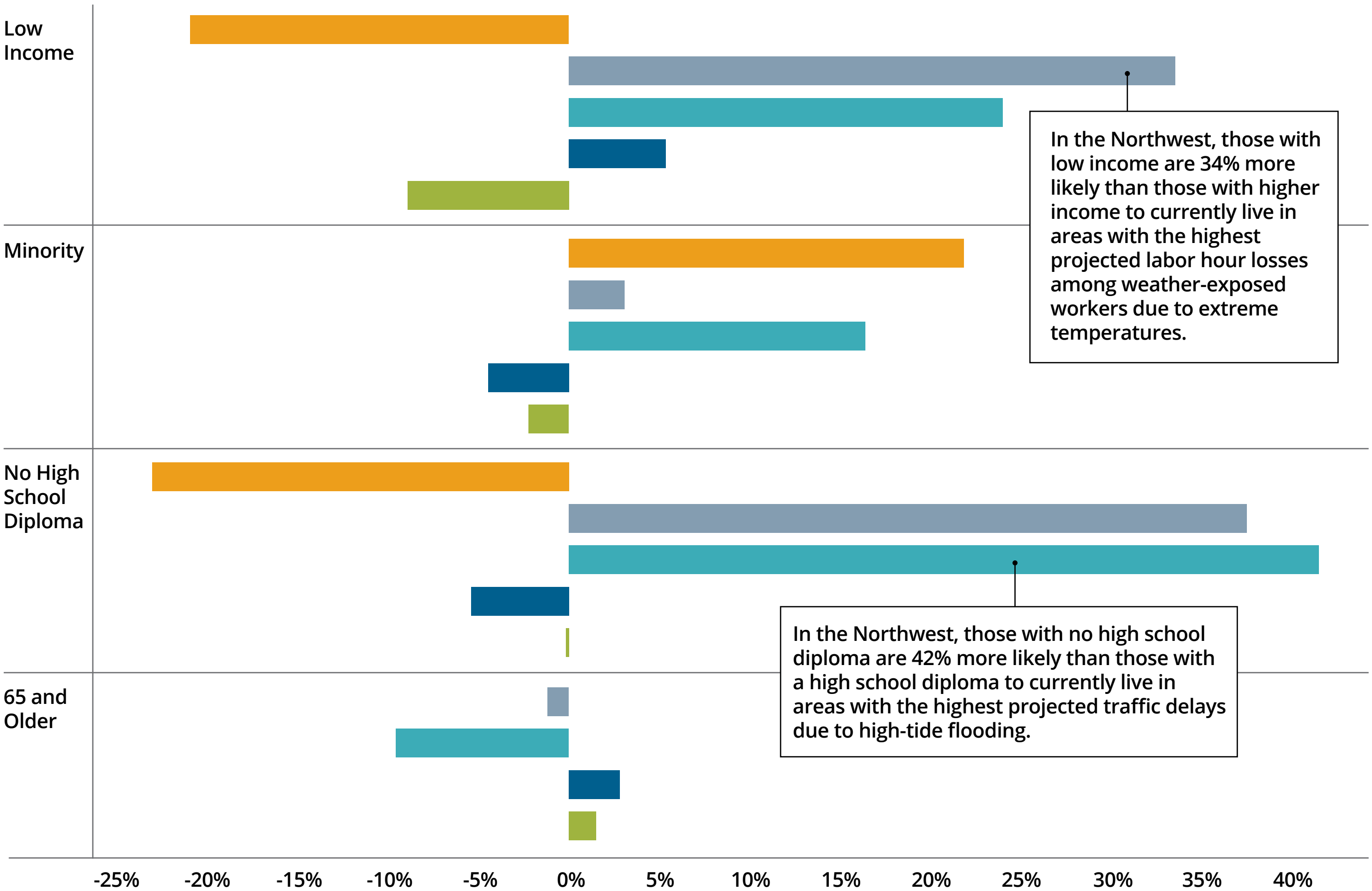
CHAPTER 10
SUMMARY OF REGIONAL RESULTS

This chapter presents a summary of the results for each region and each socially vulnerable group analyzed (Low Income, Minority, No High School Diploma, and 65 and Older). Results are presented for all key impact categories except for Extreme Temperature and Health because that analysis focuses on impacts in 49 urban areas.

SUMMARY OF REGIONAL RESULTS

Figure 10.1 – Differences in Risks to Socially Vulnerable Groups in the Northwest Relative to Reference Populations with 2°C of Global Warming or 50 cm of Global Sea Level Rise

The estimated risks for each socially vulnerable group are relative to each group's "reference" population, defined as all individuals other than those in the group being analyzed. The estimated risks presented in the chart are for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to 2000). For the inland flooding analysis, the baseline is 2001-2020. Results for additional scenarios are provided in the respective chapters and appendices.



AIR QUALITY AND HEALTH*
New asthma diagnoses in children due to particulate air pollution.

EXTREME TEMPERATURE AND LABOR
Lost labor hours for weather-exposed workers.

COASTAL FLOODING AND TRAFFIC
Traffic delays from high-tide flooding.

*Impacts not estimated for 65 and Older.

COASTAL FLOODING AND PROPERTY
Property inundation due to sea level rise.

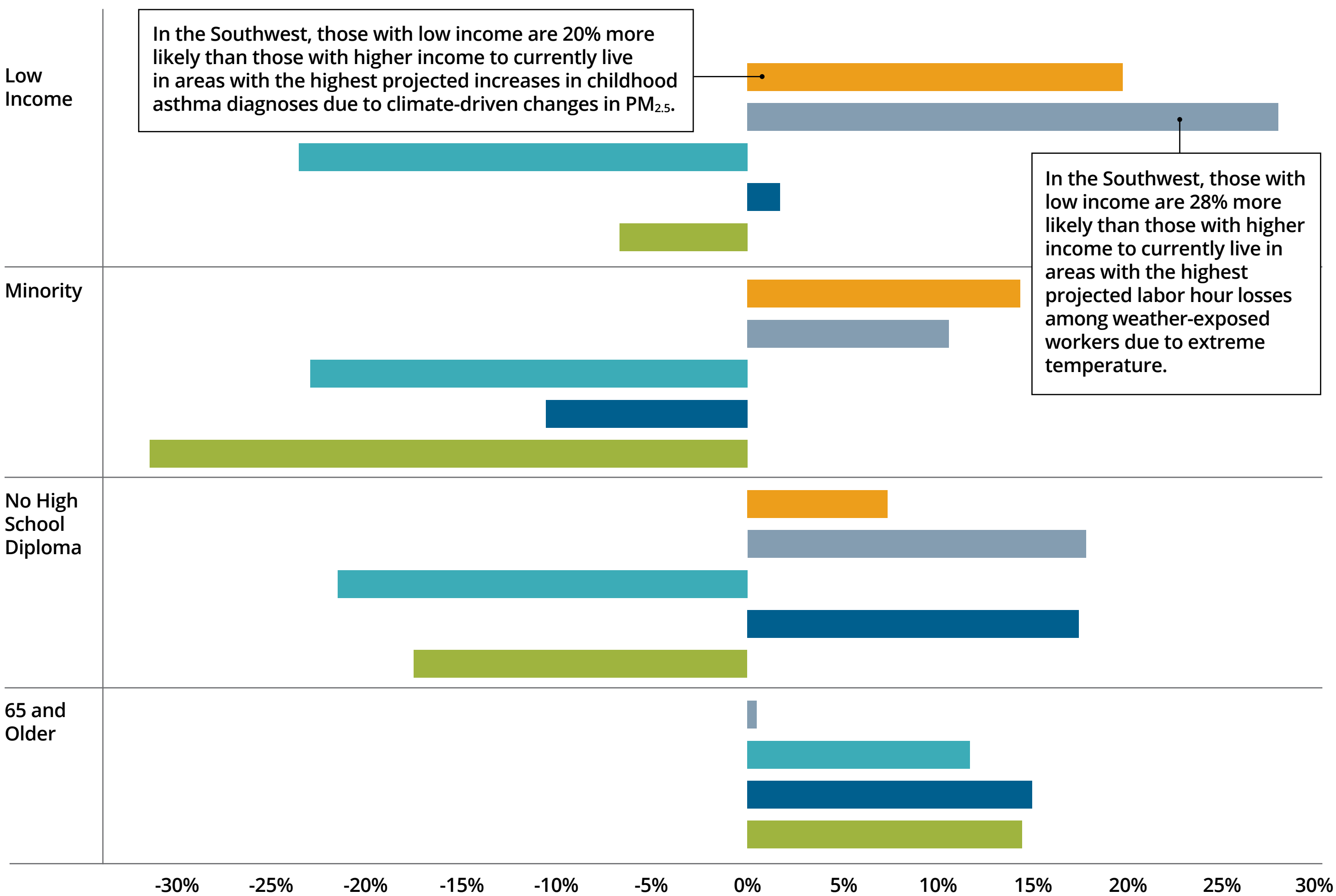
INLAND FLOODING AND PROPERTY
Property damage or loss due to inland flooding.

CHAPTER 10

SUMMARY OF REGIONAL RESULTS

Figure 10.2 – Differences in Risks to Socially Vulnerable Groups in the Southwest Relative to Reference Populations with 2°C of Global Warming or 50 cm of Global Sea Level Rise

The estimated risks for each socially vulnerable group are relative to each group's "reference" population, defined as all individuals other than those in the group being analyzed. The estimated risks presented in the chart are for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to 2000). For the inland flooding analysis, the baseline is 2001-2020. Results for additional scenarios are provided in the respective chapters and appendices.



AIR QUALITY AND HEALTH*
New asthma diagnoses in children due to particulate air pollution.

EXTREME TEMPERATURE AND LABOR
Lost labor hours for weather-exposed workers.

COASTAL FLOODING AND TRAFFIC
Traffic delays from high-tide flooding.

COASTAL FLOODING AND PROPERTY
Property inundation due to sea level rise.

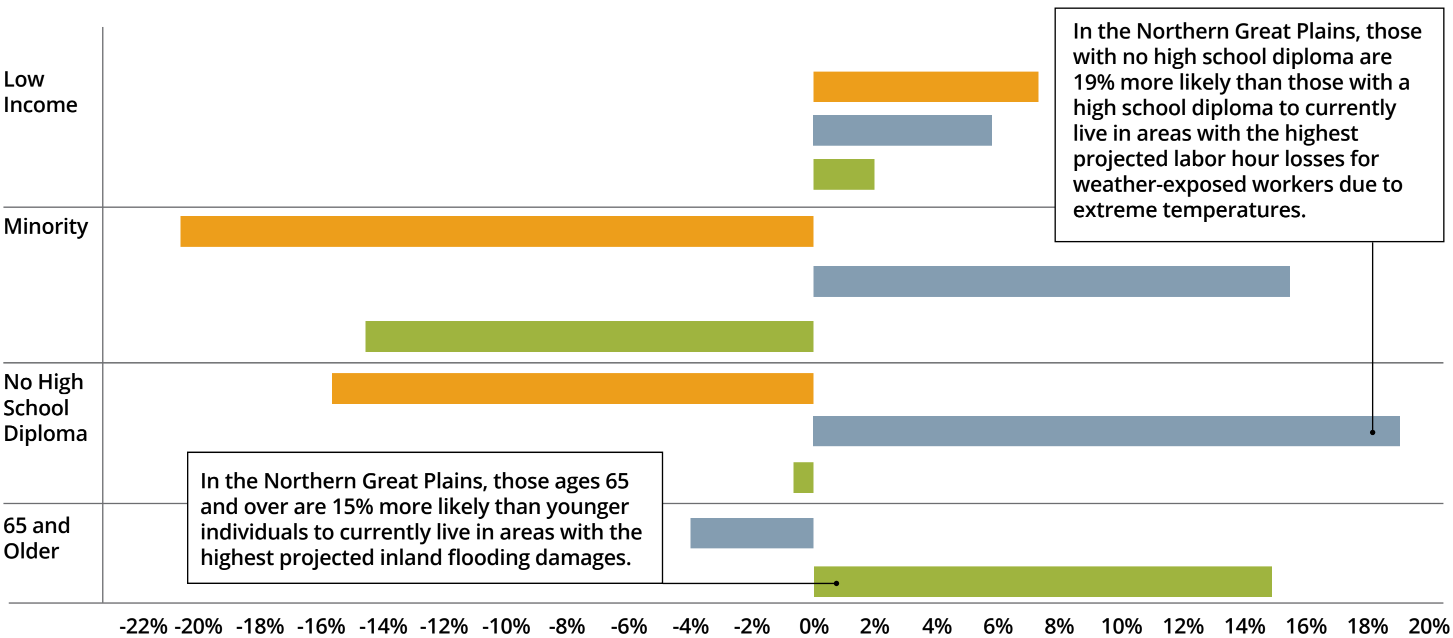
INLAND FLOODING AND PROPERTY
Property damage or loss due to inland flooding.

*Impacts not estimated for 65 and Older.

SUMMARY OF REGIONAL RESULTS

Figure 10.3 – Differences in Risks to Socially Vulnerable Groups in the Northern Great Plains Relative to Reference Populations with 2°C of Global Warming or 50 cm of Global Sea Level Rise

The estimated risks for each socially vulnerable group are relative to each group's "reference" population, defined as all individuals other than those in the group being analyzed. The estimated risks presented in the chart are for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to 2000). For the inland flooding analysis, the baseline is 2001-2020. Results for additional scenarios are provided in the respective chapters and appendices.



AIR QUALITY AND HEALTH*
New asthma diagnoses in children due to particulate air pollution.

INLAND FLOODING AND PROPERTY
Property damage or loss due to inland flooding.

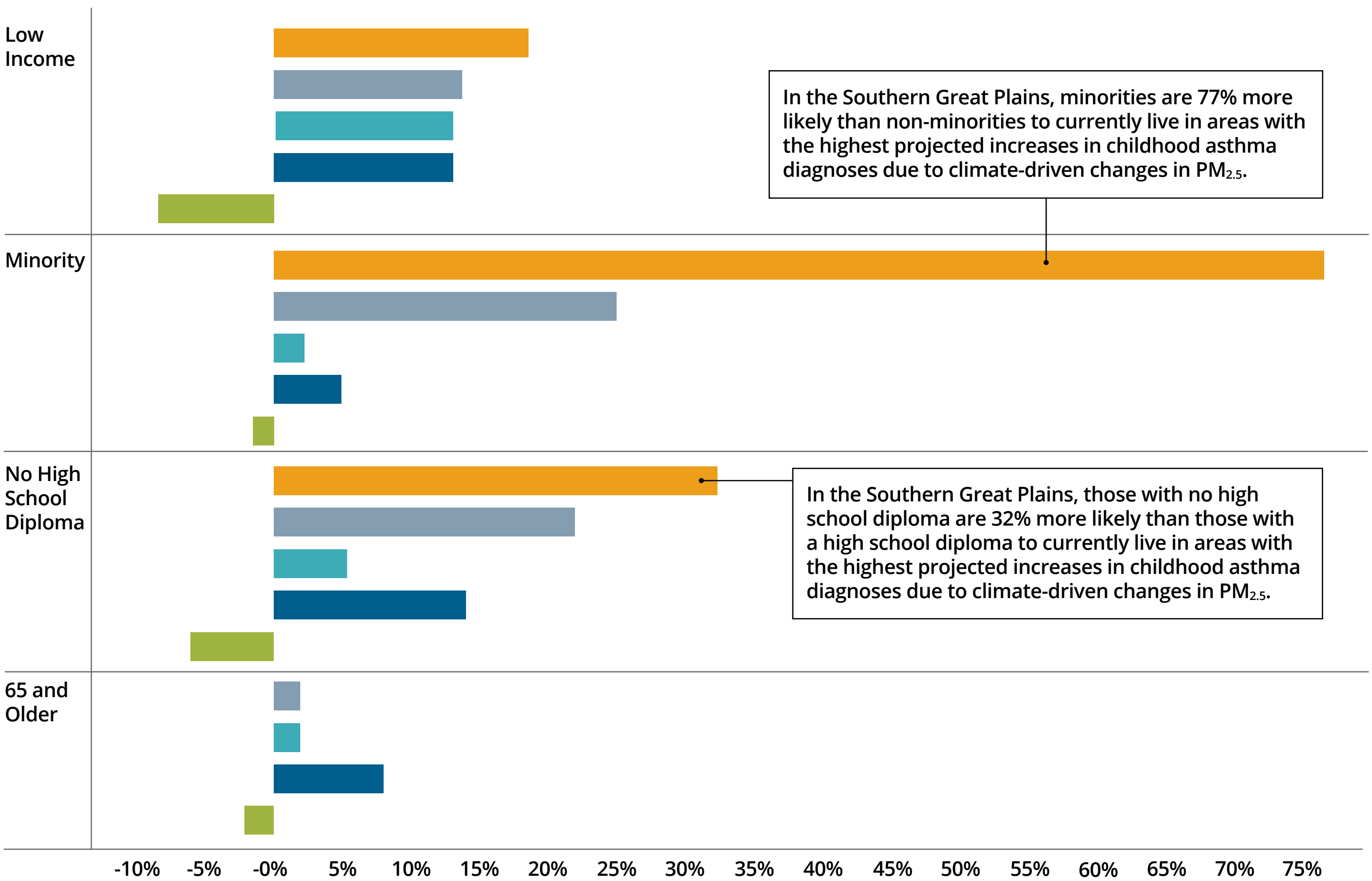
EXTREME TEMPERATURE AND LABOR
Lost labor hours for weather-exposed workers.

*Impacts not estimated for 65 and Older.

SUMMARY OF REGIONAL RESULTS

Figure 10.4 – Differences in Risks to Socially Vulnerable Groups in the Southern Great Plains Relative to Reference Populations with 2°C of Global Warming or 50 cm of Global Sea Level Rise

The estimated risks for each socially vulnerable group are relative to each group's "reference" population, defined as all individuals other than those in the group being analyzed. The estimated risks presented in the chart are for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to 2000). For the inland flooding analysis, the baseline is 2001-2020. Results for additional scenarios are provided in the respective chapters and appendices.



AIR QUALITY AND HEALTH*
New asthma diagnoses in children due to particulate air pollution.

EXTREME TEMPERATURE AND LABOR
Lost labor hours for weather-exposed workers.

COASTAL FLOODING AND TRAFFIC
Traffic delays from high-tide flooding.

*Impacts not estimated for 65 and Older.

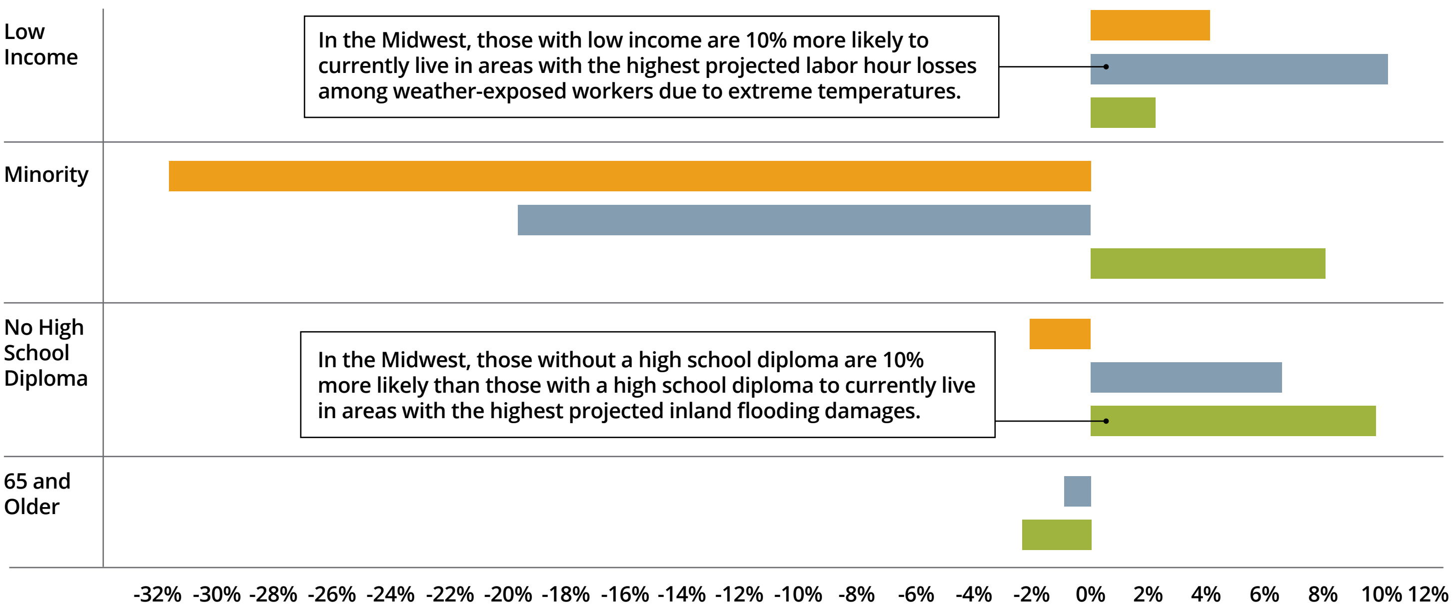
COASTAL FLOODING AND PROPERTY
Property inundation due to sea level rise.

INLAND FLOODING AND PROPERTY
Property damage or loss due to inland flooding.

SUMMARY OF REGIONAL RESULTS

Figure 10.5 – Differences in Risks to Socially Vulnerable Groups in the Midwest Relative to Reference Populations with 2°C of Global Warming or 50 cm of Global Sea Level Rise

The estimated risks for each socially vulnerable group are relative to each group's "reference" population, defined as all individuals other than those in the group being analyzed. The estimated risks presented in the chart are for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to 2000). For the inland flooding analysis, the baseline is 2001-2020. Results for additional scenarios are provided in the respective chapters and appendices.



AIR QUALITY AND HEALTH*
New asthma diagnoses in children due to particulate air pollution.

INLAND FLOODING AND PROPERTY
Property damage or loss due to inland flooding.

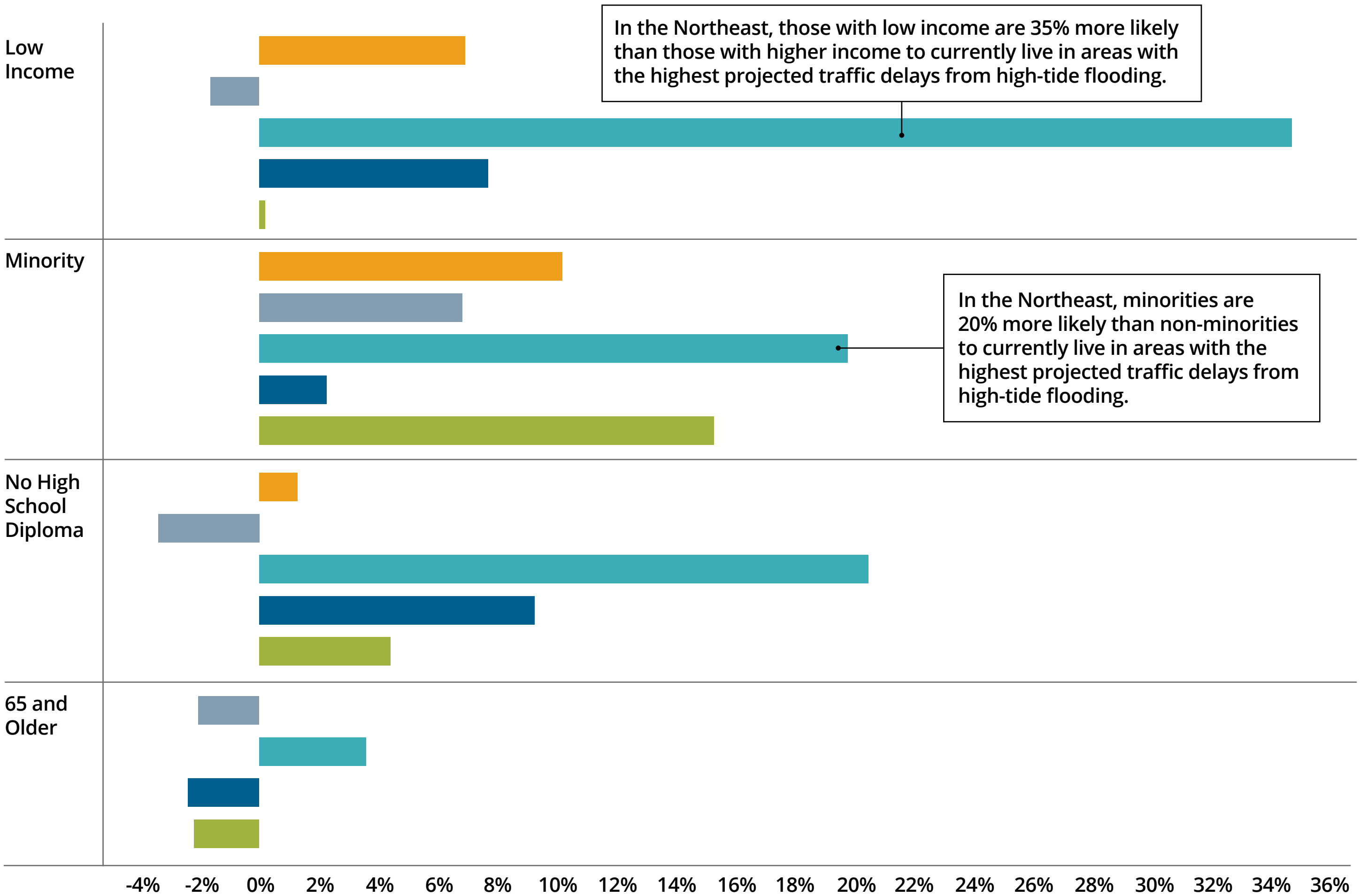
EXTREME TEMPERATURE AND LABOR
Lost labor hours for weather-exposed workers.

*Impacts not estimated for 65 and Older.

SUMMARY OF REGIONAL RESULTS

Figure 10.6 – Differences in Risks to Socially Vulnerable Groups in the Northeast Relative to Reference Populations with 2°C of Global Warming or 50 cm of Global Sea Level Rise

The estimated risks for each socially vulnerable group are relative to each group's "reference" population, defined as all individuals other than those in the group being analyzed. The estimated risks presented in the chart are for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to 2000). For the inland flooding analysis, the baseline is 2001-2020. Results for additional scenarios are provided in the respective chapters and appendices.



AIR QUALITY AND HEALTH*
New asthma diagnoses in children due to particulate air pollution.

EXTREME TEMPERATURE AND LABOR
Lost labor hours for weather-exposed workers.

COASTAL FLOODING AND TRAFFIC
Traffic delays from high-tide flooding.

COASTAL FLOODING AND PROPERTY
Property inundation due to sea level rise.

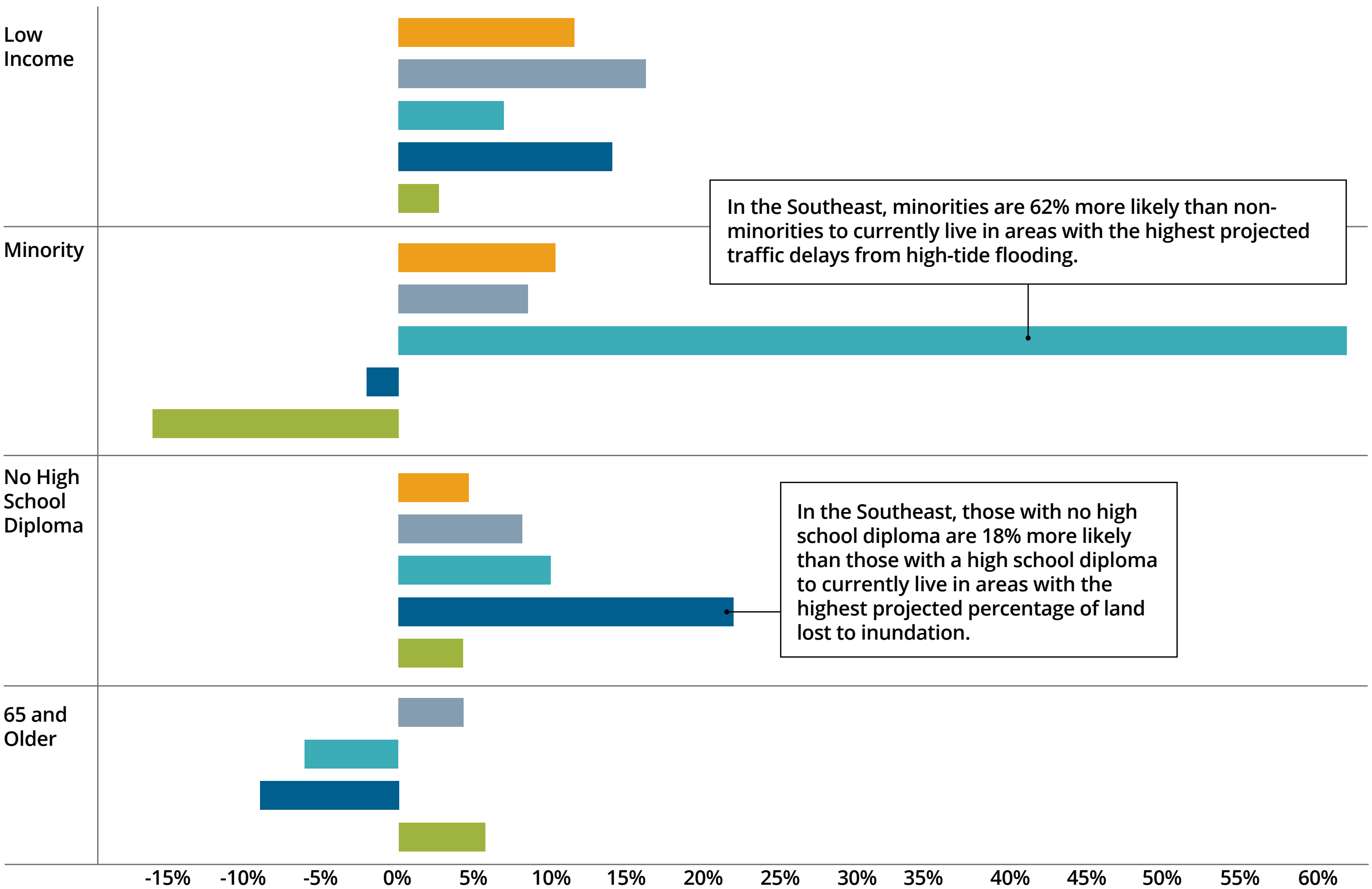
INLAND FLOODING AND PROPERTY
Property damage or loss due to inland flooding.

*Impacts not estimated for 65 and Older.

SUMMARY OF REGIONAL RESULTS

Figure 10.7 – Differences in Risks to Socially Vulnerable Groups in the Southeast Relative to Reference Populations with 2°C of Global Warming or 50 cm of Global Sea Level Rise

The estimated risks for each socially vulnerable group are relative to each group's "reference" population, defined as all individuals other than those in the group being analyzed. The estimated risks presented in the chart are for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to 2000). For the inland flooding analysis, the baseline is 2001-2020. Results for additional scenarios are provided in the respective chapters and appendices.



AIR QUALITY AND HEALTH*
New asthma diagnoses in children due to particulate air pollution.

EXTREME TEMPERATURE AND LABOR
Lost labor hours for weather-exposed workers.

COASTAL FLOODING AND TRAFFIC
Traffic delays from high-tide flooding.

COASTAL FLOODING AND PROPERTY
Property inundation due to sea level rise.

INLAND FLOODING AND PROPERTY
Property damage or loss due to inland flooding.

*Impacts not estimated for 65 and Older.

ENDNOTES

Executive Summary

1 USGCRP. 2018. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.

2 Cardona OD, van Aalst MK, Birkmann J, Fordham M, McGregor G, Perez R, Pulwarty RS, Schipper ELF, and Sinh BT. 2012. Determinants of risk: exposure and vulnerability. In Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner GK, Allen SK, Tignor M, and Midgley PM (eds.)] A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.

3 Thomas K, Hardy RD, Lazrus H, Mendez M, Orlove B, Rivera-Collazo I, Roberts JT, Rockman M, Warner BP, and Winthrop R. 2018. Explaining differential vulnerability to climate change: A social science review. WIREs Climate Change, 10(2). doi: 10.1002/wcc.565.

4 The analysis also examines the impacts of ozone on premature deaths (see Chapter 3 and Appendix D).

5 The analysis also examines exclusion of roads in some areas from protective adaptation measures (see Chapter 6 and Appendix G).

6 The estimated risks for each socially vulnerable group are calculated as the risks compared to each group's "reference" population, defined as all individuals other than those in the group being analyzed. For example, the reference population for Asian individuals includes all individuals who do not identify as Asian. For more information, please refer to the Approach chapter and Appendix C.

7 Results for other climate change scenarios are presented in the individual chapters of the report and the corresponding appendices.

8 This impact measure is calculated as the percentage of the total property value in each at-risk coastal Census block group that is projected to be lost to sea level rise inundation, in a scenario without any adaptation.

9 The estimated risks for each socially vulnerable group are calculated as the risks compared to each group's "reference" population, defined as all individuals other than those in the group being analyzed. For example, the reference population for Asian individuals includes all individuals who do not identify as Asian. For more information, please refer to the Approach chapter and Appendix C.

10 Results for other climate change scenarios are presented in the individual chapters of the report and the corresponding appendices.

11 This impact measure is calculated as the percentage of the total property value in each at-risk coastal Census block group that is projected to be lost to sea level rise inundation, in a scenario without any adaptation.

Chapter 1. Introduction

1 USGCRP, 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, DR, CW Avery, DR Easterling, KE Kunkel, KLM Lewis, TK Maycock, and BC Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.

2 USGCRP. 2018. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC (eds.)]. U.S. Global Change Research Program, Washington, DC, USA. doi: 10.7930/NCA4.2018.

3 Thomas K, Hardy RD, Lazrus H, Mendez M, Orlove B, Rivera-Collazo I, Roberts JT, Rockman M, Warner BP, and Winthrop R. 2018. Explaining differential vulnerability to climate change: A social science review. WIREs Climate Change, 10(2). doi: 10.1002/wcc.565.

4 Cardona OD, van Aalst MK, Birkmann J, Fordham M, McGregor G, Perez R, Pulwarty RS, Schipper ELF, and Sinh BT. 2012. Determinants of risk: exposure and vulnerability. In Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner GK, Allen SK, Tignor M, and Midgley PM (eds.)] A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.

5 Cardona OD, van Aalst MK, Birkmann J, Fordham M, McGregor G, Perez R, Pulwarty RS, Schipper ELF, and Sinh BT. 2012. Determinants of risk: exposure and vulnerability. In Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner GK, Allen SK, Tignor M, and Midgley PM (eds.)] A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.

6 Thomas K, Hardy RD, Lazrus H, Mendez M, Orlove B, Rivera-Collazo I, Roberts JT, Rockman M, Warner BP, and Winthrop R. 2018. Explaining differential vulnerability to climate change: A social science review. WIREs Climate Change, 10(2). doi: 10.1002/wcc.565.

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7 IPCC. 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, and White LL (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp.

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11 www.epa.gov/cira

12 U.S. EPA. 2017. Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment. U.S. Environmental Protection Agency, Washington, D.C.

Chapter 2. Approach

1 This "impacts by degree" framework has been employed in major scientific assessments, including those by the National Academies and the United Nations Intergovernmental Panel on Climate Change (IPCC). Sources: National Research Council. 2011. Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia. Washington, DC: The National Academies Press. doi: 10.17226/12877. IPCC. 2018. Summary for Policymakers. In *Global Warming of 1.5°C.* An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. [Masson-Delmotte V, Zhai P, Pörtner HO, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy E, Maycock T, Tignor M, and Waterfield T (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.

2 The higher emissions scenario corresponds to representative concentration pathway (RCP) 8.5, the lower emissions scenario corresponds to RCP4.5, and the even lower scenario corresponds to RCP2.6. For more information regarding these forcing scenarios, see Hayhoe K, Edmonds J, Kopp RE, LeGrande AN, Sanderson BM, Wehner MF, and Wuebbles DJ. 2017. Climate models, scenarios, and projections. In *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles DJ, Fahey DW, Hibbard KA, Dokken DJ, Stewart BC, and Maycock TK (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 133-160, doi: 10.7930/J0WH2N54.

3 According to Hayhoe et al., 2017, the U.S. had already experienced over 0.5°C warming by 2016 (relative to the 1986-2005 baseline used in this report).

4 The six GCMs are: CanESM2, GFDL-CM3, CCSM4, GISS-E2-R, HadGEM2-ES, and MIROC5. Please see Appendix C for more information.

5 This 20-year baseline period is also used in the NCA4 and in the Climate Change Science Report that supports it.

6 IPCC. 2018. Framing and Context: Frequently Asked Questions (FAQ). In *Global Warming of 1.5°C*. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. [Masson-Delmotte V, Zhai P, Pörtner HO, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy E, Maycock T, Tignor M, and Waterfield T (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.

7 IPCC. 2018. Summary for Policymakers. In *Global Warming of 1.5°C.* An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. [Masson-Delmotte V, Zhai P, Pörtner HO, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy E, Maycock T, Tignor M, and Waterfield T (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.

8 Paris Agreement FCCC/CP/2015/10/Add.1 https://unfccc.int/documents/909.

9 Hayhoe K, Edmonds J, Kopp RE, LeGrande AN, Sanderson BM, Wehner MF, and Wuebbles DJ. 2017. Climate models, scenarios, and projections. In *Climate Science Special Report: Fourth National Climate Assessment, Volume I*

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[Wuebbles DJ, Fahey DW, Hibbard KA, Dokken DJ, Stewart BC, and Maycock TK (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 133-160, doi: 10.7930/J0WH2N54. These ranges do not, however, capture the full range of physically plausible global average sea level rise over the 21st century, with higher rates possible due to physical feedbacks in the Antarctic icesheets.

10 This report uses the regional delineations of the National Climate Assessment. Texas is the only coastal state in the Southern Great Plains region, therefore statements about coastal impacts in this region refer to the Texas coastline.

11 Estimated "relative" sea level rise means that the estimates incorporate both projected land and sea level changes. Relative sea level rise accounts for land uplift or subsidence, oceanographic effects, and responses of the geoid and the lithosphere to shrinking land ice.

12 Based on 2020 city population estimates from the U.S. Census. For more information, please see https://www.census.gov/programs-surveys/popest/technical-documentation/research/evaluation-estimates/2020-evaluation-estimates/2010s-cities-and-towns-total.html.

13 The analysis also examines the impacts of ozone on premature deaths (see Chapter 3 and Appendix D).

14 The analysis also examines exclusion of roads in some areas from protective adaptation measures (see Chapter 6 and Appendix G).

15 The focus on highest risks of experiencing climate change impacts is consistent with recommendations for federal climate science research from a recent report from the National Academies of Sciences, Engineering, and Medicine. National Academies of Sciences, Engineering, and Medicine. 2021. Global Change Research Needs and Opportunities for 2022-2031. Washington, DC: The National Academies Press. doi: 10.17226/26055.

16 In some cases, the areas that are projected to experience higher impacts are the same across two or more analyses. See the Regional Summary chapter for more information.

17 This report estimates climate change impacts to socially vulnerable populations based on current demographic distributions, as long-term and robust projections for national changes in demographics are currently unavailable. Recent U.S. Census data indicates the following demographic trends at a national level, many of which may continue into the future: a) less migration (i.e., lower mobility rates), b) increased urbanization, c) an increasingly aged population, d) small declines in the White, non-Hispanic/Latino population, and e) the most population growth occurring among African American/Black and Hispanic/Latino racial and ethnic groups. [see https://www.census.gov/topics/population.html for additional information]. Regarding income, the share of Americans in the lower national income tier increased from 25% to 29% between 1970-2019. During that same period, the sum of total income flowing to low income households decreased from 10 to 9% [see Pew Research Center, January 2020, "Most Americans Say There Is Too Much Economic Inequality in the U.S., but Fewer Than Half Call It a Top Priority" for more information]. As for high school graduation rates, The U.S. average adjusted cohort graduation rate for public high school students increased over the first eight years it was collected, from 79 percent in 2010–11 to 85 percent in 2017–18 [see U.S. Department of Education, National Center for Education Statistics. (2020). The Condition of Education 2020 (NCES 2020-144), Public High School Graduation Rates. for more information].

18 Previous literature has demonstrated the importance of climate sensitivity assumptions in understanding a wide range of potential changes to the climate system, as well as the effect of natural variability on timing and magnitude of impacts. Sources: Paltsev S, Monier E, Scott J, Sokolov A, and Reilly J. 2013. Integrated economic and climate projections for impact assessment. Climatic Change, 131, 21-33. doi:10.1007/s10584-013-0892-3. Monier E, Gao X, Scott JR, Sokolov AP, and Schlosser CA. 2014. A framework for modeling uncertainty in regional climate change. Climatic Change, 131, 51-66. doi:10.1007/s10584-014-1112-5. Monier E, and Gao X. 2014. Climate change impacts on extreme events in the United States: an uncertainty analysis. *Climatic Change,* 131, 67-81. doi:10.1007/s10584-013-1048-1. Mills D, Jones R, Carney K, St. Juliana A, Ready R, Crimmins A, Martinich J, Shouse K, DeAngelo B, and Monier E. 2014. Quantifying and Monetizing Potential Climate Change Policy Impacts on Terrestrial Ecosystem Carbon Storage and Wildfires in the United States. *Climatic Change,* 131, 163-178. doi:10.1007/s10584-014-1118-z.

19 The Sixth Assessment of the IPCC, which is scheduled for release in summer 2021, will provide updated scenarios and temperature projections based on the CMIP6 project. However, these newer projections were not available in time for use in this report.

19 Based on 2020 city population estimates from the U.S. Census. For more information, please see https://www.census.gov/programs-surveys/popest/technical-documentation/research/evaluation-estimates/2020-evaluation-estimates/2010s-cities-and-towns-total.html.

20 Table C17002 of the American Community Survey, 2014-2018, available at www.data.census.gov

21 Table B03002 of the American Community Survey, 2014-2018, available at www.data.census.gov

22 Table B15003 of the American Community Survey, 2014-2018, available at www.data.census.gov

23 Table B01001 of the American Community Survey, 2014-2018, available at www.data.census.gov

24 Ongoing studies, such as the Inter-sectoral Impact Model Intercomparison Project (ISI-MIP), are investigating the influence of structural uncertainties across sectoral impact models. Source: Huber V, Schellnhuber HJ, Arnell

NW, Frieler K, Friend AD, Gerten D, Haddeland I, Kabat P, Lotze-Campen H, Lucht W, Parry M, Piontek F, Rosenzweig C, Schewe J, and Warszawski L. 2014. Climate impact research: beyond patchwork. *Earth System Dynamics,* 5, 399-408. doi: 10.5194/esd-5-399-2014.

25 For example, the Air Quality and Temperature Mortality analyses do not examine the compounding health risks that individuals could experience during heat waves with high ozone concentrations in the air. Although first order connectivity was achieved in limited cases (e.g., projected installation of coastal defenses in the Coastal Flooding analysis provides information on location and timing to inform where coastal roads may receive ancillary protection), improved connectivity between sectoral models would aid in gaining a more complete understanding of climate change impacts on socially vulnerable populations of the U.S.

26 Gamble JL, Balbus J, Berger M, Bouye K, Campbell V, Chief K, Conlon K, Crimmins A, Flanagan B, Gonzalez-Maddux C, Hallisey E, Hutchins S, Jantarasami L, Khoury S, Kiefer M, Kolling J, Lynn K, Manangan A, McDonald M, Morello-Frosch R, Redsteer MH, Sheffield P, Thigpen Tart K, Watson J, Whyte KP, and Wolkin AF. 2016. Ch. 9: Populations of Concern. In *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment.* U.S. Global Change Research Program, Washington, DC, 247–286.

27 Sectors where adaptation is modeled adopt broad decision rules. However, adaptation actions are typically implemented at local scales. As such, the general adaptation scenarios considered in the analyses of this report will not capture the complex issues that drive adaptation decision-making at regional and local scales. For example, the Coastal Flooding analysis considers the cost effectiveness of adaptive responses to sea-level rise inundation and storm surge damages by comparing the costs of protection to the value of those properties at risk. While many factors at the property, community, region, and national levels will determine adaptive responses to coastal risks, this sectoral analysis uses the simplistic cost/benefit metric to enable consistent comparisons for the entire coastline. The adaptation scenarios and estimates presented in all sections of this report should not be construed as recommending any specific policy or adaptive action.

28 For example, the econometric methodology used in the labor analysis would capture any extreme temperature adaptations employed by outdoor industries in the base period.

29 This example demonstrates the process for calculating risks to the population age 65 and older in the Coastal Flooding and Traffic analysis at the *national* level. To calculate risks to this population in each region, the analysis follows the same steps, except in Step 4b it identifies areas in each region where impacts are highest (i.e., in the highest third of impacts). It then proceeds through the remaining steps to estimate the comparative risks to the socially vulnerable population of interest.

Chapter 3. Air Quality and Health

1 Human activities and natural processes release precursors for ground-level ozone (O_3) and particulate matter with a diameter less than 2.5 micrometers ($PM_{2.5}$), including methane (CH4), carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOCs), sulfur dioxide (SO_2), ammonia (NH_3), organic carbon (OC), black carbon (BC), and dimethyl sulfide (DMS); and direct atmospheric pollutants, including mineral dust, sea salt, pollen, spores, and food particles. Source: C.G., P.D. Dolwick, N. Fann, L.W. Horowitz, V. Naik, R.W. Pinder, T.L. Spero, D.A. Winner, and L.H. Ziska, 2018: Air Quality. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 512–538. doi: 10.7930/NCA4.2018.CH13

2 $PM_{2.5}$ consists of fine inhalable particles with diameters that are generally 2.5 micrometers and smaller.

3 Ground-level ozone refers to ozone that is created by chemical reactions between oxides and nitrogen (NOx) and volatile organic compounds (VOC). This happens when pollutants emitted by cars, power plants, and other sources chemically react in the presence of sunlight.

4 Crimmins A, Balbus J, Gamble JL, Beard CB, Bell JE, Dodgen D, Eisen RJ, Fann N, Hawkins M, Herring SC, Jantarasami L, Mills DM, Saha M, Sarofim MC, Trtanj J, Ziska L. 2016. Executive Summary. The impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, 24 pp. doi: 10.7930/JOOPOWXS.

5 Nolte CG, Dolwick PD, Fann N, Horowitz LW, Naik V, Pinder RW, Spero TL, Winner DA, and Ziska LH. 2018. Air Quality. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 512–538. doi: 10.7930/NCA4.2018.CH13.

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8 Cole LW, and Foster SR. 2001. *From the Ground Up: Environmental Racism and the Rise of the Environmental Justice Movement*. New York and London. New York University Press.

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Review. *Environmental Health*, 12(43). doi: 10.1186/1476-069X-12-43.

10 US EPA. 2019. Chapter 12: Populations and Lifestages Potentially at Increased Risk of a Particulate Matter-Related Health Effect. Integrated Science Assessment for Particulate Matter. Research Triangle Park, NC: United States Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment-RTP Division.

11 Tessum C, Paolella D, Chambliss S, Apte J, Hill J, and Marshall J. 2021. PM2.5 polluters disproportionately and systemically affect people of color in the United States. Science Advances, 7(18). doi: 10.1126/sciadv.abf4491

12 Colmer J, Hardman I, Shimshack J, and Voorheis J. 2020. Disparities in PM2.5 air pollution in the United States. Science, 369(6503):575-578. doi: 10.1126/science.aaz9353.

13 Kiomourtzoglou MA, Schwartz J, James P, Dominici F, and Zanobetti A. 2016. PM2.5 and mortality in 207 US cities: Modification by temperature and city characteristics. *Epidemiology*, 27(2):221-227.

14 Di Q, Wang Y, Zanobetti A, Wang Y, Koutrakis P, Choirat C, Dominici F, and Schwartz JD. 2017. Air pollution and mortality in the Medicare population. *New England Journal of Medicine,* 376(26):2513-2522.

15 Sadd JL, Pastor M, Morello-Frosch R, Scoggins J, and Jesdale B. 2011. Playing It Safe: Assessing Cumulative Impact and Social Vulnerability through an Environmental Justice Screening Method in the South Coast Air Basin, California. *Int J Environ Res Public Health,* 8(5):1441-1459. doi: 10.3390/ijerph8051441.

16 Tessum C, Paolella D, Chambliss S, Apte J, Hill J, and Marshall J. 2021. PM2.5 polluters disproportionately and systemically affect people of color in the United States. Science Advances, 7(18). doi: 10.1126/sciadv.abf4491

17 US EPA. 2019. Chapter 12: Populations and Lifestages Potentially at Increased Risk of a Particulate Matter-Related Health Effect. Integrated Science Assessment for Particulate Matter. Research Triangle Park, NC: United States Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment-RTP Division.

18 Schweitzer L, and Zhou J. 2010. Neighborhood-Air Quality, Respiratory Health, and Vulnerable Populations in Compact and Sprawled Regions. *Journal of the American Planning Association,* 76(3):363-371. doi: 10.1080/01944363.2010.486623.

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29 For more information on these calculations, please see Table 3 of the Approach chapter. The calculations are weighted by the number of individuals in the relevant age groups for each impact category (0-17 for new asthma diagnoses, 0-18 for asthma ED visits, and 65 and older for premature mortality). Note that the numbers of individuals quantified in this step include all individuals and are

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not limited to the populations at risk of experiencing the impacts of premature mortality (adults 65 and older) or childhood asthma cases (individuals age 0 to 17).

30 EPA, 2021: National Air Quality –Status and Trends of Key Air Pollutants. United States Environmental Protection Agency, Office of Air Quality Planning and Standards. Available online at www.epa.gov/air-trends.

31 See Appendix D, Section 4 for details on the geographic distribution of the high-impact Census tracts used in this analysis.

32 The underlying study for childhood asthma diagnoses did not evaluate effects from changes in ozone, therefore this analysis only covers changes due to $PM_{2.5}$.

33 See Appendix D Section 4 for details on the geographic distribution of the high-impact Census tracts used in this analysis.

34 To stratify hazard ratios by race, authors of the underlying study analyzed asthma ED visits, a severe morbidity endpoint that is less frequent than asthma cases. As a result, there are fewer total asthma ED visits at 2°C and 4°C of warming, but greater disproportionality among socially vulnerable populations.

Chapter 4. Extreme Temperature and Health

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4 See, for example, Sanderson M, Arbuthnott K, Kovats S, Hajat S, and Falloon P. 2017. The use of climate information to estimate future mortality from high ambient temperature: A systematic literature review. *PLoS ONE,* 12(7). doi: 10.1371/journal.pone.0180369; Basu R, and Samet JM. 2002. Relation between Elevated Ambient Temperature and Mortality: A Review of the Epidemiologic Evidence. *Epidemiol Rev,* 24(2):190-202. doi: 10.1093/epirev/mxf007; Botzen WJW, Martinius ML, Brode P, Folkerts MA, Ignjacevic P, Estrada F, Harmsen CN, and Daanen HAM. 2020. Economic valuation of climate change-induced mortality: age dependent cold and heat mortality in the Netherlands. *Climate Change,* 162, 545-562; Bobb JF, Peng RD, Bell ML, Dominici F. Heat-related mortality and adaptation to heat in the United States. Environmental health perspectives. 2014 Aug;122(8):811-6; Hondula DM, Balling RC, Vanos JK, Georgescu M. Rising temperatures, human health, and the role of adaptation. Current climate change reports. 2015 Sep;1(3):144-54; Jenerette, G. Darrel, et al. Micro-scale urban surface temperatures are related to land-cover features and residential heat related health impacts in Phoenix, AZ USA. Landscape Ecology 31.4 (2016): 745-760.

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10 Eisenman DP, Wilhalme H, Tseng CH, Chester M, English P, Pincetl S, Fraser S, Vangala S, and Dhaliwal SK. 2016. Heat Death Associations with the built environment, social vulnerability and their interactions with rising temperature. *Health & Place,* 41, 89-99.

11 Also, adaptation is not constant over time, because lower societal adaptation (higher vulnerability) could also drive temperature mortality rates higher even in the absence of warming. See Putnam H, Hondula DM, Urban A, Berisha V, Iñiguez P, Roach M. It's not the heat, it's the vulnerability: attribution of the 2016 spike in heat-associated deaths in Maricopa County, Arizona. Environmental research letters. 2018 Sep 19;13(9):094022.

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13 Madrigano J, Jack D, Anderson GB, Bell ML, and Kinney PL. 2015. Temperature, ozone, and mortality in urban and non-urban counties in the northeastern United States. *Environ Health,* 14(3); Eisenman DP, Wilhalme H, Tseng CH, Chester M, English P, Pincetl S, Fraser S, Vangala S, and Dhaliwal SK. 2016. Heat Death Associations with the built environment, social vulnerability and their interactions with rising temperature. Health & Place, 41, 89-99; Berko J, Ingram DD, Saha S, and Parker JD. 2014. Deaths Attributed to Heat, Cold, and Other Weather Events in the United States, 2006-2010. National Health Statistical Reports No. 76, 15 pp. National Center for Health Statistics, Hyattsville, MD; Ho HC, Knudby A, Chi G, Aminipouri M, and Lai YF. 2018. Spatiotemporal analysis of regional socio-economic vulnerability change associated with heat risks in Canada. *Appl Geogr,* 95(3):61-70.

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16 Eisenman DP, Wilhalme H, Tseng CH, Chester M, English P, Pincetl S, Fraser S, Vangala S, and Dhaliwal SK. 2016. Heat Death Associations with the built environment, social vulnerability and their interactions with rising temperature. *Health & Place,* 41, 89-99.

17 Kenney WL, Craighead DH, and Alexander LM. 2014. Heat waves, aging, and human cardiovascular health. *Med Sci Sports Exerc,* 46(10):1891-1899; CDC. 2017. Natural Disasters and Severe Weather. Centers for Disease Control and Prevention, National Center for Environmental Health https://www.cdc.gov/disasters/extremeheat/heat_guide.html.

18 The analysis covers impacts in 49 large urban areas in the U.S. – in part because the best data are provided in urban areas, and in part because literature shows that the largest effects of extreme temperature mortality are likely to be in cities due to heat island effects. The underlying epidemiological relationships described in Mills et al. (2014) constraint the analysis to these 49 cities, therefore omitting large parts of the country and its population. Many factors affect how an urban population responds to extreme temperature effects, including building infrastructure, the prevalence of air conditioning, and the vulnerability of the local population to heat stress. As a result, each city in this analysis has its own city-specific response function for both heat and cold extremes.

19 Mills D, Schwartz J, Lee M, Sarofim M, Jones R, Lawson M, Duckworth M, and Deck L. 2014. Climate change impacts on extreme temperature mortality in select metropolitan areas in the United States. Climatic Change, 131, 83-95; U.S. EPA. 2017. Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment. U.S. Environmental Protection Agency, Washington, D.C.

20 For more information on these calculations, please see Table 3 of the Approach chapter.

21 See Mills D, Schwartz J, Lee M, Sarofim M, Jones R, Lawson M, Duckworth M, and Deck L. 2014. Climate change impacts on extreme temperature mortality in select metropolitan areas in the United States. Climatic Change, 131, 83-95, and other detailed results, by city, in Table 2 in Appendix E. Midwestern cities may be more to likely to see a higher mortality incidence because residents are not used to or prepared for extreme heat and may not have taken steps to adapt infrastructure or had an opportunity to acclimate to more extreme heat. In New Orleans and Orlando, the reasons for high impacts may be related to the susceptibility of their populations.

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22 Prolonged power outages from storms and other climate-driven weather events can increase the risk of temperature-related mortality, as people are not able to access air-conditioned space. This effect is not captured in the analysis of this report, likely leading to underestimated risks.

23 Xu JQ, Murphy SL, Kochanek KD, Arias E. Mortality in the United States, 2018. NCHS Data Brief, no 355. Hyattsville, MD: National Center for Health Statistics. 2020.

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25 Reference populations are defined for each socially vulnerable group as the population that does not exhibit the social vulnerability determinant in question. For example, for the low income population, the reference population is the population that is not low income. That reference population does, however, include those with other social vulnerability determinants, such as minorities, those without high school diplomas, etc.

Chapter 5. Extreme Temperature and Labor

1 See Appendix F and Figure 5.2 of this chapter.

2 Ebi KL, Balbus JM, Luber G, Bole A, Crimmins A, Glass G, Saha S, Shimamoto MM, Trtanj J, and White-Newsome JL. 2018. Human Health. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 539–571. doi: 10.7930/NCA4.2018.CH14.

3 Graff Ziven J, and Neidell M. 2014. Temperature and the allocation of time: implications for climate change. *Journal of Labor Economics*, 32(1):1-26. doi: 10.1086/671766.

4 With regards to the length of the working season for various industries (e.g., agriculture, tourism, construction), the labor method is not ideally suited to answer questions about how longer warm seasons may lead to more or less time spent working among high risk workers. Building on findings from (Graff-Zivin and Neidell 2014), the investigation of this report focuses specifically on the impact of discrete very high temperature days, which are projected to occur more frequency in the future and can have detrimental health impacts for exposed workers.

5 Graff Ziven J, and Neidell M. 2014. Temperature and the allocation of time: implications for climate change. *Journal of Labor Economics,* 32(1):1-26. doi: 10.1086/671766.

6 Park J, Hallegatte S, Bangalore M, and Sandhoefner E. 2015. Households and Heat Stress: Estimating the Distributional Consequences of Climate Change. World Bank Group Policy Research Working Paper 7479. doi: 10.1596/1813-9450-7479.

7 Heal GM, and Park J. 2016. Temperature Stress and the Direct Impact of Climate Change: A Review of an Emerging Literature. *Review of Environmental Economics and Policy,* 10(2). doi: 0.1093/reep/rew007.

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11 Gamble, J.L., J. Balbus, M. Berger, K. Bouye, V. Campbell, K. Chief, K. Conlon, A. Crimmins, B. Flanagan, C. Gonzalez-Maddux, E. Hallisey, S. Hutchins, L. Jantarasami, S. Khoury, M. Kiefer, J. Kolling, K. Lynn, A. Manangan, M. McDonald, R. Morello-Frosch, M.H. Redsteer, P. Sheffield, K. Thigpen Tart, J. Watson, K.P. Whyte, and A.F. Wolkin, 2016: Ch. 9: Populations of Concern. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, 247–286.

12 Sarofim, M.C., S. Saha, M.D. Hawkins, D.M. Mills, J. Hess, R. Horton, P. Kinney, J. Schwartz, and A. St. Juliana, 2016: Ch. 2: Temperature-Related Death and Illness. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, 43–68.

13 Degree days are measures of how warm or cold a location is. A degree day compares the mean (the average of the high and low) outdoor temperature recorded for a location to a standard temperature, usually 65° F.

14 Neidell, M., J. Graff Zivin, M. Sheahan, J. Willwerth, C. Fant, M. Sarofim, J. Martinich. (In Press) Temperature and work: Time allocated to work under varying climate and labor market conditions. PLOSONE.

15 For more information on these calculations, please see Table 3 of the Approach chapter. The analysis first calculates the total number of individuals currently living in the study area. Next, it calculates the number of individuals currently living in the area where impacts are projected to be highest. Then, it calculates the likelihood that an individual in each socially vulnerable group

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currently lives in the high-impact areas, relative to the likelihood for an individual from each corresponding reference population. Note that although the analyses quantify the numbers of all individuals in the study area and high-impact areas, it weights the populations by the portion of individuals that work in weather-exposed industries when calculating the difference in risk.

16 See Appendix F for maps showing the projected change in days over 90°F at the Census tract level.

17 See Appendix F for details on the geographic distribution of the high-impact Census tracts used in this analysis.

18 Reference populations are defined for each socially vulnerable group as the population that does not possess the social vulnerability determinant in question. For example, for the low income population, the reference population is the population that is not low income. That reference population does, however, include those with other social vulnerability determinants, such as minorities, those without high school diplomas, etc.

19 Only one of the five socially vulnerable populations examined in the report—individuals over 65 years old—is projected to be less at risk of experiencing high-end reductions in labor hours. However, the difference in risk relative to those under 65 years old is very small, at an estimated -2% in the 2°F warming scenario and -1% in the 4°F warming scenario.

Chapter 6. Coastal Flooding and Traffic

1 U.S. Department of Transportation, Federal Highway Administration. 2017. National Household Travel Survey. http://nhts.ornl.gov.

2 Jacobs JM, Cattaneo LR, Sweet W, and Mansfield T. 2018. Recent and future outlooks for nuisance flooding impacts on roadways on the US East Coast. *Transportation Research Record: The Journal of the Transportation Research Board,* 2672(2); Lewchuk W, Laflèche M, Procyk S, Cook C, Dyson D, Goldring L, Lior K, Meisner A, Shields J, Tambureno A, and Viducis P. 2016. The Precarity Penalty: How Insecure Employment Disadvantages Workers and Their Families. *Alternative Routes: A Journal of Critical Social Research,* 27; MacLeod KE, Ragland DR, Prohaska TR, Smith ML, Irmiter C, and Satariano WA. 2015. Missed or Delayed Medical Care Appointments by Older Users of Nonemergency Medical Transportation. Gerontologist, 55(6):1026-1037; Syed ST, Gerber BS, and Sharp LK. 2013. Traveling towards disease: transportation barriers to health care access. *J Community Health*, 38(5):976-993.

3 Theiss, R. The future of work: Trends and challenges for low-wage workers. Economic Policy Institute Briefing Paper #341. https://files.epi.org/2012/bp341-future-of-work.pdf

4 Kneebone E, and Holmes N. 2015. The growing distance between people and jobs in metropolitan America. Brookings Institute Metropolitan Policy Program working paper. Washington, DC. Available at: https://www.brookings.edu/wp-content/uploads/2016/07/srvy_jobsproximity.pdf.

5 Lewchuk W, Laflèche M, Procyk S, Cook C, Dyson D, Goldring L, Lior K, Meisner A, Shields J, Tambureno A, and Viducis P. 2016. The Precarity Penalty: How Insecure Employment Disadvantages Workers and Their Families. *Alternative Routes: A Journal of Critical Social Research,* 27.

6 MacLeod KE, Ragland DR, Prohaska TR, Smith ML, Irmiter C, and Satariano WA. 2015. Missed or Delayed Medical Care Appointments by Older Users of Nonemergency Medical Transportation. *Gerontologist,* 55(6):1026-1037. doi: 10.1093/geront/gnu002.

7 Syed ST, Gerber BS, and Sharp LK. 2013. Traveling towards disease: transportation barriers to health care access. *J Community Health,* 38(5):976-993. doi: 10.1007/s10900-013-9681-1.

8 Sweet W, Dusek G, Obeysekera J, and Marra JJ. 2018. Patterns and Projections of High Tide Flooding Along the U.S. Coastline Using a Common Impact Threshold. NOAA Technical Report NOSCO-OPS 086.

9 Fant C, Jacobs JM, Chinowsky P, Sweet W, Weiss N, Sias JE, Martinich J, and Neumann JE. (2021) Mere nuisance or growing threat? The physical and economic impact of high tide flooding on US road networks. *Journal of Infrastructure Systems*. doi: 10.1061/(ASCE)IS.1943-555X.0000652

10 In this analysis, the baseline levels of traffic delay include two reasonably anticipated adaptations to reduce traffic delay risk, (1) driver-initiated or official detour rerouting that directs drivers around the inundated road and (2) ancillary protection, where high tide flooding is prevented using protective strategies, such as sea walls and beach nourishment that are built to protect nearby land and structures, but also prevent flooding on roadways. These adaptations are included in all estimates of this chapter. The analysis also considers roads that could be excluded from receiving protective adaptation to mitigate high-tide flooding. The direct adaptation scenario considers the alleviation of high-tide flooding induced traffic delays through the implementation of two well established adaptation options: (1) build a sea wall to hold back the flood water, and (2) raise the road profile above the effective threshold.

11 Fant C, Jacobs JM, Chinowsky P, Sweet W, Weiss N, Sias JE, Martinich J, and Neumann JE. (In Press) Mere nuisance or growing threat? The physical and economic impact of high tide flooding on US road networks. In Review in the *Journal of Infrastructure Systems*.

12 For more information on these calculations, please see Table 3 of the Approach chapter.

13 Note that in Figure 6.2 and all results presented here for high-tide flooding, the Southeast NCA region is divided into a Gulf and Atlantic component, because of the substantial differences in local relative sea level rise and

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tidal ranges for the Gulf and Atlantic coasts (with land subsidence being higher in the Gulf area).

14 Reference populations are defined for each socially vulnerable group as the population that does not possess the social vulnerability determinant in question. For example, for the low income population, the reference population is the population that is not low income. That reference population does, however, include those with other social vulnerability determinants, such as minorities, those without high school diplomas, etc.

Chapter 7. Coastal Flooding and Property

1 NOAA. 2016. Economics and Demographics. Office for Coastal Management, National Oceanic and Atmospheric Administration. https://coast.noaa.gov/states/fast-facts/economics-and-demographics.html.

2 Coastal counties are defined according to the Federal Emergency Management Agency's definition, which states that a coastal county must have a coastline bordering the open ocean or the Great Lakes or contain coastal high hazard areas.

3 NOAA. 2016. Economics and Demographics. Office for Coastal Management, National Oceanic and Atmospheric Administration. https://coast.noaa.gov/states/fast-facts/economics-and-demographics.html.

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5 Fleming E, Payne J, Sweet W, Craghan M, Haines J, Hart JF, Stiller H, and Sutton-Grier A. 2018. Coastal Effects. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 322–352. doi: 10.7930/NCA4.2018.CH8.

6 Lieberman-Cribbon W, Gillezeau C, Schwartz RM, and Taioli E. 2020. Unequal social vulnerability to Hurricane Sandy flood exposure. *J Expo Sci Environ Epidemiol*. doi: 10.1038/s41370-020-0230-6.

7 Center for Climate Integrity. 2019. High tide tax: the price to protect coastal communities from rising seas.

8 Fleming, E., J. Payne, W. Sweet, M. Craghan, J. Haines, J.F. Hart, H. Stiller, and A. Sutton-Grier, 2018: Coastal Effects. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 322–352. doi: 10.7930/NCA4.2018.CH8

9 Moss RH, Avery S, Baja K, Burkett M, Chischilly AM, Dell J, Fleming PA, Geil K, Jacobs K, Jones A, Knowlton K, Koh J, Lemos MC, Melillo J, Pandya R, Richmond TC, Scarlett L, Snyder J, Stults M, Waple AM, Whitehead J, Zarrilli D, Ayyub BM, Fox J, Ganguly A, Joppa L, Julius S, Kirshen P, Kreutter R, McGovern A, Meyer R, Neumann J, Solecki W, Smith J, Tissot P, Yohe G, and Zimmerman R. 2019. Evaluating knowledge to support climate action: A framework for sustained assessment. Weather, Climate, and Society, 11(3):465-487. doi:10.1175/WCAS-D-18-0134.1.

10 Buchanan M, Kulp S, Cushing L, Morello-Frosch R, Nedwick T, and Strauss B. 2020. Sea level rise and coastal flooding threaten affordable housing. *Environmental Research Letters,* 15(12). doi: 10.1088/1748-9326/abb266.

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15 Please see the Approach chapter and Appendix C for more information on the SLR projections used in the analysis.

16 Please see Appendix H for more details on this approach.

17 Impacts are calculated as the ratio of total damages to total property value within each block group.

18 For more information on these calculations, please see Table 3 of the Approach chapter.

19 As described in the Approach section of this report, the global levels of sea level change are adjusted for location-specific factors (e.g., vertical land movement,

currents), to provide locally-relevant rates for determining vulnerability.

20 As this analysis is conducted at Census block group scale, it is important to note that the approach is not able to capture all of the micro-scale hydraulic and infrastructure dynamics important for precisely estimating flood risk. As such, there are likely to exist biases due to the correlations between hydrology, socioeconomics, and existing flood protection.

21 Reference populations are defined for each socially vulnerable group as the population that does not possess the social vulnerability determinant in question. For example, for the low income population, the reference population is the population that is not low income. That reference population does, however, include those with other social vulnerability determinants, such as minorities, those without high school diplomas, etc.

22 Based on groupings in the American Community Survey, this analysis groups together American Indian and Alaska Native individuals. Since there are relatively fewer Alaska Native individuals living in the Southeast, these findings are more representative of effects for American Indian individuals. In addition, it is important to reiterate that this analysis is confined to the contiguous U.S. and does not include Alaska.

23 Reference populations are defined for each socially vulnerable group as the population that does not possess the social vulnerability determinant in question. For example, for the low income population, the reference population is the population that is not low income. That reference population does, however, include those with other social vulnerability determinants, such as minorities, those without high school diplomas, etc.

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25 Other factors may include local zoning bylaws, future land use plans, the presence of development-supporting infrastructure, or proximity to sites with high cultural value. As this analysis projects potential protection and abandonment of coastal properties, it is acknowledged that there are important considerations that drive the decisions that homeowners will make in response to risks from SLR. In some cases, residents may have strong emotional and/or ancestral attachment to their land, or be resistant to leaving vulnerable properties because they do not have the social structure elsewhere or financial liquidity that would enable them to do so.

26 The areas projected to be excluded from adaptation in these regions are generally characterized by low population and structure density, which raise technical challenges for cost-effective adaptation (as modeled in the NCPM response framework), and/or lower property values.

Chapter 8. Inland Flooding and Property

1 Davenport FV, Burke M, and Diffenbaugh NS. 2021. Contribution of historical precipitation change to US flood damages. *Proceedings of the National Academy of Sciences,* 118(4). doi: 10.1073/pnas.2017524118.

2 Wobus C, Zheng P, Stein J, Lay C, Mahoney H, Lorie M, Mills D, Spies R, Szafranski B, and Martinich J. 2019. Projecting changes in expected annual damages from riverine flooding in the United States. *Earth's Future,* 7(5):516–527. doi: 10.1029/2018EF001119. Riverine flooding can also be caused by heavy snow melt (which is considered in this analysis) and ice jams (which are not considered).

3 A second type of freshwater flooding, known as pluvial flooding, is caused by the excessive rainfall itself, and is often associated with urban drainage systems reaching a state of over-capacity, rather than rain causing a river system to exceed its capacity. Pluvial flooding is also expected to grow worse as a result of climate change (see Price J, Wright L, Fant C, and Strzepek K. 2014. Calibrated Methodology for Assessing Climate Change Adaptation Costs for Urban Drainage Systems. *Urban Water Journal,* 13(4). doi: 10.1080/1573062X.2014.991740), but is not considered in this analysis.

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22 For more information on these calculations, please see Table 3 of the Approach chapter.

23 As this analysis is conducted at Census block group scale, it is important to note that the approach is not able to capture all of the micro-scale hydraulic and infrastructure dynamics important for precisely estimating flood risk. As such, there are likely to exist biases due to the correlations between hydrology, socioeconomics, and existing flood protection.

24 This analysis uses a different baseline period (2001-2020) compared to other impact analyses of this report. See Appendix I for additional details and rationale.

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